ONLINE ISSN 2976-7695

EVC2023

BOOK OF ABSTRACTS

8TH INTERNATIONAL ELECTRIC VEHICLE CONFERENCE 2023 (EVC2023)

21-23 JUNE 2023
EDINBURGH NAPIER UNIVERSITY

Online ISSN 2976-7695

8th International Electric Vehicle Conference 2023: Book of Abstracts

EVC 2023

21st – 23rd June 2023, Edinburgh, United Kingdom

ORGANIZED BY:

Transport Research Institute, Edinburgh Napier University

EDITED BY:

Firdaus Muhammad-Sukki
Nurul Aini Bani
Efstathios-Alexandros Tingas

PARTLY FUNDED BY:

The UK and Scottish Government
(HCI Skills Gateway Scheme)

PUBLISHED BY:

Edinburgh Napier University,
10 Colinton Road, Merchiston Campus, Edinburgh EH10 5DT United Kingdom

TABLE OF CONTENTS

WELCOME MESSAGE

KEYNOTE SPEAKERS

CONFERENCE AGENDA

WELCOME MESSAGE

Dear colleagues and friends,

It is with great pleasure that I welcome you all to the 8th International Conference on Electric Vehicles. As the chair of this conference, I am honoured to have the opportunity to bring together researchers, engineers, industry professionals, policymakers, and other experts from around the world to discuss the latest advances in electric vehicle technology, policy, and research.

Dr Efstathios-Alexandros Tingas
Chair,
8th International Electric Vehicles Conference

Over the past decade, electric vehicles have become an increasingly important part of the transportation landscape, with millions of electric vehicles now on the roads worldwide. This growth has been driven by advances in battery technology, electric drivetrains, and charging infrastructure, as well as by policy initiatives to reduce greenhouse gas emissions and improve air quality.

Our conference will cover a wide range of topics related to electric vehicles, including battery technology, electric motors and drivetrains, charging infrastructure, power electronics, vehicle-to-grid integration, and policy and market trends. We will also have keynote speeches from leading experts in the field on some of the most pressing issues facing the industry today.

In addition to the technical sessions and panel discussions, we will also have opportunities for networking and collaboration. I encourage all of our attendees to take advantage of these opportunities to connect with colleagues and share their ideas and experiences.

I would like to extend my sincere thanks to our programme committee, our sponsors, and our keynote speakers for their hard work and support in making this conference a success. I would also like to thank all of our attendees for their participation and contributions to the field of electric vehicles.

I hope you find this conference to be a rewarding and enriching experience, and I look forward to meeting and learning from all of you.

Best regards,

Dr Efstathios-Alexandros Tingas
Chair,
8th International Electric Vehicles Conference (EVC2023)

WELCOME MESSAGE

The 8th International Electric Vehicle Conference (EVC2023) promises to be a significant gathering of experts, researchers, and industry professionals in the field of electric mobility. This esteemed conference serves as a platform for knowledge exchange, presenting cutting-edge research and innovative technologies in the electric vehicle (EV) industry. As the Chief Editor of the conference proceedings, it is my pleasure to provide a concise overview of this remarkable event.

The EVC2023 is bringing together international participants from academia, industry, and government sectors. The conference aims to explore the latest advancements, challenges, and opportunities in the field of electric vehicles, emphasising sustainable transportation and the transition to a cleaner, greener future. The conference will cover a wide range of themes and topics related to electric vehicles, encouraging interdisciplinary discussions and collaborations. Notable areas of focus include, but are not limited to:

- **Vehicle design:** Onboard generators and hybrid EVs, Electric motor, Vehicle types, Plug-in electric vehicle, Hybrid electric vehicles, On- and off-road EVs, Components, Chassis swapping, Other in-development technologies, Heating of electric vehicles, Energy efficiency.
- **Battery:** Onboard storage, Lithium-ion battery**,** Efficiency**,** Battery swapping**,** Range**,** Battery management and intermediate storage
- **Grid:** Electricity sources, Connection to generator plants, Grid reliability, Grid capacity, Stabilization of the grid
- **Aviation:** Propulsion system, Hybrid-electric aircraft, Space rover vehicles, Airborne electric vehicles, Electrically powered spacecraft
- **Charging Station:** Energy sources, Charging components, Smart charging, Vehicle-to-Grid (V2G), Power-to-X (P2X)
- **Policy, Economics and Social Acceptance of EV:** Standard, Safety, National/International Policies, Finance support for EV, Incentive and promotion, Social acceptance of EV, Electromagnetic radiation and health implication, Cost of recharge, Electric vehicles organizations, Regional/Country update on EV.

Dr Firdaus Muhammad-Sukki
Co-Chair & Chief Editor
8th International Electric Vehicles Conference (EVC2023)

The book of abstracts for the EVC2023 will provide a comprehensive compilation of extended abstracts, encompassing the diverse range of topics presented at the conference. It will serve as a valuable resource for attendees, allowing them to delve deeper into the groundbreaking research and industry trends discussed during the event.

The EVC2023 promises to be an exceptional gathering of experts, fostering collaboration and knowledge sharing in the field of electric mobility. With its focus on sustainable transportation and the future of electric vehicles, the conference will undoubtedly contribute to the global transition towards a more sustainable and environmentally friendly transportation system. As the editor of the conference proceedings, I am confident that the book of abstracts will provide a lasting reference for researchers, practitioners, and enthusiasts alike.

We look forward to your active participation in this exciting event!

Best regards,

Dr Firdaus Muhammad-Sukki
Co-Chair & Chief Editor
8th International Electric Vehicles Conference (EVC2023)

EVC2023

KEYNOTE SPEAKERS

KEYNOTE SPEAKERS

1 Professor Phil Blythe (CBE FREng CEng FIET FCIHT)

Newcastle University, United Kingdom

Professor Phil Blythe is Professor of Intelligent Transport Systems and served as Director of the Transport Operations Research Group at Newcastle University for 13 years until stepping down from this post in June 2015 to take up a three year, 3-day a week appointment as Chief Scientific Adviser for the Department of Transport (DfT) until June 2021. In his role at the DfT he provides a challenge function to the Department on the use of science and engineering evidence in policy making and also ensuring the Department is best informed on new innovations and technologies that may impact on the delivery of transport schemes. Through the CSA network he also ensures that there is significant cross-government cooperation on science, engineering and technology issues. The network of Chief Scientific Advisers (CSA's) across Government Departments support and advise the Government Chief Scientific Adviser on all aspects of policy on science and technology. At Newcastle University Phil's research portfolio covers a wide range of areas where ITS has been applied to transport including: His primary research is forward looking and attempts to bridge the technology-policy gap in terms of what technologies may evolve to meet future policy objectives or indeed influence future policy thinking, particularly in the smart city/smart transport domain. Internationally, Phil manages a portfolio of research projects funded by the EPSRC, Europe, Industry and Government He is a member of the ERTICO (ITS Europe) Supervisory Board and advises the Commission on ITS research strategy. He chairs the IET's Transport Policy Panel and the UK's C-ITS Deployment Board and has acted as an advisor to the UK and European governments in various areas of intelligent transport and more recently also in the connected and autonomous vehicles, age-friendly and accessible transport, electromobility and smart cities agendas. Phil has devoted his academic career to the development of the research area of Intelligent Transport Systems (ITS) which is essentially the use of Information, communications and computing technology applied to transport. Phil established the first MSc level module in the UK in the field of ITS in 1997 and this has proved to be highly popular with the MSc and undergraduate students and CPD (Continuing Professional Development) delegates. Over the years at Newcastle University, Phil's research portfolio covers a wide range of areas where ITS has been applied to transport including: road to vehicle communications; road user charging and toll systems; ITS for assistive mobility, smartcards and RFID, wireless/smartdust technologies, electromobility and future intelligent infrastructure and is reflected in his research-led teaching in ITS and e-Services. His primary research is forward looking and attempts to bridge the technology-policy gap in terms of what technologies may evolve to meet future policy objectives or indeed influence future policy thinking to meet the three main challenges currently facing transport, namely: congestion, climate change and future energy vectors. Phil has been Principal Investigator (PI) and Co-Investigator on more than 70 research projects with a total value to Newcastle of over £35m. His current portfolio of projects include four EPSRC-funded projects (LC Transform, iBuild, CESI and UKCRIC), two EU funded projects (ITS Observatory and C-Mobile) as well projects funded from Government, Industry and local authorities (primarily in the C-ITS and Electromobility areas). In March 2012 Phil was awarded the Reece-Hills Medal for a lifetime personal contribution to ITS. Phil holds a number of patents for ITS and ICT related inventions, publishes widely and provides knowledge outreach, consultancy and training courses in many aspects of ITS research.

EV's – it's now time to ask the hard questions!

Abstract: The UK is moving along it's pathway toward major adoption of EVs and other zero tailpipe emissions road vehicles - with key milestones set for 2030, 2035, 2040 and 2050. Although we can congratulate ourselves on some of the successes we have had so far in moving towards these important policy objectives, there is still much more to do and some degrees of uncertainty to overcome. From his experience in both Government and academia in identifying and addressing what is needed to achieve the UK's vision of EV adoption and the provision of infrastructure to support this, Phil will raise some of the 'hard questions' and 'uncertainties' that are yet to be fully addressed and challenge the conference speaker and delegates to discuss and tackle these issues.

KEYNOTE SPEAKERS

2 Professor Cristina Corchero Garcia

Catalonia Institute for Energy Research, Spain

Cristina Serra Hunter is a professor at the UPC and Head of the Energy Systems Analytics Group at IREC. She has founded a spin-off of IREC on 2020, Bamboo Energy. She holds a M.Sc. and PhD in Statistics and Operations Research from the Polytechnic University of Catalonia (2011). She joined IREC in 2012 as postdoc researcher and she gained a Juan de la Cierva Fellowship. Her research focuses on applying advanced optimisation tools to electricity markets, smart grid, smart communities, electric vehicle and hybrid systems. Cristina lead and participated in several European, national, regional and industrial projects on energy efficiency and new technologies system integration. She has registered and patented different software solutions to optimize novel energy system integration and management. She leads the Vehicle-Grid-Integration tasks at the Hybrid and Electrical Vehicle Technology and Collaboration Programme from the International Energy Agency since 2015. She has participated in several scientific publications, national and international conferences, workshops and seminars.

KEYNOTE SPEAKERS

3

Professor Anna G. Stefanopoulou

University of Michigan, USA

Anna G. Stefanopoulou is a professor of Mechanical Engineering and William Clay Ford Professor of Technology at the University of Michigan. She obtained her Diploma (1991, Nat. Tech. Univ. of Athens, Greece) in Naval Architecture and Marine Engineering and her Ph.D. (1996, University of Michigan) in Electrical Engineering and Computer Science. She was an assistant professor (1998-2000) at the University of California, Santa Barbara, a technical specialist (1996-1997) at Ford Motor Company and a visiting professor (2006) at ETH, Zurich. She is an ASME and an IEEE Fellow, the Inaugural Chair of the ASME DSCD Energy Systems Technical Committee, a member of the SAE Dynamic System Modeling Standards Committee and a member of a U.S. National Academies committee on Vehicle Fuel Economy Standards. She was an elected member of the IEEE Control Systems Society (CSS) Board of Governors, and served as an associate editor of journals and member of multiple award committees in the IEEE and ASME societies. She is a recipient of multiple research and educational awards from SAE and ASME and selected as one of the 2002 world's most promising innovators from the MIT Technology Review. She has co-authored a book on Control of Fuel Cell Power Systems, 10 US patents, 5 best paper awards and 200 publications on estimation and control of internal combustion engines and electrochemical systems such as fuel cells, batteries, and capacitors. More than 15 invited lectures, plenaries and keynotes.

The Value of Predicting Remaining Useful Life (RUL)

Abstract: The battery Remaining Useful Life (RUL) is at the crux of the payback calculations and is often confused with the Battery State of health (SOH), that is quantified by capacity (cyclable energy) and cell resistance (power capability) that will be stored and reported in battery passports. The challenge in predicting RUL depends on identifying the physical origin of the battery degradation such as a rust-like (SEI) film growth in electrode particles, Lithium plating, mechanical particle fracture and metal dissolution. RUL can inform decisions regarding vehicle resale value, vehicle-to-grid benefits, repurposing, or recycling. Predicting RUL is thus the critical task for calculating the total cost of ownership and for creating a circular battery economy.

KEYNOTE SPEAKERS

4 Senior Professor Dr. Kashem Muttaqi (FIEAust FIET FIEEE FAAIA)

University of Wollongong, Australia

Senior Professor Dr. Kashem Muttaqi received his Bachelor of Science in Electrical and Electronic Engineering degree from Bangladesh University of Engineering and Technology (BUET), Bangladesh in 1993. He then received Masters of Engineering in Science degree from the University of Malaya (UM), Malaysia in 1997, and received his Doctor of Philosophy degree from Multimedia University (MMU), Malaysia in 2001. Currently, he is the Director of the ARC Training Centre in Energy Technologies for Future Grids, and also the Director of the Australian Power and Energy Research Institute (APERI). He is a Senior Professor at the School of Electrical, Computer and Telecommunications Engineering at the University of Wollongong. He is also serving as the Discipline Leader for Electrical Engineering at the School of Electrical, computer and Telecommunications Engineering (SECTE), University of Wollongong. He served as the Postgraduate Coursework Degree Coordinator at the School of Electrical, Computer and Telecommunications Engineering, University of Wollongong from 2008 to 2010, and the Cluster Head for 09 Engineering, Faculty of Engineering and Information Sciences (EIS) at the University of Wollongong from 2019 to 2021. He was associated with the University of Tasmania, Australia as a Research Fellow/Lecturer/Senior Lecturer from 2002 to 2007, and with the Queensland University of Technology, Australia as a Research Fellow from 2000 to 2002. Previously, he worked for Multimedia University, Malaysia as a Lecturer from 1997 to 2000. He also worked as an Electrical Executive for KTA Tenaga (Consulting Engineers) in Malaysia from 1996 to 1997. Dr. Muttaqi worked as the Deputy-Director of the Centre for Renewable Energy and Power systems (CREPS) at the University of Tasmania before he joined the University of Wollongong. In recognition of his skills in the sphere of teaching and learning, he was awarded a 'Teaching Merit Certificate' in 2004 from the University of Tasmania. He is a Senior Member of IEEE and Member of EEE Industry Applications Society, IEEE Power & Energy Society, IEEE Industrial Electronics Society, and IEEE Power Electronics Society. He is currently serving as a Paper Review Chair and Associate Editor for IEEE Transactions on Industry Applications, the Vice Chair Publication for Industrial Automation and Control Committee (IACC) of IEEE Industry Application Society (IAS), and an Editor of IEEE Transactions on Sustainable Energy and IET Generation, Transmission & Distribution. He has more than 24 years of academic experience and authored or co-authored 410 papers in international journals and conference proceedings. He has supervised more than 26 higher degree research students to completion. His research interests include distributed generation, renewable energy, electrical vehicles, smart-grids, power electronic applications, power converters, smart solid-state transformers, power system planning, emergency control, intelligent grids, artificial intelligence and machine learning applications to power systems. He is a Fellow of the Institution of Engineers Australia (FIEAust). He is also a Fellow of the Institution of Engineering and Technology (FIET).

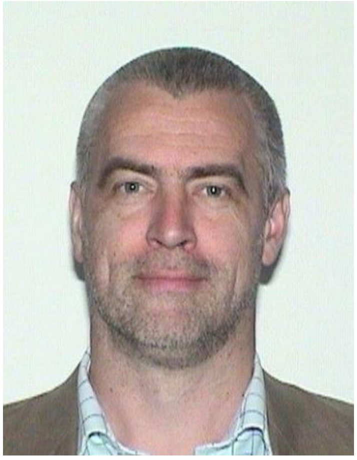
Energy Technologies for Future Grids

Abstract: Energy supply systems worldwide are experiencing transformation, with a target for a net-zero future. The pace of transformational change has been rapid and many industry sectors are finding the transition challenging. The transition to a sustainable future is seemingly evident through rapidly reducing renewable energy costs, greatly improved energy efficiencies, increasing use of smart technologies, replacing fossil-fuel powered vehicles by all-electric vehicles, and wide applications of energy storage. With this ongoing transition, there is an increasing pressure to integrate new energy technologies and systems into the existing power grid infrastructure. New technologies to address power grid stability and new ways of enhancing the capabilities of power systems are required to make transition to a more sustainable energy future. This can be achieved by increased utilization of sustainable technologies, electric vehicles and emission-free energy generating resources and their seamless integration into the present and future grids.

KEYNOTE SPEAKERS

5 Professor Andrew Cruden

University of Southampton, UK



Andrew Cruden is Professor of Energy Technology within the Department of Mechanical Engineering, University of Southampton. He is co-Director of the EPSRC Centre for Doctoral Training in Energy Storage and its Applications, Deputy Head of the School of Engineering (Infrastructure) and a member of the Training and Diversity Panel for the Faraday Institution. He obtained his BEng, MSc and PhD degrees in Electronic and Electrical Engineering from the University of Strathclyde, Glasgow, in 1989, 1990 and 1998, respectively. He had a range of research posts at Strathclyde until 1998 when he was appointed Lecturer, then promoted to Senior Lecturer in 2004 and Reader in 2010. He was appointed as Professor of Energy Technology at the University of Southampton in July 2012, within the Electro-Mechanical Research Group. In July 2013, he took up the role of Head of the Energy Technology Research Group. He is a Chartered Engineer. He has significant experience in the field of renewable energy, particularly in fuel cell technology and condition monitoring of wind turbines. The interest in fuel cell technology led, indirectly, to an interest in the field of electric vehicles, and subsequently to research activity in energy storage (both batteries and supercapacitors, with EPSRC and TSB) and traction drives (through current EPSRC funding and two TSB funded projects). He has attracted over £3M in research funding from both the Research Councils and industry, and published over 110 articles, including conferences and journal papers. He has acted a Director for the Argyll, Lomond and the Islands Energy Agency from 1998 – 2012, (www.alienergy.org.uk), a local energy agency established as a not-for-profit company to promote and develop renewable energy and energy efficiency within this locale. Additionally he was instrumental in establishing, and the first Chairman of, the Scottish Hydrogen and Fuel Cell Association (SHFCA, www.shfca.org.uk), a Trade Association within Scotland to promote hydrogen and fuel cell technology. Latterly he was the Chairman of the 4th World Hydrogen Technologies Convention (WHTC), held in Glasgow in September 2011 under the auspices of the International Hydrogen Energy Association. Previously he organised and delivered the IET Christmas Lecture series in Scotland in 2005, which delivered a talk on the history and future of electrical power generation to over 1,200 school children around Scotland.

Developing Grid Independent Electric Vehicle Charging Stations

Abstract: A transition to a net-zero transport system is one of the key goals for this century to ensure the effects of man-made climate change are limited, and perhaps, mitigated. Through the electrification of transport, polluting fossil fuels and the harmful emissions generated by their consumption can be significantly reduced. These issues span the whole of society and have wide reaching implications: if the Electric Vehicle (EV) experience is not "satisfactory" then consumers will be reluctant to make the switch.

To address this challenge, an EV charging solution that can deliver fully grid-independent, renewably powered, public charging is required. This solution should stand to: (i) facilitate the deployment of new renewable generating capacity for the purposes of EV charging; and (ii) overcome existing national grid capacity constraints for growth in the EV charging-load. (iii) underpin the creation of localised smart grids, that can flexibly support energy demand in communities under-served by the current infrastructure, further alleviating pressure on the existing electricity grid.

Through the "FEVER (Future Electric Vehicle Energy networks supporting Renewables)” concept devised in the author’s new EPSRC Programme Grant, the investigators from Southampton, Sheffield, Surrey and Portsmouth Universities are actively designing, developing and aiming to demonstrate such an EV charging solution. FEVER will use renewable generation, within an innovative off-vehicle energy storage (OVES) system, to offer a secure, year-round, grid-independent charging for EVs. Moving beyond the state-of-the-art technologies a cost-effective and socially-acceptable 'hybrid' OVES will be developed, necessary to address both the temporal (i.e. seasonal), performance and cost issues of this concept, as lithium-ion battery technology on its own is unable to enable this vision (too expensive to provide seasonal storage).

This keynote presentation will introduce some of the initial modelling to design a FEVER EV charging station and explore the issues with creating new hybrid forms of energy storage.

Initial modelling of the annual energy balance required from a mix of primary renewable energy sources versus the load demand of an anticipated EV population, will be presented and discussed. This initial modelling, undertaken using Matlab Simulink, has explored a range of scenarios and attempts to highlight the different temporal demands of the OVES. This is being supported by, initially, laboratory based testing and validation, and will ultimately progress to full-scale demonstration and characterisation.

The energy balance modelling has also facilitated initial exploration of hybridising the OVES: for example, a combination of directly connected lithium-ion and lead acid batteries. This hybrid combination helps reduce capital cost and supports higher sustainability targets by recognition of the established commercial lead-acid recycling sector, versus a solely lithium-ion based OVES. Further investigation of alternative energy storage hybrids is ongoing.

The presentation will conclude with an update on the wider FEVER project goals, surrounding public acceptance of FEVER technology and the impact of FEVER on current EV charging standards and government policy (which focus on grid connected solutions). Further information is available at: www.fever-ev.ac.uk

KEYNOTE SPEAKERS

6

Professor Iryna Zenyuk

University of California, USA

Professor Iryna Zenyuk holds a B.S. in mechanical engineering from the NYU Polytechnic School of Engineering. She continued her studies at Carnegie Mellon University, where she earned M.S. and Ph.D. Her graduate work focused on fundamental understanding meso-scale interfacial transport phenomena and electric double layers in fuel cells. Iryna was a postdoc at LBNL (Berkeley Lab) in Dr. Adam Weber's group from 2014 to 2015 investigating water-management in PEFCs using x-ray CT and modeling. She joined Tufts University as an Assistant Professor from 2015-2018 and moved to UC Irvine in 2018. Currently, she is an Associate Professor in Chemical and Biomolecular Engineering Department at UCI. She is also a Director of the 24 year old center, National Fuel Cell Research Center (NFCRC), where her mission is to accelerate the development and deployment of fuel cell technology and fuel cell systems.

Iryna has published more than 80 journal publications in electrochemical technologies area and have given more than 100 invited presentations. She also serves on Alumni Board for Tandon School of Engineering, New York University. Iryna is an Associate Editor of ACS Applied Energy Materials, and Academic Editor of iScience. She hopes to develop technologies to decarbonize difficult sectors, such as chemical manufacturing, aviation, shipping, long-haul transportation to reach net-zero emissions economy by 2050.

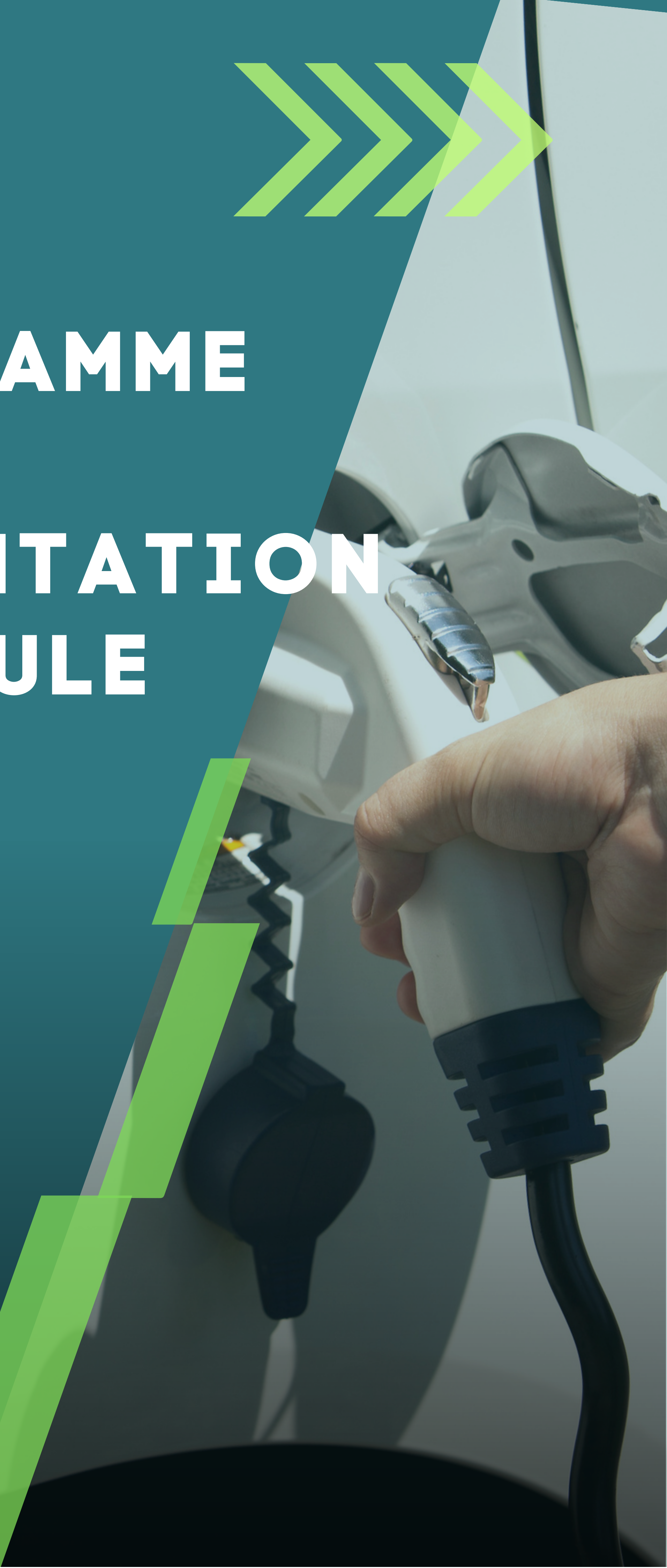
Design of Polymer Electrolyte Fuel Cells for Heavy-Duty Electric Vehicles: From Fundamentals to System-Level Studies

Abstract: The U.S. has pledged to decarbonize its economy by 2050. Decarbonization of transportation sector is critical to achieve net-zero emissions economy by 2050. Department of Energy (DOE) has issued Hydrogen Shot aiming to produce 1 kg of hydrogen for $1 in 1 decade. This '111' target is ambitious, as currently challenges of electrolyzers cost, durability and scale-up to MW scale need to be addressed. Once produced, hydrogen will be utilized in various industries, including manufacturing and it can serve as a fuel for various applications, including polymer electrolyte fuel cell (PEFCs). These technologies have advanced to reach the commercialization stage with more automotive manufacturers announcing new PEFC-based light and heavy-duty vehicles. The main advantage of the PEFCs is that they have zero emissions and produce only water. Using the DOE cost-breakdown for the 80-kW_{net} stack for light-duty vehicles, the cost of precious metal electrocatalysts remains almost unchanged as production rate increases to 0.5 M PEFC stacks per year. The cost of the electrocatalysts amounts to 31% of stack cost, for 0.5 M systems per year production rate. Platinum (Pt) or Pt-alloys are used as electrocatalysts for the oxygen reduction reaction (ORR) on the cathode side and the hydrogen oxidation reaction (HOR) on the anode side of PEFCs. Pt or Pt-alloy electrocatalysts are dispersed as nanoparticles onto a carbon-black support. DOE set a target of reducing Pt loading to 0.125 mg cm^{-2} to achieve the goal of \$12.6 kW_{net}^{-1} for a stack with power density target of 1.8 W cm^{-2}. Membrane electrode assemblies (MEAs) with lower catalyst loading are less durable, thus, the cost issue cannot be resolved without focusing on the catalyst durability issue of the PEFC stack. To reach the activity and durability targets, overall understanding of the interfaces within the MEAs are needed and their evolution during ageing.

This presentation will summarize my group's recent efforts in design of MEAs for durability and characterization tools developed to understand MEA degradation using heavy-duty drive cycle. The presentation will tie into system-level studies of hybridizing fuel cell and battery power trains to achieve most efficient and durable heavy-duty truck applications.

EVC2023

PROGRAMME & ORAL PRESENTATION SCHEDULE



PROGRAMME SCHEDULE

DATE: 21 JUNE 2023 (DAY 1)

Start time	End time	Activity
8.30am	9.20am	Registration
9.20am	9.30am	Welcome/Housekeeping
9.30am	10.30am	Keynote: Prof. Phil Blythe Chair: Prof. Emma Kendrick Room: Lindsay Stewart
10.30am	10.50am	Break
10.50am	11.10am	Parallel Sessions
11.10am	11.30am	
11.30am	11.50am	
11.50am	12.10am	
12.10apm	12.30pm	
12.30pm	1.30pm	Lunch
1.30pm	2.30pm	Keynote: Prof. Cristina Corchero Chair: Prof. Andy Cruden Room: Lindsay Stewart
2.30pm	2.50pm	Break
2.50pm	3.10pm	Parallel Sessions
3.10pm	3.30pm	
3.30pm	3.50pm	
3.50pm	4.10pm	
4.10pm	4.30pm	

PROGRAMME SCHEDULE
DATE: 22 JUNE 2023 (DAY 2)

Start time	End time	Activity
8.30am	9.20am	Registration
9.20am	9.30am	Welcome/Housekeeping
9.30am	10.30am	Keynote: Prof. Anna Stephanopoulou Chair: Prof. Miadreza Shafiekhah Room: Lindsay Stewart
10.30am	10.50am	Break
10.50am	11.10am	Parallel Sessions
11.10am	11.30am	
11.30am	11.50am	
11.50am	12.10am	
12.10apm	12.30pm	
12.30pm	1.30pm	Lunch
1.30pm	2.30pm	Keynote: Prof. Kashem Muttaqi Chair: Prof. Liana Cipcigan Room: Lindsay Stewart
2.30pm	2.50pm	Break
2.50pm	3.10pm	Parallel Sessions
3.10pm	3.30pm	
3.30pm	3.50pm	

Start time	End time	Activity
6.30pm	7.00pm	Arrival/Drinks Reception & entertainment in the Bar and Wilfred Suite, Craiglockhart
7.00pm	7.15pm	Guests to be seated in the Chapel
7.15pm	9.30pm	Food service in the Chapel
9.30pm		Finish

PROGRAMME SCHEDULE

DATE: 23 JUNE 2023 (DAY 3)

Start time	End time	Activity
8.30am	9.20am	Registration
9.20am	9.30am	Welcome/Housekeeping
9.30am	10.30am	Keynote: Prof. Andrew Cruden Chair: Prof. Haiping Du Room: Lindsay Stewart
10.30am	10.50am	Break
10.50am	11.10am	Parallel Sessions
11.10am	11.30am	
11.30am	11.50am	
11.50am	12.10am	
12.10apm	12.30pm	
12.30pm	1.30pm	Lunch
1.30pm	2.30pm	Keynote: Prof. Iryna Zenyuk Chair: Dr Patrick Jochem Room: Lindsay Stewart
2.30pm	2.50pm	Break
2.50pm	3.10pm	Parallel Sessions
3.10pm	3.30pm	
3.30pm	3.50pm	

ORAL PRESENTATION 1

DATE: 21 JUNE 2023 | TIME: 10:50-12:30

Theme: Charging Station/Charging components
Location: Room 1/06

Theme: Vehicle design/Energy efficiency/Electric Motor
Location: Room 3/03

Theme: Vehicle design/ Efficiency and Performance
Location: Room 3/11

ORAL PRESENTATION 2

DATE: 21 JUNE 2023 | TIME: 14:50-16:30

Theme: Lithium-ion battery
Location: Room 1/06

Theme: Policy, Economics and Social Acceptance of EV
Location: Room 3/03

Theme: Charging Station/Energy sources/P2G
Location:

ORAL PRESENTATION 3

DATE: 21 JUNE 2023 | TIME: 10:50-12:30

Theme: Battery Range/Efficiency/Management
Location: Room 1/06

Paper ID	Presentation Details	Page
9	Thermodynamics, Heat Transfer, and Renewable Charging of Electric Vehicles *Efstathios E. Michaelides*	77
27	A Comparative Study of Novel Designs OF Liquid-Cooled Battery Thermal Management Systems *Pranjali Tete, Sandeep Joshi and Mahendra Gupta*	78
81	Optimisation of Electric Vehicle Battery Size *Niall Jones, Simon Nazarenus, Konstantinos Stamatis, Andreas Zachariah and Liana Cipcigan*	80
43	Electric Buses Battery Sizing Optimisation using an Agent-Based Modelling Approach *Simon Nazarenus, Konstantinos Stamatis and Liana Cipcigan*	82
AS1	Parametric Study on Lead-Acid Battery in an Electric Powertrain *Daksha Moodbidri Renuka, Axit Ghanshyamnhai Thakar, Gopika Namboothiri, Ahmed Rezk and Jose Sodre*	84

Theme: Vehicle/Power-to-Grid (V2G/P2G)
Location: Room 3/03

Time	Presentation Details	Page
22	Systematic Review on Phase-Shift Optimization Strategies of Dual Active Bridge based DC-DC Converter *Osama Majeed Butt, Rana Hasnat Ahmed and Muhammad Husnain Ashfaq*	86
28	Diary-Based Evaluation of Bidirectional Electric Vehicle Charging In a Long-Term Study: Method and Insights *Bettina Kämpfe and Corinna Braun*	89
41	EVs and Their Charging – In or Out? User Acceptance of Bidirectional Charging in Germany *Vera M. Fahrner, Moritz Bergfeld and Christine Eisenmann*	91
72	Exploring the Feasibility of Battery Electric and Fuel Cell Electric Vehicles as Peaker Plant Substitutes in Low Wind and Irradiation Conditions *Nies Reininghaus, Tobias Tiedemann, Michael Kroener and Martin Vehse*	93
23	Combining Urban Fleet Vehicle Operation with Reducing Energy Wastage in Light Rail Systems *Fiona McBride, Erica Ballantyne[2] and David Stone*	95

Theme: Policy, Economics and Social Acceptance of EVs
Location: Room 3/11

Paper ID	Presentation Details	Page
8	Long-haul Electric Truck Routing with Coordinated Driver Schedule and Charging Activities: When and Where to Charge *Xi Cheng and Jane Lin*	97
18	Establishment of the National Centre For E-Vehicle & Sustainable Technology (EVST) *Oliver Shaw, Ian Smith and Mark Busfield*	99
96	Optimizing Infrastructure for Large-Scale Electrification of Trucks: A Fixed Route Approach *Amir Davatgari, Taner Cokyasar, Anirudh Subramanyam, Jeffrey Larson, and Abolfazl (Kouros) Mohammadian*	101
19	How can Sustainable Business Models and Innovative Value Chains Accelerate the Transformation of Electric Vehicles? *Rudolf Schnee, Nathalie Kroichvili, Daniela Chrenko and Reiner Kriesten*	103
21	Attractiveness and Business Model Potential of the Spot Market Optimized Charging of Electric Vehicles *Valerie Ziemsky and Florian Biedenbach*	105

ORAL PRESENTATION 4

DATE: 22 JUNE 2023 | TIME: 14:50-15:50

Theme: Incentive and Promotion of EVs
Location:

Paper ID	Presentation Details	Page
5	Carrot or Stick? How Policy Type Influences Consumer Intention to Purchase Electric Vehicles *Shaherah Jordan*	107
39	The Ongoing Electrification In Public Fleet: Lessons Learned From The Public Safety Electrification Experience In Brazil *Márcio Almeida Có and Flávia Luciane Consoni*	109
77	An Overview on Charging Tariff Schemes and Incentives: The eCharge4Drivers Project *Evangelos Karfopoulos, Jaume Roca, Jaume Mata, Angel Lopez, Villy Portouli and Angelos Amditis*	111

Theme: Grid
Location: Room 3/03

Paper ID	Presentation Details	Page
35	Design of the Community-to-Vehicle-to-Community (C2V2C) for enhanced electro-mobility in photovoltaic energy-sharing building communities *Pei Huang*	113
64	The Role of EV Parking Lots for Supporting the Distribution System Operation Considering EV Uncertainties *Mahoor Ebrahimi, Mahan Ebrahimi, Miadreza Shafiekhah and Hannu Laaksonen*	115
82	Indicators for Providing Carbon Impact Feedback for EV Users *Nana Kofi Twum-Duah, Muhammad Salman Shahid, Lucas Hajiro Neves Mosquini, Frédéric Wurtz and Benoît Delinchant*	117

Theme: Sustainable Electric Vehicle Design and Operation
Location: Room 3/11

Paper ID	Presentation Details	Page
6	Application of Solid Oxide Fuel Cells on Hybrid Electric Vehicles Operating in Fleet *Giulia Sandrini, Marco Gadola and Daniel Chindamo*	119
14	Investigating the Impact of Electricity Rationing on Rural EV Charging *Thomas R. McKinney, Erica E.F. Ballantyne and David A. Stone*	121
24	Maximizing Wireless Power Transmission for Electric Vehicles with High-Intensity Laser Power Beaming and Optical Orthogonal Frequency Division Multiplexing *Jeongsook Eom, Gunzung Kim and Yongwan Park*	123

ORAL PRESENTATION 5

DATE: 22 JUNE 2023 | TIME: 10:50-12:30

Theme: Battery/Battery Management and Intermediate Storage
Location: Room 1/06

Theme: Smart Charging
Location: Room 3/03

Theme: Advanced Electric Vehicle Technologies and Components
Location: Room 3/11

ORAL PRESENTATION 6

DATE: 22 JUNE 2023 | TIME: 14:50-15:50

Theme: Social Acceptance of EVs
Location: Room 1/06

Theme: Smart Charging/V2G
Location: Room 3/03

Theme: Vehicle design/Efficiency and Performance
Location: Room 3/11

EVC2023

ABSTRACTS

Cyber Attack Detection for Integrated Onboard Electric Vehicle Chargers subject to Stochastic Charging Coordination

Ali Arsalan[1*], Laxman Timilsina[2], Grace Muriithi[3], Behnaz Papari[4], and Christopher S. Edrington[5]

[1,3,4]Automotive Engineering Department, Clemson University, South Carolina, USA
[2,5]Holcombe Department of Electrical and Computer Engineering, Clemson University, South Carolina, USA
*Corresponding author: aarsala@clemson.edu
Distribution A. Approved for public release; distribution unlimited. (OPSEC 7175)

Abstract – Power Electronic Systems (PESs) are the building blocks of onboard/offboard chargers and propulsion systems in smart EV infrastructure. These PESs are connected to an IOT-based communication network for coordinated control, thus devising an integrated cyber-physical system (CPS), which is highly vulnerable to cyber-attacks. The charging coordination algorithms having hundreds of EVs and associated charging sessions feed in a stochastic control input to onboard EV chargers. Hence, it results in a detection failure as it is most likely that a pure data-driven-based cyber-attack detection approach can assume a normal condition as an abnormality. Therefore, a model predictive control (MPC), incorporated with a data-driven learning network, is proposed in this paper with application to integrated onboard EV chargers. The proposed approach can effectively distinguish between the normal and tempered responses of the system addressing the aleatory behaviour of cooperative control while enhancing cyber-attack detection accuracy.

1. Introduction

With the increasing number of EVs, EV supply equipment (EVSE) employs efficient charging coordination algorithms with smartly distributed charging sessions [1]. These EVSEs can be generally categorized into on-board and off-board strategies. Integrated onboard chargers (IOCs) exploit the existing EV propulsion system components, such as motor winding and power electronic systems (PES). The increasing penetration of IoT-based EV infrastructure has made EV PES vulnerable to cyber-attacks. A compromised power converter in an IOC can overcharge or deplete the EV battery while destabilizing the normal operation of the energy management system (EMS). Generally, software-based cyber-attack detection is preferred for PESs. These detection algorithms can be subcategorized into model and data-based strategies. In the model-based approach, a physics-based parametric relationship of the system is used to predict the output and compared with the measured output to detect the intrusion [2]. In contrast, data-driven is the model-free approach that uses the system's output data to train a learning network, and abnormal conditions are detected based on the observed and predicted data. At the same time, the stochastic behaviour of EVSE charging coordination and EMS nonlinearities leads to training failure in pure data-driven approaches. Therefore, an MPC-based machine learning (ML) algorithm is proposed in this research to address this challenge while enhancing cyberattack detection accuracy.

2. Methodology

Direct Power Control (DPC) is considered an effective control technique for PWM-based power converters, which is integrated with model predictive control (MPC) via duty cycle optimization to obtain better steady-state performance [3]. The configuration of the three-phase voltage source PWM bidirectional traction inverter with a DPC-based control layer is shown in Fig. 1. The duty cycle for the active vector is optimized by considering the power error minimization objective function, resulting in the predicted values of active and reactive power. A residual vector is obtained by using the estimated values and the measured values from the sensor's feedback. The obtained residual is used as an input to train a long short-term memory (LSTM)-based learning network. The learning network is further connected with a fully connected layer to predict the class labels. Next, a SoftMax layer is used to obtain a uniform probability distribution for the predicted outputs, which is further connected to a classification layer to differentiate between normal and abnormal conditions.

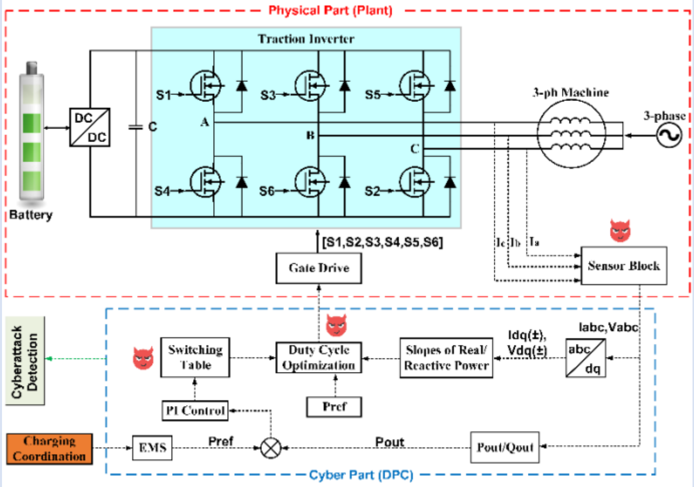


Fig. 1: Schematic of Integrated Onboard Charger for EV.

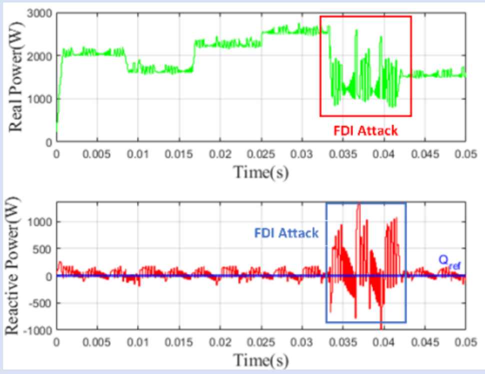


Fig. 2: Normal and FDI attack response.

3. Results and Discussion

To validate the proposed approach, various false data injection attacks will be applied on the most vulnerable blocks of the control layer of IOC, as shown in Fig.1. The impact of stochastic charging coordination on the real power of the traction inverter with different charging sessions is shown in Fig. 2. An FDI attack on the inverter's switching frequency is considered, which increased the power fluctuations resulting in a higher value of total harmonic distortion exceeding the maximum limit of 5%. A simple data-driven detection is most likely to fail in distinguishing between normal and abnormal conditions while considering normal conditions as abnormality due to a highly stochastic operation of IOC. In contrast, the proposed MPC-based ML approach has shown high accuracy for cyber-attack detection by training the learning network by using residual values from MPC rather than measured values.

4. Conclusion

In this article, an MPC-based ML approach is presented for cyber-attack detection under highly varying operating conditions of IOCs. The proposed approach performs better in cyber-attack detection than the standalone data-driven strategies. Despite the better efficiency, there is still a challenge to distinguish between cyber-attack and physical faults to enhance usability in practical scenarios.

Keywords: integrated onboard chargers; cyber-attack; machine learning; model predictive control

Acknowledgment

This work was supported by the Simulation-Based Reliability and Safety Program (SIMBRS) for modelling and simulating military ground vehicle systems under the technical services contract No. W56HZV-17-C-0095 with the U.S. Army DEVCOM Ground Vehicle Systems Center (GVSC).

References

[1] E. Gumrukcu, A. Arsalan, G. Muriithi, C. Joglekar, A. Aboulebdeh, M. A. Zehir, B. Papari and A. Monti, "Impact of Cyber-attacks on EV Charging Coordination: The Case of Single Point of Failure," in 2022 4th Global Power, Energy and Communication Conference (GPECOM), 2022.

[2] J. Giraldo, D. Urbina, A. Cardenas, J. Valente, M. Faisal, J. Ruths, N. O. Tippenhauer, H. Sandberg and R. Candell, "A survey of physics-based attack detection in cyber-physical systems," ACM Computing Surveys (CSUR), vol. 51, p. 1–36, 2018.

[3] Y. Zhang, C. Qu and J. Gao, "Performance improvement of direct power control of PWM rectifier under unbalanced network," IEEE Transactions on Power Electronics, vol. 32, p. 2319–2328, 2016.

Stochastic Modeling of Electric Vehicle Charging Behavior

Yao Tang[1], K.T. Chau[1*] and Tengbo Yang[1]

[1]Department of Electrical and Electronic Engineering, The University of Hong Kong, Hong Kong, China
*Corresponding author: ktchau@eee.hku.hk

Abstract – This paper develops a stochastic model to predict the electric vehicle (EV) charging behavior in which the personal characteristic in conjunction with the driving route and charging station (CS) location are considered. Firstly, the route and state-of-charge are initialized. Secondly, the demand of connection or disconnection with the charger is modeled. Finally, the accessibility of CS is considered to predict the charging behavior. The outcome includes when and where to charge, and the energy and duration of charging. Simulations are carried out to deduce the EV load profile in each CS and study the impact of driving anxiety on the charging demand.

1. Introduction

With ever increasing concern on environment, electric vehicles (EVs) have received attention worldwide [1]. An appropriate charging infrastructure is the key to accelerate the EV penetration. Thus, the EV charging behavior model is particularly essential for the deployment of EVs. Generally, relevant researches utilized the historical collected data to describe the drivers' charging habits [2]. However, different specifications limited the generalization ability, and the personal characteristic was neglected. Recently, a stochastic model was developed to deal with the above problems [3]. However, it assumed that the battery could be charged immediately, which was impractical. Therefore, in this paper, a stochastic model considering the personal characteristic in conjunction with the driving route and charging station (CS) location will be developed. The simulation results will show the EV load profile of each CS and investigate the impact of driving anxiety on the charging demand.

2. Methodology

The charging behavior model is depicted as Algorithm 1. Firstly, the accessible CS is calculated, which is the CS within a certain distance of the route. The next part is to iterate each node r_i to record the outputs. If there is no accessible CS after r_i, whether to charge at node r_i is determined by the state-of-charge (SOC) at the destination node, which ensures that the SOC at the end is still at the expected level. Then, predicting if there is any request to connect with the charger, if not, the SOC_i will be based on the time and energy consumed on the road; if yes, when there is a CS at the node r_i, the EV will be charged immediately. If the node does not have a CS, based on the accessible CS, select the CS with minimum extra distance to charge, and the CS along the route has higher priority than the one out of route. During charging, the time and SOC_i are recorded based on charging rate and duration. Therefore, by iteration, the EV demand profile in each CS can be calculated based on time and SOC information.

Algorithm 1 Charging behavior model

```
Input: Initial SOC, CS placement, departure time, route.
Output: arrival time, departure time, SOC_i in each road junction r_i.
1: Calculate accessible CS along the route.
2: for r_i in route R do
3:     if no accessible CS after r_i then
4:         calculate whether to charge based on SOC at the destination.
5:     else
6:         calculate whether to charge based on SOC at the node r_i.
7:     end if
8:     if request to connect to the charger then
9:         if CS in r_i then
10:            while not request to disconnect from the charger do
11:                record time and SOC_i.
12:            end while
13:            go to line 2.
14:        else
15:            Search accessible CS based on minimum extra distance; update route based on decided CS; record time and SOC_i; go to line 2.
16:        end if
17:    else
18:        record time and SOC_i; update accessible CS.
19:    end if
20: end for
```

3. Results and Discussion

The simulation is carried out on MATLAB. The number of routes is 5000, which are formed randomly. The initial departure time of route is generated based on peak hours: namely, 31.25%, 31.25% and 37% of routes are started from 7:00 to 9:00, 17:00 to 19:00 and other hours, respectively. The road map is shown in Fig. 1(a). The black and red nodes are road nodes and CSs, respectively. The darker colour along the links represents higher traffic flow. Fig. 1(b) shows the EV load profile. The peak demand appears around 13:00 and 21:00, and the trends of different CSs are similar. Also, it can be found that during peak hour, a certain number of EVs start their routes, so the demand also starts increasing. Therefore, in this model, the peak value of EV demand lags behind the peak hour of the EV initial departure time. Table 1 lists the charging demand values under different driving anxieties. The parameters x_q and x_p are introduced in [3] to describe the anxiety. Higher x_p indicates that EV drivers will charge more once connecting with a charger. Thus, the sum, average and standard deviation of power demand increase with higher x_p. Higher x_q indicates that the drivers will charge even the battery SOC is at a relatively sufficient level. Thus, the corresponding sum and average of power demand increase while the standard deviation decreases.

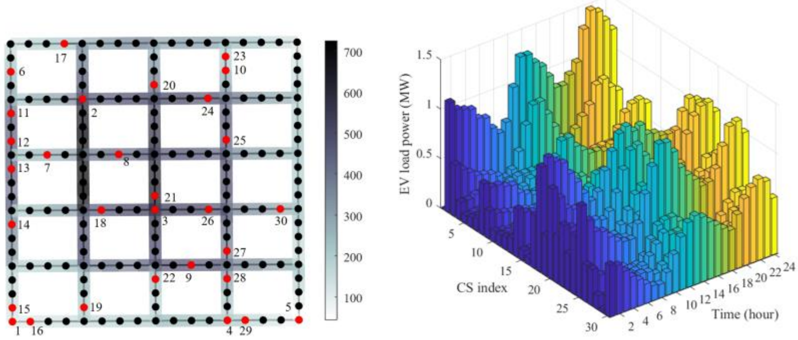


Fig. 1: Simulation results in 24 hours. (a) Road network and traffic flow. (b) EV load power of each CS

Table 1: Impact of driving anxiety on EV load profile

Parameter x_q	Parameter x_p	Sum (MW)	Average (kW)	Standard deviation (kW)
30	95	291.4	404.8	106.4
30	75	255.4	354.7	70.2
30	55	201.7	280.8	63.5
55	75	295.6	410.5	63.9
75	75	403.7	560.7	59.8

4. Conclusion

This paper proposes a charging behavior model of EVs considering the personal characteristic in conjunction with the route and CS location. The stochastic modeling is employed to predict whether connecting or disconnecting with a charger. The results show that the peak charging demand appears after the peak hour of EV initial departure time. Also, they illustrate that severe driving anxiety can significantly increase the EV charging demand.

Keywords: Electric Vehicle; Charging Behavior Modeling, Charging Station Placement.

Acknowledgement

This work was supported by a grant from the Hong Kong Research Grants Council, Hong Kong Special Administrative Region, China, under Project T23-701/20-R.

References

[1] K. T. Chau, Energy Systems for Electric and Hybrid Vehicles. The Institution of Engineering and Technology, 2016.

[2] J. Bollerslev et al., "Coincidence Factors for Domestic EV Charging From Driving and Plug-In Behavior," IEEE Transactions on Transportation Electrification, vol. 8, no. 1, pp. 808-819, 2022.

[3] Z. Fotouhi et al., "A General Model for EV Drivers' Charging Behavior," IEEE Transactions on Vehicular Technology, vol. 68, no. 8, pp. 7368-7382, 2019.

A Conceptual Representation of Real-Time and Long-Term Decision-Making in the Roll-Out and Exploitation of Public EV Charging Infrastructure in Neighbourhoods

Mylene van der Koogh[1* 2*], Emile Chappin[2*] Renee Heller[1*] and Zofia Lukszo[2*]

[1]Energy & Innovation, Faculty of Technology, Amsterdam University of Applied Sciences, NL
[2]Energy & Industry, Faculty of Technology, Policy and Management, Delft University of Technology, NL
*Corresponding author: m.l.van.der.koogh@hva.nl

1. Introduction

The Netherlands is one of the leading countries in public charging infrastructure, and they expect their electric vehicle (EV) fleet to grow to 1.9 million by 2030, which is translated into a need for up to 1.7 million charging points in the upcoming years [1]. In the initial roll-out of Dutch public EV infrastructure, strategies were straightforward. Charging points were installed based on citizen requests, or spread out over an area to anticipate new adoption. In later stages, the data of existing charging points was used to determine effective expansions of the charging network. Because of future policy, the adoption of new electric vehicles is expected to be high. Barriers such as limited electricity grid capacity and parking vs charging challenges could hamper this fast adoption. There are different solutions that we can apply to facilitate this new adoption. Existing infrastructure can be equipped with smart charging and V2G, which take into account grid conditions. External batteries can buffer surplus electricity and help manage demand during peak hours. New charging infrastructure can be installed, and grids can be expanded, although grid expansions are considered an intensive procedure. This scale-up also brings challenges. Charging demand will only grow, whereas resources and personnel are limited. This is why new strategies to develop and prioritize areas should be investigated. We intend to study the roll-out and decision mechanism strategies using a data informed agent-based model representing a large variety of neighbourhoods in the Netherlands. In this study, we conceptualize a decision-making mechanism for the future roll-out of EV charging infrastructure, our main question being *'How can the decision landscape of EV infrastructure roll-out be represented to simulate charging management strategies in neighbourhoods?'*

2. Methodology

Goal: The goal is to represent the decision landscape for the various stakeholders involved in the rollout of the charging infrastructure, so that it can be implemented in an agent-based model. The model aims to explore how the infrastructure can be adjusted and resources can be divided over multiple neighbourhoods, taking into account different goals, adoption rates, grid conditions and the costs- and scarcity of resources in a neighbourhood. This enables an assessment of the emerging patterns, such as charging satisfaction, spillover effects and equity.
Data: Available data for this project includes charging session data (location, time, kWh, charging speed) of four large Dutch municipalities [2], sample meter data of medium voltage transformer stations from a local grid operator, and open neighbourhood data (socio-economic, environment, facilities) from the Dutch Central Bureau of Statistics [3].
Approach: To conceptualize the decision landscape of EV infrastructure roll-out and management, we follow these steps:

1. Identify the important stakeholders, indicators and solutions in managing EV charging scale-ups (literature & previous study)
2. Conceptualize the relationships using a flow diagram
3. Summarize the interactions using logic and behaviour rules (literature)
4. Analyse data to determine location parameters, finetune settings, grid parameters, and charging distributions (data analysis)
5. Implement the outcomes of the above steps in a software environment for validation and future simulation purposes (not in this part of the study)

3. (Expected) Analysis

The model implements the charging management strategies in Table 1, which were inspired by literature, other projects, and a previous study where we interviewed stakeholders [4].

Table 1 : Charging management strategies that were selected to explore in the model

Real-time (daily loop)	Long-term (policy loop)
Smart charging, Vehicle-to-Grid,	Update Charging Points, Roll-out of (new) Charging Points
Use external battery, DC / Fast charging	Install external battery, Grid expansions
Reject session	Do Nothing

The decision-making process to manage EV infrastructure scale-up contains two different loops:
Short-term (every 15 minutes) This loop consists of four important steps for each neighbourhood:

1. decoupling previous charging sessions (based on state of charge (SoC) and dice-roll)
2. connect new sessions to the nearest charging point that is not occupied
3. select a charging protocol based on grid capacity, occupancy rates, SoC, user and charging point constraints. Update existing charging sessions with new protocols if necessary.
4. Update lists (capacity, occupancy, SoC, enabled protocol)

Fig 1: visual aid of neighbourhood structure in the model with example parameters

Policy loop (once a year) During the policy loop, each neighbourhood is governed by an 'administrator' (in reality, a joined effort of the local policy maker, grid operator and charging point operator). Administrators receive a ranking based on their needs (occupancy, failed sessions, spillover, and capacity). There are limited resources available, and all administrators pick a resource one-by-one until the bucket is empty. Administrators of underdeveloped areas (low previous investment, low number of charging points) will eventually be prioritized, regardless of occupancy rates and failed sessions.

4. (Expected) Results

The results of the conceptualization include logical rules, distributions of parameters, parameter settings and flow diagrams based on a combination of real data and results from the literature. This conceptualization can be used in the future initialization and simulation of the decision mechanisms in rolling out and using EV charging infrastructure. The authors have since started working on this initialization in an agent-based NETLOGO model, and expect to show preliminary results during the conference.

Keywords: electric vehicle charging, energy policy, energy transition

Acknowledgement
This study is part of the NWO-funded Future Charging Project (RAAK.PRO03.128).

References

[1] Rijksoverheid. (2022). Government stimulates environmental-friendly driving [Accessed: 2023-01-26]. https://www.rijksoverheid.nl/onderwerpen/auto/overheid-stimuleert-milieuvriendelijker-rijden
[2] Maasse, S., van den Hoed, R. (2019). Charging Data Management , five issues to solve. *EVS 2019 - 32nd International Electric Vehicle Symposium and Exhibition, May, Lyon, France*
[3] Central Bureau of Statistics (2022) Key statistics neighbourhoods 2004-2022 [Accessed: 2022-12-01] https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/wijk-en-buurtstatistieken
[4] van der Koogh, M., Chappin, E., Heller, R., Lukszo, Z., (2022). Stakeholder prioritizations for electric vehicle charging across time periods *3rd International Conference on Energy & Social Science : Energy and Climate Transformations, June, Manchester, UK*

Possibility of Reducing the Effects of Harmonic Distortion in Fast Charging Technologies for Electric Vehicles

Emmanuel Mudaheranwa[1,2*], H. Berkem Sonder[1], Carlos Ugalde Loo[1], and Liana Cipcigan[1]

[1]School of Engineering, Cardiff University, United Kingdom
[2]Integrated Polytechnic Reginal College Karongi, Rwanda Polytechnic, Rwanda
*Corresponding author: mudaheranwae@cardiff.ac.uk

Abstract – Connecting a significant range of electric vehicles (EV) to the grid, especially for the purpose of rapid recharging, may give rise to a number of technological challenges or may have substantial effects on power networks, such as the introduction of harmonic components. If there are large number of EVs all receiving rapid charging during the same moment, the permissible normal range for voltage profile distortion is likely to be exceeded. A viable option for charging electric cars is to do so with photovoltaic energy. The purpose of this paper is to introduce an advanced control of PV inverters when they are being employed as active filters. Simulations have shown that the suggested control works effectively. The findings during simulations prove that by implementing the suggested regulations framework, the overall harmonic distortion (THD) of both voltage and current is brought down to levels that are acceptable by industry standards.

1. Introduction

The total harmonic distortion of the supply voltage, which includes all harmonics up to the 40th, need not to be above 8% in order to comply with the requirements of the standard EN 50160 [3]. Because of the considerable current, rapid chargers have a significant effect on the voltage quality, particularly at the point of connection. This is in particular the case when the battery is first being charged [4].

Considering that the price of oil, petrol, gasoline, coal and gas, and electricity is all on the rise, investing in a photovoltaic energy system is one approach to stabilize these costs over the long term. The application of photovoltaics as a charging method for EVs is an effective solution. During the day, when solar energy generation is at its peak, rapid charging for electric vehicles is typically utilized. A PV power plant is something that can be built in a fuelling station and has the potential to supply a variety of auxiliary services.

In this work, an improved mechanism is introduced in to minimize harmonics introduced by EV rapid chargers. This control makes use of the PV inverter in order to function as an active filter.

2. Methodology

A rapid charging system for EVs is shown in Fig. 1a, complete with five fast chargers for these vehicles. A line cable of one hundred meters in length and a transformer rated at 250 kVA and 20/0.4 kV are used to connect the rapid charging station to the network. At the same location as the charging station, a photovoltaic power plant with a capacity of 43 kW has been erected. The photovoltaic system needs to be outfitted with a high switching frequency charger in order for it to have the capability to correct for high order harmonics. This photovoltaic inverter is being utilized to reduce the amount of harmonics that are being produced by fours electric vehicles chargers.

The design of the battery charger depicted in Fig.1b, is made up of two segments: a DC/DC converter that is bidirectional and a DC/AC converter. The DC/DC converter is utilized in this investigation as a bidirectional chopper to facilitate the charging of the battery. A connection has been made between the 3-phase Voltage Source Inverter and the utility grid. To reduce the impact of the grid current's high frequency band, an EMI filter is utilized.

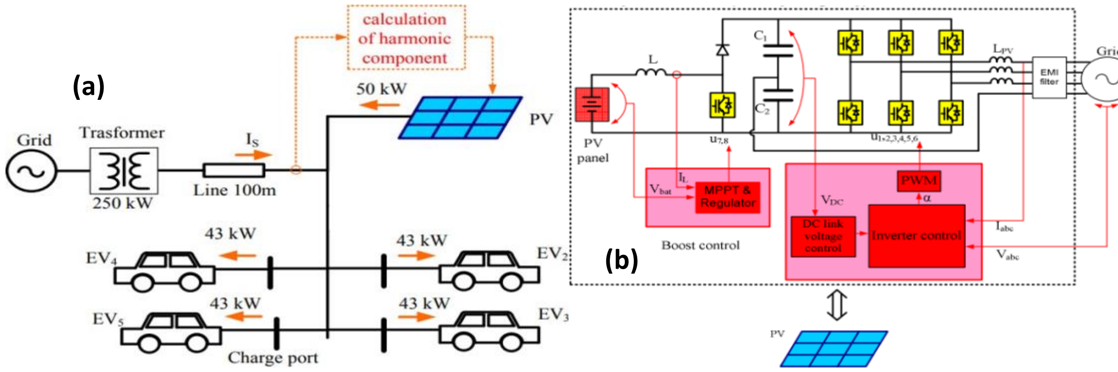


Fig.1: 1a: A group of 4 EVs equipped with a rapid charging station and a photovoltaic system, 1b: PV system topology and control structure

3. Results and Discussion

The value of currents and voltage that was recorded at the bus both with as well as without suggested regulation is shown in Fig.2. It demonstrates that the suggested control method, which makes use of PV inverter, is obviously effective in mitigating the harmonics compositions.

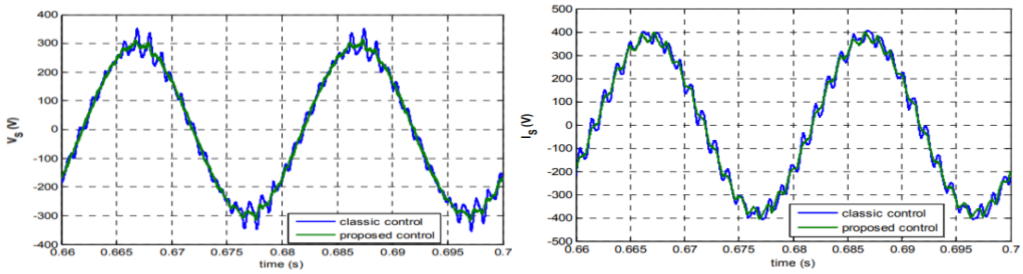


Fig. 2: Voltage measured at bus with and without the proposed control (left). Total current measured at bus S with and without the proposed control (Right)

4. Conclusion

The filtering of harmonics through the utilization of the suggested control is undeniably helpful. The results of a number of simulations have borne up the validity of this approach to problem solving. On the other hand, there is a concern over the switching losses that may be incurred by the battery chargers as a result of the active filtering process. In the realm of energy conservation, future work will put the efforts to determine how, where, and what type of vehicle is capable of maintaining the performance.

Keywords: fast charging; harmonic distortion; solar energy

Acknowledgement

This work was supported by DT E Network+, funded by EPSRC, grant reference EP /S032053/1.

References

[1] Start, D. J. (1995, November). A review of the new CENELEC standard EN 50160. In IEE Colloquium on Issues in Power Quality (pp. 4-1). IET.

[2] Laurent J. Masson, “Fast Charging an EV: AC/DC Questions and Renault's Answers”, November 21, 2012.

12 Pulse High power Active Rectifier for Electric Vehicle Charging

MohamadTaha[1*], Ali M. A. Almaktoof [2]

[1]Electrical and Computer Engineering Department Rafik Hariri University Lebanon
[2]Faculty of Engineering- Cape Peninsula University of Technology- South Africa
*tahamh@rhu.edu.lb

Abstract – Cars industry pushes very fast toward Electric Vehicle (EV). AC to DC charging station leads to big challenges for the power grid due to the heavy stress caused by electric powered vehicle, especially when many vehicles are loading their accumulators simultaneously. The commercial success of electric vehicles (EVs) relies heavily on the presence of high-efficiency charging stations with low harmonics and good power factor. To improvise the power factor and to boost up the output voltage, this paper presents analysis study and a simulation model of 12 Pulse High Power AC/DC Active Rectifier for EV charging stations. In this study, 12 pulse AC-DC converter topologies, providing bidirectional power flow, and plays a double role as ac/dc converter for power factor correction and as well as dc converter for output regulation. This converter circuit is simulated using PSIM software and results been observed. The simulation results in different conditions of operation are presented to highlight the feasibility and advantages of the proposed active rectifier for electric vehicle charging, where the EV charger meets the requirements of high efficiency, high output voltage and good power quality with low THDs.

1. Introduction

The modern cars industry, EV is growing very fast and DC supply will play an important part in charging stations. In the transportation electrification, the pure electric vehicles (EVs) are becoming an emerging technology and power sector because of their zero emission. In EV, Power Electronics segment plays a very important part in controlling the energy and improving power quality. EVs have been enhanced significantly to allow for a long driving range using novel battery technologies and fast-charging stations. The growth of the EV market has led to the significant issues of coming up with novel and innovative ideas to charge them [1–3]. Conventional 12 pulse rectifier using Diode Bridge one of the simplest converters since does not require any control loop, however, this type of converter has a fixed DC output with high THD in the input current compared with the proposed 12 Pulse Active Rectifier. The system has the ability to stabilize variable output voltage. Using a decoupling feed-forward control method by DQ frame technique, the magnitude and the phase of the input current can be controlled and hence the power transfer that occurs between the AC and DC sides can also be controlled. The design of this system poses significant challenges due to the nature of the load range and requires many features such as [4]:

1. Sinusoidal and low harmonics contents on supply current.
2. High input power factor must be achieved to minimize reactive power requirements.
3. Power density must be maximized for minimum size and weight.

2. Methodology

12 pulse diode rectifier is fed from three phase star connected transformer on the primary side, star and delta transformers on the secondary side . Each transformer on the secondary side feeds a three phase 6 pulse rectifier and they add together to form a 12 pulse rectifier, this configuration gives 30 degrees of phase shift which gave perfect harmonic cancelation. In three phase 6 pulse rectifier the dominated harmonics are the 5^{th} and 7^{th} and this why THD is quite high. With 12-pulse arrangement, the 5^{th} and 7^{th} harmonics are cancelled. The series has harmonics of an order of $12k\pm1$ and the harmonics current of orders $6k\pm1$ (k is an odd number) circulate between the two converter transformers but do not penetrate the grid power system network. Since the magnitude of each harmonic is proportional to the reciprocal of the harmonic number, therefore the 12 pulse rectifier has a lower THD. For further THD reduction, 12 Pulse Active Rectifier could be used, this is shown in Figure (1).

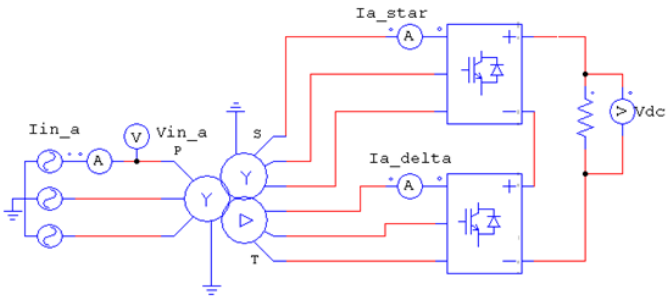


Fig. 1. AC/ DC 12 pulse boost converter

3. Results and Discussion

As primarily simulation, Figure 2 shows the current and voltage waveforms for the of phase (a) and the DC voltage. Many advantages are associated with this type of converter:

-The power factor could be controlled by using DQ vector control.

-THD is very low.

-Bidirectional power flow

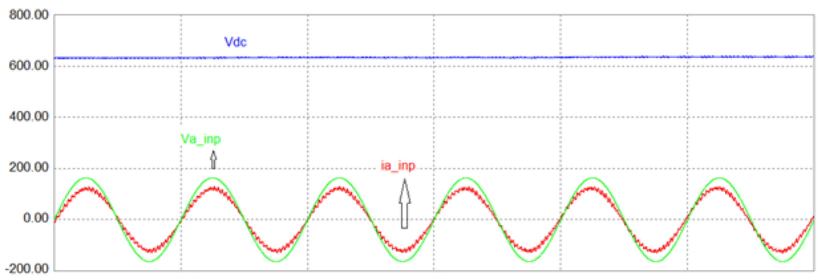


Fig. 2 current and voltage waveforms for the of phase (a) and the DC voltage

4. Conclusion.

With the future use of advanced power electronic 12 pulse active rectifier gives a very good beneficial approach within EV charging stations. Low frequencies current harmonics could be eliminated and there is the possibility to operate the rectifier at variable power factor in order to provide system level benefits. and keeping the input current harmonics low.

Keywords: THD, Active rectifier, Boost converter, Power factor, Vector control

Acknowledgment

Authors wish to acknowledge support and encouragement from Rafik Hariri University - Lebanon and Cape Peninsula University of Technology- South Africa.

References

[1] Kesler M, Kisacikoglu MC, Tolbert LM (2014) Vehicle-to-grid reacative power operation using plug-in electric vehicle bidirectional ofboard charger. IEEE Trans Ind Electron 61:6778–6784

[2] Xu NZ, Chung CY (2016) Reliability evaluation of distribution systems including vehicle-to-home and vehicle-to-grid. IEEE Trans Power Syst 31:759–768

[3] Yilmaz M, Krein PT (2013) Review of the impact of vehicle-to grid technologies on distribution systems and utility interfaces. IEEE Trans Power Electron 28:5673–5689

[4] *Sangeeta Sarali D*, Shailaja P. *Mitigation* Of. Harmonics Using Thyristor Based 12 Pulse. Voltage Source PWM Rectifier. In: IJRET Volume 1 Issue 3, Nov 2012 , p 267-271

Integrated Cooling/Hvac System Design and Control Strategy for Reconfigurable Light Electric Vehicle

Daniele Chiappini[1*], Pere Canals[2], Laura Tribioli[1] and Gino Bella[1]

[1]University of Rome Niccolò Cusano, Italy
[2]Applus+ IDIADA, Spain
*Corresponding author: daniele.chiappini@unicusano.it

Abstract – In the recent panorama, the use of conventional passenger vehicles has been discouraged from European level up to local municipalities. "Reconfigurable light electric vehicle" REFLECTIVE project targets at developing a light, fully electric vehicle capable of performing safely, efficiently, and multifacetedly in urban environments. By this way, it would be possible to fill the gap with the final user perception and electric vehicles market penetration. Moreover, in order to improve occupants' comfort, HVAC system has been considered as well, a feature which is not usually implemented in such a kind of vehicle. This paper will show results obtained for the integrated cooling/HVAC circuits in terms of energy efficiency and occupants' comfort, with particular focus on proper battery operations. The battery thermal management is integrated into the HVAC, indeed.

1. Introduction

The main features in terms of innovation of REFLECTIVE project have been already presented in a previous publication, [1]. For the sake of brevity these will not be here presented. Thus, this paper deals with the analysis, design and control strategy optimization of an innovative integrated cooling/HVAC system for a light electric vehicle (developed within the H2020 framework – REFLECTIVE). The main idea is to integrate the battery thermal management system with the HVAC used to guarantee comfort into the cabin. Thus, a specific control logic has to be implemented in order to contemporary assure occupants' comfort and battery life duration. In addition, due to unavailability of heat from internal combustion engine, a dedicated heater circuit has to be implemented. In order to reduce energy consumption at the PTC branch, a recuperator heat exchanger has been considered, so to recover the heat at the powertrain output. Thus, the hot coolant flowing out the e-motor will be sent to the recuperator in order to heat-up the liquid at the PTC branch, in order to reduce battery energy consumption. Obtained results are definitely encouraging. In fact, significant energy saving can be achieved through the use of the recuperator during driving and the battery thermal management can be fruitfully fulfilled without the need of a specific circuit, only by using conditioned air from the HVAC/cabin section.

2. Methodology

The first steps of the activity have been devoted to the definition of the thermal loads and needs. In fact, the cooling circuit has to guarantee the proper operating conditions for a set of sub-systems, namely, conductive and wireless charging and powertrain assembly. While the HVAC system has been used both to guarantee the comfort at the cabin, having evaluated all the loads, [2], and the battery proper temperature maintenance. After having fixed all the needs and constraints for the different sub-systems, several circuit configurations have been analyzed. At the end, the circuit layout depicted in the following Figure 1 has been proposed.

3. Results and Discussion

Different working conditions have been considered in order to test and develop the control strategy of the proposed system. Namely, these are charging during winter and summer and driving during winter and summer. Constant vehicle speed (50 km/h) at maximum load have been considered so to simulate the worst-case scenario. For the sake of brevity, only one synthetical figure will be reported in the following. More specifically, Figure 2 depicts the cabin and battery temperature during winter operations (0 °C of ambient temperature).

As one can note, the battery, after having passed the initial heating transient, safely operates in between 25 °C and 30 °C. The cabin, on the other hand is warmed up to a comfort temperature of 24 °C. However, when cooling is needed at the battery, the HVAC flow is addressed to the battery, which has the priority. However, after having cooled down the battery, the cabin heating can be started again.

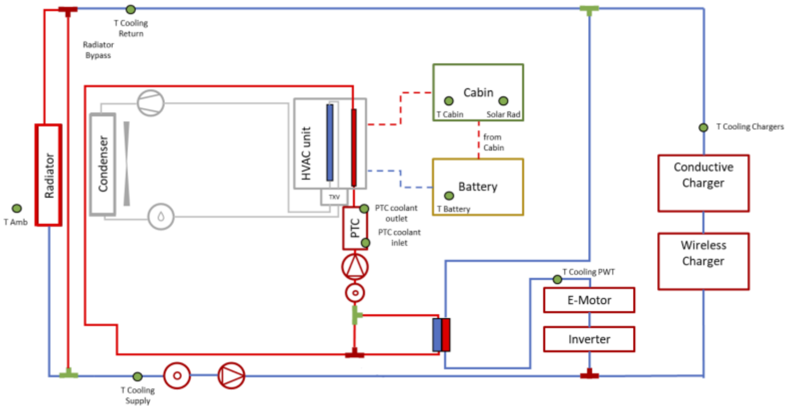


Fig. 1: Combined Layout configuration for REFLECTIVE cooling/HVAC systems.

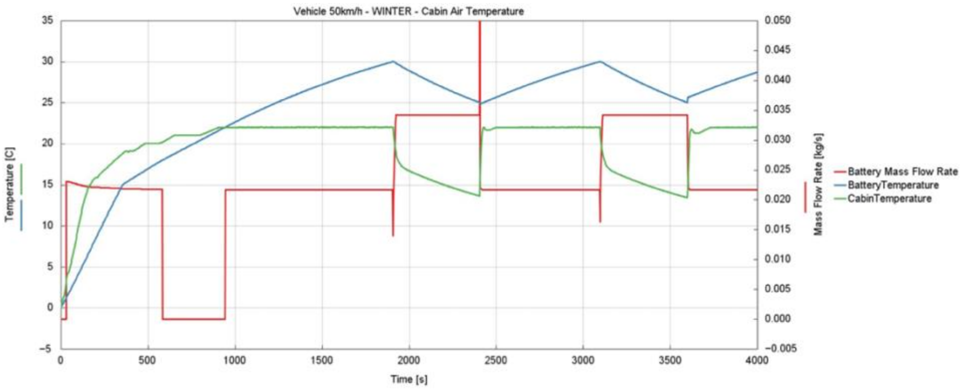


Fig. 2: Temperature evolution at battery and cabin during winter scenario driving.

However, it is important to point out that both the battery and the powertrain are generating the maximum heat possible during the whole simulation, with apparent penalization with respect to the real driving conditions.

4. Conclusion

This preliminary work shows the effectiveness of the developed coupled cooling/HVAC system. Further analysis will highlight results for an opportunely designed urban driving cycle, so to fully exploit the benefit of such an approach.

Keywords: Cooling System; Battery Thermal Management; Electric Powertrain; HVAC System; Energy efficiency.

Acknowledgement
This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 101006747.

References

[1] Pippuri-Mäkeläinen, J., Tribioli, L., Chiappini, D., Pasqualino, P. et al., Transforming Urban Transportation via Safe, Innovative Light Vehicles, SAE Technical Paper 2022-24-0001, 2022.
[2] Mendecka, B.M., Chiappini, D., and Bella, G., Cooling Performance of an Modified R744 Air Conditioning System with Vortex Tube and Internal Heat Exchanger for an Electric Vehicle, SAE Technical Paper 2021-24-0098, 2021.

Maximization of Energy Recovery Under Braking Through an Appropriate Regenerative Braking Logic Which Takes Into Account the Locking Limit of the Wheels

Giulia Sandrini[1*], Daniel Chindamo[1] and Marco Gadola[1]

[1]Department of Mechanical and Industrial Engineering, University of Brescia, I-25123 Brescia, Italy (G.S.: g.sandrini005@unibs.it; D.C.: daniel.chindamo@unibs.it; M.G.: marco.gadola@unibs.it)
*Corresponding author: g.sandrini005@unibs.it

Abstract – This extended abstract presents a regenerative braking logic to be adopted on full electric vehicles with front, rear-drive or all-wheel drive with one motor for each axle, which aims at maximizing energy recovery under braking, avoiding wheel locking thus preventing vehicle instability. The logic implies the adoption of a brake-by-wire system i.e. the hydraulic braking system can be activated independently from the brake pedal. As a matter of fact with the pedal pressed, the logic gives priority to the braking action of the electric motor(s) which acts as a generator, thus maximizing energy recovery, however taking into account various limitations, including the wheel locking limit, ensuring the stability of the vehicle. When the electric motor cannot satisfy the regenerative torque request, braking is integrated with the help of the hydraulic brakes, whose contribution aims to bring the braking towards a condition of optimal braking distribution. The front and rear hydraulic systems must therefore be independent of each other and controllable separately. This logic was tested via simulation, and it emerged that, on the WLTC driving cycle, the logic saved about 30% in consumption compared to the same vehicle without regenerative recovery, and about 23% compared to a logic commonly adopted on the market. On cycle US06, it saves about 24% and 19%, respectively.

1. Introduction

A strong limitation of full electric vehicles is the limited range compared to traditional internal combustion engine vehicles. For this reason, it is very important to manage energy on board the vehicle in the best possible way, minimizing consumption and maximizing energy recovery when braking. The adoption of a suitable regenerative braking logic is therefore essential for increasing the range of the electric vehicle without increasing the vehicle weight by increasing the capacity of the battery pack.

In this work a regenerative braking logic (RB logic) is therefore presented, which aims at maximizing the use of the regenerative motor torque during braking, minimizing the action of traditional brakes which dissipate energy. The RB logic is a MATLAB/Simulink model that can be adopted on full electric vehicles with front, rear-drive or all-wheel drive with one motor for each axle, which aims at maximizing energy recovery under braking, avoiding wheel locking and the related vehicle instability.

The RB logic was tested using VI-CarRealTime software and the TEST model described in [1].

2. Methodology

The RB logic maximizes the energy recovery by giving priority to the action of the electric motor(s) during braking and then integrating the braking action with the traditional hydraulic system, taking into account various limitations (wheel lock limit, motor limitations, battery pack limitations) and ensuring the vehicle stability, according to the diagram presented in Fig. 1. Model inputs are the brake demand, the longitudinal vehicle deceleration, the lateral vehicle acceleration, the vehicle speed, the angular velocity of the wheels and of the motors, the battery voltage, the maximum charging current of the battery pack. The RB logic, from these inputs, starting from the brake demand imposed by the driver, calculates the following outputs: the front and rear brake pressure, and the front and rear motor torque. On the front and rear wheel drive vehicle, the RB logic gives priority to the braking action of the electric motor which acts as a generator, thus maximizing energy recovery, however taking into account the above-mentioned limitations. When the electric motor cannot satisfy the regenerative torque request, due to limitations of the motor itself or due to the locking limitation of the drive axle wheels, braking is integrated with the hydraulic brakes, whose contribution aims to bring the braking towards a condition of optimal braking distribution. In the case of an all-wheel drive vehicle, the regenerative torque will be distributed between the two motors in such a way as to satisfy the optimal braking distribution, in the event that this does not clash with the possibility of maximizing energy recovery, otherwise the braking torque bias will be moved towards an axle, always avoiding the instability of the vehicle. For its operation, the logic implies a brake pedal independent of the traditional hydraulic braking system and a front and a rear hydraulic system independent of each other and controllable separately.

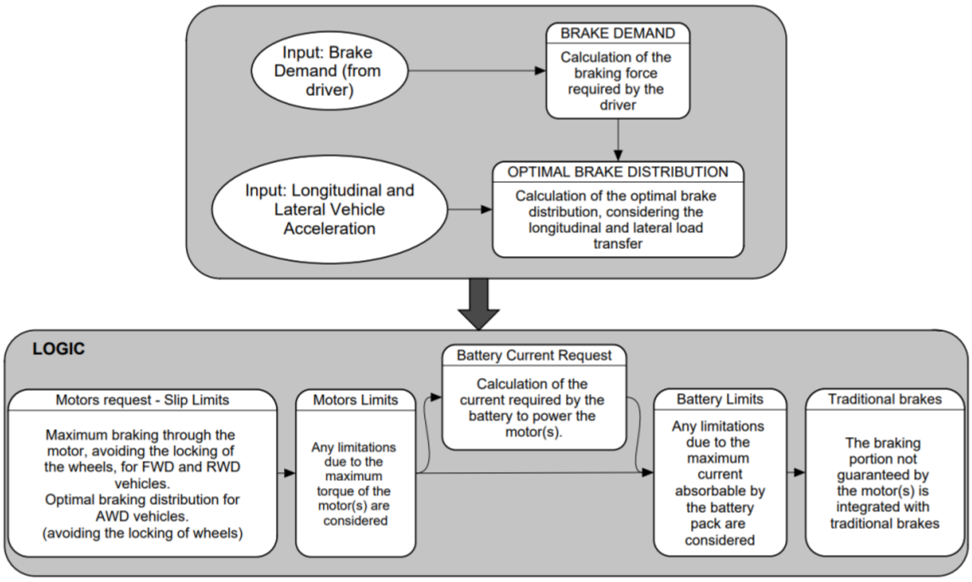


Fig. 1: Structure of the regenerative braking logic. For more calculation detail see paper [2].

3. Results and Discussion

The simulation tests carried out with VI-CarRealTime have shown that the RB logic does not compromise the original stability of the vehicle, while from the simulation carried out through the TEST model described in [1,2] it emerged that, on the WLTC driving cycle, for front, rear and all-wheel drive vehicles, the logic saved between 29.5 and 30.3% in consumption compared to the same vehicle without regenerative recovery, and 22.6–23.5% compared to a logic commonly adopted on the market [1]. On cycle US06, it saves 23.9–24.4% and 19.0–19.5%, respectively. The RB logic performs better in terms of energy savings on relatively mild cycles (WLTC) compared to more intense cycles (US06).

4. Conclusion

The RB logic aims at maximizing energy recovery, giving priority during braking to the electric motors which act as generators, avoiding vehicle instability and bringing the system into optimal braking distribution condition by approaching this latter condition. Thanks to this logic, it is possible to obtain energy savings of around 20%, which varies according to the vehicle and the driving cycle considered.

Keywords: regenerative braking logic; electric vehicle; energy optimization; energy recovery; vehicle stability.

References

[1] G. Sandrini, M. Gadola, D. Chindamo, Longitudinal dynamics simulation tool for hybrid APU and full electric vehicle, Energies (Basel), 14, 2021. https://doi.org/10.3390/en14041207.

[2] G. Sandrini, D. Chindamo, M. Gadola, Regenerative Braking Logic That Maximizes Energy Recovery Ensuring the Vehicle Stability, Energies (Basel), 15, 2022. https://doi.org/10.3390/en15165846

Calculation and Analysis of Heat Load of Automotive Air Conditioning

Xuefeng Lin[1], Weiwei Zhao[1], Tongtong Zhang[1], Song Yang[1] and Yulong Ding[1*]

[1] Birmingham Centre for Energy Storage & School of Chemical Engineering, University of Birmingham, Birmingham, B15 2TT, United Kingdom
*Corresponding author: y.ding@bham.ac.uk

Abstract – As an important part of the automotive auxiliary system, the automotive air-conditioning system consumes a considerable portion of the power of the fuel engine or power battery. In order to reasonably design the refrigeration capacity of air conditioning, it is very important to determine the heat load of the vehicle. This paper takes a Hyundai SUV as a research object to introduce the source of heat load and an empirical load calculation method and to compare and analyze the load under typical weather conditions in summer and winter under urban conditions. The calculation results show that vehicle speed and intensity of solar radiation and temperature difference between the inside and outside of the passenger compartment are the most important influencing factor.

1. Introduction

The car air conditioner is used to regulate the temperature, humidity, airflow speed, etc. in the car. In order to ensure that the passenger compartment is in a more comfortable environment, the heat load calculation is essential when designing a certain type of air conditioner in the vehicle. The heat exchange between the car compartment and the outside environment is carried out through three ways: heat conduction, convection, and radiation[1]. Due to the ever-changing external conditions, the vehicle motion state is also changing constantly, and the heat transfer between each other is in an unstable state, so it is very difficult to accurately calculate the vehicle heat load. In this paper, the steady-state heat load calculation method is used to calculate the heat load of Hyundai KONA SUV.

2. Methodology

Due to the complex and changeable use environment and conditions of vehicles, there are many sources of heat load in vehicles[2]. In general, the heat load in the vehicle includes the heat transfer through the body glass, the vehicle enclosure, the engine compartment, and the heat load generated by the passengers, electrical appliances, and fresh air in the vehicle, expressed as,

$$Q_T = Q_G + Q_B + Q_U + Q_P + Q_A + Q_S$$

where, Q_T is the total heat load in the vehicle, in W; Q_G is the heat transferred into the vehicle through the glass, in W; Q_B is the heat transmitted through the vehicle enclosure, in W; Q_U is the heat from the engine compartment, in W; Q_P is the heat generated by passengers in the vehicle, in W; Q_A is the heat brought by the inflow air, in W; Q_S is the heat generated by the electrical appliances in the vehicle, in W.

3. Results and Discussion

Take Hyundai KONA as the model vehicle, obtain the thermal conductivity, convective heat transfer coefficient and vehicle related calculation dimensions of various materials required for calculation through vehicle engineering manuals and reference materials, and substitute the calculation parameters into the calculation formula to obtain the results.

Figure 1 shows the influence of the speed of 36km/h, the solar radiation intensity of 730W/m^2, the indoor temperature of 18 ℃ and the outdoor temperature of 30 ℃ on the heat load. The factors with the largest heat load are the heat transfer of the vehicle enclosure structure, the heat transfer of the vehicle glass and the heat transfer of the fresh air.

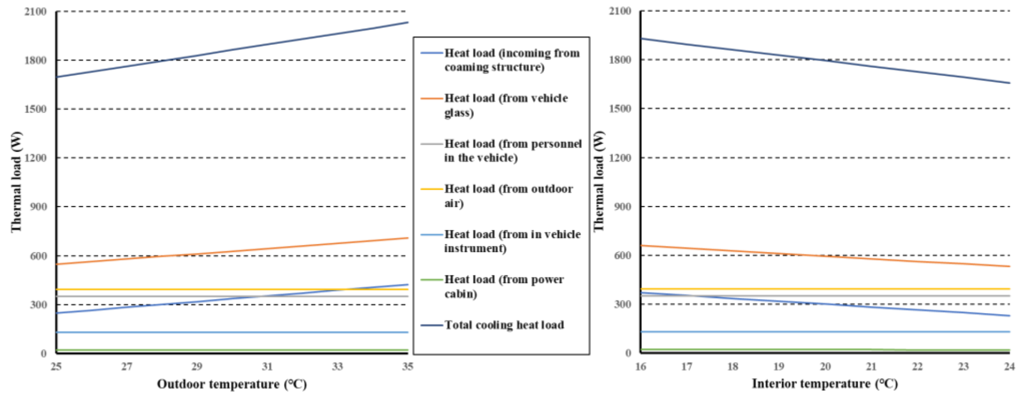


Fig. 1: Effect of outdoor temperature and Interior temperature on cooling heat load

Figure 2 shows the composition of the heat load inside the car with different solar radiation intensity. The indoor and outdoor temperatures are 18 ℃ and 30 ℃ respectively, and the vehicle speed is 36km/h. When the solar radiation intensity increases, the heat transfer load of the car glass increases significantly. In addition, when the outdoor temperature is significantly lower than the indoor temperature, the change of solar radiation intensity has the greatest impact on the heat transfer load of fresh air.

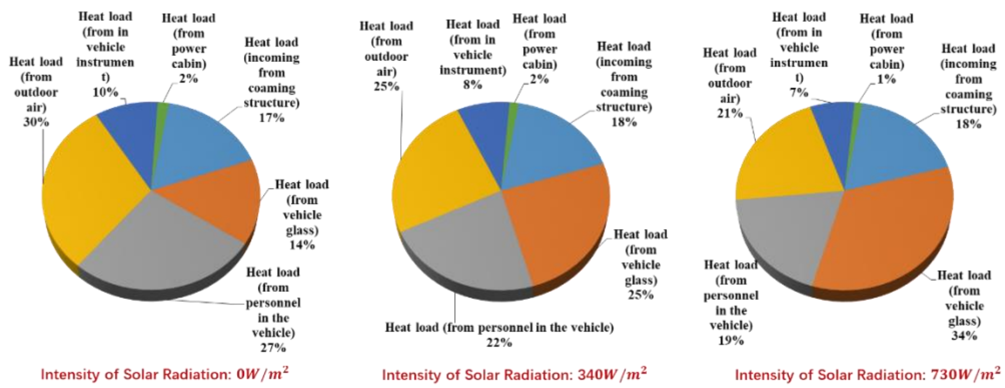


Fig. 2: Effect of intensity of solar radiation on cooling heat load (Night, Cloudy, Sunny)

4. Conclusion

[1]. The main sources of heat load in the vehicle are the heat transfer of the vehicle envelope, the heat transfer of the vehicle glass and the fresh air load. The use of glass film with low solar transmittance and body thermal insulation materials with low thermal conductivity can reduce the heat load and effectively control the heat source;

[2]. The solar intensity, vehicle speed and temperature difference inside and outside the vehicle are the main factors affecting the heat load inside the vehicle.

Keywords: automobile air conditioning; heat load; calculation and analysis; air conditioning design.

Acknowledgement

Thanks for the guidance of Professor Yulong Ding and the help of Dr. Weiwei Zhao, Dr. Tongtong Zhang, Dr. Song Yang, as well as the financial support of Birmingham Centre for Energy Storage.

References

[1] Jha K K, Bhanot V, Ryali V. A simple model for calculating vehicle thermal loads[R]. SAE Technical Paper, 2013.

[2] Vinofer B P, Rajakumar S. Cooling load calculation and design of air conditioning system in automobile[J]. International journal of research in social sciences & humanities, 2016, 6(1): 94-103.

Evaluation of the Environmental Benefit of an Eco-Design Strategy on the Life Cycle Assessment of a Permanent Magnet High Speed Electric Motor

Filippo Giolito[1], Antonella Accardo[1*] and Ezio Spessa[1]

[1]Dipartimento Energia "Galileo Ferraris", CARS@Polito, Politecnico di Torino, c.so Duca degli Abruzzi 24, 10129 Torino, Italy;
*Corresponding author: antonella.accardo@polito.it

Abstract – First, a permanent magnet high speed electric motor is identified as a baseline for the study. Then, a cradle-to-grave environmental life cycle assessment of the baseline electric motor is conducted based on primary data. Second, an eco-design strategy focused on weight reduction is performed and the environmental life cycle assessment of the eco-designed electric motor is conducted. The environmental impacts of the two electric motors are compared and the environmental savings are quantified. Preliminary results obtained for the baseline show that the use stage is the main contributor in almost all the impact categories except the category related to resource use, minerals and metals where raw material acquisition and processing stage is the main contributor.

1. Introduction

With the rising electrification of the vehicle fleet in Europe, there is a need to develop highly efficient, compact and lightweight electric motors. In addition, there is an increasing attention on the sustainability of electrical components in the transport sector. Eco-design strategies are now being researched to reduce the environmental impacts of the transport sector in order to reach the goal of net-zero emissions.

Regarding the state of the art, the application of eco-design strategies to electric motors reveals to be a cutting-edge topic. Very few publications [1-5] focus on the electric motor in a sustainability perspective most of which exclude relevant life cycle stages such as the End-of-Life (EoL) [1,2] or do not focus on eco-design strategies [1-3] or are outdated [4,5]. This study aims at exploring the environmental savings derived from an eco-design strategy based on the weight reduction of a Permanent Magnet high Speed electric Motor **(**PMSM) suitable for automotive application. With this purpose, Life Cycle Assessment (LCA) is applied including all the relevant life cycle stages that concerns the product under study and basing on primary data provided by AVL Italia S.R.L.

2. Methodology

This study is conducted in compliance with ISO 14040 and ISO 14044 standards. Hereafter, the adopted LCA methodology and the main assumptions are described.

The purpose of this study is to assess the environmental savings resulting from the implementation of an eco-design strategy based on light weighting a PMSM suitable for automotive application. For this purpose, first, the potential life cycle environmental impacts of a selected PMSM are evaluated, then, they are compared with the ones obtained adopting a lightweight design of the housing.

To ensure comparability both the PMSMs use the same Nd(Dy)FeB magnets and provide the same performances: peak power 240kW; peak torque 171 Nm. The powertrain unit in which each of them is assumed to be placed is composed of two PMSMs with dedicated inverters and a single gearing unit characterized by a transmission ratio of 16.7.

The system boundary includes all the life cycle stages of the PMSM (i.e., raw material acquisition and processing, manufacturing, distribution, use, collection at EoL, EoL).

For what concerns data sources, primary data based on the Bill Of Materials (BOM) provided by AVL Italia S.R.L and their suppliers are used. Secondary data from relevant LCA databases (i.e., Ecoinvent) or from selected literature studies are used as background datasets and for those processes not directly covered by the company. For instance, the manufacturing stage is modelled adapting secondary data from [1] and assuming a production volume of 5000 motors/year and that the location of the manufacturing plant is in Reggio Emilia (Italy). Distribution stage to European retailers is modelled basing on the electric vehicle sales in Europe in 2022. The EoL stage is modelled adapting an existing Ecoinvent dataset for *Used internal combustion engine, passenger car {GLO}/shredding* to the PMSMs under study in order to take into account the difference in chemical composition with an internal combustion engine.

Regarding the functional unit, one driven km over a selected Worldwide harmonized Light vehicles Test Cycle (WLTC) is assumed. Both the PMSMs are assumed to be installed in a passenger car with 150,000 km lifetime. For what concern the use stage, two 1D longitudinal simulation models assuming a passenger car equipped with the two

PMSMs, respectively, are developed based on primary data provided by the company (e.g., efficiency map, test vehicle specifics) obtained through a WLTC test conducted on the baseline PMSM.

3. Results and Discussion

Fig. 1 shows the life cycle environmental impacts of the baseline PMSM for the six more relevant impact categories. Results are normalized and weighted according to the normalization and weighting factors used in the EF 3.0 method. According to Fig. 1, due to the electricity production, the use stage (yellow bars) is the main contributor in all the most relevant impact categories. Moreover, due to critical resources involved in PMSM production (i.e., copper and rare earth elements), the most relevant impact category is resource use, minerals and metals for which the most relevant life cycle stage is the raw material acquisition and processing stage (orange bars).

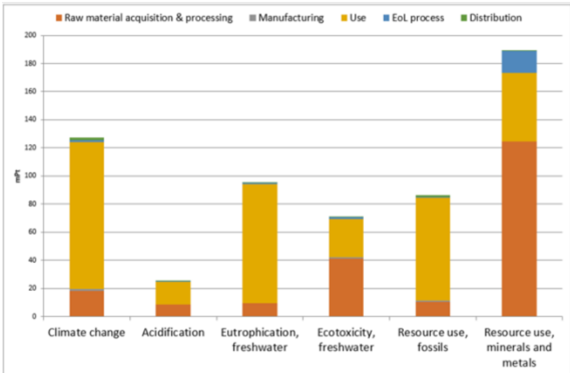


Fig. 1: Life cycle environmental impacts of the baseline PMSM (normalized and weighted results)

4. Conclusion

The LCA assessment conducted on the baseline PMSM shows predominance of use stage as main impact contributor and resource use as main impact category. This is due to electricity production and critical resources involved in the PMSM production, respectively. Full manuscript will show the results of the comparison between the baseline and the lightweight PMSMs aiming at quantifying the environmental savings obtained with the eco-design solution proposed.

Keywords: permanent magnet electric motor (PMSM); LCA; high speed electric motor; automotive.

References

[1] Anders Nordelöf, Scalable electric traction motor, permanent magnet (PMSM) for EVs, Springerlink.com, 23 March 2017.
[2] Anders Nordelöf, Life cycle assessment of permanent magnet electric traction motors, https://www.elsevier.com/locate/trd , 11 December 2018.
[3] Anton Rassõlkin, Life cycle analysis of electrical motor-drive system based on electrical machine type, www.eap.ee/proceedings , 14 May 2020
[4] Hongyue Jin, Comparative Life Cycle Assessment of NdFeB Magnets: Virgin Production versus Magnet-to-Magnet Recycling, www.sciencedirect.com , 2016
[5] S. Orlova , Lifecycle Analysis of Different Motors from the Standpoint of Environmental Impact, https://sciendo.com/article/10.1515/lpts-2016-0042 , 01/12/2016

Trends in High Voltage Inverter Systems

Jeffrey Loeliger[1] and Lukas Gorel[2*]

[1]Jeffrey Loeliger, NXP Laboratories UK Ltd, United Kingdom
[2]Lukas Gorel, NXP Semiconductors, Czech Republic
*Corresponding author: jeff.loeliger@nxp.com

Abstract – Current BEV (Battery Electric Vehicle) technology is effective but where is it going in the future? This paper looks at the current trends in the EV (Electric Vehicle) market to increase efficiency and range as well as reducing cost. While there are many ways to accomplish these goals, this paper will concentrate on the enhancement of electronic control modules.

1. Introduction

In order to provide an easy transition to EVs, it is desirable to have their functionality as close to that of combustion vehicles as possible. A key concern, in the move to EVs, is undoubtedly range. Electric vehicles typically have a shorter range, and longer refuelling time, than their equivalent combustion counterparts.

There are many factors that affect vehicle range with weight being a key contributor. The increase in development of bigger and heavier EVs is therefore a worrying market trend. Often manufacturers increase battery size with the aim of extending range. Ultimately, however, the added weight from the larger batteries can decrease the range and significantly add to the cost of the EV. Battery addition is therefore not an optimal solution for range extension.

A better approach is to increase efficiency and decrease weight which extends the range of the EV and potentially reduces vehicle cost and running expenses. A significant contributor to achieving this is the inclusion of more efficient enhanced control high voltage inverter modules in the vehicle.

2. Methodology

As a semiconductor vendor in the automotive market, we have the opportunity to discuss current and future EV concepts with vehicle manufacturers and Tier 1 suppliers. Through these discussions, along with our own research, there are some clear high voltage inverter trends in the EV market.

3. Results and Discussion

The key trends evident in the future of EV manufacturing involve the power driver, motor type, motor architecture and electronic requirements.

Power driver

Currently most EVs use Silicon IGBTs (Insulated Gate Bipolar Transistor) or SiC (Silicon Carbide) MOSFETs (Metal Oxide Semiconductor Field Effect Transistor) as the high power devices to drive the motor. The current trend is for all manufacturers to move to SiC MOSFETs in the near future with a possible move to GaN (Gallium Nitride) beyond that. There is some work currently underway on GaO (Gallium Oxide) as a possible successor to GaN.

The EV industry's current transition from Si IGBTs to SiC MOSFETs is to increase motor efficiency. The switching losses for SiC are significantly lower than for Si as shown in Figure 1. GaN will continue to drive this downward trend providing future switching loss reduction.

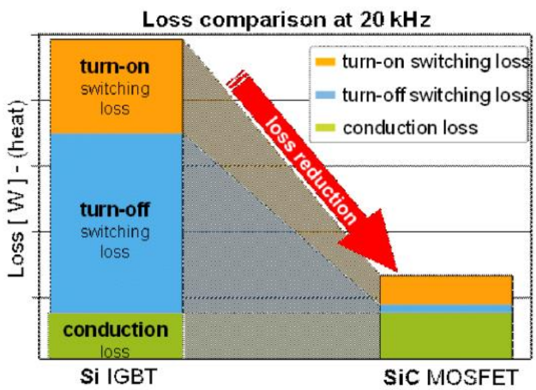


Figure 1. Switching loses

Motor type

AC (Alternating Current) induction and PMSM (Permanent Magnet Synchronous Motor) motors are used in most EVs today. Manufactures continue to refine these motors but it is unlikely there will be a large increase in efficiency or reduction in cost due to these refinements. A new motor type that looks promising is the Axial flux motor. The main advantages of Axial flux motors are:

- Better shape for typical automotive applications - Motors are "pancake" style with a larger diameter but relatively thin.
- Lower weight
- Higher power density
- Lower RPM which means it may be able to be directly coupled removing the gearbox or transmission for further weight reduction.

Motor architecture

Most vehicles currently use 3 phase motors but it is expected that 6 phase motors will be used more in the future. 6 phase motors are beneficial in systems requiring higher safety such as autonomous drive applications. A common configuration for 6 phase motors is equivalent to two 3-phase motors combined together. The advantage of this configuration is that there can be a failure on a single phase but the motor is still able to operate.

Another advantage of a 6 phase motor is that less current is needed in each motor winding to get the same power output. This means that the wire in each motor winding can be smaller in diameter allowing it to be packed closer together to produce a stronger magnetic field. The main disadvantage is that the number of power switching devices is doubled which increases cost however lower current devices can be used which are cheaper and help offset this increase.

Electronics

The first three EV trends discussed put extra demands on the electronic modules controlling the motors. The MCUs need advanced features to realize the efficiencies and benefits of the new requirements.

The new power drivers and motor architectures require higher frequency output signals and higher speed control loops. This means that the MCU (MicroController Unit) needs CPU (Central Processing Unit) cores and motor control co-processors with greater performance and PWMs (Pulse Width Modulation) with increased resolution.

MCUs are becoming more powerful and integrated to meet the developing trend in EV requirements. Increased power allows more than one application to be run on a single MCU at a time. The resulting reduction in MCU number allows for fewer ECUs (Electronic Control Unit), reducing overall size, complexity and weight of the control module.

MCUs are integrating more features to reduce external components. Functionality, such as the external resolver position decoder, can be moved into the MCU by using a combination of hardware and software.

Many semiconductor manufacturers are developing their portfolio to meet the demands of the trends identified in the EV market. As an example, NXP has a new device, the S32K396, targeted at advanced motor control and the running of multiple applications simultaneously. It provides the performance and features required by EV manufacturers in their development of higher performance, extended range EVs.

Hybrids

While this paper has looked specifically at EVs the same principles can be applied to HEVs (Hybrid Electric Vehicles) to gain the same advantages. In addition, a high level domain controller can coordinate the combustion and electric motors to create a more efficient system. Using advanced control methods, like Model Predictive Control (MPC), a high level domain controller can increase MPG by 4.5 %. [1]

4. Conclusion

To allow a comfortable and socially acceptable transition from combustion vehicles to EVs, improved range is essential. To achieve this, trends in EV power driver and motor architecture indicate the need for higher performance MCUs. Research indicates that future, higher efficiency systems will use 6 phase, Axial flux motors driven by GaN power devices requiring advanced MCUs like the NXP S32K396 to control them.

Keywords: Electric Vehicle; High Voltage Inverter; Advanced MCU.

References

[1] Cavaninim Majecki, Grimble, Sasikumar, Li and Hillier, Processor-In-the-Loop Demonstration of MPC for HEVs Energy Management, IFAC Conference Papers Online, 2022, page177.

Adaptive Energy Management Strategy for Extended Range Electric Vehicles Optimization

Yong Chen[1], Jinwang Pan[1] and Changyin Wei[2*]

[1] School of Mechanical Engineering, Guangxi University, China
[2]Hubei Key Laboratory of Power System Design and Test for Electrical Vehicle, Hubei University of Arts and Science, China

*Corresponding author: weiag2@163.com

Abstract –In order to ensure a reasonable energy distribution of multi-energy sources in different driving scenarios, it is necessary to study the energy management strategy of the extended range EV. In view of the randomness of road information and working conditions and the nonlinear characteristics of energy management, the study of adaptive energy management strategy based on road slope information is of great significance for the advancement of key technologies of extended range electric vehicles.

1）According to the automobile system dynamics theory and the relation between the drag torque and drive torque provided by the road surface, the whole vehicle dynamics model is established and verified. The basic parameter matching and selection of the power system(APU), drive motor and power battery) of the extender electric logistics vehicle were carried out.

2）In order to solve the energy management problem of the extended program electric logistics vehicle, an adaptive thermostatic energy management strategy and a power follower energy strategy based on road slope information were proposed. Aiming at the problem of APU optimal working curve search, the efficiency curve of extender under the same speed and torque distribution was obtained by using the method of cubic polynomial, and then the golden section method was used to search the optimal working curve and optimal working point of APU. The parameters of energy management strategy were optimized under different working conditions and road slope information. The equivalent fuel consumption was taken as fuel economy index, and the improved genetic algorithm was applied to optimize the strategy. In C-WTVC and CHTC-HT two circulation conditions of different grade of fuel economy simulation on the research object, the simulation results show that under different conditions of road slope information through improved adaptive genetic algorithm to optimize the energy management strategy can effectively improve fuel economy performance, power battery SOC fluctuation under control, improve the battery life.

Multi-Objective Optimisation of Gear Ratios in Two-Speed Dual Clutch Transmissions for Electric Vehicles

Yiyi Liang[1], Haiping Du[2*]

[1]School of Electrical, Computer and Telecommunications Engineering, University of Wollongong, Australia
[2]School of Electrical, Computer and Telecommunications Engineering, University of Wollongong, Australia
*Corresponding author: Hdu@uow.edu.au

Abstract –: The matching of the parameters inside a powertrain system of an electric vehicle (EV) is designed to accommodate the designed requirements concerning economic and dynamic performances. In this paper, a pure electric vehicle(PEV) is set as the research object and the parameter matching method of the driving motor and the gear ratios is explored according to the vehicle performing requirements considering both the common urban as well as suburban driving cycles and the road conditions such as operating on the straight roads and climbing scenarios. Furthermore, gear ratios are set as the variables and the particle swarm optimization (PSO) algorithm is applied to optimize the gear ratios by setting the energy consumption of the common driving cycles and acceleration time as the objective function in order to minimise the usage of energy regarding the dynamic performances as constraints. A two-speed dual clutch EV simulation platform is constructed in MATLAB/Simulink to perform shifting between two gears. This model is built in order to verify the rationality of the gear ratio design and demonstrate the enhancement in economic performance.

1. Introduction

Electric vehicles have gradually been receiving more attention worldwide because of their advantages such as reduced noise, less energy consumption and zero pollution. In the face of the energy crisis and environmental degradation, these developments are necessary. At the moment, PEVs primarily use a single transmission with a fixed speed gear ratio reducer, which has a simple construction and low cost but has limited performance. For instance, the performance of operating at low speed and high climbing is not as impressive, and the drive motor is limited to a certain efficiency range. A two-speed transmission can improve the economic performance of PEVs by engaging two gears at the same time so the drive motor works in the high-efficiency region as much as possible. Two-speed transmissions, however, come with some technical difficulties including the design of gear ratios and motor parameters. Based on those backgrounds, researchers have conducted several investigations into the optimisation of gear ratios. It was proposed in [1] that gear ratio optimization could be used to maximize motor efficiency and mileage as an objective function. In literature [2] optimisation of gear ratios is implemented through particle swarm optimization (PSO), which results in a better driving range and energy consumption. Literature [3] demonstrates the amendment of gear ratios by global optimization genetic algorithm. Generally speaking, the selection of gear ratios is a multi-objective solution as smaller gear ratios can increase maximum speed while larger gear ratios can improve acceleration performance and enhance climbing ability [4-5]. In this study, the gear ratio is designed with matching the parameters of the driving motor and gear ratio constraints. A two-speed dual-clutch transmission (DCT) simulation platform is constructed which includes the vehicle dynamic model, gear shifting module, driving motor module and driver model. Simulated tests are being conducted, and the results show an improvement in economic performance.

2. Methodology

1. Conduct the analysis of urban and suburban driving cycles. New European Driving Cycles (NEDC), Urban Dynamometer Driving Schedules (UDDS), Highway Fuel Economy Tests (HWFET), and US06 drive cycles are studied here.
2. Determine the parameters of the drive motor and gear ratios based on the analysation of the driving cycles and road conditions. The calculation of the maximum motor torque and power is conducted.
3. Set up the objective function and investigate the constraints of gear ratios. Apply the algorithm to figure out the optimal gear ratios.
4. Construct the simulation platform and perform the simulation. Analyse the results.

3. Results and Discussion

The outline of the NEDC driving cycle:

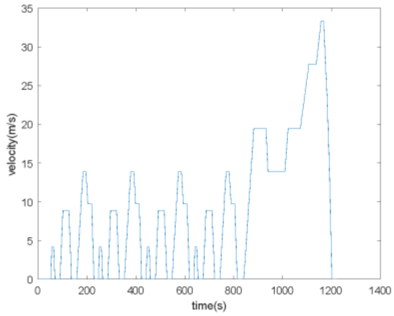


Fig. 1: NEDC driving cycle

The motor torque obtained from each driving cycles based on the most frequently operated power for each cycle:

Table 1. Motor Torque and driving cycle

Driving Cycle	Motor Torque(N)
NEDC	72.2901
UDDS	52.0105
HWFET	93.4696
US06	111.6397

4. Conclusion

Throughout this study, the approach of matching parameters of electric motors and transmission systems is explored in addressing vehicle requirements. Moreover, the PSO algorithm is applied on the gear ratios to select the optimal gear ratios that can minimise the utilisation of energy. The entire vehicle model containing two-speed DCT is constructed in Matlab/Simulink to perform gear shifting to optimise vehicle consumption.

Keywords: pure electric vehicle; gear ratio; particle swarm optimisation; two speed dual-clutch transmission

Acknowledgement

The author would like to thank Professor Haiping Du for his guidance. This research is supported by ARC LP190100603.

References

[1] P. D. Walker, S. Abdul Rahman, B. Zhu, and N. Zhang, “Modelling, Simulations, and Optimisation of Electric Vehicles for Analysis of Transmission Ratio Selection,” Advances in Mechanical Engineering, vol. 5, p. 340435, Jan. 2013.

[2] Q. Gu and X. S. Cheng, "Electric vehicle transmission gear ratio optimization based on particle swarm optimization," Applied Mechanics and Materials, vol. 187, pp. 20-26, 2012.

[3] J.Sheng, B.Zhang, B.Zhu et al, “Parameter optimization and experimental comparison of the two-speed pure electric vehicle transmission system,”, China Mechanical Engineering, 30(7):63,2019

[4] Y. M. Wang, C. Q. Du, X. N. Li, and F. W. Yan, “Transmission Ratio Optimization of Electric Vehicle Powertrain,” Applied Mechanics and Materials, vol. 397–400, pp. 987–992, Sep. 2013

[5] K. Kwon, M. Seo, and S. Min, “Efficient multi-objective optimization of gear ratios and motor torque distribution for electric vehicles with two-motor and two-speed powertrain system,” Applied Energy, p. 114190, Nov. 2019.

Thermal-Mechanical Energy Harvesting for EV Through Liquid- Solid Nanotriboelectrification

Weiwei Zhao[1], Yaroslav Grosu[2], Song Yang[1], Tongtong Zhang[1], Yongliang Li[1], Yulong Ding[1,*]

[1]Birmingham Centre for Energy Storage (BCES) and School of Chemical Engineering, University of Birmingham, Birmingham, B15 2TT, United Kingdom
[2]CIC Energigune, Albert Einstein 48, Miñano, Álava 01510, Spain
*Corresponding author: y.ding@bham.ac.uk

Abstract – New methods and apparatuses for simultaneously conversing mechanical work of undesired vibrations and heat from environments into electricity using nanotriboelectrification have been developed. This work will contribute to increasing the energy efficiency of a broad range of commercial apparatuses, including EVs, reduce their energy consumption, and contribute to the overall goal of the world towards a carbon dioxide neutral society.

1. Introduction and Methodology

When aqueous solution is forced to into a cycle of entering and exiting from a hydrophobic nanoporous material, the liquid and solid acquire opposite electric charges because of nanotriboelectrification. These charges can be collected and generate current. In this work, the energy driving the liquids entry (intrusion) to and exit (extrusion) from the nanopores is the vibrational energy, i.e. cyclic displacement inside the shock absorber when driving. This process also passively harvests ambient heat when the fluid is pushed into the nanopores. Thus, mechanical and thermal energy, in terms of vibrational displacement and ambient heat energy, have been harvested and converted into electric charges via nanotriboelectrification during the non-wetting liquid intrusion-extrusion process [1].

2. Results and Discussion

Conventionally, shock absorber is the device dampen the vehicle vibration by dissipating the mechanical vibrations into wasted energy in form of heat. The wasted energy occupies 10% of total energy, which limits the travelling range of EVs. In literature, solutions of harvesting this wasted energy such as triboelectric generators or electromagnetic generators mostly use mechanical energy as input, convert mechanical energy to electricity, and produce heat because of thermal dynamic dissipation (Fig. 1b). Their nominal conversion efficiencies are commonly lower than 10% [2]. With the non-wetting liquid/solid intrusion-extrusion nanotriboelectrification approach, taking both vibrations and thermal energy from the environment as input (Fig. 1c), the nominal conversion efficiency can reach 82% [3,4].

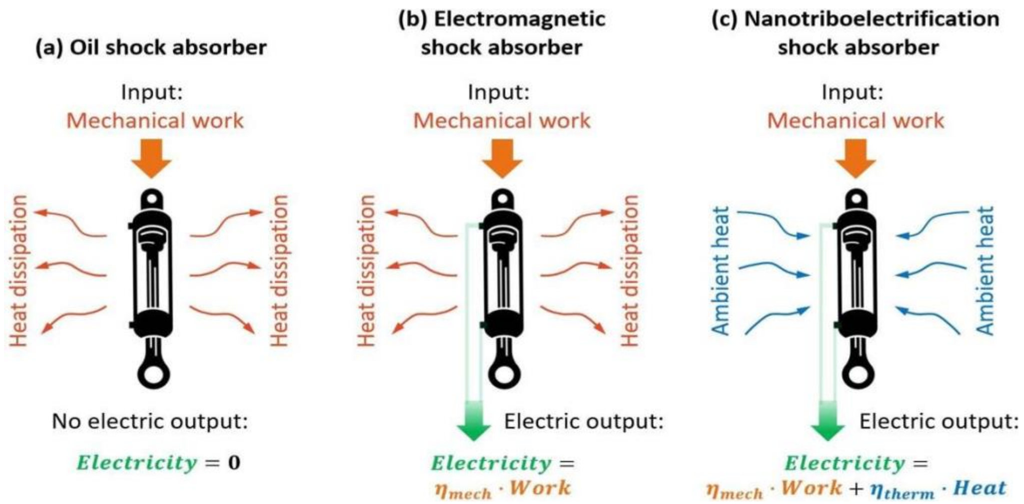


Fig. 1: Schematic diagrams of energy flow of shock-absorbers

3. Conclusion

Liquid-solid nanotriboelectrification based on intrusion/extrusion in non-wetting porous media could impact automobile industry, particularly in terms of EVs' travelling range extension and efficiency enhancement.

Keywords: Vibrational energy harvesting; Thermal energy harvesting; Intrusion-Extrusion; Liquid- solid nanotriboelectrification; Electrical vehicles.

Acknowledgement

This work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101017858.

References

[1] YG*, AF, JN, J-PG. J. Phys. Chem. C, 2017, 121, 21, 11499-507.
[2] YM, DG, EL, XW. Nano Energy, 2015, 15, 227-34.
[3] YG, MM, VAE, SP, MC et al. ACS Appl Mater Interfaces, 2017, 9. 7044-9.
[4] WZ, TZ, HK, YD*. Energy, 2022, 257, 124697.

Impact of Ultrasonic and Laser Multi-Welds on Electro-Thermal Behaviours of Battery Tab Interconnects

Indranil Manna[1], Nikhil Kumar[2] and Abhishek Das[1*]

[1]Department of Mechanical Engineering, Indian Institute of Technology Delhi, New Delhi 110016, India
[2]WMG, The University of Warwick, Coventry CV4 8GJ, United Kingdom

*Corresponding author: abhi@mech.iitd.ac.in

Abstract – Typically, ultrasonic metal welding and laser welding are employed to produce tab-to-tab interconnects for automotive battery packs or energy storage devices. This paper investigated the effect of multiple ultrasonic nuggets and laser seams on electrical resistance and thermal performance at the tab-to-tab interconnects. Results show that electrical contact resistance was decreased by 54% when a 5 mm diameter circular laser weld-based tab-to-tab connection was replaced with six circular welds of the same diameter.

1. Introduction

Efficient manufacturing of electric vehicles (EVs) battery packs is in high demand to meet the high-volume production need [1]. To connect the individual cells into modules, efficient joining methods are needed. Ultrasonic metal welding and laser welding are the most suitable joining methods to produce tab-to-tab or tab-to-busbar connections for pouch cells, as identified by Das et al. [1]. In the literature, research works have been reported on electrical and thermal characterisation, mostly considering single-joint configurations [2, 3]. However, the impact of placing multiple ultrasonic weld nuggets or laser welded seams on electrical resistance and temperature rise at the tab-to-tab interconnects is not fully understood when charge/discharge current is applied. Therefore, this paper is focused on identifying the importance of multiple weld nuggets or seams on electrical and thermal performances.

2. Methodology

In this study, 0.4 mm aluminium (Al) and 0.3 mm nickel-plated copper (Cu[Ni]) tabs of 45×45 mm were used, where Al was placed on top of Cu[Ni] tabs in lap configuration with an overlap of 25×45 mm. Schematic representations of test coupons and set-ups are shown in Fig. 1.

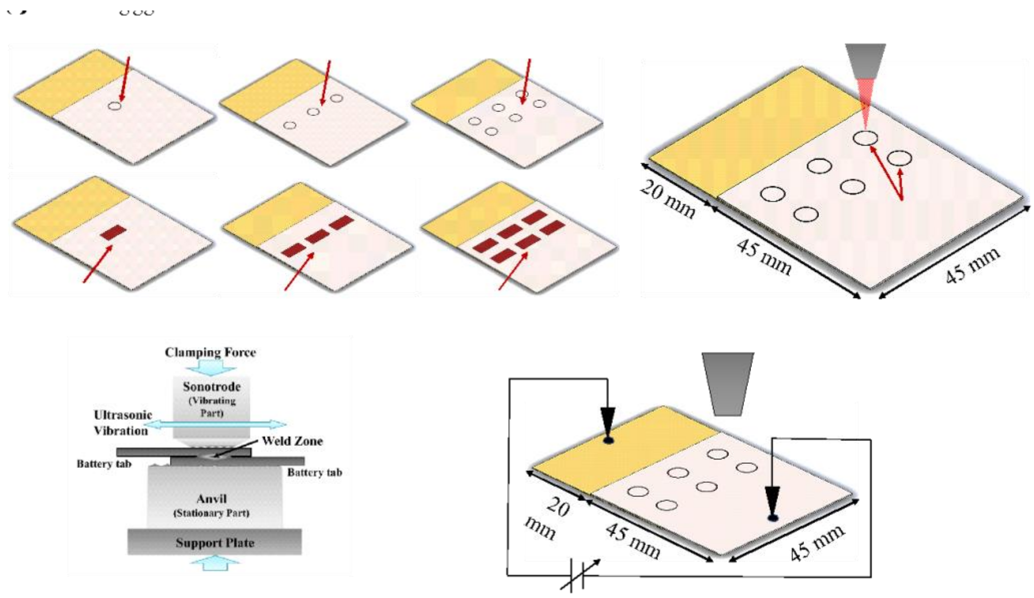


Fig. 1: Schematic of (a) laser welded samples, (b) ultrasonic metal welded samples, (c) ultrasonic welding, (d) laser welding, and (e) resistance and temperature measurement set-up.

A YLR-150W Quasi-CW IR laser having 1.5 kW peak power was used for producing the laser seams using 450 W laser power, 2 msec pulse on time, 50 Hz pulse frequency, 500 mm/min welding speed, 0.4 mm circular wobble amplitude, and 600 Hz wobble frequency. In case of ultrasonic welding, ultrasonic frequency 20 kHz, welding pressure 2.5 bar, amplitude 50 µm, and welding time 0.3 sec were used to produce ultrasonic weld nuggets. Each circular laser welding seam was 5 mm in diameter, and each ultrasonic welding nugget was produced using a Sonotrode of 5×10 mm^2. For laser welding, tab-to-tab connections were produced with 1, 3, 6 and 9 circular seams.

For ultrasonic welding, tab-to-tab connections were produced with 1, 3 and 6 ultrasonic nuggets and could not produce 9 nuggets due to space limitation. After the welding, the joint resistance of samples was measured by passing a 150 amp current for 3 min. Using the thermal camera, the joint temperature rise was measured for laser welded joints when 100-, 150- and 200-amp currents were passed for 3 min.

3. Results and Discussion

It was observed that a single circular laser seam had a maximum joint resistance of 0.054 mΩ, which was decreased by 37.04%, 53.70% and 57.4% for 3, 6 and 9 seams (Fig. 2(a)). Also, for ultrasonic welding, the highest resistance was noticed in the single nugget specimen, which is about 0.043 mΩ. By increasing the weld nuggets to 3 and 6, the joint resistance was decreased by 18.60% and 27.90%, respectively. So, the resistance value decreased with the increasing number of weld nuggets/seams. For Laser welding, this change is more, and one of the main reasons was the joining area distributed over a large area. But, in case of 9 circular laser welds, the change was only 8% compared to 6 circular laser welds. In addition, temperature rise due to the ohmic heating at the joint was proportional to the joint resistance. Fig. 2(b), shows the joint temperature response when 150 amp current was passed through 1, 3 and 6 laser welded specimens. Similarly, for 6 circular laser seam-based samples, the maximum temperatures were about 31.7°C, 44.2°C, and 66.7°C for 100 amp, 150 amp and 200 amp current supply for 3 min, respectively.

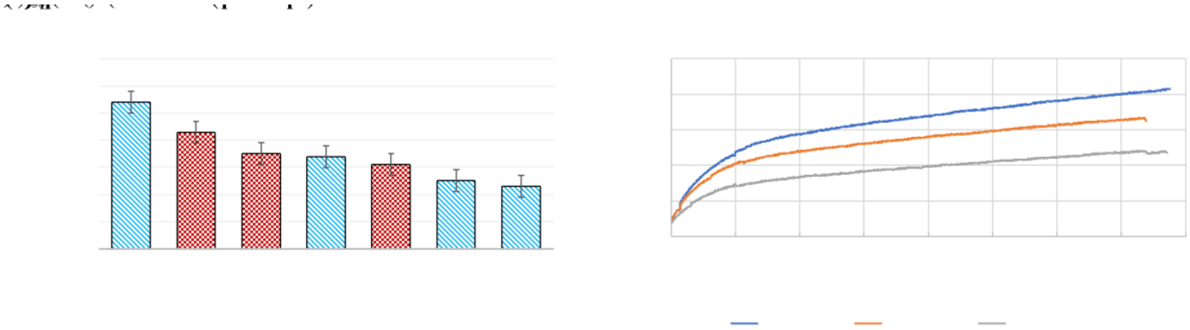


Fig. 2: (a) Joint resistance of ultrasonic and laser welded samples, (b) Temperature rise profiles of 1, 3 and 6 circular laser welded seams when 150 amp current was passed for 3 min.

4. Conclusion

This paper compared the impact of multiple ultrasonic weld nuggets and laser-welded seams with their electrical and thermal behaviours. The drop in resistance and temperature were observed in relation with the multiple nuggets and laser seams. This result showed that the current ultrasonic joining method can be replaced with emerging laser welding.

Keywords: Electric vehicles; laser welding; ultrasonic metal welding; joint resistance; temperature rise

Acknowledgement

This research is partially supported by WMG Centre High Value Manufacturing (HVM) Catapult at The University of Warwick, UK and the Department of Mechanical Engineering, IIT Delhi, India.

References

[1] A Das, D Li, D Williams, D Greenwood, Joining Technologies for Automotive Battery Systems Manufacturing, World Electric Vehicle Journal 9 (2), 2018, 22.

[2] T Solchenbach, P Plapper, W Cai, Electrical performance of laser braze-welded aluminium–copper interconnects, Journal of Manufacturing Processes 16(2), 2014,183-9.

[3] A Das, I Masters, P Haney, Modelling the impact of laser micro-joint shape and size on resistance and temperature for Electric Vehicle battery joining application, Journal of Energy Storage 52, 2022, 104868.

Thermal Energy Storage to Increase The Range of Electric Vehicles under Cold Ambient Conditions

Bartolucci Lorenzo[1*], Cennamo Edoardo[1], Cordiner Stefano[1], Grattarola Federico[1*], Mulone Vincenzo[1], Pasquale Stefano[1], Pasqualini Ferdinando[1], Giraudo Gabriele[2], Aimo Boot Marco[2]

[1]Department of Industrial Engineering, University of Rome Tor Vergata, Via del Politecnico 1, 00133, Rome, Italy
[2]Iveco Group, Electrification Technologies, Italy
*Corresponding authors: lorenzo.bartolucci@uniroma2.it, federico.grattarola@uniroma2.it

Abstract – In the last decade, the electric vehicle technology has been establishing and shows a great potential to become predominant in mobility sector. One of the critical problems of current technology is a limited vehicle range compared to extended charging times. Energy consumption of HVAC unit, especially in winter season, can remarkably affect the range. This work evaluates the benefits of introducing a thermal energy storage able to recover the regenerative braking energy excess, in terms of range extension of a light duty commercial vehicle. Results show potential benefits up to 15% of increase in vehicle range under extreme conditions.

1. Introduction

The range reduction of an electric vehicle due to auxiliaries energy consumption, such as cabin heating, is a major challenge for the diffusion of electric vehicles in commercial fleets, in particular in cold ambient conditions [1]. The most diffused technology for cabin heating is the Positive Temperature Coefficient heater, and its use in extreme winter conditions can have a significant negative impact on vehicle range [2]. Storage technologies and thermal management control strategies are, therefore, key elements for the improvement of vehicle performance [3]. This paper aims to evaluate the advantages achievable in terms of range extension by adopting an electrically heated Temperature Thermal Energy Storage (TES) [4].

2. Methodology

A digital twin of a light duty commercial vehicle, including all the auxiliaries and a detailed cabin thermal model, has been developed in MATLAB/Simulink/Simscape framework (see Fig. 1), whose performances were previously validated through experimental campaigns, and simulations have been carried out under severe winter conditions. The baseline model of the HVAC system is implemented with a 7 kW PTC heater to meet the cabin thermal needs. A TES has been added to the vehicle numerical model in series with the PTC in order to preheat the inlet air. In this configuration, the vehicle is able to store the regenerative braking energy excess, occurring when battery management system limits the maximum recharge current, through electrical resistances heating up the thermal energy storage.

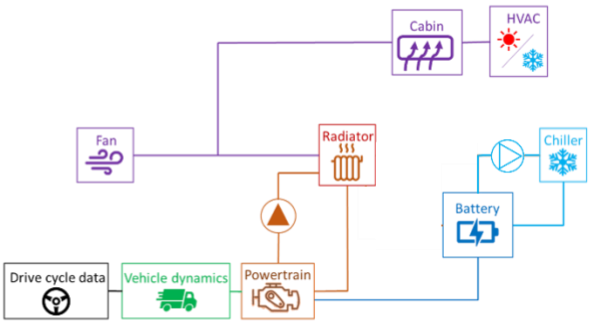


Fig. 1: Proposed light duty commercial vehicle layout.

3. Results and Discussion

A TES with an energy density of about 150 Wh/kg has been chosen for the simulations from a set of thermal energy storage devices, in accordance with the results reported in [4].

The benefits of the introduction of the TES that is able to store the regenerative energy excess are evaluated in terms of driving range extension. Simulations are performed in different external ambient temperature and promising results have been achieved under cold conditions down to -5°C, lowering the specific consumption by almost 15%, if compared with the baseline configuration of the vehicle. Numerical analysis has shown that the TES system is able to provide up to 60% of the total cabin heating demand needed by the HVAC system, occurring when external temperature is set to 0°C.

4. Conclusion

In the present work a digital twin model has been used for evaluating the benefits that can arise from the introduction of a Thermal Energy Storage (TES) into the HVAC system of a Light Duty commercial Electric Vehicle (EV). The major findings can be resumed in the following points:

- A gain of almost 15% on the vehicle range has been obtained with use of TES, under cold conditions;
- The TES is able to provide up to 60% of the total heating demand with an external temperature of 0 °C.

Keywords: electric vehicle; thermal energy storage; digital twin; driving range; electric heating.

References

[1] J. R. M. Delos Reyes, R. v. Parsons, and R. Hoemsen, “Winter Happens: The Effect of Ambient Temperature on the Travel Range of Electric Vehicles,” *IEEE Trans Veh Technol*, vol. 65, no. 6, pp. 4016–4022, Jun. 2016, doi: 10.1109/TVT.2016.2544178.
[2] L. Horrein, A. Bouscayrol, W. Lhomme, and C. Depature, “Impact of Heating System on the Range of an Electric Vehicle,” *IEEE Trans Veh Technol*, vol. 66, no. 6, pp. 4668–4677, Jun. 2017, doi: 10.1109/TVT.2016.2615095.
[3] A. Lajunen, Y. Yang, and A. Emadi, “Review of Cabin Thermal Management for Electrified Passenger Vehicles,” *IEEE Transactions on Vehicular Technology*, vol. 69, no. 6. Institute of Electrical and Electronics Engineers Inc., pp. 6025–6040, Jun. 01, 2020. doi: 10.1109/TVT.2020.2988468.
[4] V. Dreißigacker and S. Belik, “High temperature solid media thermal energy storage system with high effective storage densities for flexible heat supply in electric vehicles,” *Appl Therm Eng*, vol. 149, pp. 173–179, Feb. 2019, doi: 10.1016/j.applthermaleng.2018.12.026.

Degradation Abatement in Hybrid Electric Vehicles using Data-Driven Technique

Laxman Timilsina[1*], Bill R. Badr[2], Ali Arsalan[3], Phuong H. Hoang[4], Gokhan Ozkan[5], Behnaz Papari[6] and Christopher S. Edrington[7]

[1,2,7] The Holcombe Department of Electrical and Computer Engineering, Clemson University, US
[4] Operation Technology Inc, US
[5] Dominion Energy Innovation Centre, Clemson University, US
[3,6] Department of Automotive Engineering, Clemson University, US
*Corresponding author: ltimils@clemson.edu
Distribution A. Approved for public release, distribution unlimited. (OPSEC 7174)

Abstract – Electrified transportation is considered one of the most feasible technological solutions to address the growing climate change challenges in the electric transportation sector. However, the batteries used in electric vehicles (EVs) and hybrid electric vehicles (HEVs) have limited life. The degradation of the battery is accelerated by the operating conditions of the vehicle, which further reduces its life and increases the reliability and economic concerns for the vehicle's operation. This paper provides a technique to minimize the degradation of the battery used in HEVs called a prognostic-based control framework. A data-driven method is used to predict the degradation path of the battery. Depending on the degradation, the control strategy of the system is reconfigured to reduce the degradation and increase the battery's operating life.

1. Introduction

Electric vehicles (EVs), whether battery electric vehicles (BEV) or hybrid electric vehicles (HEV) are considered next-generation transportation that uses alternative energy storage systems to replace or in conjunction with an internal combustion engine. In an HEV, multiple power-generating sources supply power to the load. Batteries are currently the most preferred ESS for energy storage in EVs because of their high energy density, small size, and reliability [1]. Due to the presence of multiple sources in HEV, energy management (EM) is necessary, whose goal is to optimally allocate the power between these sources. While allocating the power, the main objective of the EM is to reduce the fuel consumption by the vehicle [1]. While doing so, the EM does not look at the degradation of the battery that can increase the vehicle's operating cost in the near future. Hence, in HEV, it can be stated that the degradation of the battery depends on the strategy of the EM [1]. Besides this, operating conditions like temperature, charging current, discharging current, and depth of discharge (DoD) accelerate the degradation [2]. The EM does not consider any of these aspects; hence a comprehensive control strategy is required.

This paper proposes a degradation abatement technique in HEVs named prognostic-based control framework. A neural network is used to model the degradation of the battery. The predicted degradation path of the battery is used to find the degradation rate cost, which is sent to EM and included in its objective function. Depending on the new objective function, EM reallocates the power between the engine and the battery, ensuring no compromise in the vehicle's operation.

2. Methodology

Here a prognostic-based control framework is proposed, which has three distinct and essential components, as shown in Fig. 1. A general recurrent neural network (RNN) is used to predict the degradation trajectory, which can handle both fixed and varying operating conditions. To train this model external database of battery degradation and actual operating condition from the HEV are used. Based on this model, the degradation forecasting (DF) layer will predict the degradation rate cost and feeds into the EM. This input is included in the objective function of EM. EM will reconfigure the power allocation between the engine and battery and send the power references back to the vehicle.

3. Results and Discussion

The implementation of a prognostic-basic control framework on the HEV decreases the degradation path followed by the vehicle, as shown in Fig. 2. The vehicle is run for 100 US06 drive cycles. The result indicates that the vehicle with prognostic-based control framework implementation (shown by the orange line) has a reduced degradation path compared to the vehicle run without prognostic-based control (shown by the blue line). This is the result from [3], using Markov's chain to predict the degradation path. In this paper, however, a neural network will be used to overcome the demerits of Markov's chain process. Also, with the decrease in the degradation path, the operating cost of the vehicle will decrease, which will be verified in the final paper.

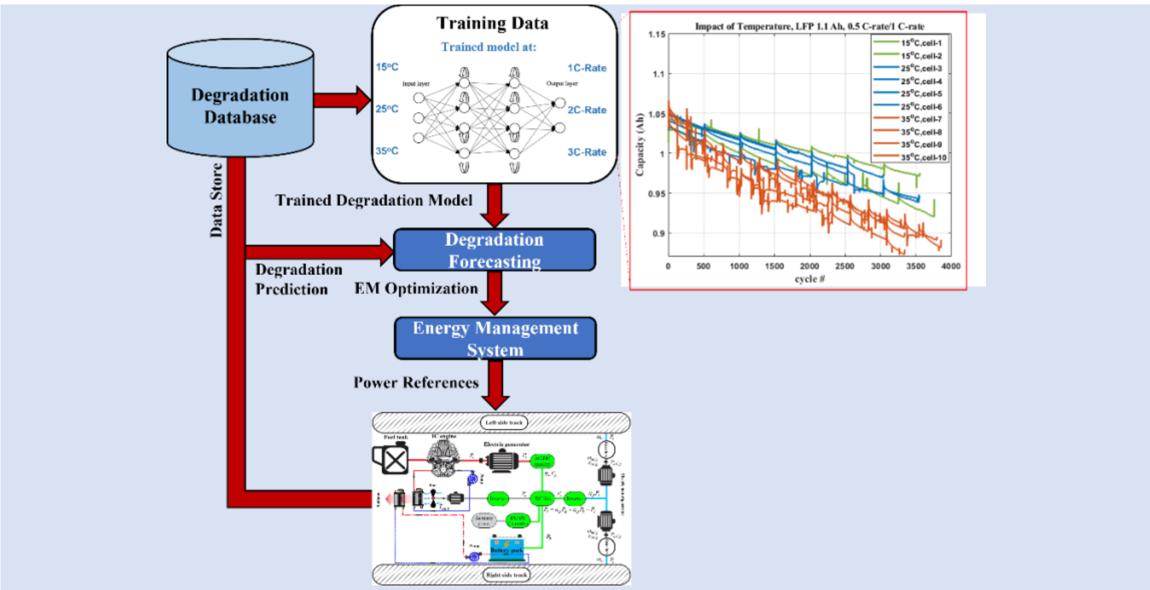


Fig. 1: Prognostic-Based Control Framework

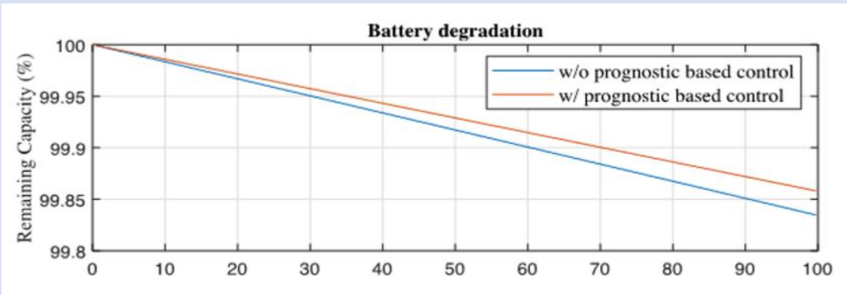


Fig. 2: Battery Degradation Path with and without Prognostic-Based Control

4. Conclusion

The use of a DF layer, in addition to EM in an HEV, can increase the operating life of the battery and decrease the overall operating cost of the vehicle. An HEV model based on power flow will be modelled and run for multiple drive cycles in Typhoon to validate this control strategy, and a numerical simulation will be conducted. Finally, with the implementation of the proposed strategy, the total cost of fuel consumption by the vehicle and the degradation of the battery will be minimized, thus reducing the operating cost of the vehicle.

Keywords: degradation abatement; battery degradation; battery life prediction; electric and hybrid electric vehicles; energy storage system

Acknowledgment

This work was supported by the Simulation-Based Reliability and Safety Program (SIMBRS) for modeling and simulation of military ground vehicle systems, under the technical services contract No. W56HZV-17-C-0095 with the U.S. Army DEVCOM Ground Vehicle Systems Center (GVSC).

References

[1] Song, Z., Hofmann, H., Li, J., Hou, J. et al., “Energy Management Strategies Comparison for Electric Vehicles with Hybrid Energy Storage System,” Applied Energy 134 (2014, ISSN: 03062619)

[2] Lu, Jiahuan, et al. "Battery degradation prediction against uncertain future conditions with recurrent neural network enabled deep learning." Energy Storage Materials (2022).

[3] Hoang PH, Ozkan G, Badr P, Timilsina L, Edrington C. A Prognostic Based Control Framework for Hybrid Electric Vehicles. SAE Technical Paper; 2022 Mar 29.

State of Power Estimation of a LCO Battery for a Formula Student Vehicle

Adriano Schommer[1*], Denise Morrey[1] and Gordana Collier[1]

[1]Oxford Brookes University, Wheatley Campus, Oxford, OX33 1HX
*Corresponding author: adriano.schommer@brookes.ac.uk

Abstract – Lithium-ion cells operate under a narrow range of voltage, current, and temperature limits, which requires a battery management system (BMS) to sense, control and balance the battery pack. The state of power (SOP) estimation is a fundamental algorithm of the BMS. It operates as a dynamic safety limit, preventing rapid ageing and optimizing power delivery. This paper demonstrates the modelling aspects of a model-based state of power estimation used in a Formula Student electric vehicle. It utilises the open-source database Battery Test Consortium (BTC) provided by Oxford Brookes University.

1. Introduction

Over the last few years, the Formula Student competition has transitioned from internal combustion engines to electric powertrains. The increased complexity of the power source and the many challenges of a high-performance vehicle requires sophisticated algorithms to predict the battery performance and states of charge, health, and power. These algorithms need to run-real time in a microcontroller. Therefore, a balance between accuracy and computational cost is paramount for successful deployment. SOP algorithms based on the battery's equivalent circuit models (ECM) are the most common approach for complying with real-time capabilities and accuracy [1]. The SOP acts as a safety boundary to limit the battery pack operation [1]. It predicts the maximum power demand the battery pack can tolerate before exceeding any cell capability and dictates vehicle acceleration performance, climbing ability, and charge current limits for regenerative braking [2]. This paper follows the definition of [3], where SOP is the amount of charge or discharge power sustained over a delta time without violating any cell design limit. The proposed model uses a 1RC ECM characterized by open-source data provided by the battery test consortium (BTC) of Oxford Brookes University [4]. Using a bisection search algorithm, the maximum available power is estimated for a moving prediction horizon of 20 seconds.

2. Methodology

The characterization of the 1RC ECM consisted of the open circuit voltage (OCV) modelling as a function of SOC at various operating temperatures and the identification of the ohmic resistances, the charge-transfer resistance, and the double layer capacitance, also at different temperature setpoints. The OCV(SOC) curve was extracted directly from a pseudo-OCV test performed at 1/25 C-rate at 5, 15, 25, 35 and 45°C, tested in a controlled thermal chamber. The charge-transfer resistance and the double-layer capacitance identification were made offline to create an efficient lookup table processed from the BTC data. More specifically the hybrid pulse power characterization (HPPC) test profile was used as input to a recursive least squares (RLS) regression algorithm. For the sake of reduced complexity and computational cost, the offline method was preferred.

The SOP algorithm is based on [3]. Figure 1 illustrates the architecture of the algorithm. It is divided into three parts. I – the battery model, II – the ECM-based SOP algorithm and III – the multi-constraint algorithm. The battery model takes current (i), voltage (V) and temperature (T) to estimate the resistances, capacitance, and cell capacity. Then, the power limit is estimated as a function of the calculated current limit and the voltage drop due to the load input at the end of the future horizon.

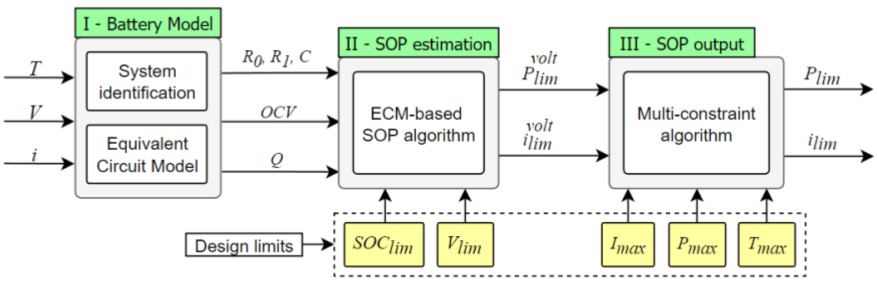


Fig. 1: Schematic of the ECM-based state of power estimation algorithm

The current limit $i_{min,k}^{chg,volt}$ is defined as in Equation 1 for charging current. And the discharge limits are similar.

$$i_{min,k}^{chg,volt} = \frac{OCV(SOC(t)) - V_c(t)\exp\left(-\frac{\Delta t}{R_1 C}\right) - V_{max}}{\frac{\eta_c \Delta t}{Q}\frac{\partial OCV(SOC)}{\partial SOC}\Big|_{SOC=SOC(t)} + R_0 + R_1\left[1-\exp\left(-\frac{\Delta t}{R_1 C}\right)\right]} \quad (1)$$

Finally, the multi-constraint algorithm compares the limits imposed by hard design constraints such as maximum power, current and temperature to define the lowermost limit applicable.

3. Preliminary results

The voltage response within 20 seconds of a moving horizon was evaluated in a dynamic drive cycle representative of a Formula Student Endurance event. The upper and lower limits of voltage were within the boundaries imposed by the design limits. Because the accuracy of the SOP algorithm is directly related to the accuracy of the ECM model, the model was compared to the HPPC load profile and the Formula Student drive cycle. For the HPPC data, the voltage error was within 2% and for the dynamic drive cycle within 3%. Different approaches for system identification could be tested to improve results further and are currently being addressed.

4. Conclusion

The ECM-based algorithm using the bisection method provides a robust and inexpensive state of power estimation, able to enforce the battery within the design limits imposed. The method proposed in this paper can take advantage of publicly available data provided by the BTC to populate the model and validate the results at various temperatures and load conditions.

Keywords ECM; battery modelling; state estimation; LCO; available power

Acknowledgement

The authors wish to thank all sponsors on behalf of the Oxford Brookes Racing team.

References

[1] L. Yang, Y. Cai, Y. Yang, Z. Deng, Supervisory long-term prediction of state of available power for lithium-ion batteries in electric vehicles, Applied Energy 257 (2020) 114006.

[2] L. Pei, C. Zhu, T. Wang, R. Lu, C. Chan, Online peak power prediction based on a parameter and state estimator for lithium-ion batteries in electric vehicles, Energy 66 (2014) 766-778.

[3] G. L. Plett, High-performance battery-pack power estimation using a dynamic cell model, IEEE Transactions on vehicular technology 53 (2004) 1586-1593.

[4] Planden, B., Lukow, K. (2021). Battery Test Consortium. Version v0.1.0. Available at: https://github.com/Oxford-Brookes-HVES/BTC

Analysis of Electric Vehicles Battery Ageing Associated to Smart Charging Controls

Jorge Nájera[1*], Jaime R. Arribas[2], Rosa M. de Castro[2], Hugo Mendonça[2], Marcos Blanco[1], Gustavo Navarro[1] and Marcos Lafoz[1]

[1]CIEMAT, Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, 28040 Madrid, Spain
[2]E.T.S.I. Industriales, Universidad Politécnica de Madrid, 28006 Madrid, Spain
*Corresponding author: Jorge.Najera@ciemat.es / Jorge.Najera@externos.ciemat.es

Abstract – EVs smart charging controls emerge as a possibility to overcome voltage quality issues caused by the increasing penetration of EVs in LV networks. However, those controls influence the EV battery lifespan. Four decentralized smart charging controls have been analysed, finding slight variations in the battery ageing evolution with respect to a standard EV charge.

1. Introduction

The increasing penetration of EVs in low-voltage (LV) distribution networks is likely to become a challenge for distribution system operators (DSOs) since it can lead to power quality issues. The coordinate effect of both EVs and household loads highly contributes to the unbalanced operation of the network, which results in voltage quality concerns such as under-voltage conditions and voltage unbalance. In this framework, EVs smart charging controls emerge as a possibility to overcome those voltage quality issues.

Among the specialized literature, smart charging controls can be divided into centralized and decentralized architectures, whose advantages and disadvantages have been discussed in [1]. Considering that cost and robustness are similar in both architectures, the decentralized control tends to be a more practical solution, since it is based on local measurements and does not need additional communication infrastructure. In addition to the classification between centralized and decentralized architectures, EV smart charging controls can be divided into those controls suitable for being implemented in a single-phase charger, and those applicable to three-phase chargers.

Commonly, the implementation of EV smart charging controls has been studied from the LV network point of view, but less attention has been paid to the increased battery ageing associated to those controls. This paper analyses the EV battery ageing associated to the implementation of the most relevant decentralized smart charging controls for improving voltage quality in LV networks.

2. Methodology

The selected decentralized smart charging controls are: active power droop control (Droop P), reactive power droop control (Droop Q) [3], load balancing control (LB) [4], and sequence compensation control (SC) [5].

The EV charger selected for this paper has been modelled in MATLAB Simulink and replicates a bidirectional charger topology. Typical values of commercial EV chargers has been selected for the AC inductive filter, DC filter, and DC-link capacitor.

The battery model, also developed in MATLAB Simulink, includes a voltage/runtime model, thermal model, and complete ageing model. The battery model has been developed and validated in [5]. The EV battery has been parameterized with a commercial Li-ion NMC battery.

The controls are compared to a base case charging/discharging scenario. This base case includes one cycle per day, starting with a 100% discharge cycle at 0.1C, and followed by a complete charge with 3.68 kW. The ambient temperature is fixed at 25ºC, and no forced refrigeration is included. The results are evaluated after 1000 complete cycles. A relative comparison between charging controls is proposed, so general trends can be observed. Hence, typical profiles for Droop P, Droop Q and SC controls are selected.

3. Results and Discussion

The battery ageing results associated to the different charging profiles are shown in Fig. 1. A maximum difference of 0.8035% SoH is observed after 1000 cycles between Droop P and Droop Q max scenarios.

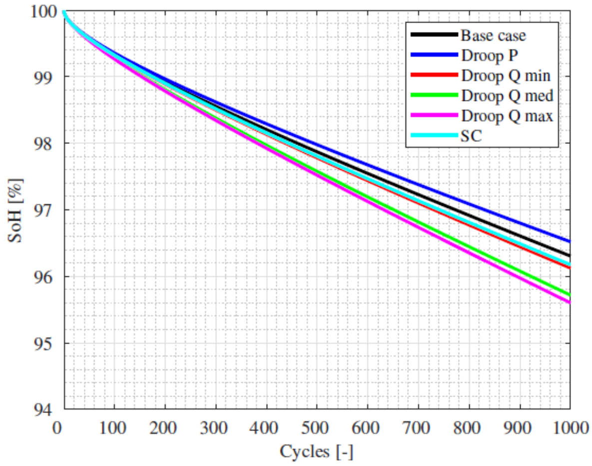


Fig. 1: Battery ageing associated to the different charging profiles.

4. Conclusion

The approach taken in this paper to evaluate the battery ageing associated to each charging control shows that there are little variations between them. These variations occur due to a higher temperature when dealing with high rates of reactive power, which could be potentially corrected.

Keywords: battery ageing; smart charging; voltage unbalance; under-voltage; LV network.

Acknowledgement

This paper has been partially funded by the research projects “DESARROLLO DE UNA METODOLOGÍA PARA DETERMINAR ARQUITECTURA ÓPTIMA DE SISTEMA HÍBRIDO BASADO EN CONFIGURACIONES DE PILA DE COMBUSTIBLE (MULTYSTACK-HD). Plan nacional. Reference: PID2021-125592OB-I00” and “SEGVAUTO 4.0-CM: SEGURIDAD DE VEHICULOS PARA UNA MOVILIDAD INTELIGENTE, SOSTENIBLE, SEGURA E INTEGRADORA. CONVOCATORIA DE PROGRAMAS DE I+D EN TECNOLOGÍA/2018 Orden 4411/2018, de 13 de diciembre. Reference: S2018/EMT- 4362”.

References

[1] Farooq, Shaik Mullapathi, et al. "Certificate based security mechanisms in vehicular ad-hoc networks based on IEC 61850 and IEEE WAVE standards." *Electronics* 8.1 (2019): 96.

[2] Knezović, Katarina, and Mattia Marinelli. "Phase-wise enhanced voltage support from electric vehicles in a Danish low-voltage distribution grid." *Electric Power Systems Research* 140 (2016): 274-283.

[3] Weckx, Sam, and Johan Driesen. "Load balancing with EV chargers and PV inverters in unbalanced distribution grids." *IEEE Transactions on Sustainable Energy* 6.2 (2015): 635-643.

[4] Caldon, R., M. Coppo, and R. Turri. "Distributed voltage control strategy for LV networks with inverter-interfaced generators." *Electric Power Systems Research* 107 (2014): 85-92.

[5] Nájera Álvarez, Jorge. *Study and Analysis of the Behavior of LFP and NMC Electric Vehicle Batteries concerning their Ageing and their Integration into the Power Grid*. Diss. Industriales, 2020.

Mechanical Characterization and Modelling of Lithium-Ion Batteries

Davide Clerici[1]*, Francesca Pistorio[1], Salvatore Martelli[1], Francesco Mocera[1] and Aurelio Somà[1]

[1]Politecnico di Torino, Corso Duca degli Abruzzi 24, Torino, Italy
*Corresponding author: davide.clerici@polito.it

Abstract – Mechanical phenomena in lithium-ion batteries are one of the main sources of damage, as well as an indicator of battery health and charge. Then, a deep study of these phenomena may improve battery life, management and safety. The stress and fracture due to lithium intercalation are computed with an electrochemical-mechanical model. Furthermore, thickness change measurements on batteries with different chemistries are carried out, to compare volume change characteristics to eventually extrapolate charge and health states.

1. Introduction

Lithium ions are inserted (and extracted) in the microstructure of active material particles of electrode with opposite polarity during battery operation. These processes, referred to as "(de)intercalation" cause volume change and stress in the active material particles [1]. When a lithium ion gets into the microstructure of the active material causes its deformation, proportional to the concentration of lithium ions [1]. The deformation of the active material microstructure has an impact on the electrode volume change, and on the entire battery ultimately, in a measurable way [2-3]. The uneven distribution is caused by the diffusion of lithium ions in active material particles; e.g. during insertion a greater concentration of lithium ions arises in the external areas compared to the core [1].

Two distinct goals are pursued: (a) Calculating the mechanical stress and fracture behaviour of active materials, to quantify the source of damage due to mechanical phenomena during battery operation [1,4,5]. (b) Measurement of cell deformation during operation, comparing the results of different chemistries and aiming to exploit these characteristics to estimate charge and health state, refining the battery management [2-3].

2. Methodology

Mechanical phenomena in lithium ion batteries give rise to two main topics: (a) Stress, fracture and damaging; (b) LIB volume change.

Stress fracture and damaging. An electrochemical-mechanical model has been implemented to compute the concentration of lithium ions arising in the active material particle during battery operation, the stress due to their inhomogeneous distribution [1], is the driving force for the fracture mechanics model [4]. The concentration of lithium ions has been computed with a transport model coupled with mechanics, indeed lithium concentration and hydrostatic stress are the driving force of lithium diffusion within the active material particles. Once the concentration field is known, stress are calculated with a mechanical model, taking into account the elastic and chemical deformation due to lithium ions [1]. Once the stress is known, a fracture mechanical model is implemented in Ansys to compute the stress intensity facture, and to identify the likely of fracture with different operating conditions and active materials [5].

Battery volume change. A multi-scale model is implemented to compute battery deformation from atomic scale (deformation of the lattice microstructure of active materials of electrodes), to battery scale [4]. Volume change of batteries with different chemistry is measured during different operating conditions (current rate) with optical sensors [2]. Experimental methodology and algorithm has been patented [3] and both method and model are validated with experiments [4].

3. Results and Discussion

Figure 1a shows the thickness change measurements carried out during battery operation at different current rates on different cell chemistries and format. The results shows that batteries swell during charge and shrinks during discharge, as the expansion of the anode is greater than the shrinkage of the cathode during charge, vice-versa during discharge. Furthermore, results show that thickness change is slightly affected by current rate, especially with respect to voltage. Then, this feature can be effective to estimate the state of charge of the batteries. Health can be estimated as well on the basis of the shift of the thickness change curves [2-3]. For sake of brevity, the validation of the multiscale model with the results of Figure 1a is not reported here.

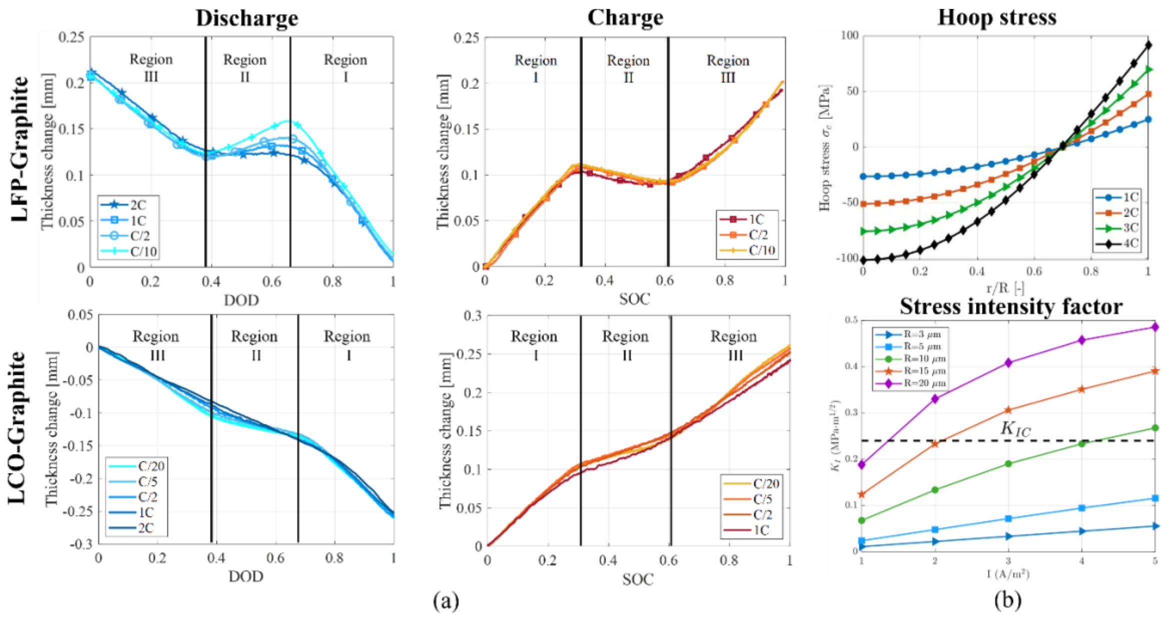


Fig. 1. (a) Thickness change measurements on different cell chemistries and formats, as a function of the state of charge (SOC) or depth of discharge (DOD=1-SOC). (b) Electrochemical-mechanical model results: hoop stress as a function of the particle radius and stress intensity factor as a function of current rate, calculated for different particle radii.

A brief results of the electrochemical mechanical modelling is reported in Figure 1b, hoop stress within the active material particle is reported as a function of the particle radius. The graph shows that tensile stress occurs on the particle surface during lithium extraction (vice-versa during insertion), leading to fracture [1]. Stress intensity factor is calculated for different current rate and microstructure size (particle radius) [4]. It is shown that some combinations of particle radius and battery operation lead to the overcome of the fracture toughness threshold (KIC), causing severe damage and battery performance decay [5-6].

4. Conclusion

Lithium concentration, stress and ultimately stress intensity facture is computed to quantify mechanical damage in lithium ion battery according to different battery operations and active materials. Battery deformation is computed with a multi-scale model starting from the atomic scale up to the battery scale. The results of the model are validated with experimental measurements. The battery deformation can be used to improve state of charge and state of health estimations according to a recent patent [2].

Keywords: Lithium ion battery; electrochemical-mechanical modelling; fracture mechanics; experimental mechanics; battery deformation.

References

[1] Clerici Davide, Francesco Mocera, Aurelio Somà, Analytical solution for coupled diffusion induced stress model for lithium-ion battery, Energies, 13, 7, 2020, 1717.
[2] Aurelio Somà, Francesco Mocera, Device and method to measure and estimation of state of charge of health of a battery, Patent IT20210016583 2021-06-24 and WO2022IB55841 2022-06-23
[3] Clerici Davide et al., Electrochemical-mechanical multi-scale model and validation with thickness change measurements in prismatic lithium-ion batteries, Journal of power sources, 542, 2022, 231735.
[4] Clerici Davide et al., Analysis of fracture behaviour in active materials for lithium ion batteries, IOP Conference Series: Materials Science and Engineering, 1214, 1, 2020, 012018.
[5] Francesca Pistorio, Clerici Davide Francesco Mocera, Aurelio Somà, Review on the Experimental Characterization of Fracture in Active Material for Lithium-Ion Batteries, Energies, 15, 23, 2022, 9168.

Exploring the Relationship between Temperature Gradients and Unbalanced Aging in Parallel-Connected Cells of EV Battery Packs

Haosong He[1] and Xiangjie Chen[1*]

[1] Centre for Renewable Energy Systems Technology (CREST), Loughborough University, U.K
*Corresponding author: x.j.chen@lboro.ac.uk

Abstract –In order to maximise the battery longevity and ensure safety, EV battery packs need to be equipped with an active battery thermal management system (BTMS), ensuring that the temperature of the cells are maintained at this optimal temperature range (20℃-45℃). However, current design of BTMSs cannot completely eliminate the temperature gradient within the pack, yielding uneven temperature distribution among cells (usually up to5 °C), which leads to uneven aging speeds within the cells. Additionally, it is also difficult for Battery management systems (BMS) to directly measure the currents flowing through each parallel-connected cell, making it challenging to actively balance the cells. To investigate the pack-level current distribution and aging trends caused by temperature gradients from , this paper adopts a Lumped Single Particle Model (LSPM) coupled with Arrhenius dependency to investigate the influence of temperature on current distribution and resulting unbalanced aging rates. A Panasonic NCR18650PF battery pack (4S6P) with cells connected in parallel is used as the case study prototype. The results indicated that a 5 °C temperature difference can introduce a 0.002 SOC difference in 7 days under 1C cycling.

1. Introduction

Lithium-ion cells present various merits such as the high energy density, long cycle life, and low self- Lithium-ion cells offer various benefits, including high energy density, long cycle life, and low self-discharge rate, making them the optimal power source for electric vehicles (EVs) [1]. However, cell aging is a significant concern in the EV industry, leading to a decline in performance over time due to irreversible physical and chemical changes. To slow the aging speed, cells are parallel and serially connected in an EV battery pack, significantly reducing the discharging C-rate while meeting the same power requirement [2]. However, the use of a large number of cells also introduces cell inconsistency issues. This paper numerically investigates the influence of temperature gradient on current distribution and uneven aging speed among cells in parallel connection based on LSPM. The investigated model's configuration is 4p6s 18650 cells cooled by a liquid BTMS with a serpentine-shaped cooling pipe.

2. Methodology

This paper numerically investigates uneven ageing caused by temperature gradients in a battery pack composed of 24 individual Panasonic NCR18650PF cells arranged in 4s6p. Fig. 1 illustrates the configuration of the battery pack (4p6s) in which the cells are wrapped by an aluminium cooling pipe, connected to steel busbar connectors on the top and bottom surfaces, and throughout the steel terminals. The simulations in this work were performed using COMSOL Multiphysics 6.1. The electrochemical model of the cell is based on the LSPM, a reduced-order electrochemical model proposed by Ekström et al. [3]. The electrochemical behaviours of cells under different temperatures were estimated by incorporating an Arrhenius dependency into the temperature-sensitive parameters. To estimate the aging rate, a semi-empirical aging model is introduced to the LSPM, where a parasitic loss current is adopted to calculate the cell's capacity loss.

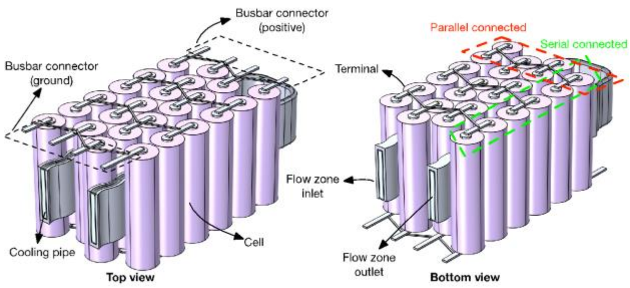


Fig. 1: Schematic views of the coupled model: cells are configured in 4s6p, where the top and bottom surfaces are connected to the steel busbar throughout the steel terminals, and wrapped by an aluminium cooling pipe.

3. Results and Discussion

This section numerically investigates the uneven aging of the pack caused by a temperature gradient. The pack is cycled between 18 V to 25.2 V at a 1C rate for 7 days and cooled by water with an inlet temperature of 25 °C and a flow rate of 0.01 m/s. Fig. 2 demonstrates the impact that temperature gradient can have on the aging of parallel-connected cells within a battery pack, which can be found that temperature distribution within the pack can be non-uniform, with differences of up to 5°C occurring between individual cells. This variation in temperature can lead to uneven aging of the cells. Specifically, the simulation found that a 5°C temperature difference can introduce a 0.002 state of charge (SOC) difference in 7 days under 1C cycling. These findings underscore the importance of BTMS in EV battery packs, as well as the need for advanced BTMS that can accurately monitor and balance the current distribution among cells.

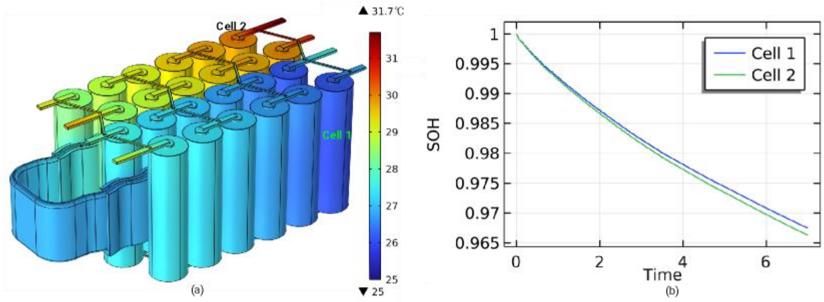


Fig. 2: (a) The temperature distribution at 0.5h under 1C discharge and (b) the ageing rate in 7 days.

4. Conclusion

It is important to take into consideration the impact of temperature gradient on the ageing of parallel-connected cells. This study reveals that even a small temperature difference of 5 °C can introduce a notable difference in SOC over seven days. This finding highlights the need for proper thermal management and temperature control in battery systems to ensure even ageing and improve overall performance and longevity. Future research and development efforts should focus on identifying effective strategies for managing temperature gradients in parallel-connected cells to optimize their performance and extend their lifespan.

Keywords: Lithium-ion cell, Ageing

Acknowledgement

This work is acknowledges the use of the Lovelace HPC service at Loughborough University.

References

[1] Beard, Kirby W. Linden's handbook of batteries. McGraw-Hill Education, 2019.

[2] Bishop, Justin DK, et al. "Evaluating the impact of V2G services on the degradation of batteries in PHEV and EV." Applied energy 111 (2013): 206-218.

[3] Ekström, Henrik, Björn Fridholm, and Göran Lindbergh. "Comparison of lumped diffusion models for voltage prediction of a lithium-ion battery cell during dynamic loads." Journal of Power Sources 402 (2018): 296-300.

Strategic Integration of Electric Vehicles: An Australian Analysis

Benjamin James[1*], Charlie Hargroves[1], and Scott Dwyer[2]

[1]Curtin University Sustainable Policy Institute, Australia
[2]Institute for Sustainable Futures, University of Technology Sydney, Australia
*Corresponding author: ben.j.james@curtin.edu.au

Abstract - This paper presents the challenges and opportunities of strategic electric vehicle (EV) grid integration with a particular focus on its status and outlook in Australia. EVs are a critical part of many countries net zero commitments because electrification is a key piece in the puzzle to decarbonise the transport sector. Approaches are needed to ensure EVs and their charging practices can be incorporated within the electricity grid cost-effectively, while increasing system reliability and stability, supporting transport decarbonisation, and ensuring other societal benefits. Australia is a large country with a relatively small population which poses challenges for both EV charging and electricity distribution infrastructure provision. However, other market characteristics (such as high solar PV adoption among households) and the rapidly decarbonising grid make Australia an useful case study. Especially for how challenges over range, grid integration, and lack of domestic EV production is leading to new innovations that could inform steps towards more rapid EV adoption in other jurisdictions. This paper will discuss the challenges and opportunities of electric vehicle (EV) uptake in Australia based on a national consultation and workshop series involving stakeholders from the energy and transport sectors.

1. Introduction

With a high reliance on fossil fuels, transport is responsible for 37% of carbon dioxide emissions globally [1]. Transport plays a critical role in helping society function, from the transportation of goods and services to aiding the pursuit of leisure, education, and work activities. However, with a high reliance on fossil fuels it is responsible for 37% of carbon dioxide emissions. Electrifying the sector is therefore a key piece in the puzzle to decarbonise this part of the global economy and reduce our reliance on fossil fuels.

Transport is Australia's second largest source of carbon emissions (19%) with over half of these emissions from passenger vehicles and steady increases until the start of the COVID pandemic [2]. As a large country with a relatively small population concentrated in coastal cities, Australia faces both generic and specific challenges to EV adoption and grid integration posed by its geography, population, and demographics. Despite the challenges, EV adoption and public charging deployment has been growing in Australia but it has been lagging behind other countries similar in terms of population, economy, or standard of living [3]. Sales of EVs in Australia increased 65% in 2022 on the previous year, but still only represents 3% of all vehicle sales [4].

To integrate EVs effectively means developing approaches to ensure EVs and their charging practices can be incorporated within the electricity grid cost-effectively, while increasing system reliability and stability, supporting transport decarbonisation, and ensuring other societal benefits. The integration of EVs with Australia's extensive but ageing electricity network poses major challenges for decarbonising transport, while the highest high levels of solar PV adoption in the world and the rapidly decarbonising grid presents opportunities. This makes Australia an useful case study for how challenges over range, grid integration, and lack of domestic EV production is leading to new innovations that could inform steps towards more rapid EV adoption in other jurisdictions. This analysis can lead to informative lessons for the delivery of more resilient national transport and energy systems [5].

2. Methodology

There were four main stages that comprised the methodology for exploring the strategic integration of EVs, as shown in Figure 1. This approach would ensure the focus on the growing Australian uptake of renewable energy and electrified transport provides unique opportunities for mutually beneficial strategies.

Figure 1: Approach to assessing Australian status of strategic EV integration

3. Results and Discussion

The results of the literature review, national consultation, and workshop series found the following challenges facing EV integration:

1. Policy, regulations, and standards that aren't fit for purpose.
2. Ambiguous costs and benefits.
3. Uncertainty of consumer attitudes, behaviour, and acceptance of different charging practices.
4. Technical challenges that included visibility on the distribution grid, network congestion from increased peak demand, balancing supply and demand, voltage & frequency issues, EV battery degradation, and cybersecurity.

However, these challenges were found to be balanced by the following opportunities:

1. Reduced emissions by supporting higher levels of renewable energy on the grid.
2. Multiple values streams can be unlocked.
3. Reduced costs for EV users, energy consumers, fleet operators, and network businesses.
4. Mitigated electricity network issues from additional load and increasing renewable capacity.

Analyses of the Australian case can lead to informative lessons for the delivery of more resilient future national transport and energy systems

4. Conclusion

Despite the many challenges are posed by the complex interactions at the convergence of the transport and energy systems, the many opportunities will lead to continued interest in strategically integrating EVs from researchers, industry, government, EV owners, and the general public.

Keywords: Electric vehicles; Grid integration; Sustainable transport; Australia; Case study

Acknowledgement

The authors appreciate the work and projects of the Sustainable Built Environment National Research Centre, and the RACE for 2030 Cooperative Research Centre.

References

[1] International Energy Agency. World Energy Outlook 2022. OECD Publishing: Paris, 2022

[2] Australian Government. Quarterly Update of Australia's National Greenhouse Gas Inventory: June 2022; Australian Government, Department of Climate Change, Energy, the Environment and Water: Canberra, Australia, 2022.

[3] Dwyer, S.; Moutou, C.; Nagrath, K.; Wyndham, J.; McIntosh, L.; Chapman, D. An Australian Perspective on Local Government Investment in Electric Vehicle Charging Infrastructure. Sustainability 2021, 13, 6590. https://doi.org/ 10.3390/su13126590

[4] Electric Vehicle Council. State of Electric Vehicles; Electric Vehicle Council: Sydney, Australia, 2022.

[5] Hargroves, K. and James, B. Considering the role of Transport Agencies in the Electro-Mobility Transition, Sustainable Built Environment National Research Centre (SBEnrc): Perth, Australia, 2021.

Regional Electric Vehicle Energy Consumption and Carbon Emissions in Great Britain

Yazan Al-Wreikat[1] and José Ricardo Sodré[2*]

[1]University of Southampton, Faculty of Engineering and Physical Sciences, UK
[2]Aston University, Department of Mechanical, Biomedical and Design Engineering, UK
*Corresponding author: j.sodre@aston.ac.uk

Abstract – This work presents the regional differences in electric vehicle (EV) real-world energy consumption and associated carbon emissions during charging in Great Britain (GB). A model was developed considering the variability in road traffic, ambient temperature, and electricity grid profile between the GB regions on EV carbon emissions under uncontrolled and smart scenarios. The results show the variations in EV energy consumption and carbon emissions impacted by where, when, and how an EV is driven and charged. Carbon emission reduction varies from 5% to 33% between the regions when switching to delayed smart charging, shifting the charging process outside peak hours. An optimised smart charging that moves the charging events to periods of low grid carbon intensity reduces carbon emissions from 6% to 55%, affected by region grid carbon intensity and energy consumption.

1. Introduction

The deployment of EVs depends on the optimisation of charging infrastructure to attend local charging demand [1]. Analysis of EV driving behaviour and charging patterns provides valuable information to reduce carbon dioxide (CO2) emissions and develop charging infrastructure. EV energy consumption is influenced by ambient temperature and road traffic [2]. CO2 emissions from charging an EV vary depending on grid mix, energy consumption and charging behaviour. This work aims to evaluate EV energy consumption and CO2 emissions under different charging scenarios on a sub-national basis.

2. Methodology

Annual EV energy consumption was calculated by estimating the monthly distance covered per car in each GB region divided by road class – motorway, rural and urban – extracted from road traffic database. The monthly ambient temperature for every region was obtained from Met Office data to account for temperature impact on energy consumption. The relation between temperature and specific energy consumption under different road classes was based on real driving cycle (RDC) from a previous work by the authors [2]. Monthly grid carbon intensity profiles for each region were built using the half-hourly data from the 2019 National Grid Carbon Intensity API [3].

The initial model analysis measures the impact of uncontrolled charging on CO2 emissions, considering the plug-in time starts at 6 pm and ends at 7 am to reflect home charging situation. The model was extended to evaluate the impact on CO2 emissions when delaying charging after 10 pm to reflect the new Electric Vehicle (Smart Charge Points) regulation. An optimisation charging model was created to provide an optimal schedule to minimise CO2 emissions in each region.

3. Results and Discussion

Figure 1 shows the variation of EV annual energy consumption when driving in each region divided by road class, considering the differences in mileage, road class and ambient temperature between the regions. The low temperatures in northern regions cause an increase in energy consumption. While North East and North West regions

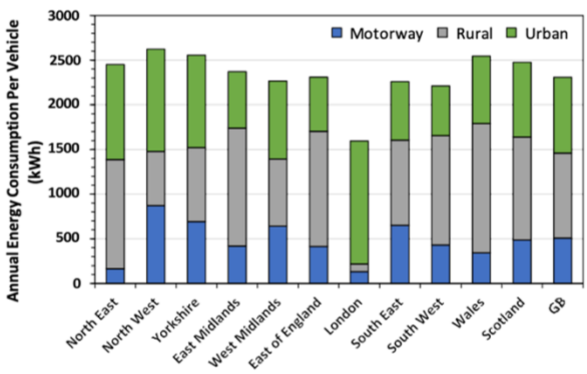


Fig. 1: Annual EV energy consumption by road class in each region of Great Britain.

have similar mileage, driving in North East presents lower energy consumption due to the higher portion of rural driving, which is less affected by temperature. London has the lowest energy consumption because of the low mileage. The EV real-world driving range have the highest drop from the advertised Worldwide Harmonised Light Vehicle Test Procedure (WLTP) range in Scotland, followed by North West, with 18% and 17%, respectively. London has the lowest impact, dropping the range from WLTP to RDC by 8%, compared to the national average of 15%.

Figure 2 shows CO2 emissions per km under different charging scenarios in each region. Charging an EV daily results in higher CO2 emissions than charging when the battery state of charge (SOC) drops to a certain level under uncontrolled charging. CO2 emissions are reduced from 5% to 33% by delaying the charging, and between 6% and 55% under optimised charging due to the regional grid profile. Routine charging schedule allows more flexibility to move the charging event to times of low carbon intensity.

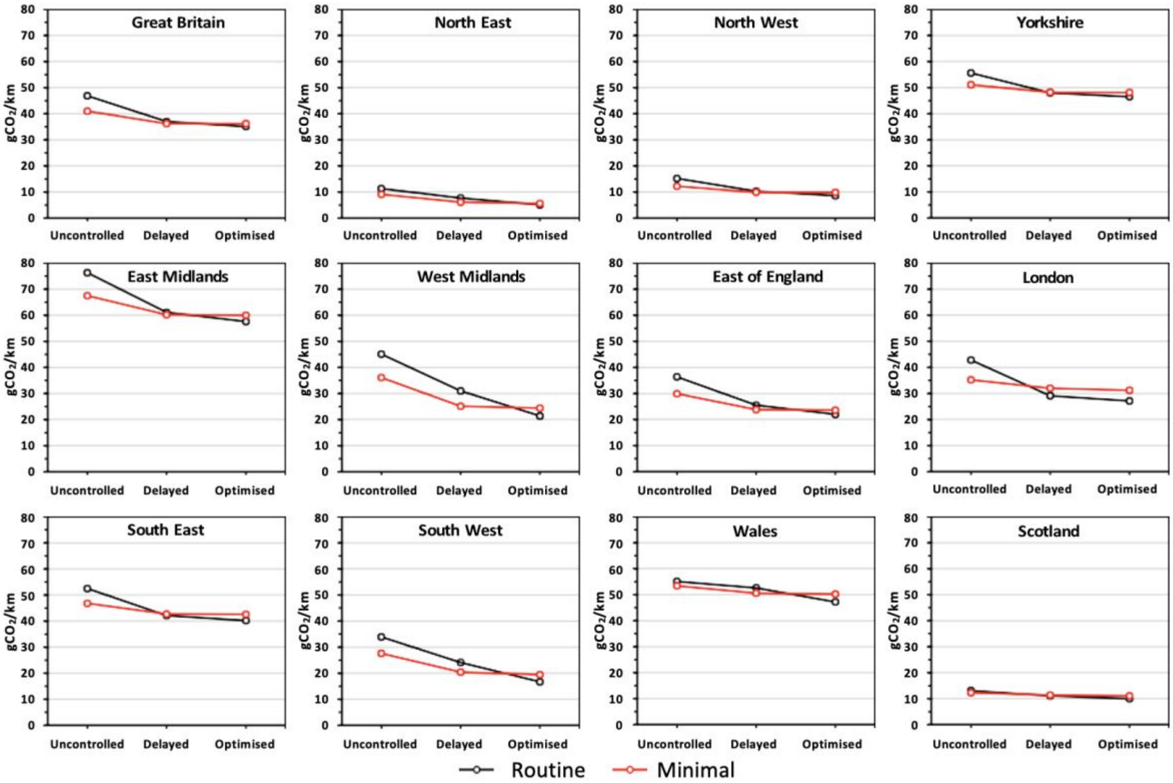


Fig. 2: Carbon emissions per km under different charging scenarios for each region.

4. Conclusion

The lower temperatures of the northern regions of GB increase EV energy consumption in comparison with the southern regions. The highest energy consumption is observed for the North West, of about 62% over London, which shows the lowest value. The differences are not only due to temperature, but by other factors like annual mileage, road class, and grid profile in each region. Regional differences on CO2 emissions under uncontrolled and smart charging present North East, North West and Scotland showing the lowest values, mostly due to longer rural driving and cleaner electricity matrix. On the other hand, East Midlands show the highest CO2 emissions, from 50% to 70% more than GB average.

Keywords electric vehicles; energy consumption; carbon emissions; regional differences; charging time

References

[1] Mourad A, Hennebel M. The Optimal Deployment of Recharging Stations for Electric Vehicles Based on Mobility Flows and Electric Grid Specifications. IEEE PES Innovative Smart Grid Technologies Europe. 2020. 534-538.

[2] Al-Wreikat Y, Serrano C, Sodré JR. Effects of ambient temperature and trip characteristics on the energy consumption of an electric vehicle. Energy. 238. 2022. 122028.

[3] National Grid. Carbon Intensity API. https://carbonintensity.org.uk/.

Commercial Fleet Vehicle Additions and Replacements and Potential Market Penetration for Electric Vehicles

Konstadinos Goulias[1*] and Hui Shi[1]

[1]Deaprtment of Geography and GeoTrans Laboratory, University of California Santa Barbara, USA
*Corresponding author: kgoulias@UCSB.EDU

1. Introduction

California has been at the forefront of electromobility and is also showing faster rising of sales than any other state in United States (https://evadoption.com/ev-market-share/ev-market-share-state/). This is further strengthened by California's latest proposed legislation dubbed "California Blueprint" that pushes the electromobility higher to include the electrification of ports, heavy-duty trucks, school and public transit buses and 100,000 new charging stations in California by the end of 2023. With increasing market penetration of Plugin Hybrid Electric Vehicles (PHEV) and Battery Electric Vehicles (BEV), battery charging infrastructure deployment that provides cheaper and more convenient charging options becomes a priority and the California Energy Commission's investment of $100 million for the Clean Transportation Program is setting the background for acceleration in infrastructure development and deployment as well as provision of incentives for vehicle purchase. Commercial fleets can play a major role in this rapid evolution not only for the transportation system but also for an envisioned integrated system of energy production (e.g., photovoltaics) and consumption in a "smart grid." However, the demand for PHEVs and BEVs by commercial fleets has received scant attention in research. Commercial fleets are vehicle fleets of large corporations, rental car companies, utilities, and government agencies. Depending on the definition of the commercial sector and the inclusion of small and large companies current estimates show a nationwide commercial fleet of a little over 8 million vehicles that is approximately 3% of the total US vehicle fleet. If a similar ratio applies to California, commercial fleets may be close to 1 million vehicles in California. Considering that fleet renewal and adoption of PHEVs and BEVs is part of a more complex planning cycle, it is worth digging deeper into ways to increase market penetration of these vehicle types and customize incentives to different fleets. In this analysis we identify groups of commercial fleets based on the attributes of the next vehicle planned to be added to a fleet and the propensity of replacing a current vehicle with an electric vehicle. From survey data we identify at least two major segments that desire PHEVs and BEVs as replacements of current vehicles in their fleet.

2. Methodology

In this analysis we use data from the California Energy Commission's (CEC) commercial vehicle fleet surveys in 2017 (herein dubbed CEC2017). This survey contains questions to fleet managers about the size and composition of the current fleet, desired attributes of the next vehicle to be added to the current fleet (either as addition or replacement of a previously purchased or leased vehicle), and a series of choice experiments to contrast vehicle attributes. In this paper using the CEC 2017 data we explore the purchase intentions and the relationships between the next vehicle and the current fleet using a technique that combines categorical with continuous vehicle attribute data. The questions from 1712 participants in CEC2017 survey that we analyze jointly to derive market segments are:

- When do you think you may purchase or lease one or more light-duty vehicles that will be company-owned/leased and/or used for business purposes in California at least 50% of the time? This was recoded as <= 5years and > 5years
- Will the next vehicle your company plans on acquiring most likely be new or used?
- Will the next vehicle your company plans on acquiring most likely be purchased or leased?
- Will the next vehicle your company plans on acquiring be an addition to your fleet or a replacement?
- What type of vehicle is your company most likely to purchase or lease next? This answer is one of 13 options from a subcompact car to a full-size large van.
- What type of engine/fuel type is the next vehicle your company acquires most likely to have? This answer is one of Gasoline, Hybrid (Gasoline), Plug-in Hybrid Electric vehicle (PHEV), Gasoline-ethanol Flex Fuel vehicle (E85 FFV), Diesel, Compressed Natural Gas (CNG) vehicle, Full Electric Vehicle, and Hydrogen vehicle.
- About how many miles per gallon (MPG or MPGe) do you expect your company's next vehicle to get, on average? (city/highway combined average)
- About how much money do you expect the company will spend to purchase/lease its next vehicle?

These are six categorical variables and two continuous variables. Extracting principal components from these variables requires to develop projections of the observed data clouds on principal axes using the counts of observations in each category of the categorical variables. For the MPG/MPGe and vehicle price proceed with the usual projection on principal components and their derivation using single value decomposition [1]. This technique produces principal components representing dimensions of the desired vehicle characteristics (price, efficiency, size and fuel type, timing of vehicle procurement, replacement of current vehicle or addition to the fleet, and intended purchase of new, used, or lease). In this application we retained 8 principal components capturing approximately 91.55% of the variance in the variables listed above. Then, these principal components are used in a hierarchical clustering routine to extract market segments (clusters) with systematic differences and similarities in their principal components and by reflection of the projection on the principal components of the original variables. In this way the compositions of these segments can be presented in terms of the next vehicle characteristics. We also studied the correlation of market segment membership with current fleet composition and fleet owner firm type, location, EV facilities, and use of other transportation services.

3. Results and Discussion

As mentioned earlier the PHEV and BEV market segments were derived using cluster analysis on principal components and then cluster membership is analyzed based on desired/expected vehicle attributes by the respondents and compared to the overall sample responses. The two segments of interest here are the predominantly PHEV and BEV segments. The PHEV segment (204 from the 1712 respondents) contains 43.5% of the total responses preferring a PHEV to replace a current vehicle in the fleet, it is a segment that is composed of 100% PHEV preferring respondents and 99.51% of them expect to purchase a small vehicle within 5 years. The average price they expect to pay is approximately $27,000 and the expected efficiency to be about 55 MPG/MPGe. The BEV segment (217 from the 1712 respondents) contains 99.50% of the BEV preferring respondents who are only 11.6% of the 1712. This segment also prefers small vehicles to replace vehicles in their fleet, possibly leasing and expecting to pay approximately $46,800 with an efficiency of about 100 MPGe. The other four segments are dominated by gasoline, diesel, and natural gas internal combustion engine vehicles and all of lower vehicle price than the overall average which is approximately $31,600. We also find that construction firms are less likely to opt for PHEV or BEV and health firms show the opposite but their membership is spread in multiple market segments. Firms with investment in EV facilities and high preference for fuel efficiency are more likely to be the PHEV and BEV segments.

4. Conclusion

Cluster analysis to identify segments here shows a substantial demand size for PHEV and BEV in commercial fleets with PHEVs replacing smaller vehicles and expected to show higher efficiency and lower price than the overall average. BEVs are also replacing mostly smaller vehicles and expected to have almost double the efficiency of PHEVs and almost $20,000 higher price. The majority of fleet managers expect to replace current fleet vehicles with more efficient models of any fuel but at lower cost if they select internal combustion engine vehicles.

Keywords electric vehicles; commercial fleet; market segments; vehicle attributes.

References

[1] Husson, F., Le, S., & Pagès, J. (2017). *Exploratory Multivariate Analysis by Example Using R*. CRC Press.

An Autoregressive Spatial Stochastic Frontier Analysis to Quantify the Sales Efficiency of the Electric Vehicle Market: An Application to 88 Demonstration Cities in China

Andrea Pellegrini[1], Yao Xusheng[*] and John Rose[3]

[1]University of Technology Sydney, Business School, Australia
[2] University of Technology Sydney, Business School, Australia
[3]University of Sydney, Institute of Transport and Logistics studies, Australia
*Corresponding author: Andrea.Pellegrini@uts.edu.au

Abstract –This study proposes using an autoregressive spatial stochastic frontier model to quantity the sales efficiency of the electric vehicle market in 88 Chinese demonstration cities from 2016 to 2021, while also accommodating potential spatial dependence. The empirical findings suggest that increasing the number of public chargers have a strong positive impact on EV adoption. Further, augmenting the gasoline price as a form of fuel tax also positively drives the demand for electric cars. By exploiting the feature of the stochastic frontier model, it is also possible to estimate that the 88 cities as a whole could have sold 83,404 electric cars more than what they actually did from 2016 to 2021, if a fuel tax of 20% on petrol had been introduced.

1. Introduction

According to the International Energy Agency (IEA), transportation related emissions made up 27 percent of the total carbon emissions produced in 2021, three quarters of which were generated from road trip travels, followed by shipping and aviation sources (IEA, 2022). To invert this negative trajectory, several countries so far have introduced a wide range of structural reforms to accelerate the mass adoption of electric vehicles (EVs), which experts unanimously deem the most viable option to diminish emissions generated from transportation. In 2009, for example, China announced the first *Ten Cities and Thousand Vehicles* project which aimed at selling at least 1000 electric cars in each of the ten demonstration cities that took part in the project through the provision of one-off purchase subsidy. After three years, the Chinese government introduced the second demonstration project brining the overall number of cities to 88. As a result, China is now the market leader with more than 3.5 million electric cars sold in 2021 (around 53% of global EV sales), with an increment year on year of almost 50 percent (IEA, 2021).

Within the transportation literature, numerous studies have thus far resorted to aggregate level econometric models to predict the impact of government policy actions on the EV sales. Typically, such studies utilize historical sales data collected either at national or at international level, and use linear or log-linear regressions models to undertake prediction exercises. In so doing, however, analysts are unable to quantity as to whether the electric vehicle market is really efficient. This study seeks to bridge this gap in the literature by developing an autoregressive spatial stochastic frontier analysis that computes the maximum level of sales achievable given a set of inputs. The use of a spatial structure is particularly appealing insofar as it captures potential neighborhood effects that may arise when neighboring areas implement similar decarbonizing strategies. The proposed model is applied to monthly EV sales data that each Traffic Management Bureau office of the 88 cities involved in the Chinese demonstration project collected between January 2016 and December 2017.

2. Methodology

Unlike linear-log regressions models, the stochastic frontier allows for estimating the maximum level of production that a firm could potentially achieve given a specific set of inputs. In this study, we exploit the features of stochastic frontier models to quantify the maximum level of sales that each pilot city could have possibly achieved as a function of specific inputs in the timeframe under scrutiny. The list of inputs that we adopt for the estimation comprises all the supportive measures that Chinese government has introduced since 2016: purchase subsidies, charger subsides, convention vehicle purchase restrictions, conventional vehicle driving restrictions *plus* number of public electric chargers available in each city as proxy for infrastructure investments. In addition to this, we include socio-economic and environmental characteristics of the city (population density km2, level of temperature, petrol price and level of PM2) and Covid-19 related measures (movement restrictions, financial support). It is important to highlight that whilst electric vehicle sales are observed, the stochastic frontier is latent. By calculating the difference between the latent stochastic frontier and the observed EV sales, it is possible to determinate the economic efficiency of each city for each month of the study.

3. Results and Discussion

Overall the estimated parameters have the expected signs and provide interesting insights into EV adoption in China. Specifically, we find that the number of public chargers available at the city level positively impacts on the frontier of EV sales, suggesting that the more electric vehicle chargers are deployed the more electric cars can be potentially sold. Further, there is a statistically significant and positive spatial effect that emerges from the interaction of the number of public chargers and the distance matrix. This indicates that there exists a strong positive spill-over effect that is attributable to the investments on charging infrastructure undertaken in the neighbouring cities. The coefficient associated with petrol price is statistically significant and positive, and hence we can conclude that as the gasoline prices increases so does the adoption of electric cars. As expected, all measures that the National Chinese Government so far has implemented to restrict the sell and movement of conventional vehicles have strong positive effects on the EV sales frontier. In similar vein, we found that the more subsidies are deployed for the construction/operation of public chargers, the higher the EV sales frontier is. Finally, the parameter related to conventional vehicle sales is found to be statistically significant and negative, indicating that the increase of traditional vehicle sales strongly diminishes the number of newly registered electric vehicles. Also, it appears that the sales of conventional vehicles reported in the neighbouring areas have a strong negative effect on the electric cars sold within the same area, thus revealing the presence of an additional spill-over effect.

As discussed in the previous section, the stochastic frontier model provides the analyst with the ability to calculate the economic efficiency of the EV market. If the estimated frontier is lower (higher) than the observed EV sales reported, then we can conclude that we are in the presence of inefficiency (efficiency). Within this context of application, inefficiency means that the inputs could have been better *maximized* to consolidate the number of electric vehicles sold in each pilot city for each year under evaluation. The results from our simulation exercise reveal that the 88 cities as a whole could have sold 83,404 electric cars more than what they actually did from 2016 to 2021, if a fuel tax of 20% on petrol had been introduced. A further interesting simulation result is that if the 88 cities had augmented the number of public chargers by 30% each year, the EV sales would have achieved an overall increment of approximately 78 000 units.

4. Conclusion

This study seeks to explore what policy initiatives the 88 pilot Chinese cities could have exploited better so as to strengthen the number of newly registered electric cars. The proposed simulation exercise highlights that the introduction of a fuel tax would have resulted in around 85 thousand electric vehicles more on roads, resulting in lower carbon emissions generated from road travel trips. Also, it appears clear that investments in charger infrastructure needs to be strongly support as the more public chargers are deployed, the less prospect clients are concerned about range anxiety, the more electric cars are sold.

Keywords Electric vehicle uptake, Stochastic frontier, Spatial Economics, Chinese demonstration project, Structural reforms.

References

[1] International Energy Agency, (2021) International Energy Outlook.
[2] International Energy Agency, (2022) International Energy Outlook.

Electrical Architecture for Ultrafast Charging Station

D. Zambrano-Prada, A. Blanch-Fortuna, J.A. Barrado-Rodrigo, L. Vázquez-Seisdedos, O. López-Santos, A. El Aroudi and L. Martinez-Salamero

Universitat Rovira i Virgili, Tarragona, Spain
*Corresponding author: davidalejandro.zambrano@urv.cat

Abstract –This report proposes the electrical architecture of an ultrafast charging station for electric vehicles (EVs), which is based on a hybrid energy distribution system made up of an AC bus and two DC buses, each one of different voltage. The proposal is the result of a Montecarlo's statistical analysis of real traffic data that leads to estimate the power demand of the electric vehicles that would access the station.

1. Introduction

EVs' charging in highway routes requires absorbing a great amount of energy in short time to ensure an uninterruptible travel. Charging stations provide points of fast charging by connecting external power suppliers that deliver DC current to the vehicle battery. Standards for fast charging are pointing out to maximum power levels between 50 and 150kW, which results in charging times between 10 to 30 minutes. In this context, ultrafast charge implies charging times less than 10 minutes, and an increase of the output power suppliers up to 350 kW. The analysis of the state-of-the-art shows that the design and implementation of ultrafast charging stations is in an incipient stage, where many alternatives are open to solve the problem. The aim of this work is to contribute to the design and sizing of an ultrafast charging station (UFCS) using real traffic data to estimate the charge profile of the station.

2. Methodology

The charge profile is obtained by considering stochastic assumptions regarding the number of vehicles accessing the station, the distribution of vehicles in time, and the state of charge of the battery. A case study corresponding to the AP 7 highway in Spain connecting Tarragona and Barcelona has been considered, the corresponding traffic data having been obtained in the Spanish Ministry of Transportation, Mobility and Urban Agenda (https://www.mitma.gob.es/; accessed Feb. 02, 2021). In addition, the number of EVs has been estimated from the total Spanish fleet, where 0.18 % of the total were electric cars in 2019. The access time has been modelled by a uniform random variable with one second resolution, the battery capacity has been described by a Gaussian variable with an expected value of μ=62 kWh and standard deviation σ=24 kWh while the battery state of the charge (SOC) has been characterized by μ=35% and σ=7.5% in the range from 0.2% to 50% of the total capacity. An algorithm based on Montecarlo's simulation has been implemented with the following constraints: i) no input nor output queues in the station ii) an unlimited number of charging points. Besides, the following three charging protocol cases have been considered: case 1) charge with a reference of constant power of 350 kW to reach 80% of SOC, case 2) charge with a reference of variable power for a charging time of 10 minutes, case 3) similar than case 2 but with a charging time of 5 minutes.

3. Results and Discussion

Charge profiles with 25, 50, 100, 200 and 300 EVs per day have been simulated, the three first values corresponding to 25, 50 and 100% of the EVs circulating in AP7 highway. The other two values are charge extrapolations. For each simulation, 1000 iterations were performed reproducing the same number of operation days of the station. Table 1 shows a summary of the simulation by illustrating the station occupation percentage according to the number of vehicles charged simultaneously in each case. Case 3 would correspond to an intermediate situation between an ideal dispatching and a process with a relatively relaxed charging time and can be used as a reference for comparative purposes. Under a low or moderate charge demand, the station could work with only 4 points of ultrafast charging 99% of the time. A supervising system could handle the queue time and ensure a continuous service due to the low probability of a higher occupation.

Table 1. Percentage of occupation for three charging method cases.

		Case 1					Case 2					Case 3				
		25	**50**	**100**	**200**	**300**	**25**	**50**	**100**	**200**	**300**	**25**	**50**	**100**	**200**	**300**
Station occupation	Empty	92,26	85,24	73,43	56,03	44,46	84,46	72,20	54,62	35,01	25,61	91,78	84,49	72,21	54,47	42,89
	1	7,33	13,24	21,25	28,22	28,52	13,88	21,98	28,20	25,88	20,19	7,77	13,82	21,94	28,38	28,20
	2	0,39	1,41	4,53	11,29	16,16	1,55	4,91	12,00	18,67	17,73	0,42	1,56	4,92	12,00	16,75
	3	0,02	0,11	0,70	3,42	7,19	0,11	0,80	3,93	11,35	14,55	0,02	0,13	0,81	3,89	7,89
	4	0,00	0,01	0,08	0,84	2,62	0,01	0,10	1,00	5,62	10,21	0,00	0,01	0,11	1,01	3,02
	5 or more	0,00	0,00	0,01	0,20	1,05	0,00	0,01	0,25	3,47	11,71	0,00	0,00	0,01	0,25	1,25

4. Conclusion

Taking into account the simulation results, an electrical architecture for the charging station is proposed based on an AC bus plus two DC buses as illustrated in Fig.1.

(i) The 1500 DC V is devoted to the charge of the EV limiting the maximum current to 1000 A (4 charging points). This high voltage allows the reduction of the number of modules in the charging points using DC-to-DC switching converters of voltage step –down nature that allow high levels of output current. The ESS is located in this bus for the direct flux of power.

(ii) The 380 V bus works as an intermediate element in the power flux between the 1500 V bus and the low voltage AC network. The renewable energy generators are located here.

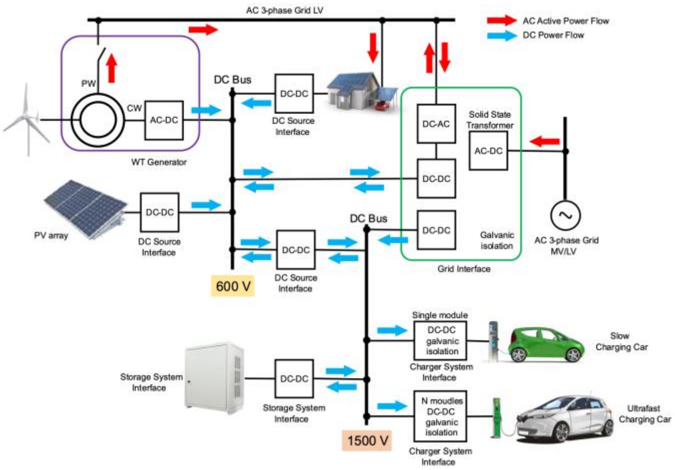


Fig. 1. Electrical Architecture for UFCS.

Keywords Ultrafast charge; hybrid energy distribution; Montecarlo's simulation; low voltage DC.

Acknowledgement

This work has been sponsored by the Spanish Ministry of Science and Innovation under grants PID2019-111443RB100 and PID2020-120151RB-I00.

References

[1] M. A. H. Rafi and J. Bauman, "A Comprehensive Review of DC Fast Charging Stations with Energy Storage: Architectures, Power Converters, and Analysis," IEEE Trans. Transp. Electrif., 2020, doi: 10.1109/TTE.2020.3015743.

[2] C. Suarez and W. Martinez, "Fast and Ultra-Fast Charging for Battery Electric Vehicles - A Review," in 2019 IEEE Energy Conversion Congress and Exposition, ECCE 2019, Sep. 2019, pp. 569–575, doi: 10.1109/ECCE.2019.8912594.

[3] S. Srdic and S. Lukic, "Toward Extreme Fast Charging: Challenges and Opportunities in Directly Connecting to Medium-Voltage Line," IEEE Electrif. Mag., vol. 7, no. 1, pp. 22–31, Mar. 2019, doi: 10.1109/MELE.2018.2889547.

Integration of Drivers' Routines into Lifecycle Assessment of Electric Vehicles

Apostolos Vavouris[1*], Lina Stankovic[1] and Vladimir Stankovic[1]

[1]Department of Electronic & Electrical Engineering, University of Strathclyde, United Kingdom
*Corresponding author: apostolos.vavouris@strath.ac.uk

Abstract – With the aim of minimising Green House Gases (GHGs) emissions, older Internal Combustion Engine Vehicles (ICEVs) are being banned from circulating in city centres around the world. Different legislations have been passed to phase-out of ICEVs with the parallel introduction of cleaner means of transportation such as Electric Vehicles (EVs), Plug-In Hybrid EVs (PHEVs), and Fuel Cell EVs (FCEVs). Different Life Cycle Assessment (LCA) models that calculate the carbon footprint of vehicles have been published. However, these models tend to average the carbon footprint per energy unit throughout the day – instead of measuring the actual carbon footprint during charging times, which is directly correlated to the generation mixture at that specific point – and therefore fail to accurately map emissions. In this paper actual time of charging is incorporated in LCA aiming to increase the accuracy and the fairness of the comparison of the different technologies, while at the same time comparing with actual consumption data gathered from different countries in Europe and North America.

1. Introduction

As of today, there are approximately 660,000 EVs in the United Kingdom's roads, a number that is expected to sky-rocket in the coming years. Although the manufacturing and recycling process – powertrain, batteries, and end-of-life – of these vehicles is more carbon intensive, the usage of electricity instead of fossil fuels can compensate the higher CO_2 emissions [3], especially with the use of renewables. To compare GHG emissions between technologies, different Life Cycle Assessment (LCA) models have been proposed to quantify vehicles' lifetime carbon footprint. These models, in general, focus on different parts of the lifecycle of EVs, including mining and processing of raw materials, manufacturing of the powertrain, usage and end-of life. Although a lot of research has been performed on LCAs and estimation of total CO_2 emissions during a vehicle's production and recycling stage [1, 2], there is still a research gap regarding factors influencing GHG emission quantification during usage, which contributes to a significant share of emissions [3]. Compared to ICEVs where fuel's footprint is not affected by the time of refuelling, EVs fuel impact to the GHGs is dynamically changing and directly correlated to the generation mixture during the charging period. The objective of this paper is to augment existing EV LCA models and enhance their accuracy by including usage factors that impose specific time of charging patterns. Results are compared with current LCA models.

2. Methodology

In this section the steps – summarised in Fig. 1 – followed to assess the carbon footprint of different technologies are presented and propose a new EV LCA model. As this study focuses on the effects of the EVs' usage compared to ICEVs', carbon emissions involved during the production and end-of-life stages are calculated as in [3]. Fossil fuels carbon footprint is correlated with the penetration of renewable fuels that made up 7% of the total road and non-road machinery fuel in the UK in 2022. Considering the Indirect Land-Use Change (ILUC), there is a 77% aggregate saving in terms of GHGs emissions. Compared to ICEVs, whose fuel refill timing is not correlated to their carbon footprint, EVs are using energy that is instantaneously produced in the grid. Therefore, data regarding the generation mixture as well as their CO_2 emissions were gathered through the Electricity System Operators (ESOs) on a half-hourly interval for a period of 1 year (01/01/2022 – 31/12/2022). Based on the Department of Transport survey data, user preferences regarding charging times were used for the modelling of different users' profiles. In addition, 30 min resolution smart metering households' energy data of EV owners spread across different countries including Norway and Germany were used. A one-year simulation of the actual footprint based on the charging time – as identified through the surveys and the actual electricity consumption of different households – was performed. Results were then extrapolated to a vehicle's full lifetime – i.e., the total expected mileage before withdrawal from circulation.

Fig. 1: Usage assessment flowchart

3. Results and Discussion

Fig. 2 illustrates a comparison of the GHG emissions between the ICEV and EV model of [3] compared to the proposed model, where user-charging-routine information is integrated into the models. A medium-sized vehicle with an estimated usage of 225,000 km in its lifetime is assessed in three different households. In the UK household, based on survey data, EVs are usually charged during evening hours (18:00 – 22:00), demonstrating a 3.8% (~2.5 tCO_2) increase in its carbon footprint, a fact that is expected due to the peaking power plants that are introduced to the grid to meet the increased demand. In the German household, based on the smart metering data, the EV is charged mainly during night (00:00 – 06:00) – when the grid is less stretched and therefore base power plants can handle the load. A reduction of 12.9% (~12 tCO_2) in emissions is observed. Lastly, for the Norway's household, according to smart metering data, although it is exhibiting a similar behaviour with German one – i.e., charging during night hours – a negligible reduction (~0.3 tCO_2) in total CO_2 emissions is observed. This is due to the particular nature of Norway's generation mixture which consists almost exclusively of hydro generation and therefore peak demand is not covered with the use of carbon intensive peaker plants.

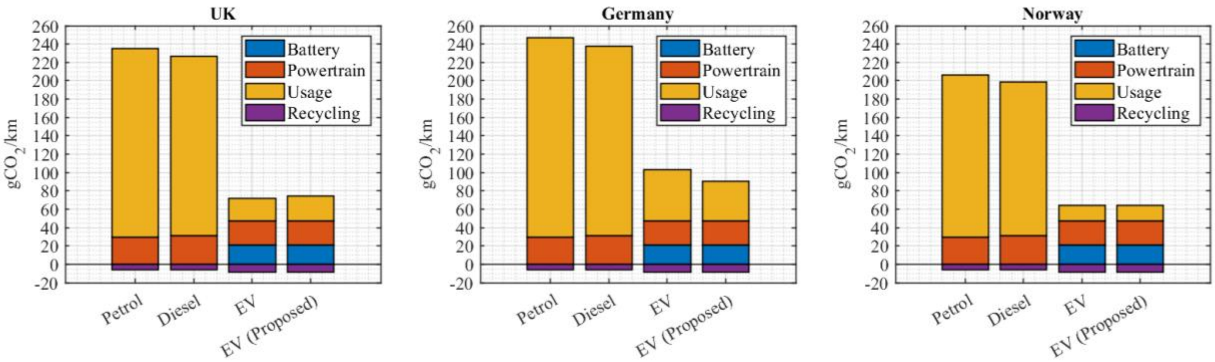


Fig. 2: LCA of a mid-sized vehicle in three different case studies, UK, Germany and Norway

4. Conclusion

In contrast with ICEVs, where refuelling timing does not affect the carbon emissions, EVs' charging routines can greatly affect the actual GHGs emissions during its lifetime. From the initial results presented in Section 3, lifecycle emissions per vehicle type can vary from -12.9% up to +3.8% considering the different users' charging routines. This research is especially timely given the introduction of load-shifting initiatives throughout the world with an aim to reduce CO_2 emissions, as well as the introduction of smart chargers that can be programmed to charge during specific time periods. Full paper will include results obtained for different charging routines as well as different users' usage – i.e., private and commercial. Particular attention will be given in quantifying the effect of different geographical areas, both on regional and national level, to the actual carbon footprint of each technology.

Keywords Electric Vehicles (EVs); Life Cycle Assessment (LCA); Energy Sources; Smart Charging; Non-Intrusive Load Monitoring (NILM)

Acknowledgement

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 955422.

References

[1] Marmiroli, B., Messagie, M., Dotelli, G. and Van Mierlo, J., Electricity generation in LCA of electric vehicles: A review, applied sciences, 8, 8, 2018, p.1384.
[2] Verma, S., Dwivedi, G. and Verma, P., Life cycle assessment of electric vehicles in comparison to combustion engine vehicles: A review, Materials Today: Proceedings, 49, 2022, pp.217-222.
[3] T&E's analysis of electric car lifecycle CO_2 emissions, Transport & Environment, 2022.

Investigation of a Cost-Effective Electric Vehicle Charging Station Assisted by a Photovoltaic Solar Energy System

Abdullah Dik*, Siddig A. Omer and Rabah Boukhanouf

Department of Architecture and Built Environment, Faculty of Engineering, The University of Nottingham, Nottingham NG7 2RD, UK
*Corresponding author: abdullah.dik@nottingham.ac.uk

Abstract – The impact of increased power demand on electricity grids due to the projected expansion of electric vehicles (EVs) could be lessened by integrating renewable energy-fed EV charging stations. The study aims to evaluate different combinations of electric vehicle chargers technology for use in an EV charging station powered by a photovoltaic solar system. Then a technical, economic and environmental feasibility analysis of the EV charging station is presented in this paper.

1. Introduction

Replacing current fossil-fuelled modes of transport with electric vehicles represents the most robust tool for achieving zero-carbon targets. However, a smooth transition is crucial both to reduce the carbon footprint of the electricity networks and build more capacity to meet the expected extra demand for power. As the number of EVs is projected to increase rapidly, developing renewable energy-supported EV charging stations could address the nexus of electrification of transportation and green battery- charge operations.

This paper aims to evaluate an EV charging station which combines five different types of charger technology supported by a PV solar energy system for application in a parking area at the University of Nottingham, UK. A stochastic approach is used to calculate EVs' charging demand. Also, the study provides six different charging station scenarios to determine the best combination of 3kW and 7kW capacity chargers. This study will provide a preliminary investigation of future charging stations to be established in the campus parking areas to evaluate the best combination of charge capacity and charger rate, solar energy potential and economic viability of the installation.

2. Methodology

This study uses a computer-modelling to estimate the solar energy potential of the location and presents a stochastic approach to the selection and sizing of five separate charging ports for the individual EV charging station. Fig.1 shows a flow chart of the steps used in developing the methodology of this study. The potential of solar energy resources and the effect of environmental parameters on the location are obtained from Photovoltaic Geographical Information System (PVGIS) [1]. A mathematical tool is then developed to determine the power generation capacity of the PV system to meet the total load of the EV charging station.

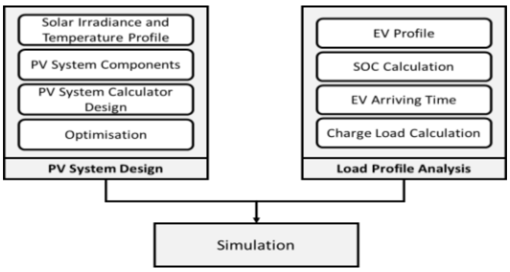


Fig. 1: The summary of the applied methodology

To assess accurately the charging station power load, the computer model of EV takes into account of the number, type of EVs and state of charges (SOCs) [2]. The total hourly load of the EV chargers is determined using a stochastic approach to provide randomness and uncertainty. Then, the average battery capacities were determined by considering the UK's current EV trends. After then, the model generated an EV dataset with EVs and randomly assigned a battery capacity to each vehicle in the dataset. The Gaussian distribution is then used to generate the dataset's random SOCs of each vehicle. In this case, it is assumed that the SOCs of the EVs to be charged will be varied between 20% and 50%, and an EV battery is considered fully charged when it reaches 80% of its maximum charging capacity. Additionally, in this study, the efficiency of the chargers is taken as 90% [3].

A preliminary investigation revealed that EV chargers used at the University of Nottingham Campus are rated at 3kW and 7 kW power output. In this study, the same type and power level of chargers' technology are considered to create a five-charging port station, as shown in Table 1.

Table 1: The charger port combinations

Charging Station Combination	3 kW Charger	7 kW Charger
1	5	0
2	0	5
3	3	2
4	2	3
5	4	1
6	1	4

3. Results and Discussion

The solar resources simulation tool shows a large fluctuation in available solar radiation ranging from 180 Wh/m^2 on average in winter to 277 Wh/m^2 in summer. Therefore, a full feasibility analysis is required to evaluate the most economical combination scenario. This situation may cause surplus energy production and unnecessary investment cost due to excessive energy potential in the summer months. Since the system optimization has yet to be completed, detailed PV system results will be given in the full paper.

The initial modelling results, Fig. 2, show the hourly electricity demand of the charging stations the daily demand for charging stations ranges from 95 kWh to 145 kWh. In addition, when the electricity exchange between the selected PV system and the grid is considered, at least a 171.5 m^2 solar array area is needed for a system that meets 95 kWh electricity demand.

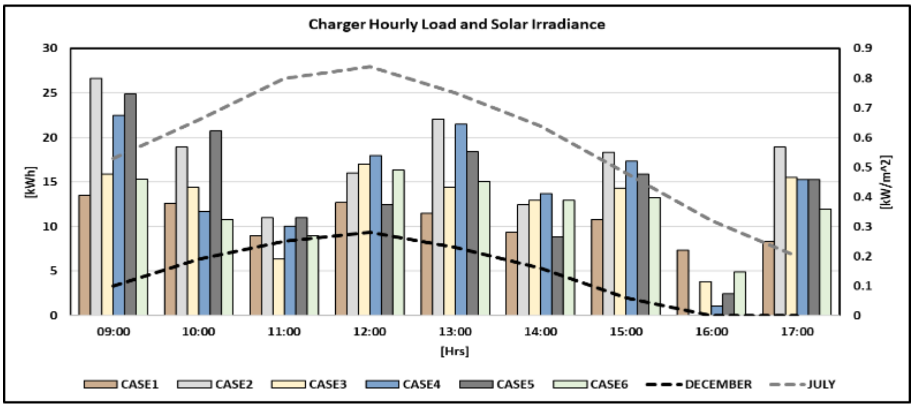


Fig. 2: The hourly charging demand of the cases and solar potential of the location

4. Conclusion

Some initial results are given in the result section. However, the full paper will detail the PV system and EV charger optimizations and cost and environmental analysis of the cases.

Keywords PV Solar Energy; Electric Vehicle (EV); EV Charging; EV charge station; Renewable energy sources (RES)

References

[1] Photovoltaic Geographical Information System (PVGIS) [06.02.2023]; Available from: https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP.

[2] DfT. Licensed Ultra Low Emission Vehicles by Body Type and Propulsion or Fuel Type; Department for Transport (DfT) Statistics. 2022 [06.02.2023]; Available from: https://www.gov.uk/government/statistical-data-sets/vehicle-licensing-statistics-data-tables#ultra-low-emission-vehicles.

[3] Jian, L., Z. Yongqiang, and K. Hyoungmi, The potential and economics of EV smart charging: A case study in Shanghai. Energy policy, 2018. 119: p. 206-214.

Thermodynamics, Heat Transfer, and Renewable Charging of Electric Vehicles

Efstathios E. Michaelides

Department of Engineering, TCU, Fort Worth, Texas, USA
E.Michaelides@tcu.edu

Abstract – When all vehicles, including electric vehicles, complete a round trip and their tank or battery is charged to the initial state, the vehicles execute a thermodynamic cycle. This article uses the classical thermodynamic analysis to examine several characteristics and salient features of electric vehicles including:

1. **The well-to-wheels efficiency of electric vehicles.**
2. **The carbon dioxide emissions associated with the use of electric vehicles supplied by the electricity grids of several countries.**
3. **The convective heat transfer to or from the cabin of the vehicle and the effects of the use of air conditioning, heat pumps, or resistance heating.**
4. **Infrastructure for charging electric vehicles with renewable energy sources.**
5. **The effects of electric vehicle charging on the capacity of national and regional electricity grids.**
6. **Energy storage in a fleet of electric vehicles for use in buildings.**

In addition to the thermodynamic analysis of these characteristics, the paper will include numerical examples pertaining to the use of electric vehicles in Texas, with reference to the ERCOT electricity grid.

A Comparative Study of Novel Designs of Liquid-Cooled Battery Thermal Management Systems

Pranjali Tete[1], Sandeep Joshi[1]* and Mahendra Gupta[1]

[1]Shri Ramdeobaba College of Engineering and Management, Nagpur, India 440013
*Corresponding author: joshiss@rknec.edu

Abstract – The Li-ion battery has emerged as the heart of electric vehicles. The efficient thermal management of these lithium-ion batteries is an important aspect of electric vehicles for their safety and improved performance. The present work proposes two innovative and efficient modular designs of battery cooling systems. The designs are modeled with 5S1P and 5S5P cell configurations, and their performance is evaluated using computational fluid dynamics (CFD) for heat generation and maximum temperature rise. The effect of heat generation rate and coolant flow on the thermal behaviour of the battery modules has been thoroughly studied under different discharge rates. The performance of the systems was estimated using theoretical analysis and compared with the CFD simulations. It has been found that the maximum temperature of battery module obtained in designs 1 & 2 is 33.84°C and 27.89°C respectively and the maximum temperature difference between adjacent batteries is below 5 Deg.C. The details of the innovative designs and the performance analysis have been discussed in this article.

1. Introduction

The automobile industry is transforming into a new era, with a focus on environmentally sustainable vehicles that emit zero emissions, minimal noise, and low power consumption. To accomplish this, the development of electric vehicles (EVs) and hybrid electric vehicles (HEVs) has received much interest around the world. One of the challenges for EVs is the development of an effective battery thermal management system (BTMS) [1]. Lithium-ion batteries (LIBs) have gained more attention in the electronics market owing to their high energy density, long cycle life, stable charge-discharge rates, and capacity [2–5]. These work as promising energy storage devices for EVs and various electronic applications as well. Li-ion batteries generate a significant amount of heat while being charged and discharged, which raises the temperature of the battery pack collectively. Hence, a BTMS is designed to keep the battery safe and efficient while ensuring that the temperature stays within the safe operating range [2]. The ideal temperature range for LIBs is 15–35°C [2–5] and there should be no more than a 5°C temperature variation between adjacent cells [2–5]. Numerous researchers are working on the development of an efficient BTMS worldwide by considering the various parameters that may affect the performance and life cycle of LIBs. The development of an efficient and compact BTMS is one of the major areas of improvement in EVs, which eventually relates to its range, safety, economy, and reliability.

2. Methodology

In the present work, two different novel designs of the battery pack with different cooling arrangements have been modeled and analyzed. Two modular battery packs with rectangular duct (for 5S1P configuration) and square duct (for 5S5P configuration) as shown in Fig. 1 and Fig. 2 for the passage of coolant are designed. An active liquid cooling technique is implemented in these battery modules with water as a coolant. Firstly, the thermal performance of the battery modules without any cooling techniques under natural convection is investigated numerically using the computational fluid dynamics (CFD) software package ANSYS Fluent 2021R1. Then, a series of CFD simulations have been performed for both battery modules using water as a coolant under different discharge rates. Finally, the simulation results are validated using mathematical models based on the empirical correlations of heat transfer.

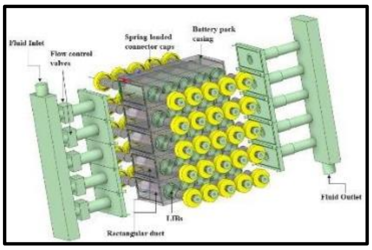


Fig. 1: Battery module with rectangular duct (5S1P)

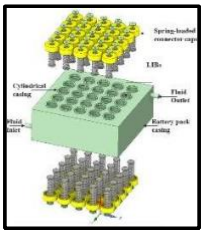
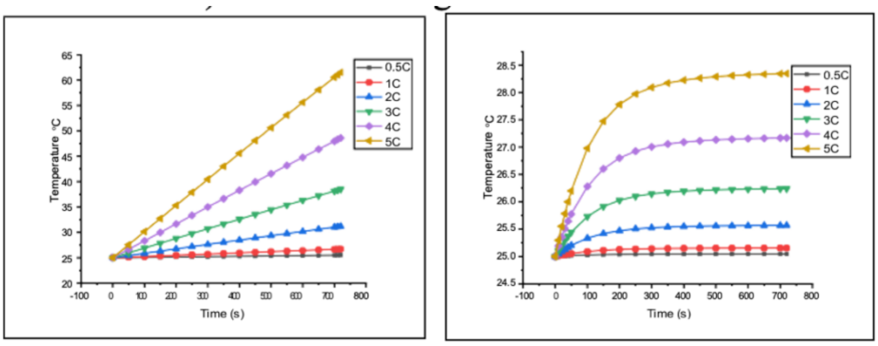


Fig. 2: Battery module with square duct (5S5P)

3. Results and Discussion

In this study, a comparative analysis is performed between two novel modular designs of the battery modules using the active liquid cooling technique. The thermal behaviour of these battery modules is investigated numerically using CFD simulations under various operating conditions and a sample result (with fixed flow rate of water) is shown in Fig. 3.



(a) (b)

Fig. 3: Temperature profile of the battery pack at different discharge rates for 5S1P configuration (a) without cooling (b) with water cooling

4. Conclusion

Thermal management of lithium-ion batteries is a crucial factor for the safety and performance of electric vehicles. In this study, two different designs of battery cooling systems have been investigated and compared for their thermal behaviour. It has been observed that both systems provide efficient thermal management under higher discharge rates using water as a coolant. It has been found that the maximum temperature of battery module obtained in designs 1 & 2 is 33.84 °C and 27.89 °C respectively and the maximum temperature difference between adjacent batteries is below 5 °C. A relative error of 1.02% is obtained between the theoretical and simulation results.

Keywords active liquid cooling system, battery thermal management, lithium-ion batteries, electric vehicles

Acknowledgment

This work is supported by Shri Ramdeobaba College of Engineering and Management, Nagpur, Maharashtra, India.

References

[1] Choudhari VG, Dhoble AS, Panchal S. Numerical analysis of different fin structures in phase change material module for battery thermal management system and its optimization. Int J Heat Mass Transf 2020;163. https://doi.org/10.1016/j.ijheatmasstransfer.2020.120434.

[2] Liu C, Xu D, Weng J, Zhou S, Li W, Wan Y, et al. Phase change materials application in battery thermal management system: A review. Materials (Basel) 2020;13:1–37. https://doi.org/10.3390/ma13204622.

[3] Kong D, Peng R, Ping P, Du J, Chen G, Wen J. A novel battery thermal management system coupling with PCM and optimized controllable liquid cooling for different ambient temperatures. Energy Convers Manag 2020; 204:112280. https://doi.org/10.1016/j.enconman.2019.112280.

[4] Hekmat S, Molaeimanesh GR. Hybrid thermal management of a Li-ion battery module with phase change material and cooling water pipes: An experimental investigation. Appl Therm Eng 2020;166:114759. https://doi.org/10.1016/j.applthermaleng.2019.114759.

[5] Tete PR, Gupta MM, Joshi SS. Developments in battery thermal management systems for electric vehicles : A technical review State of Power. J Energy Storage 2021;35:102255. https://doi.org/10.1016/j.est.2021.102255.

Optimisation of Electric Vehicle Battery Size

Niall Jones[1*], Simon Nazarenus[1], Konstantinos Stamatis[1], Andreas Zachariah[2] and Liana Cipcigan[1]

[1]School of Engineering, Cardiff University, UK
[2]CEO Co-founder, EVSerious Ltd, UK
[*]Niall Jones: JonesN76@cardiff.ac.uk

Abstract – Energy storage and battery technology have taken centre stage in the race to reduce automotive carbon emissions to net zero by 2030. However, underlying key issues such as resource scarcity must be solved before the automotive industry becomes 100% reliant on electric vehicles. The research conducted in this paper has proposed viable solutions to this through modelling of real driver data. It was found that 95% of all trips were able to be completed by a 50kWh battery where 75% of trips were less 50km. However, when an increased number of charging stations are available within a 300 metre radius the optimal size reduces to 30 – 40 kWh which will enable a 30% cost reduction in EV batteries.

1. Introduction and Objective

In June 2019, parliament issued law requiring the government to reduce the UK's net emissions of greenhouse gases by 100% in relation to levels in 1990 by 2050. Cars accounted for 55.6% of carbon emissions in transport in 2019 and need to be electrified accordingly [1]. Energy storage, especially in the case of battery technology will be at the forefront of the solution as by 2030 sale of new petrol or diesel cars and vans will be banned [2].

The main objective of this paper is to find an optimised solution to allow a smooth transition to EV alternatives once the 2030 deadline arrives whilst also being conscious about the scarcity of the elements needed to construct these batteries. This paper models real driver trips using the multi-agent software AnyLogic where the real data of travel patterns of different drivers is used as an input. Based on the travel behaviour and travel distance optimal battery size for each driver is proposed. Different types and number of charging stations are included in the model with the goal of finding the link between charging type with availability and battery range which determined the optimal charging routine and battery size.

2. Methodology

Individual driver data has been collected through a mobile app and were used for the case study. The driver data has been inserted into an agent based AnyLogic model where specific points on the driver's route have been marked using parameterised agents on a GIS map. The points on the map are connected via the use of a state chart that allows parameters to be set for the vehicle as it moves through different states, such as: outside temperature, altitude, speed, and acceleration.

The battery is modelled by a fluid tank where valves open and close allowing the battery to discharge and charge. The rate of discharge is determined by the speed, acceleration and altitude parameters from the state chart which will change when the agent enters a new state. Two different charging methods are examined alongside two different charging availabilities. The different charging methods are: one slow charge at home when battery level is less than 20%, and a few fast charges throughout the day. The availability and locations of charging is split into two models. The first model uses a map of known street chargers already in circulation and inserts 10 random chargers into the simulation where the vehicle can move to if it is within 300 metres when battery level is less than 20%. The second model uses around 100 charging stations which incorporates chargers already in circulation and petrol forecourts which shows the potential benefits of a large scale charging infrastructure if the petrol stations are translated into chargers. Charging is determined by a go/no-go decision that is integrated into the same state chart that determines the cars speed, location etc. This is done by the fluid model sending a message "Battery Low" or "Battery Full" when the battery has reached 20% or 100% respectively which in turn triggers the vehicle agent to move to the nearest charging station agent if it is within a 300 metre radius.

3. Results and Discussion

From the driver data 95% of trips could be completed by the average EV battery size of around 50kWh where roughly 75% of trips were less than 50km. The comparison of charging station availability within a radius of 300 metres when the car battery is below 20% concluded that an increased number of charging stations will allow battery size to be decreased to between 30 – 40kWh with 20 – 30 minute fast charges.

A cost benefit analysis determined the advantages of increasing charging stations concluding that by reducing the battery size the cost of an EV could reduce by 20% to 30% without major disruptions in performance. The cost of upgrading the grid infrastructure and the purchasing of charging equipment to accommodate for additional fast chargers were taken into account and it was found that a break-even points in costs would be attainable before 2035.

4. Conclusion

This paper has concluded that the average electric vehicle battery size can be decreased from 50kWh to 30kWh – 40kWh when supported by a large scale charging infrastructure which will benefit consumers through a 30% reduction in EV battery cost.

The results of this paper demonstrate the importance of a high level charging infrastructure which will aid UK government decisions to ensure charging infrastructure will be reliable, accessible, and meet driver demand by 2030 [2].

Keywords Lithium batteries; Aging mechanisms; Driver behaviour; Charging methods; Battery simulation.

Acknowledgement Special thanks to EVSerious Ltd for providing the real driver data.

References

[1] Department for Transport. Decarbonising Transport: A Better, Greener Britain. 2021. Available online: https://www.gov.uk/government/publications/transport-decarbonisation-plan (Accessed on 28. January 2023).

[2] HM Government., *"Net Zero Strategy: Build Back Greener."* OGL., London, United Kingdom, 2021. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf

Electric Buses Battery Sizing Optimisation using an Agent-Based Modelling Approach

Simon Nazarenus[1*], Konstantinos Stamatis[1] and Liana Cipcigan[1]

[1] Cardiff University, School of Engineering, Wales, UK
*Corresponding author: sim_naz@uni-bremen.de

Abstract – This study presents a comprehensive agent-based model that simulates the energy consumption of battery electric buses (BEBs) under different environmental and traffic conditions. It estimates the required battery size for BEBs as well as the network load to optimise the charging infrastructure. GPS coordinates, average speed and temperature profiles are used to calculate the energy consumption. The results of a case study for a bus route in Cardiff show that the size of the current BEB battery costs can be significantly reduced by optimising the charging infrastructure, for example it is obtained a reduction by £80,700 per bus through end-line charging compared to overnight charging. Fast charging and occasionally wireless charging achieve the lowest required capacities of 38.2 kWh and 45.8 kWh respectively, however, the grid load is significantly higher for fast charging.

1. Introduction

To achieve decarbonisation of the transport sector, a structural change from individual transport to public transport is necessary. In 2019, buses were responsible for 3.1 MtCO2e emissions in the UK [1]. To reduce the emissions, various climate-neutral drive systems for buses are being proposed, such as buses powered by hydrogen or biofuels [2]. However, these two technologies cannot be implemented on a large scale in a foreseeable future [3]. Consequently, BEBs are the most promising solution for rapid decarbonisation. Yet, three main challenges can be identified regarding BEBs:

- The range of BEBs is dependent on battery capacity with current market available chemistries having smaller available range than fossil fuel busses [4].
- The upfront capital expenditure (CapEx) of purchasing BEB's can be high due to the price and size of the batteries [2].
- The transition to BEB may require significant investments in upgrading the charging and grid infrastructure [4].

A potential solution to help addressing these issues would be to utilize different charging methods (e.g. occasional wireless or fast, end-of-line, overnight) in order to reduce battery size and manage network demand [4].

In this paper an agent-based model was developed using AnyLogic that processes travel data and simulates energy consumption and battery demands for different charging methods. It further calculates the net load curves, and allows conclusions to be drawn about the optimal charging infrastructure and battery size for different bus lines. To the best of the authors' knowledge, this is the first agent-based model that evaluates geographic data of buses at given times, then projects them onto different charging infrastructures, and as a result calculates the required battery size and the network load.

2. Methodology

In the AnyLogic model that was built, each bus is defined as an agent, its driving patterns is based on the discrete event modelling approach and uses GPS data for the bus route and timestamps to emulate driving behaviour. Several factors are considered to accurately model the battery load including speed, temperature variation, number of stops, traffic, and passenger occupancy [5]. Flowcharts are used to simulate the battery of each bus and the summation of the current flows entering the batteries results in the load curve that the electricity grid must provide.

3. Results and Discussion

The functionality of the model is demonstrated in a case study for bus routes in Cardiff in which different charging infrastructures were simulated and compared in terms of required battery size, economic performance, and network load. Table 1 presents the results based on Cardiff City Circle line. The cost of the battery is estimated by multiplying the maximum discharge capacity by the price per kWh (500 £/kWh) [2].

Table 1: Discharge Capacity (DC) for different charging options and climate conditions

Charging Infrastructure	Average DC (kWh)	Max. DC Spring (kWh)	Max. DC Summer (kWh)	Max. DC Fall (kWh)	Max. DC Winter (kWh)	Battery Price (£)
End-of-Line	47.5	55.1	51.2	55.1	58.4	29,200
Overnight	120.0	204.5	195.8	203.1	219.8	109,900
Occasionally Wireless	35.1	42.5	38.6	42.5	45.8	22,900
Fast Charging	27.3	33.0	31.0	24.5	38.2	19,500

Occasional fast charging requires the smallest battery capacity, but also leads to high grid load peaks (240 kW for three BEBs). In comparison, wireless charging also has comparatively small battery sizes, however, it has significantly smaller power peaks, but it is not as energy efficient. End-of-line charging requires the second largest capacity, although it offers the advantage that fast chargers only need to be installed at the base. Overnight charging requires a much larger capacity (219.8 kWh) than the other three charging infrastructures and therefore leads to significant costs for bus acquisition. However, during the night the grid availability and electricity costs can be an advantage.

4. Conclusion

The developed agent-based model provides reliable estimations of the energy consumption of a bus line under different environmental and traffic conditions. The case study in Cardiff demonstrated that the installation of fast charging points can reduce the required battery size by a factor of more than ten compared to commercially available buses such as the MAN Lion's City 10 E. However, each solution has it owns benefits and drawbacks, and further studies will consider the whole infrastructure investment costs and full life cycle costs of the BEBs, as the different charging methods can impact the battery degradation differently.

Keywords: Battery Electric Busses, battery capacity, multi-agent modelling, battery charging

Acknowledgement We are grateful for support from the Decarbonising Transport through Electrification (DTE) Network+ funded by EPSRC grant reference EP/S032053/1.

References

[1] Department for Transport. Decarbonising Transport: A Better, Greener Britain. 2021. Available online: https://www.gov.uk/government/publications/transport-decarbonisation-plan (Accessed on 24. January 2023).
[2] MILES, John; POTTER, Stephen. Developing a viable electric bus service: The Milton Keynes demonstration project. Research in Transportation Economics, 2014, 48. Jg., S. 357-363.
[3] KING, Julia. The King Review of low-carbon cars: part I: the potential for CO2 reduction. HM Treasury, 2007.
[4] BASMA, Hussein, et al. Assessing the charging load of battery electric bus fleet for different types of charging infrastructure. In: 2021 IEEE transportation electrification conference & expo (ITEC). IEEE, 2021. S. 887-892.
[5] BASMA, Hussein, et al. Comprehensive energy modelling methodology for battery electric buses. Energy, 2020, 207. Jg., S. 118241.

Parametric Study on Lead-Acid Battery in an Electric Powertrain

Daksha Moodbidri Renuka, Axit Ghanshyamnhai Thakar, Gopika Namboothiri, Ahmed Rezk* and Jose Sodre

Future Vehicle Technologies, Aston University, Birmingham, B4 7ET, UK First
*Corresponding author: a.rezk@aston.ac.uk

Abstract – There has been an increasing interest in electric and hybrid powertrains as the primary vehicle to decarbonise the roads. It is essential to study the performance of electrified vehicle batteries, as it is the most susceptible to performance degradation due to the ambient temperature. This study investigates a lead-acid battery integrated into a simplified powertrain that drives F24 GreenPower electric car under the NEDC drive cycle. The parametric study showed a progressive increase in the battery's temperature of up to 35°. The temperature decreases later on as the drive cycle decreases in speed.

1. Introduction

Fuel efficiency and reduced greenhouse gas emissions make electric and hybrid vehicles essential for environmentally friendly transportation and road decarbonisation. Nevertheless, recent studies show that electric vehicles contribute considerably to greenhouse gas emissions due to their insatiable appetite for electricity, especially in countries with limited renewable energy generation capacity and the components waste at the end-of-life cycle. Emphasising electric waste materials, substantial investment to deal with used automobile batteries' chemical and electrical components (Sergio Manzetti, 2015). Lead-acid batteries, the earliest rechargeable battery technology, have dominated the market for over a century despite their relatively low storage capacity. Lead-acid batteries offer several benefits, including their low cost. One of them is their use for standby applications; this is true for most automobiles, where the "starting battery" activates the engine, maintains electrical power during inactivity, and controls the car's electrical voltage (Berndt, 2001).

2. Methodology

Ricardo Ignite platform was employed to computationally undertake a parametric study on utilising a led-acid battery working in an electrical powertrain. It allows users to couple drive cycles to determine the optimal matching between the battery and the powertrain for a location. Based on the GreenPower F24 car, a powertrain model was established and validated, as shown in Figure 1. The powertrain comprises a battery, motor, vehicle, and speed reduction gear. The specific driving cycle is chosen, and other components, such as heat capacitors and convection, can be coupled to the battery. The parametric study was undertaken, and based on various weather temperatures observed in that particular location, the optimal operating temperature for each of the distinct driving cycles was hypothesised.

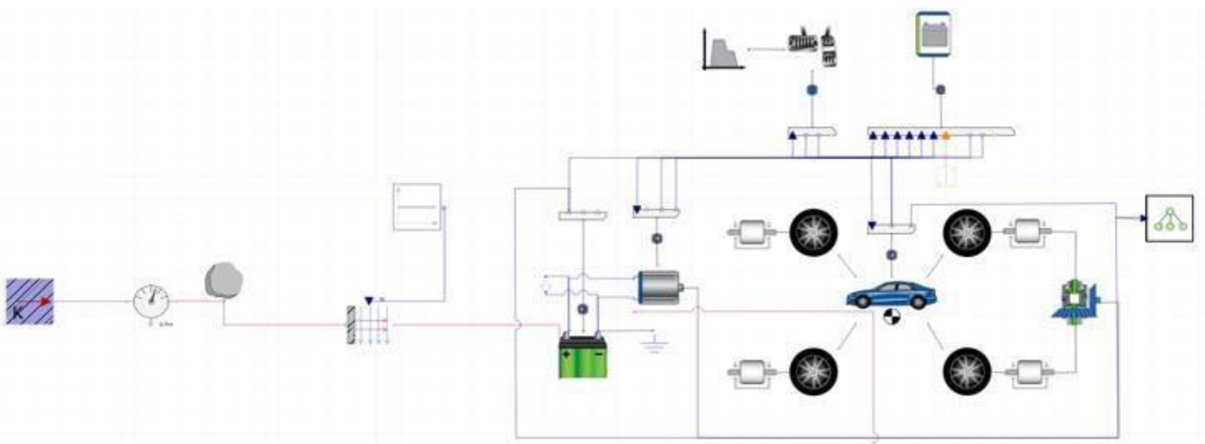


Figure 1 – block diagram of the electric powertrain

3. Results and Discussion

The NEDC drive cycle was employed as an example, as in Figure 2. In this case, as the speed increases over the course of time, it can be noticed that there was a progressive increase in the temperature of the battery, which was then observed to decrease later on as the drive cycle decreased in speed. Regarding the State of Charge (SOC), the battery levels are expected to fall gradually throughout the investigated period as the battery continues to run while simultaneously losing power. This may be observed as a progressive reduction in the battery levels over a period of time. Following the completion of the investigation, it was found that the tested battery appears to function quite well when subjected to the NEDC driving cycle. Notably, Europe's average temperature ranges from 20 to 30 °C. The graphic reveals that the highest temperature that may be reached while the machine runs is 34 °C. Because the battery's temperature is not very anomalous, it may be anticipated that the rate of cell degradation and the battery's life cycle will be improved.

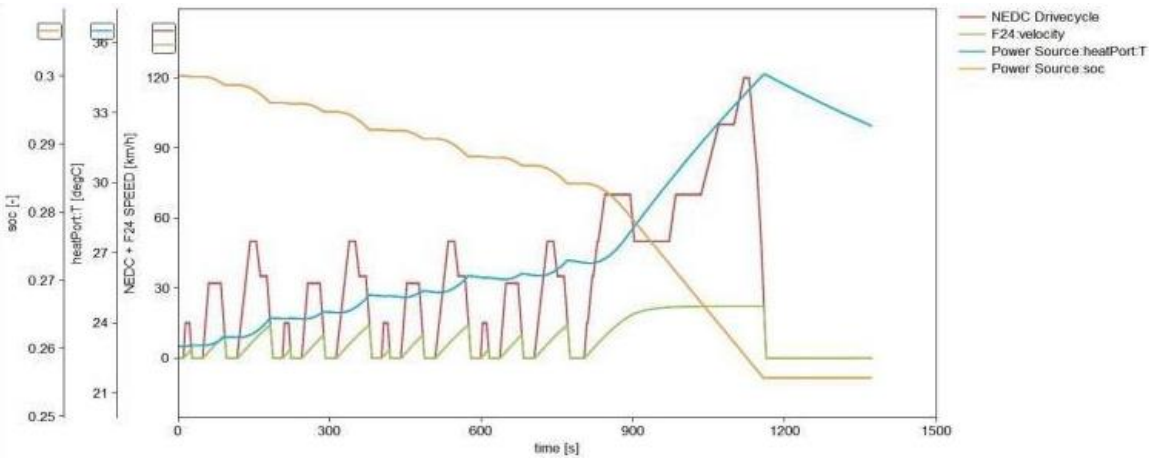


Figure 2 - Battery Thermal Analysis Results

4. Conclusion

Given that the battery is an essential part of an electric vehicle (EV), thermal analysis of the battery is an essential characteristic. Furthermore, because batteries can catch fire and pose a risk, it is crucial to conduct thermal studies and determine the temperature at which they operate most effectively. As a result, utilising a user-friendly computational tool like Ricardo Ignite supports the development of an efficient electrified powertrain. Batteries can be subjected to in-depth examination, during which they can be simulated against several driving cycles to better understand the battery's whole history.

References

[1] Berndt, D., 2001. Valve-regulated lead acid batteries. *SceinceDirect,* 100(1-2), pp. 29-46.

[2] Sergio Manzetti, F. M., 2015. Electric vehicle battery technologies: From present state to future systems. *ScienceDirect,* Volume 51, pp. 1004-1012.

Systematic Review on Phase-Shift Optimization Strategies of Dual Active Bridge based DC-DC Converter

Osama Majeed Butt[1], Rana Hasnat Ahmed[2], Muhammad Husnain Ashfaq[3]

[1]Institute Electrical Electronics & Computer Engineering, University of the Punjab, Lahore 54590, Pakistan
[2]University of Engineering and Technology, Lahore 54000, Pakistan
[3]UM Power Energy Dedicated Advanced Centre (UMPEDAC), University of Malaya, Kuala Lumpur 59990, Malaysia
*Corresponding author: osama.ee@pu.edu.pk

Abstract – Bidirectional DC-DC converters (BDC) between high and low voltage buses are the most promising in latest research for their use cases in microgrids. Specifically, the dual active bridge (DAB) topology of BDC has vast number of applications and its ability to transmit power in both directions makes it effective for utilities in consumer-prosumer setup. In recent years, a substantial amount of research has been conducted to eliminate one of the crucial drawbacks of DABs which is the mitigation of DC-Bias current resulting from practical limitations of switches. DC-Bias current is the leading cause of switch stress resulting in reduced converter reliability and efficiency. Numerous strategies have been devised to overcome this issue which includes methods like flux suppression, dynamic optimization, transient control, and piecewise linear transient phase shift optimization. In each of these categories several studies devised various techniques to increase operation efficiency, the dynamic response optimization (including model predictive controls and ANNs) can also be seen in recent research trends. This state-of-the-art systematic review is conducted on the recent developments in phase shift optimization techniques developed to increase the overall efficiency of isolated DABs. Considering it as a wide research discipline, the intervention criteria of searching the relevant primary studies is chosen to be strict. Some systematic reviews accommodate all the recent studies of this area, this review particularly is conducted to enhance the view only towards the phase shift-based optimization strategies and provide boarder insights of DAB optimization to researchers and engineers.

1. Introduction

Micro-grid is an advanced architecture combining renewable energy sources (RES) with traditional and modern grids in harmony. One of the requirements in completing the micro-grid architecture to efficiently support the applications like Electric Vehicles (EVs) is the use of device named bidirectional DC-DC converter (BDC) between high and low voltage buses. BDCs take energy from both sides, convert it to the required voltage and transmit. So, they are specifically useful in scenarios where grid requires extra energy of consumer (intentional back-feeding) to utilize it in another place. Different topologies and control schemes of BDC exists in literature – the most recent review on this lists 16 topologies of isolated (8) and non-isolated (8) converters and also enlist and reviewed the control strategies (with their limitations) to mitigate the efficiency problems of BDC [1, 2].

An advanced topology named dual active bridges (DAB) to better handle high frequency isolated BDC was proposed, and it gained extensive attention [3]. DAB topology consists of eight switches combined to form two galvanic-ally isolated bridges and with the features like high power density, flexible power regulation, fast dynamic response, zero voltage switching (ZVS) and wide soft switching range, it is one of the most recognized inventions [4, 5]. While being recognized as one of the promising topologies, DAB is not perfect. As an ideal device (in theory) its efficiency should be 100% but due to discrepancies in practical switches the switch stress and magnetic saturation of transformer core increases resulting in decreased efficiency and reliability. The inconsistencies of switches' gate driving voltage, terminal voltage pulse, dynamic phase shift adjustment increases the DC-Bias (DB) current which in excess leads switch stress. Existence of DB current is a practical issue because of the inconsistency between theory and practice [4]. For high frequency (HF) transformers, HFDB adds more problems making it difficult for transformer to attenuate the oscillations.

For performance improvement the mitigation of DAB problems like DC-Bias, Current Stress, Dead-band, and others an optimization technique belongs to some of this category is required. The systematic review conducted here summarize all the major studies using phase shift modulation (PSM) optimization technique (alone or in hybrid) to solve DAB problem.

2. Results and Discussion

Table 1: Systematic Literature Review of 15 Papers (* is on First Proposals) [I] – Improvements, [P] – Problems/Limitations, [N] – Novel

Notes	Related PSM	Summary & Results
Novel PSM to increase system power performance up-to 30%	*DPS	[I] Reactive power ↓, voltage ripple ↓, Power capability (33%) ↑, output capacitance ↓, Inrush Current ↓, Deadband Influence ↓ [P] Complex to solve for variable phase shifts, because of 3D independent control surface of 2 phase shifts ($D_1 \wedge D_2$) [N] DPS strategy (variable phase shift) introduced
Improve Performance - Low Surge and Stable Power	DPS	[N] Modified DPS with bidirectional inner phase and outer phase with wide operation region [I] Stability with no compromise on efficiency ↑, Surge current ↓ [P] Voltage is restricted to 30V (light-load conditions)
Cooperative TPS (CTPS) - Improve Current Characteristics	TPS	[I] Current Stress ↓, Efficiency ↑, RMD ↑ [N] CTPS is proposed to eliminate dual-side flow back currents. [N] Optimize for the tuning region. [P] Increased DC-Bias current and deadband
Improve Performance - Transient Elimination	TPS	[N] Introduced less complicated version of TPS (ITPS) [I] No compromise on efficiency, Stability ↑, DC-Bias ↓
Improve Performance	TPS	[N] Use Lagrange multiplier to minimize the RMS current [N] Derive the analytical less complex mathematical model of TPS [I] Efficiency (min RMS current through optimization) ↑
Enhanced SPS - Improve Performance by adding a special DOF	SPS	[N] Peripheral current controller for DAB is proposed. [I] Dynamic performance (achieve 1-cycle settling time) ↑
Novel PSM increased stability	*TPS	[N] Lyapunov function of each stage of TPS [N] Novel method to analyze the stability of any engineering system. [I] TPS controlled converter stability ↑
Unified TPS (UTPS) - Minimize Current Stress and Achieved full soft switching	TPS	[N] Introduced KKT optimization algorithm. [I] Efficiency ↑ of DAB controlled with UTPS, ZVS achieved
Hybrid SPS with a new modulation scheme (zero-voltage) Paper didn't mention the specificity of PS but as the shift ratio is same and thus categorized in SPS	ZVS	[N] Introduced Zero-Voltage modulation. [I] Substantial increase in converter efficiency ↑
Novel Extended DPS is presented	DPS	[N] Propose EDPS, find optimal phase-shift points of EDPS and determine the reasons of not achieving the ZVS [I] Achieved ZVS (through optimization), system effectiveness ↑
Load current estimation with SPS for better dynamic performance	SPS	[N] Introduce LCE+SPS with delay compensation. [I] Speed-up the dynamic performance, efficiency ↑, stability ↑ [P] Research with other PSM and modulation schemes is needed
Hybrid SPS with STgPS & STzPS	SPS	[N] Introduced hybrid scheme combining TgPS, PS and TzPS [I] Efficiency ↑, transformer filter volume ↓ [P] No comparison with other modulation strategy

Variable Switching Frequency introduced to eradicate the need of DC-Link Capacitor for ZVS improvement	SPS, DPS	[N] Novel single-dual PSM technique [I] Achieved ZVS both for light and heavy load [I] Eliminate the need of DC-Link capacitor through VFS
Solved a problem of CTPS	TPS	[I] Dead band ↓, DC-Bias transients ↓
Novel PSM to reduce current stress and improve efficiency	*EPS	Same as DPS [N] Did stability analysis

3. Conclusion

Systematic literature review of 15 IEEE journal papers is conducted on the piecewise linear transient phase-shift optimization techniques of isolated dual active bridge DC-DC converter, to enhance the view on current research and development. Some studies use optimization techniques on objective function developed by investigating the cause of low efficiency/stability and after minimization of that function achieve better results. Studies with DC-Bias elimination and dead-band were also conducted. This review gives the surface idea of research progress in performance improvement of DBA and is organized systematically to facilitate reader. Other strategies to optimize the performance of DABs also exist (like dynamic control), and these were also selected if some relation with phase shift is linked to it.

Keywords Dual active bridge; DC-DC converter; phase shift modulation; Bi-directional Convertor

References

[1] S. A. Gorji, H. G. Sahebi, M. Ektesabi, and A. B. Rad, "Topologies and control schemes of bidirectional DC–DC power converters: An overview," IEEE Access, vol. 7, pp. 117997-118019, 2019.
[2] S. Dahale, A. Das, N. M. Pindoriya, and S. Rajendran, "An overview of DC-DC converter topologies and controls in DC microgrid," in 2017 7th International Conference on Power Systems (ICPS), 2017, pp. 410-415.
[3] R. W. De Doncker, D. M. Divan, and M. H. Kheraluwala, "A three-phase soft-switched high-power-density DC/DC converter for high-power applications," IEEE transactions on industry applications, vol. 27, pp. 63-73, 1991.
[4] B. Zhao, Q. Song, W. Liu, and Y. Zhao, "Transient DC bias and current impact effects of high-frequency-isolated bidirectional DC–DC converter in practice," IEEE Transactions on Power Electronics, vol. 31, pp. 3203-3216, 2015.
[5] Q. Bu, H. Wen, H. Shi, and Y. Zhu, "A comparative review of high-frequency transient dc bias current mitigation strategies in dual-active-bridge dc–dc converters under phase-shift modulations," IEEE Transactions on Industry Applications, vol. 58, pp. 2166-2182, 2021.

Diary-Based Evaluation of Bidirectional Electric Vehicle Charging in a Long-Term Study: Method and Insights

Bettina Kämpfe[1*] and Corinna Braun[2]

[1]Cognitive & Engineering Psychology, Chemnitz University of Technology, Chemnitz, Germany
[2]Chair of Marketing and Innovation, University of Passau, Passau, Germany
*Corresponding author: bettina.kaempfe@psychologie.tu-chemnitz.de

1. Introduction

Bidirectional charging of battery electric vehicles (BEVs) provides a promising solution in terms of grid stabilisation and integration of renewable energy. As an energy-balancing tool, bidirectionally charged BEVs could offer benefits to individual consumers, energy providers and society in general. However, BEVs primarily have to fulfil users' mobility needs. Therefore, one of the biggest challenges in bidirectional charging management is balancing users' mobility needs and energy requirements of the home or public electricity grid optimally. In order to investigate the suitability of a bidirectional charging system for everyday use, we accompanied twenty pilot users in a long-term study lasting 15 months. From July 2021 to September 2022, users recorded their charging-related experiences in online diaries. We pursued two goals with this: (1) the continuous recording of subjectively meaningful experiences around bidirectional charging and (2) the identification of barriers to bidirectional charging. Despite its increasing relevance, prior user research that reflects real experiences with bidirectional charging is sparse as the concept is not yet freely available in Europe. Most studies explore acceptance in hypothetical scenarios. However, it has been shown that direct experience has a significant influence on acceptance [1]. Our results identify factors that influence acceptance in a real-world context of use. Furthermore, we tested the use of semi-structured online-diaries in a long-term study to answer the research questions (I) whether diaries are suitable as a data collection tool for a longer period of time, (II) whether the quality and quantity of entries change over time, and (III) how diaries should be optimally designed to maintain motivation for entries.

2. Methodology

The participants of this diary study were twenty pilot users who took part in the German pilot project "Bidirectional Charging Management". They were equipped with a bidirectional charging system at home containing a BEV, a wallbox and a charging app. In addition, the photovoltaic modules (PV) of sixteen participants were integrated into their bidirectional charging system. From July 2021 to September 2022, participants gradually tested the use of the system and different use cases, namely Vehicle-to-Grid (V2G), Business-to-Consumer (B2C) and Vehicle-to-Home (V2H), if a PV was installed. The participants were asked to record all subjectively significant (positive, challenging or negative) experiences in their personal experience diary. For this purpose, they were given a personal account on the "IDX platform" using a QR code or a personal internet login. After logging in, they could choose between new or change entry. Each entry requested the following data: (a) date and time of the experience, (b) concerned system element, (c) rating of the experience (positive, negative, challenging), (d) experienced emotion, (e) text or image description of the experience, and (f) free description of further ideas, wishes or suggestions. If the entry concerned a problem, participants were asked to provide additional information about the problem and its consequences, as well as about the problem-solving process, its success and their satisfaction with the solution and support. The participants were able to change an entry within a week.

3. Results and Discussion

Throughout the study period, the pilot users reported a total of 72 experiences in the diaries, mostly concerning the wallbox (29%), the charging process (24%) or the charging app (14%). 28 entries (6 positive, 14 negative, and 8 challenging experiences) were made during the first three months of the pilot phase (July - September 2021) and 21 entries (3 positive, 12 negative, and 6 challenging experiences) in the second three months (October - December 2021). In the first half of 2022, only two entries (both positive experiences) were recorded (in January and in May). In the last three months of the study, the participants reported 21 experiences (6 positive, 13 negative and 2 challenging experiences). About 75% of all entries described a challenge or a negative event. Thereby, 69% of the negative experiences arose from the wallbox or the charging process and were associated with negative emotions. In contrast, challenges were not experienced negatively and the emotions were described as neutral. Here, too, the most frequently mentioned challenges concerned the wallbox in connection with the charging cable. Other challenges, for example, referred to the pilot users' fears of making mistakes when using the app or the system. Positive experiences were recorded less than negative experiences. Reported positive experiences related to the BEV, customer support and other experiences. The number and type of entries varied widely between the participants, from none at all to 15 experiences per pilot user, with some pilot users describing only negative experiences.

With regard to the goals pursued through the use of the diaries, the following can be summarised: (1) Negative experiences and challenges are more meaningful to the participants than positive ones. On the one hand, the result can be attributed to the "negativity bias", i.e. to the proclivity to "attend to, learn from, and use negative information far more than positive information" [2]. On the other hand, it may indicate that the reduction of barriers can increase the acceptance of bidirectional charging more effectively than the implementation of incentives to use the technology. (2) These barriers are primarily of a technical nature. The system must function without errors. Subjective barriers such as fear of one's own errors or a faulty system play a rather subordinate role. Regarding the suitability of diaries in long-term studies, we found: (I) Diaries are only conditionally suitable as a data collection tool for a longer time period, as participants seemed to be less motivated to make entries. The number of entries was rather low and varied greatly between the individual participants, some did not record any entries at all. Furthermore, the described negativity bias could significantly distort the results. (II) Both the number and type of entries varied over time. In the second half of the study period, the proportion of reported positive and negative experiences improved. This may be due to fixing bugs in the system and improving the technology. (III) It is recommended to collect experiences only topic-related and for certain time periods, i.e. not for every event that occurred but at fixed intervals. Participants could be asked about their experiences at defined points in time by a voice message or a phone call instead of an open diary where one might forget to record events.

4. Conclusion

Through the implementation of experience diaries, barriers in the use of bidirectional charging could be identified. These mainly concern technical problems. To raise the acceptance of bidirectional charging, the reduction of barriers seems to be more promising than the implementation of incentives to use the technology. However, the method has limitations and should be adapted. In order to achieve a high usage and acceptance of the diaries, the effort should be reduced and the users should be explicitly asked to make an entry. Alternatively, culture probes or contextual inquiry might be useful evaluation methods.

Keywords: bidirectional charging; user experience; diary studies; V2X; electric vehicle (EV).

Acknowledgement

This study was part of the research project "BDL – Bidirektionales Lademanagement" ("Bidirectional Charging Management", reference no. 01MV18004G), funded by the German Federal Ministry for Economic Affairs and Climate Action.

References

[1] Schmalfuß, F., Mair, C., Döbelt, S., Kämpfe, B., Wüstemann, R., Krems, J. F., & Keinath, A., User responses to a smart charging system in Germany: Battery electric vehicle driver motivation, attitudes and acceptance. Energy Research & Social Science, 9, 2015, 60-71.

[2] Vaish, A., Grossmann, T., & Woodward, A., Not all emotions are created equal: the negativity bias in social-emotional development. Psychological bulletin, 134, 3, 2008, 383.

EVs and their charging – in or out? User acceptance of bidirectional charging in Germany

Vera M. Fahrner[1]*, Moritz Bergfeld[1], Christine Eisenmann[1]

[1]Institute of Transport Research, German Aerospace Center, Germany
*Corresponding author: Vera.Fahrner@DLR.de

Abstract – Electric vehicle battery capacity can be used to store energy and redistribute it to the grid during peak load, while vehicles are connected to the grid. This concept of bidirectional charging is evaluated with regard to user acceptance. By assessing user acceptance through focus group discussions, we find indications on how the introduction and adoption of bidirectional charging can be implemented for everyday use. Results are expected to differ between home owners and people who rent. We also expect user acceptance to depend on whether electric vehicles are used routinely or spontaneously.

1. Introduction and Objective

Acceptance of a new technology by users is crucial for this innovation to then be used and adopted, which has been evaluated in a number of models and theories [1]. This is especially true for innovations with which users interact directly. If designed appropriately, bidirectional charging can contribute significantly to making the energy system more flexible and thus help increase the share of renewable electricity. However, the success of this technology depends on its suitability for everyday use and the acceptance of users. Therefore, it is essential to evaluate acceptance factors as well as drivers and barriers for bidirectional charging from the users' perspective. We aim to derive recommendations on how bidirectional charging can be implemented in an appropriate way, so that electric vehicle (EV) users will adopt bidirectional charging in their mobility.

2. Methodology

Moderated exchanges between selected participants (i.e., focus group discussions) are particularly suitable for exploring new topics. The structured discussions follow a guideline that focusses on EV-owners' understanding of bidirectional charging, their expected behavioural changes when using bidirectional charging, the potential of integrating bidirectional charging into their own (domestic) energy system, advantages and disadvantages of bidirectional charging and differences in the requirements of different user groups for bidirectional charging. As bidirectional charging is a relatively new concept, these aspects are of a rather exploratory nature. However, as a theoretical basis, we also include the perceived ease of use and perceived usefulness of bidirectional charging, which are key components of the technology acceptance model [2].

In a first screening (i.e., a questionnaire sent to participants in advance to the focus group discussion), socio-demographic, and vehicle-related as well as household-related aspects are queried. For example, information regarding age, vehicle model and household size are to be gathered. The discussions are to be differentiated on the basis of the housing situation. This means that at least one discussion should be conducted only with people who own their home and one with people who rent. This differentiation is based on the assumption that owners are more likely to have a private parking space and thus a private charging facility. In addition, compared to people who rent, it is assumed that home owners are more concerned with energy services and the possibilities of integrating the EV into the home energy system, since they bear greater responsibility in their household energy system. The (private) ownership of a photovoltaic system (PV-system) is also of great interest in this context due to the potential of sector coupling.

Three focus group discussions with EV owners will be conducted in March 2023. The discussions will be transcribed and then analysed using the software MAXQDA [3]. We plan on following a rather inductive approach of analysis [4]. Nevertheless, we already have some assumptions on relevant aspects, as we also bear acceptance variables in mind. Therefore, we will employ a hybrid form of analysis as proposed by Kuckartz [5].

3. Results and Discussion

For the present, as we will conduct the discussions in March 2023, our results are a depiction of what we expect to be found and discussed. We assume that participants will report that they expect changes in their EV-use when employing bidirectional charging. For example, daily drives could be communicated to the vehicle along with a minimum range needed before departure. Thus, we assume, that participants daily or routine trips would be easily incorporated into the use of bidirectional charging. Nevertheless, we expect that participants could perceive some difficulty with bidirectional charging and spontaneous trips. Additionally, we expect some differences between home owners and people who rent, especially with regard to the integration of bidirectional charging to the own home and energy system. In general, we expect a high level of knowledge regarding energy supply and consumption from the participants. It will be interesting to see if these supposed results can be supported after we have conducted our discussions.

4. Conclusion

Acceptance and adoption go hand in hand. Thus, for an innovation to prevail, it is essential to examine user acceptance. The current paper proposes a methodology for the analysis of user acceptance of bidirectional charging. When designed appropriately, bidirectional charging is one means to help ensure an efficient energy system. However, the technology can only reach its full potential if user acceptance is ensured and future users are involved in the development process. The current study provides early information and insights into what users require, thereby contributing to the development of the technology and policy mechanisms.

Keywords – bidirectional charging; user acceptance; smart grid; focus group discussions

Acknowledgement

We report no conflict of interest. This research was funded by the German Aerospace Center within the project FFAE (“Fokusanwendungen, Fahrzeugstrukturen, Antriebsstrang und Energiemanagement“ [focus applications, vehicle structures, powertrain and energy managing]).

References

[1] Taherdoost, H., A review of technology acceptance and adoption models and theories, In Procedia Manufacturing, 22, 2018, 960-967.

[2] Davis, F. D., A technology acceptance model for empirically testing new end-user information systems: Theory and results, Doctoral Dissertation, Massachusetts Institute of Technology, 1985.

[3] MAXQDA, Software für qualitative Datenanalyse [Software for qualitative data analysis], VERBI Software, Consult. Sozialforschung GmbH, Berlin, Deutschland, 1989 – 2021.

[4] Mayring, P., Qualitative Inhaltsanalyse [Qualitative Content Analysis], Beltz, 2003.

[5] Kuckartz, U., Three Basic Methods of Qualitative Text Analysis, In: Qualitative Text Analysis; A Guide to Methods, Practice & Using Software, SAGE Publications, 2013, pp. 65-120.

Exploring the Feasibility of Battery Electric and Fuel Cell Electric Vehicles as Peaker Plant Substitutes in Low Wind and Irradiation Conditions

Nies Reininghaus[1*], Tobias Tiedemann[1], Michael Kroener[1] and **Martin Vehse[1]**

[1] DLR Institute of Networked Energy Systems, Carl-von-Ossietzky-Str. 15, 26129 Oldenburg, Germany
*Corresponding author: nies.reininghaus@dlr.de

Abstract – In this paper we present a comparison between using battery electric vehicles (BEV) and fuel cell electric vehicles (FCEV) to span dark wind doldrums ("Dunkelflaute") in a future energy system with a high penetration of renewable energy generation.

1. Introduction

As the penetration of renewable energy sources increases, the need for flexibility in the power grid becomes more pressing. With the transition from fossil fuels, such as natural gas and oil, to more sustainable options for heating like heat pumps, electricity demand during cold periods is expected to rise. A study conducted by [1] predicts a difference of 10 GW in peak power generation demand for a year with low wind and PV generation, i.e. a cold dark wind doldrum (cold "Dunkelflaute") condition, compared to an average weather year in Germany by 2050. This demand cannot be met by traditional load shifting methods alone. To meet this demand, costly peaker power plants (which only operate a few hours a year) or multi-purpose facilities may be required. One potential strategy for these energy systems is the integration of Battery Electric Vehicles (BEVs) with bidirectional charging functionality for households and heat pumps. This approach leverages the energy stored in BEVs to meet increased demand for electricity and heat. An alternative solution involves the use of Fuel Cell Electric Vehicles (FCEVs) to convert stored green hydrogen into both, electricity and heat. The FCEV solution benefits from access to chemically stored energy in the form of hydrogen, whereas BEVs rely on available energy that is already stored in the battery, and would be limited in situations with a lack of renewable energy generation. These dual-use cases have the added benefit of increasing the energy system's resilience, while, in the case of FCEVs, at the same time the waste heat of hydrogen reconversion can be utilized for an increased overall efficiency.

2. Methodology

For the determination of both thermal and electric energy transfer efficiencies from an FCEV to a building energy system, a docking station prototype was set up in the laboratory of the German Aerospace Centre in Oldenburg. The thermal setup includes a plate heat exchanger, ultrasonic and magnetic-inductive flow sensors, temperature and pressure sensors, valves, and pumps. These components are used to transfer thermal energy from the FCEV's high-temperature cooling circuit to a thermal laboratory sink via a set of independent circulation systems and a storage tank. The electrical components include a DC power connector, a DC switch, and a DC sink, which are used to transfer direct current out of the FCEV and to control the power output. Measurements at different DC-power output levels and cooling inlet temperatures were performed [2].

Furthermore, the use of regenerative FCEVs supplying a neighbourhood was simulated in the Python framework OEMOF, which optimizes energy flows in a cost-controlled manner. The neighbourhood considered in the simulation consists of 19 buildings, inhabited by 252 people, with the number of residents determined from statistical data. Electric and thermal load profiles of each building were generated for a time period of one year, considering the individual behaviour of the residents using the software "LoadProfileGenerator". Heating load in this simulation is set at 25 kWh/m²/a for comparison reasons, which is lower than the heating load used in a prior publication [2]. The simulations examine different scenarios, including scenarios with increasing numbers of BEVs used by the residents, leading to a higher demand of electricity for charging, based on an average commuting distance in Germany and an average BEV consumption of ~170 Wh/km.

3. Results and Discussion

We used the docking station to determine the net electric efficiency as the ratio of chemical energy in the form of hydrogen consumed by the fuel cell vehicle to the electric energy drawn from the FCEV. The worst net electric efficiency of 37% occurs at the lowest electric power applied, which may be related to the fuel cells power system design. For electric output powers of 5 kW and above, net electric efficiency level off at around 53%. To convert the efficiency values into characteristic curves for simulations, linear regression was used. For the simulations, we assumed that 1 kW net electric power is the minimum power at which the FCEVs or the virtual power plant may be operated and that efficiencies remain constant above 9 kW net electric power.

These measured efficiencies affect the power requirements in the neighbourhood, with less power needed during both the day and night. Additionally, the number of BEVs that are charged daily does have an influence on the required power from the grid, with the vehicles being able to charge flexibly in time. Nevertheless, more power is needed during night-time as the number of vehicles charged increases. The BEVs can thus be used for short term storage of electrical energy and peak power demand shifting, if bidirectional charging would be possible. As some of the vehicles would always remain parked (and connected) to the buildings, they can serve as a replacement of stationary batteries. A necessary requirement for this would be the knowledge of charging states and mobility needs to intelligently integrate the vehicles into the control system of such a system.

4. Conclusion

We used measurements and simulations to determine the amount of heat that can be generated by FCEVs, and how it can be used to save electricity in a simulated neighbourhood. The results show that as the number of BEVs in a neighborhood increases, more heat is generated, which can be used to save electricity. Using the waste heat of the FCEV, approximately 14% of the total electricity demand can be reduced, if electrical pumps are used for heat generation. On the other hand, the BEVs can be used to replace a stationary electric storage to provide flexibility, e.g. peak power shifting. Thereby the total power demand from the grid can be lowered, although the overall electrical energy demand is increased by the mobility needs of the inhabitants. Thus, hydrogen as a seasonally storable chemical energy carrier, can be used to provide power and energy for a longer period of time than a full battery charge of a BEV would be able to, in this low renewable power generation scenario. The drawback of a lower overall conversion efficiency of hydrogen produced via water electrolysis can be improved using the waste heat from the fuel cell directly for space and warm water heating.

Keywords: dark wind doldrum; fuel cell electric vehicle; battery electric vehicle; hydrogen; renewable energy

Acknowledgement

We thank Jan Dasenbrock for his contributions to building the docking station and performing the experiments.

References

[1] Aurora Energy, The impact of weather in a high renewables power system, 2021

[2] T. Tiedemann, M. Kroener, M. Vehse, C. Agert, Fuel cell electrical vehicles as mobile coupled heat and power backup-plant in neighbourhoods, Energies 15 (7) (2022)

Combining Urban Fleet Vehicle Operation with Reducing Energy Wastage in Light Rail Systems

Fiona McBride[1*], Erica Ballantyne[2] and David Stone[3]

[1]Management School, University of Sheffield, UK
[2]Management School, University of Sheffield, UK
[3]Department of Electrical and Electronic Engineering, University of Sheffield, UK
*fcmcbride1@sheffield.ac.uk

Abstract – Fleet electric vehicles offer excellent potential for vehicle-to-grid operation, as a result of their predictable use patterns. This paper investigates the potential for linking up urban fleet electric vehicles with wasted energy from urban light rail networks. Vehicle-to-grid charging could be deployed to reduce energy wastage from light rail, while serving as temporary energy storage on the tram system to reduce energy requirements during acceleration and providing an energy supply for fleets of electric vehicles based in urban areas.

1. Introduction

Urban fleet vehicles such as buses, taxis and delivery vans are increasingly a target for electrification [1]. Fleet vehicles are typically stored at depots close to urban areas when not in use. They also tend to follow reasonably short, pre-planned routes, so are unlikely to exceed their range [1], [2]. Both route predictability and depot storage make fleet vehicles well-suited to vehicle-to-grid charging. As the estimated time and distance of a vehicle's next journey is known, therefore the required state of charge of each battery is somewhat predictable.

Urban light rail transit systems typically have their own power network with dedicated supply substations. When a tram/train slows down, regenerative braking is employed to convert its kinetic energy into electrical energy, some of which is then reused by the train to power auxiliary aspects such as heating and lighting. If another train is nearby in the same supply section, some of this regenerative energy may be diverted to it, reducing power draw from the substations. However, much of the energy produced by regenerative braking in light rail vehicles is wasted, as the supply system is not designed to redistribute it effectively. Excess regenerated energy causes the distribution system voltage to rise to unacceptable and potentially damaging levels, so is disposed of via a heat dump in resistors on the train roof [4].

Preliminary studies [5] have shown that vehicle-to-grid charging could be employed to reduce wasted regenerative braking energy. Linking urban light rail networks up with bus or delivery depots close to the tracks would allow vehicles at those sites to act as temporary energy storage, returning regenerative braking energy to the rail network to power nearby accelerating trains to reduce the total energy drawn from the substations. Fleet vehicles could also be left in a state of charge appropriate to their next planned use. In this paper, a case study based on Edinburgh's tram system is presented as an indicative estimate of how vehicle-to-grid charging could be linked with regenerative braking energy.

2. Methodology

In order to determine how much excess regenerative braking energy is available in each energy supply section along the rail network, the Edinburgh tram system has been modelled in MATLAB. The model draws on GPS data taken from tram journeys to determine where trams brake. Information such as the tram timetable will be used to estimate how often trams are able to reuse regenerative braking energy. Energy availability throughout the day will be linked to potential logistics locations along the network to develop indicative examples of how vehicle-to-grid charging could be effectively deployed.

3. Results and Discussion

Results from this study will include estimates of the regenerative braking energy that is realistically available in each energy supply section along the tram route between the Edinburgh Airport and West End stops. These estimates will account for energy reuse between nearby trams, as well as other factors such as line resistance. Energy availability figures will be combined with information on locations of fleet vehicles close to the Edinburgh tram route (as shown in Figure 1) to produce indicative estimates of how many vehicles of relevant types would be needed for effective vehicle-to-grid charging throughout the day.

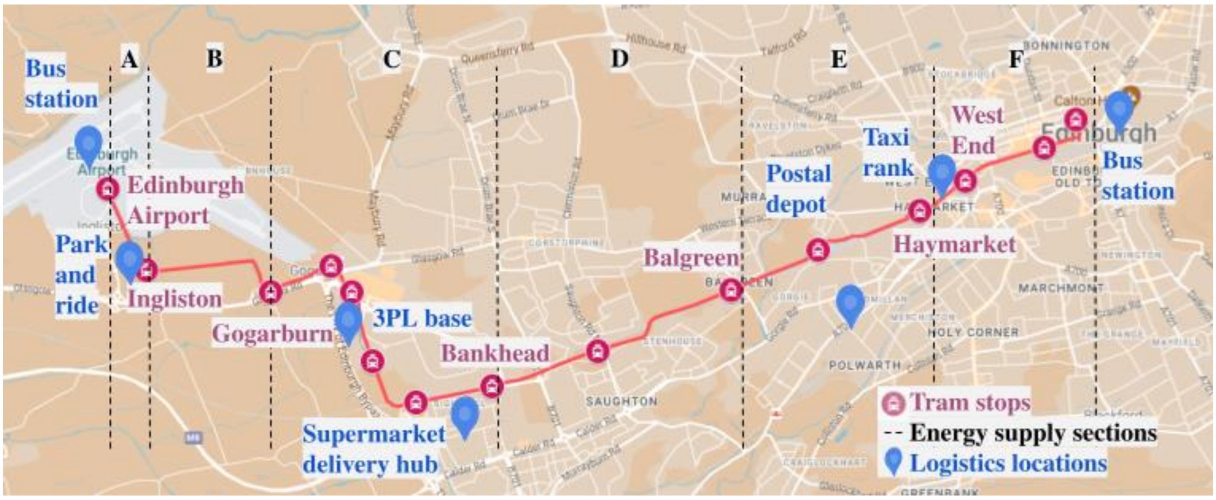


Fig. 1: Map showing Edinburgh tram route, with annotations indicating energy supply sections and sites for potential logistics linkups.

4. Conclusion

Linking fleets of electric vehicles to urban light rail networks via vehicle-to-grid charging can reduce regenerative braking energy wastage from the rail network and provide a reliable vehicle charging opportunity. The former is achieved by using the vehicle batteries as temporary energy storage for the rail system. Even when no excess regenerative braking energy is available for fleet vehicle charging, installing chargers linked to a rail network comes at a reduced cost, as no extra substations and limited extra wiring are needed compared to installing entirely new charging points.

Such a strategy would reduce the energy required for both the light rail system and the vehicle fleet. It may also increase use of fleet electric vehicles in urban areas, which in turn would have positive impacts for both local carbon dioxide emissions and urban air quality.

Keywords

Vehicle-to-grid, electric vehicles, fleet vehicles, regenerative braking

References

[1] ‘Global EV Outlook 2022 – Analysis’, IEA. https://www.iea.org/reports/global-ev-outlook-2022 .

[2] A. Tsakalidis, J. Krause, A. Julea, E. Peduzzi, E. Pisoni, and C. Thiel, ‘Electric light commercial vehicles: Are they the sleeping giant of electromobility?’, Transp. Res. Part Transp. Environ., vol. 86, p. 102421, Sep. 2020, doi: 10.1016/j.trd.2020.102421.

[3] ‘Global EV Outlook 2021 – Analysis’, IEA. https://www.iea.org/reports/global-ev-outlook-2021.

[4] T. Zhang, R. Zhao, E. E. F. Ballantyne, and David. A. Stone, ‘Increasing urban tram system efficiency, with battery storage and electric vehicle charging’, Transp. Res. Part Transp. Environ., vol. 80, p. 102254, Mar. 2020, doi: 10.1016/j.trd.2020.102254.

[5] T. Zhang, E. E. F. Ballantyne, R. Zhao, and D. A. Stone, ‘Technical and economic feasibility of increasing tram system efficiency with EV batteries’, Transp. Res. Part Transp. Environ., vol. 91, p. 102681, Feb. 2021, doi: 10.1016/j.trd.2020.102681.

Long-haul Electric Truck Routing with Coordinated Driver Schedule and Charging Activities: When and Where to Charge

Xi Cheng[1] and Jane Lin[2*]

[1]Department of Civil, Materials, and Environmental Engineering, University of Illinois Chicago, 60607, U.S.A.
[2]Department of Civil, Materials, and Environmental Engineering & Institute for Environmental Science and Policy, University of Illinois Chicago, 60607, U.S.A.
*Corresponding author: janelin@uic.edu

1. Introduction

The Biden-Harris Administration has committed to achieving a goal in the transportation sector that 100% of new sales for light and medium-duty vehicles will be electrified from the White House [1]. There are four key obstacles for long-haul e-truck adoption from a carrier's perspective in the US context: 1) insufficient policy incentives for long-haul e-truck adoption – most of the current federal and state regulations and programs are for passenger EVs; 2) lack of charging infrastructure on the interstate highways (see the Federal Highway Administration EV corridors [2]); 3) high initial adoption cost for long-haul e-truck due to the high battery cost; and 4) long battery charging time compared to diesel refueling despite the rapid advancement in battery and charging technologies.

To this end our study aims to find a charging and siting strategy that will make long-haul e-truck routing comparable to that of diesel truck, and demonstrate the feasibility of e-truck adoption. Specifically, the research questions to be answered by this study are: Where to deploy charging stations along the interstate highways? How to coordinate and synchronize truck routing, driver schedule and charging activities under the U.S. Hour of Service (HOS) regulations [3]? How many chargers should be installed at a charging station?

For the first question, the FHWA EV corridor ready designation specifically requires public DC fast charging stations must be within 1 mile from interstate highways to avoid unnecessarily long detour. Therefore, we propose to have charging stations at selected candidate truck stops (over 90% privately owned) and rest areas (all public facilities) along the interstate highways. Currently no commercial activities are permitted at rest areas, which are public facilities. Therefore, this is a hypothetical investigation to explore the potential benefits if the law were to be revisited. Furthermore, long-haul trucks must take rest periodically along the trips according to the HOS regulations. The break/rest time is unpaid time for truck drivers. It is logical to synchronize the charging activities with the mandatory break/rest time to minimize the unpaid time and the total journey time from the viewpoints of both the fleet operator and the driver. Thus, rest areas and truck stops are considered attractive candidate charging sites for long-haul trucks.

2. Methodology

We propose an optimization model called an e-truck routing problem with coordinated driver schedule and charging activities (eTRP-DSCA) to determine a set of routes, and their corresponding schedules, which synchronizes the charging scheduling of the electric long-haul truck fleets. The objective of the eTRP-DSCA is to minimize the total cost as the sum of the following: *vehicle purchase cost* (converted to per mile cost over life time), *driver's* wage while on duty, *routing energy cost* that is proportional to the distance traveled, *idling energy cost* when the driver is off duty (and not paid), and *penalty* caused by unpunctual arrivals at customer locations.

We consider the following key operating conditions/constraints in the eTRP-DSCA: (i) drivers follow the US HOS regulations [3]; (ii) charging stations are located only at truck stops and/or rest areas along the interstate highway; (iii) each charging station has a charging capacity; (iv) charging schedule must be in-sync with a driver's rest/break schedule; (v) State of Charge (SoC) of a battery must remain above a comfortable driving range at all time - 20% of the full battery capacity is assumed [4]; and (vi) battery is fully charged each time.

3. Results and Discussion

We applied the model to three interstate routes: (a) I-55N from St. Louis to Chicago (298 miles), (b) Non-toll interstate highways from Chicago to Atlanta (758 miles), and (c) I-15N and I-70E from Los Angeles to Denver (1040 miles). The results are shown in Table 1. Compared to the conventional diesel truck, e-truck takes an expected longer time (~20-30%) to finish the journey but saves about 30-35% of total operating cost and over 70% of energy. If the latter two metrics outweigh the journey time, e-truck is a promising alternative to diesel truck with appropriate charging infrastructure shown in Figure 1 (only the LA-Denver route is shown due to space limit).

Table 1. Model results of numerical experiments

Truck type	Cumulative driving time (hrs)	Break time (hrs)	Rest time (hrs)	Total journey time (hrs)	Total cost ($)	Energy consumption (kWh)
(a) I-55N from St. Louis to Chicago (298 miles)						
Diesel truck	5.418	-	-	5.418	483.29	2021.43
E-truck	5.418	1.468	-	6.889	333.80	596.73
Difference				**27.2%**	**-30.9%**	**-70.5%**
(b) Non-toll interstate highways from Chicago to Atlanta (758 miles)						
Diesel truck	13.749	-	10	23.749	1270.70	5453.80
E-truck	13.749	4.548	10	28.297	852.29	1518.00
Difference				**19.2%**	**-32.9%**	**-72.2%**
(c) I-15N and I-70E from Los Angeles to Denver (1040 miles)						
Diesel truck	19.473	0.5	10	29.973	1801.62	7308.27
E-truck	19.473	5.815	10	35.287	1188.41	2087.91
Difference				**17.7%**	**-34.0%**	**-71.7%**

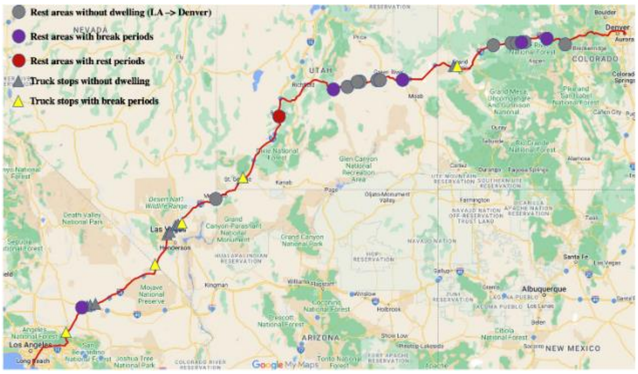


Figure 1. Charging sites along I-15N and I-70E from Los Angeles to Denver (1040 miles)

4. Conclusion

Through a mathematical optimization model, this study shows that, with careful schedule coordination and charging facility siting, it is feasible to build an EV ready corridor at selected rest areas and truck stops as charging stations to facility long-haul e-truck operations. Next, we will expand the study to the entire national interstate highway network.

Keywords: long-haul electric truck; hours of service (HOS) regulations; charging station siting; rest area/truck stop; e-truck routing problem with coordinated driver schedule and charging activities

Acknowledgement

This study is partially funded by the Illinois Department of Transportation through the Illinois Center for Transportation project No. R27-239.

References

[1] The White House, "Executive Order on Tackling the Climate Crisis at Home and Abroad", Jan. 27, 2021.
[2] Federal Highway Administration. EV corridors, last accessed January 19, 2023.
[3] Federal Motor Carrier Safety Administration. Hours of service, last accessed January 19, 2023.
[4] Hu, L., Dong, J., & Lin, Z. (2019) Modeling charging behavior of battery electric vehicle drivers: A cumulative prospect theory-based approach. *Transportation Research Part C: Emerging Technologies*, 102, 474-489.

Establishment of the National Centre For E-Vehicle & Sustainable Technology (EVST)

Oliver Shaw[1*], Ian Smith[2] and Mark Busfield[3]

[1]Head of Centre, EVST, University of Bolton, UK
[2]Project Consultant, University of Bolton, UK
[3]Director, NCME, University of Bolton, UK
*Corresponding author: o.shaw@bolton.ac.uk

1. Introduction

The UK government has set ambitious targets to reduce carbon emissions and combat climate change, with a focus on the widespread adoption of electric vehicles (EVs). Alongside, the government has announced plans to phase out the sale of new petrol and diesel cars by 2030, and to invest in infrastructure such as EV charging stations to support this transition. Additionally, financial incentives, such as grants and tax breaks, are being offered to encourage individuals and businesses to switch to EVs. The adoption of EVs is seen as a key step in achieving the UK's goal of becoming a net-zero carbon economy by 2050 [1], [2].

The University of Bolton Group comprises three institutions: the University of Bolton, Bolton College and Alliance Learning. Programmes of study are delivered across all academic levels from T-level (Level 3) right through HNC/D (Levels 4 and 5), Bachelor and Masters degrees (Levels 6 and 7) and on to Doctoral degrees (Level 8). Higher and degree apprenticeship programmes across many vocational sectors are also offered.

A strength of the university group is the educational delivery and research carried out in the fields of both automotive and motorsport engineering. Specifically, the university's National Centre for Motorsport Engineering (NCME) is recognised as a national centre of excellence in automotive performance engineering and motorsport engineering, working in collaboration with some of the leading motorsport organisations, race teams and industrial partners on many knowledge transfer projects.

A recent major initiative of the university, led out by NCME, is the establishment of the National Centre for e-Vehicle and Sustainable Technology (EVST). This Centre – established in 2022 – is a collaborative venture between the university group and key partners from industry. Its principal purpose is to provide education and training at a range of levels to support the electric, hybrid and hydrogen cell powered vehicles (both lightweight and heavy) maintenance sector. Whilst all vehicle manufacturers have developed and launched various electric and sustainable models to market, there is a well-recognised skills shortage in the maintenance of these vehicles.

EVST will provide the educational base and industry-focussed training for a range of technician and engineer roles to address this skills shortage, initially in the North-West of England and growing to cover the rest of Great Britain. The educational portfolio offers different levels of apprenticeships and full-time diplomas and degrees. The benefits of a single centre offering a range of qualifications, education and training are already recognised by industry, and a network of employers and professional bodies are working cooperatively with EVST to provide input to the curriculum development and a stream of apprentices. Alongside the maintenance of light and heavy e-vehicles, EVST will also offer apprenticeships, diplomas and degrees in charging infrastructure through Bolton College and the university's School of Engineering.

2. Methodology

Before the EVST was launched, an extensive piece of market research was carried out by the university into the existing provision of e-vehicle related education and training across the UK. This was to establish the national picture of provision and inform the programmes portfolio to be offered by EVST. Table 1 summarises the key findings from the research.

Table 1 : Market research key findings (April 2022), updated (Dec 2022)

	Finding
1	There is no industry focused, Sustainable & Electric Automotive Engineering provision (u/g & p/g) in NW England and Scotland.
2	Opportunity exists for the University of Bolton to become established as the only BEng & MSc EV provider in North West.
3	Most universities (currently) exclude smart/autonomous vehicles from their provision.
4	No progression-focused college provision for EV exists in the NW region.

From the research it was concluded that there was an identifiable need for a national centre, such as EVST, to be established swiftly to both help to address the e-vehicle sector skills shortage and feed into the national and regional skills agenda, to increase the transition from internal combustion engine vehicles to e-vehicles. This, in turn, will help strengthen the national economic growth and positively develop social inclusion.

Following this work, the EVST was launched with financial support from the university. An Industrial Advisory Board (IAB), chaired by the Chairman of NRG Fleet Services was established and comprises key players from employers (vehicles and charging infrastructure) and professional organisations such as IMI and IRTEC.

3. Results and Discussion

Drawing on valuable input from the IAB, the educational portfolio has been established by the academic teams. This has been an excellent example of industry-academia collaboration. Apprenticeship programmes aligned to relevant apprenticeship standards and two new IEng level programmes (*BEng(Hons) Sustainable and Electric Vehicle Engineering* and *BEng (Hons) Sustainable and Electric Vehicle Engineering with Industrial Placement*) are validated and are in the UCAS catalogue for September 2023 intake.

4. Conclusion

In less than one year, the idea of a centre for e-vehicle education and research in the North West of England has become an established entity, ready and open for business. The rapid establishment of EVST has been helped by the collaborative input and support from industry, professional organisations and employers. The Centre will deliver a much needed boost to addressing the significant skills shortage currently being experienced in the electric and sustainable vehicles maintenance sectors.

Keywords e-vehicles; sustainable technologies; skills shortage, education; training

References

[1] Department for Transport, HM Government, The Road to Zero: Next steps towards cleaner road transport and delivering our Industrial Strategy, Department of Transport, London, 2018.

[2] Department for Transport, HM Government, Future of transport regulatory review consultation: Zero emission vehicles, Department of Transport, London, 2021.

Optimizing Infrastructure for Large-Scale Electrification of Trucks: A Fixed Route Approach

Amir Davatgari[1, *], Taner Cokyasar[2, 3], Anirudh Subramanyam[2, 4], Jeffrey Larson[2], and Abolfazl (Kouros) Mohammadian[1]

[1]University of Illinois Chicago, 1200 W Harrison St., Chicago, 60607, IL, USA
[2]Argonne National Laboratory, 9700 S. Cass Avenue, Lemont, 60439, IL, USA
[3]TrOpt R&D, Balcali mah., Saricam, 01330, Adana, Turkey
[4]The Pennsylvania State University, 201 Old Main, University Park, 16802, PA, USA
*Corresponding author: adavat2@uic.edu

1. Introduction

The aim of this study is to tackle the challenges of electrifying trucks, particularly in terms of designing the required infrastructure. Creating a comprehensive infrastructure plan for large-scale electrification projects can be complicated due to various factors such as the placement of charging stations and scheduling recharging activities. Prior research has attempted to solve the electric vehicle location routing problem (EVLRP) to address this issue (1-5), but the freight industry has a different approach. They base their early electrification decisions on the characteristics of existing routes and prioritize shorter routes than the electric vehicle (EV) range, only installing EV supply equipment (EVSE) at depots. Rather than optimizing or scheduling recharging activities, they assume each new EV comes with an EVSE. To address this gap, we formally describe the EVSE Location and Capacity Allocation problem (EVSELCA) problem and construct an MILP model that focuses on fixed routes.

2. Methodology

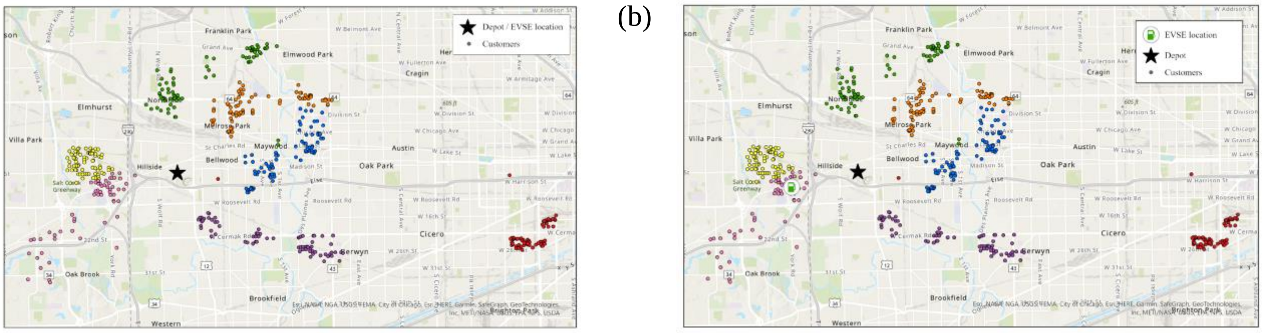
We develop a MILP model that solves the EVSELCA problem. The objective of this model is to minimize the cost of EVs completing their daily operations while respecting operational constraints, such as total route time and charging queues. The model decision variables include the location, number, and type of chargers, as well as the spatio-temporal scheduling of truck recharging. The objective function minimizes detouring, waiting, recharging, energy consumption, EVSE facility, and installation costs, subject to operational constraints, demand conservation constraint, and battery capacity constraints. The model makes several critical assumptions, including deterministic customer demand, maintenance of customer visit sequences in routes, identical driving range for EVs, linear relationship between recharging time and energy received from an EVSE type, linear relationship between travel time and energy spent by EVs, and prior knowledge of candidate EVSE locations.

3. Results and Discussion

The proposed model was tested in a real-life case study with two scenarios. In scenario 1, the depot and two other locations were considered as candidate sites for installing EVSEs, while in scenario 2, EVSEs were not allocated to the depot but could be installed in the other two locations. All trucks were assumed to start with a maximum battery capacity and finish daily operations with at least 80% of the maximum battery capacity. However, in scenario 2, the trucks could not recharge at the destination depot, so a lower limit was set for the desired final battery capacity to avoid infeasibility. The solution showed that in scenario 1, an EVSE was installed in the depot, while in scenario 2, an EVSE was installed in a different location, as shown in the visual representation in Figure 1.

The solution's key findings are summarized in Table 1. In both scenarios, the model allocates one EVSE type 3 at one location. This could be because trucks have an operational time limit. So, the model suggests installing an EVSE type 3 with a relatively short recharging time than other types to keep trucks below the time limit cap. The average charging time for both scenarios are almost the same because the routes' initial and desired final battery capacities were the same in both scenarios. The average waiting time in scenario 1 was lower than of scenario 2 because all trucks in scenario 1 recharged at the end of the day when they returned to the depot, and trucks arrived at the depot at different times. Therefore, the waiting time for recharging was lower. The average detour time for scenario 1 is zero because all trucks recharged at the end of the day when they returned to depot, which eliminates detour for recharging. However, in scenario 2, trucks needed to recharge at a public location and had to detour to recharging facilities.

(a) (b)



scenario 1 scenario 2

Figure 1: Case study solution visualization.

Table 1: Solution key findings.

Scenario	EVSE design	Avg. charging time (minute)	Avg. waiting time (minute)	Avg. detouring time (minute)
1	1 EVSE type 3	6.76	3.84	0
2	1 EVSE type 3	7.32	6.41	11.32

4. Conclusion

To solve the EVSELCA problem, we developed an MILP with a focus on fixed routes. The model was tested on a case study. Since EVSE are thought to be adopted both only at depots and only at non-depot locations, two scenarios were dedicated to assess the difference. Although the route configurations impacted the solutions, the only depot recharging scenario dominated the other one in terms of total cost comparison. As a key take away, we found that depots should be considered as candidate recharging facilities in the planning of the EVSELCA. The problem involves determining when and where to recharge EVs, how many chargers to allocate, and how to schedule recharging while minimizing waiting times and operational constraints. The MILP model developed in this study addresses these concerns but may not be scalable to larger problems. A heuristic or meta-heuristic solution is needed and is considered as future work.

Keywords: EVSE location and capacity allocation, Freight electrification, Optimization

Acknowledgement

This material is based upon work supported by the U.S. Department of Energy, Office of Science, under contract number DE-AC02-06CH11357. This report and the work described were sponsored by the U.S. Department of Energy (DOE) Vehicle Technologies Office (VTO) under the Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility Laboratory Consortium, an initiative of the Energy Efficient Mobility Systems (EEMS) Program.

References

[1] Yang, J. and H. Sun, Battery swap station location-routing problem with capacitated electric vehicles. Computers & operations research, Vol. 55, 2015, pp. 217–232.106.
[2] Hof, J., M. Schneider, and D. Goeke, Solving the battery swap station location routing problem with capacitated electric vehicles using an AVNS algorithm for vehicle routing problems with intermediate stops. Transportation research part B: methodological, Vol. 97, 2017, pp. 102–112.
[3] Schiffer, M. and G. Walther, The electric location routing problem with time windows and partial recharging. European journal of operational research, Vol. 260, No. 3, 2017, pp. 995–1013.
[4] Schiffer, M., M. Schneider, and G. Laporte, Designing sustainable mid-haul logistics networks with intra-route multi-resource facilities. European Journal of Operational Research, Vol. 265, No. 2, 2018, pp. 517–532
[5] Schiffer, M. and G. Walther, An adaptive large neighborhood search for the location routing problem with intra-route facilities. Transportation Science, Vol. 52, No. 2, 2018, pp. 331–352.

How can Sustainable Business Models and Innovative Value Chains Accelerate the Transformation of Electric Vehicles?

Rudolf Schnee[1], Nathalie Kroichvili[1], Daniela Chrenko[1] and Reiner Kriesten[2]

[1] FEMTO-ST Institute, Univ. Bourgogne Franche-Comté, UTBM, CNRS, Belfort, France
[2] Institute for Energy Efficient Mobility, University of Applied Science Karlsruhe, Germany
*Corresponding author: rudolf.schnee@utbm.fr

Abstract – Limited resources, climate change and urban mobility lead to a changed mobility behaviour in population. Automobile manufacturers are responding to these new challenges by developing electric vehicles that have already reached a high technological level. Extended ranges and high reliability show that electric vehicles are comparable to vehicles with internal combustion engines. Nevertheless, manufacturers are failing in selling these vehicles in sufficient numbers without substantial subsidies from the local states. Therefore, companies are forced to reconsider and change their business models because existing business model approaches do not sufficiently cover the requirements for electromobility business. Sustainable business models are a promising solution, as they consider the elements of environmental friendliness and social aspects and have therefore a good basis for electromobility. For a successful sustainable business model for electromobility also a comprehensive eco-system with all necessary stakeholders of the various stages of the value chain is needed and forms the basis for a newly designed framework. The framework of sustainable business models has been examined in a case study with charging stations to illustrate the applicability.

1. Introduction

The demand for environmentally friendly and individual mobility has grown rapidly in recent years and poses high expectations for research, development, and production. Customer surveys show that interest in electric vehicles has increased considerably in the last few years [1]. Additionally, the development of electric vehicles has now reached a status where they are on a level with vehicles with internal combustion engines (ICE) in terms of range and daily usability. Also, the number of charging stations is increasing constantly, so that the fear from customers that they will break down with an electric vehicle becomes less. Although the conditions for the transformation of electric mobility are strong, car manufacturers can only sell their electric vehicles with high subsidies from governments and their profit margin are low or even negative. Reasons for this are that electric vehicles are offered with the same business model as vehicles with combustion engines. In addition, automotive manufacturers have not managed to adapt their value chains to the new environment necessitated by electromobility. The questions are how automotive companies can adapt their existing business model so they can make profit with electric vehicles (EV) and are independent from state subsidies? Also, how should the value chain can be adapted so that further sales of additional products and services are possible? The new created framework for sustainable business models for electromobility (SBMEM) can be used as a basis for creating innovative business models for electromobility or as an examination of existing ones. To demonstrate the applicability of the framework of SBMEM, it is illustrated in a case study with charging stations.

2. Methodology

The research is based on an integrative literature research in different steps and follows the recommendations of Creswell [2] and Easterby-Smith [3]. A search of peer-reviewed literature is conducted using scientific databases. The search is limited to the years between 2010 and 2023, since research area has gained importance in recent years. In the first step, business models and sustainable business models are comprehensively examined and understood to be able to identify suitable components for the framework. In the next step the gaps between existing business models from automotive companies and sustainable business models will be analysed. This shows that existing business models for electromobility cover only partial aspects and are incomplete. Based on these findings, a framework for SBMEM is being developed that combines environmental, social, and economic aspects. This satisfies the demands of the customers as well as the possibility for the companies to make profits.

3. Results and Discussion

The result of the paper is the conceptual framework of SBMEM (Figure 1) that promotes and supports the transformation of electromobility. The elements of a conventional business model value proposition, value creation and delivery and value capture are placed on an equal basis in a row, while the other components of environmental and social aspects are transversal, supplemented by the new dimension of economic. To ensure that the products and services can also be provided, the ecosystem for electromobility is added to ensure the satisfaction of the customer's value proposition. The case study with representative operators of charging stations confirms the approach of the framework of SBMEM.

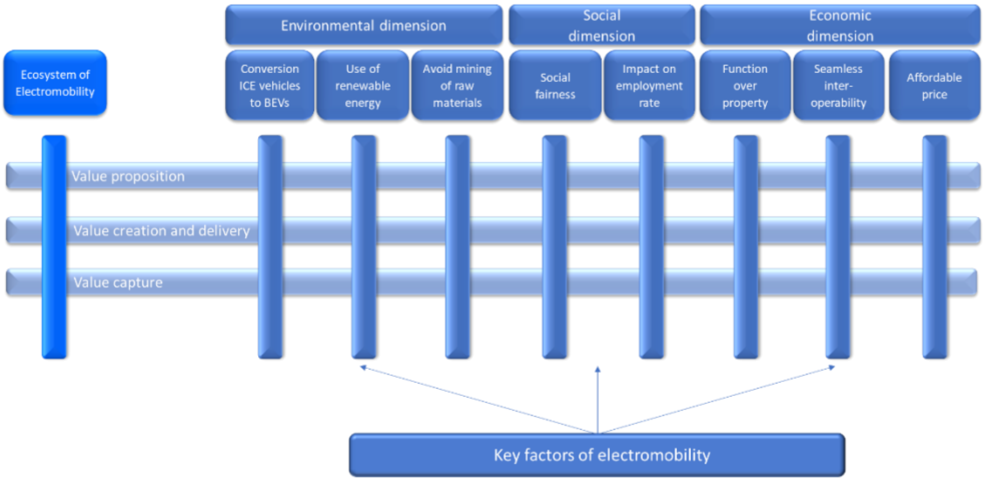


Fig. 1: Synthetic view of the framework of SBMEM

4. Conclusion

The paper shows that conventional business models are not sufficient for the transformation of electromobility. It is necessary to enhance the elements of environment and social attributes to emphasize and consider the importance of sustainability. The framework enables companies to satisfy the environmental and social demands of their customers as well as the potential to make a profit.

Keywords: electric vehicle; transformation; sustainable business models; e-mobility

Acknowledgement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] R. Cordera, L. Dell'Olio, A. Ibeas, and J. de D. Ortúzar, "Demand for environmentally friendly vehicles: A review and new evidence," *Int. J. Sustain. Transp.*, vol. 13, no. 3, pp. 210–223, Mar. 2019, doi: 10.1080/15568318.2018.1459969.

[2] J. W. Creswell, *Research design: Qualitative, Quantitative,and Mixed Methods Approaches*, 4.th. Los Angels, London, New Dehli, Singapore: SAGEPublications. Inc., 2009.

[3] M. Easterby-Smith, R. Thorpe, and P. Jackson, *Management and business research*, 6th ed. Los Angels, London, New Dehli, Singapore, Wahsington DC, Melbourne: Sage Publications Inc., 2018.

Attractiveness and Business Model Potential of the Spot Market Optimized Charging of Electric Vehicles

Valerie Ziemsky[1*] and Florian Biedenbach[2]

[1]Valerie Ziemsky, Forschungsstelle für Energiewirtschaft e.V. (FfE), Germany
[2]Florian Biedenbach, Forschungsstelle für Energiewirtschaft e.V. (FfE), Germany
*Corresponding author: vziemsky@ffe.de

Abstract – The spot market optimized charging of electric vehicles offers a savings potential for charging costs. At the same time, it reduces end consumers' flexibility and increases price risk. We analyze the financial attractiveness of this use case for electric vehicle drivers as well as electricity providers and aggregators by combining acceptance studies on the required annual revenue with simulations of the potential savings on charging costs. The results show, that the acceptance barrier of the electric vehicle drivers is difficult to overcome, yet there is a potential margin for electricity providers or aggregators to integrate into their business models.

1. Introduction

Electric vehicles (EVs) can be charged according to different optimization goals. Often, controlled charging of EVs is combined with a variable electricity tariff. By offering varying electricity prices at different times of the day or season to end consumers they reflect price fluctuations on the spot market. In the course of the German energy transition, a law that requires electricity providers to offer a variable electricity tariff to household customers has been passed (§ 41a (2) EnWG). Shifting the electricity consumption to times of lower electricity prices creates a savings potential for end consumers. However, variable tariffs restrict the flexibility of end consumers and expose them to a higher price risk.

The research project Trade-EVs II (Trade of Renewable, Aggregated, and Distributed Energy by Electric Vehicles) investigates the aggregation and subsequent marketing of the flexibility of EV fleets to reduce their operating costs. Together with the project partners, we developed use cases for the controlled charging of EVs. In this paper, we focus on the spot market optimized charging of private EVs at a single-family home. [1]

The basis for a widespread implementation of this use case is not only the technical feasibility, but two essential factors: First, the willingness of EV drivers to apply a charge load control (acceptance to use variable electricity tariffs) and second, profitable business models for the participating companies.

Hence, two central research questions arise:

- Is the annual savings potential of the spot market optimized charging of an EV sufficient for EV drivers to accept the resulting higher price risk and reduction in flexibility?
- How big is the potential margin for electricity providers and aggregators to offer variable electricity tariffs and respective charge load schedules for EV drivers?

2. Methodology

We investigate the research questions by matching potential revenues from the spot market optimized charging of EVs with the willingness of EV drivers to use variable electricity tariffs and shift their load consumption. The simulations for the savings potential in charging costs for EV drivers were conducted with an optimization model as described in [2]. The scenarios comprised a dynamic electricity price tariff. To define the required end consumer's minimum yearly savings amount to accept to apply the spot market optimized charging of their EV we conducted a literature review of acceptance studies. Thereby we could define a compulsory minimum revenue that EV drivers need to earn in order to charge their EV spot market optimized.

By subtracting the minimum required savings potential for variable electricity tariffs from the savings potential of spot market optimized charging, we received a margin that determines the remaining revenue potential for the electricity provider and the aggregator and whether the use case is attractive for EV drivers. The work was conducted for Germany, conclusions for other European countries can be derived.

3. Results and Discussion

The acceptance studies on using a variable electricity tariff show that a minimum compensation of 130 to 306 €/a is required to compensate end consumers for the restricted flexibility and higher price risk [3] [4]. Initial investments in the required technical equipment (charging station, energy management system, smart meter) are not considered.
The simulations take into account German day-ahead spot market prices from 2019 and yield in a savings potential for private EV drivers of 17 to 200 €/a when using a dynamic electricity tariff and 40 to 160 €/a when using a Time-of-Use electricity tariff [2]. The calculated margin of the minimum compensation for EV drivers and the savings

potential from charging an EV using a variable electricity tariff results in -289 to 70 €/a for a dynamic electricity tariff and -266 to 30 €/a for a Time-of-Use electricity tariff. The margin constitutes a higher risk than potential reward for EV drivers resulting in an aversion to use a variable electricity tariff. Hence, the business model potential for electricity providers and aggregators is low. However, we expect a higher savings potential for charging an EV with a variable electricity tariff and hence, a more accurate prediction of the resulting margin for the spot market prices of 2021 and 2022. Therefore, we will conduct new simulations for 2021 and 2022 day-ahead and intraday spot market prices using the same method. In the paper, we aim to make a statement regarding financial business model potential for electricity providers and aggregators by analyzing the margin.

The relatively high acceptance barrier of variable electricity tariff users together with relatively low annual savings potential only leaves little room for profitable business models. With increasing expected price spreads on electricity spot markets, the savings potential might increase in the future. Other factors than financial rewards might improve acceptance for variable electricity tariffs, e.g. creating a green conscience, environmental protection or more efficient energy usage [4]. Electricity providers and aggregators should consider to include these incentives into their marketing activities.

4. Conclusion

We analyzed the financial attractiveness of the spot market optimized charging of EVs for both, offering businesses (electricity provider and aggregator) and end consumers. Under current conditions, the spot market optimized charging of an EV is not attractive for end consumers, resulting in low business model potential for electricity providers and aggregators. With the final simulation results we will be able to predict from a financial perspective, whether EV drivers will apply this use case in future and whether the use case leaves room for business model potential.

Keywords: Use case; variable electricity tariff; customer acceptance; business model potential

Funding

The described contents were developed by the FfE in the project “Trade-EVs II” funded by the German federal ministry for economic affairs and climate action (BMWK) (funding code: 01MV20006E).

References

[1] Biedenbach, F. & Ziemsky, V.: Use-Cases, Akteure & Zielgruppen: Mit SAP, EWS und Nextmove in die Zukunft des gesteuerten Ladens. Munich: FfE, 2021.

[2] Biedenbach, F. & Ziemsky, V.: Opportunity or Risk? Model-based Optimization of Electric Vehicle Charging Costs for Different Types of Variable Tariffs from a Consumer Perspective. In: CIRED Porto Workshop 2022 E-mobility and power distribution systems; Munich: FfE, 2022.

[3] Hinterstocker, M.; Beck, F. & von Roon, S.: Die Auswirkung variabler Stromtarife auf das Verhalten von Haushaltskunden. In: Energiewirtschaftliche Tagesfragen 68. Jg. (2018) Heft 7/8. Munich: FfE, 2018.

[4] Johnsen, D. et al.: Gesteuertes Laden von Elektrofahrzeugen über Preisanreize - Anwendungsbeispiele und Handlungsbedarf. Cologne: TÜV Rheinland Consulting GmbH, 2020.

Carrot or Stick? How Policy Type Influences Consumer Intention To Purchase Electric Vehicles

Shaherah Jordan[1]

[1]University of East London, England
*Corresponding author: s.jordan@uel.ac.uk

Abstract – The potential for widespread electric vehicle adoption is contingent on the effectiveness of policy interventions. The types of potential policy interventions that governments can implement are seemingly wide ranging but are effectively a core set of policy functions that are implemented in the way that is most appropriate for the area in question. Policy makers need to take into account the different types of responses that may be triggered as a result of an intervention. Due to the novelty of EVs, assumptions need to be made about consumer attitudes and behaviour in order to establish policies with the intention of encourage growth. One such assumption is that people are more likely to respond positively to policy interventions that incentivise rather than those that disincentivise. Analysis of responses to pending policy interventions in London supports this assumption.

1. Introduction

Public policy is a set of decisions made by governments and other political actors addressing a public issue through influence or change [1]. Policy ultimately seeks to change behaviour by changing attitudes and beliefs, offering new technology or providing financial or material incentives [2]. EV adoption can be influenced by both environmental policy and transport policy. In the context of pro-environmental behaviour, policy measures are used to attempt to curb unsustainable behaviours which have contributed to climate change and poor air quality [3].

EV interventions either seek to influence the public by incentivising (pulling) or disincentivising (pushing) [5]. Policy measures which disincentivise effectively make the behaviours in question less attractive through measures like taxation. Policy measures which incentivise make the behaviours in questions more attractive through interventions like subsidies. Policy measures that incentivise are thought to be more effective because they reduced the perceived cost of the desired behaviour.

In 2020, it was announced that the Ultra Low Emission Zone in London would be expanded to cover a majority of the city meaning non-compliant vehicles would be charged £12.50 when entering or driving through the zone. Although the policy effectively disincentivised London drivers, the novelty of the execution made it interesting for analysis into public response.

2. Methodology

The objective of this research was to examine participants' responses to novel EV policy interventions. A survey was distributed to 476 London drivers and responses to the range of planned and existing EV policy interventions were analysed. At the time of the survey, the Ultra Low Emission Zone was a planned intervention. Six policy interventions were tested for awareness and likelihood to motivate the respondent to purchase an EV:

- Grant towards Low Emission vehicle
- Vehicle Excise Duty (VED) Exemption
- Ultra Low Emission Zone (ULEZ)
- Home Charging Point Installation
- Congestion Charge Exemption
- Discounted Parking

3. Results and Discussion

Responses from this sample indicate that the sample responded to the incentives in a way that supports the concept of policies that incentivise as greater motivators of change than policies that disincentivise.

When respondents were asked how likely they were to purchase an EV if the ULEZ expansion was confirmed to start in Autumn 2021, 47% were likely and 53% were unlikely. Of the six interventions tested, the ULEZ was the only intervention that disincentivised and was the third likely reason respondents would consider switching to EVs after a grant towards a low emission vehicle and Vehicle Excise Duty (VED) exemption as shown in Table 1.

Table 1 - Motivators for purchasing an EV
Responses to the question: '*Which of the following would be the main reason that you considered purchasing an EV?*'

Grant towards Low Emission vehicle	Incentive	43%
Vehicle Excise Duty (VED) Exemption	Incentive	21%
Ultra Low Emission Zone (ULEZ)	Disincentive	13%
Home Charging Point Installation	Incentive	11%
Congestion Charge Exemption	Incentive	10%
Discounted Parking	Incentive	2%
n=424		

The ULEZ was the intervention that respondents were most aware of (prompted and unprompted) yet, only 13% of respondents cited the ULEZ as the main reason they would consider switching to an EV. Given that attitudes are a precursor to behaviours, understanding the impact of intervention types could be advantageous for policy makers. Future research into policy interventions should take into account the impact of combined interventions.

4. Conclusion

Policy interventions have the potential to convert ICE drivers into EV drivers if implemented strategically and effectively. Policies that incentivise were more likely to elicit a desired response among London drivers than those that disincentivised. This is particularly remarkable considering one of the interventions that were tested was novel and disruptive. However, when policy makers are considering these interventions, consideration should be given to the different segments of society to ensure that some interventions do not disproportionately incentivise or disincentivise.

Keywords electric vehicles; policy interventions, consumer intention

References

[1] Hassel, A. (2015). Public Policy. In J. D. Wright (Ed.), International Encyclopedia of the Social & Behavioral Sciences (2nd ed., pp. 569–575). Elsevier.
[2] Stern, P. C. (1999). Information, incentives and pro-environmental consumer behaviour. Journal of Consumer Policy, 22, 461–479.
[3] Hargreaves, T. (2011). Practice-ing behaviour change: Applying social practice theory to pro-environmental behaviour change. Journal of Consumer Culture, 11(1), 79–99.
[4] Brückmann, G., & Bernauer, T. (2020). What drives public support for policies to enhance electric vehicle adoption? Environmental Research Letters, 15(9).

The Ongoing Electrification in Public Fleet: Lessons Learned from the Public Safety Electrification Experience in Brazil

Márcio Almeida Có[1,2*] and Flávia Luciane Consoni[2]

[1]Ifes, Federal Institute of Education, Science and Technology of Espírito Santo, Brazil
[2]Unicamp, State University of Campinas, Brazil
*Corresponding author: marcio@ifes.edu.br

Abstract – This work reports the pioneering experience, among Brazilian cities, of public safety electric fleet implantation. Through documental analysis and interviews with managers and drivers, it discusses the step-by-step process of implantation and the acquired knowledge, from which lessons and guidelines can be drawn for the electrification of fleets in the public service with an emphasis on public safety.

1. Introduction

Transport is an intensive fossil energy-consuming activity that generates a significant impact on the emission of greenhouse gases. Thus, the energetic transition to zero-emission vehicles is one of the ways to achieve the emission reduction targets agreed upon by the nations [1, 2, 3].

From transitions toward sustainability perspective, electric vehicles (EV) tend to replace a dominant technology regime. For this reason, several dimension barriers should be overcome, since not only this transition implies technological change, but it also implies on users' practices, regulation, infrastructure, in addition to cultural and market aspects [4]. The main barriers are related to acquisition costs, existence of charging and support infrastructure, as well as a set of uncertainties and lack of knowledge about the technology and misperception around the ease of usability of these vehicles [3].

Public fleet, such as others commercial electric fleet present an intense usage, can use centralized recharging stations, and are managed by professionals with better comprehension of costs and actives lifetime [1]. Despite these advantages, they still encounter early adoption resistance. For this reason, government contracts can make an important contribution to overcoming knowledge gaps through technology diffusion.

The factors that influence the decision to adopt electric vehicle fleets in corporations can be classified into three categories: the technological factors, which deal with the reduction of emissions, costs, maintenance, charging infrastructure, system reliability, among others; the intrinsic ones, that deal with issues such as companies' environmental consciousness and sustainability plans, managers' attitude, and user acceptance. Finally, the external influences such as the regulations, public policies, incentives for financing, electricity prices, among others [5].

The electric transition of corporate fleets goes through two instances in organizations: the decision of managers and the perception of end users. There are studies that focus on the factors that influence the decision by fleet managers and others that deal with the individual acceptance of the employee for the use of new technology in the context of the organization [2].

The intrinsic values of organizations, linked to social responsibility and environmental consciousness, pioneering advantages, improvement in the public image of the company, in addition to the benefits granted by governments through public policies were identified as the main factors that motivate the adoption of EVs in corporate fleets, in research in Europe and the USA [1, 5]. From the perspective of the electrification of public fleets, in addition to the gains linked to the reduction of emissions and operational gains, the role of the government as a promoting agent is also highlighted, in a "demonstration effect" that contributes to popularize the technology.

In order, to understand the Brazilian situation related to the adoption of public fleets of electric vehicles, this work sought, through exploratory and descriptive studies, to contribute to the construction of a knowledge base to collaborate in overcoming EVs adoption barriers in these fleets, bringing, in this study, the specificities of the use of the fleet in public safety activities.

2. Methodology

This is an exploratory study, of a pioneering case among Brazilian cities, of public safety electrified fleet implementation in the city of São José dos Campos (SJC), in the State of São Paulo (Brazil), conducted through managers and fleet users interviews in January 2023, complemented by surveying the organization's documents and information. The case study and the qualitative procedures are justified for two reasons: first, to the low level of EVs fleet adoption in Brazilian public organizations, and second, because this method allows an in-depth exploration of the process of electrifying fleet in this public organization. In interviews with fleet managers the factors that influence fleet manager adoption decision were discussed, as well as the main barriers, users´ resistance, business models, environmental agenda, and operating costs. With the users, emphasis was given to the uncertainties and resistance in the beginning, the question of autonomy and way of recharging, ending with positive and negative outcomes, considering the activities carried out by public safety comparing to a combustion vehicle.

3. Results and Discussion

In 2018, the management of the municipality of SJC replaced the fleet of thirty combustion cars for electric ones. The business model was also changed, establishing a rent contract. Comparing with previous combustion vehicles operational indicators, the reduction in fuel costs reached the range of R$ 1 million annually, and the unavailability of vehicles for city guard activities was significantly reduced. Evaluating the use of the electrified fleet in carrying out its activities, an increase in comfort for users in their consecutive 12-hour shifts was verified. Torque, acceleration, and low noise level were identified as positive points, but autonomy and ground height were regarded as negative aspects of the fleet in the performance of public safety functions.

4. Conclusion

The electrification of the corporate fleet used in public safety in the city of SJC presents positive and relevant operational results when rent is chosen as a business model. The electric vehicle improved comfort, agility in displacements, presence of extensive policing in the city and contributed to reducing pollutant emissions. This study allowed recognizing that, to minimize the influence of the type of vehicle on the core activities, attention must be paid when it comes to the technical specifications of the vehicles and chargers in terms of autonomy and charging time, in addition to the EV´s height to floor. Furthermore, this experience allowed the municipality to accumulate enough knowledge to improve the requirements incorporated in the new price taken underway, which aims to increase the number of electric vehicles in the city's public fleet.

Keywords: electric vehicle; public safety; corporate fleet.

Acknowledgement

Secretariat for Citizen Protection of the City Hall of São José dos Campos/ SP

References

[1] Sierzchula W., Factors influencing fleet manager adoption of electric vehicles. Transportation Research Part D, 2014, 126-134.

[2] Roemer E., Henseler J., The dynamics of electric vehicle acceptance in corporate fleets: Evidence from Germany. Technology in Society, 2022.

[3] Vuichard P., Electrifying the company car: Identifying hard and soft barriers among fleet managers in Switzerland. Energy Research & Social Science, 2021.

[4] Geels, I. F. W., The dynamics of transitions in socio-technical systems: A multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860-1930). Technology Analysis and Strategic Management, 2005, 17(4), 445–476.

[5] Bae Y., Mitra S. K., Rindt C. R., Ritchie S. G. Factors influencing alternative fuel adoption decisions in heavy-duty vehicle fleets. Transportation Research Part D 102; 2022.

An Overview on Charging Tariff Schemes and Incentives: The eCharge4Drivers Project

Evangelos Karfopoulos[1], Jaume Roca[2], Jaume Mata[2], Angel Lopez[2], Villy Portouli and Angelos Amditis[1]

[1] Institute of Communication & Computer Systems, Greece
[2] Barcelona de serveis municipals SA, Spain

Abstract – This paper aims to provide an overview of the charging tariffs and e-mobility schemes adopted in different EU cities based on a survey conducted within the EU project eCharge4Drivers. The outcomes of the survey are presented and analysed in order to extract a generalised tariffication formula which allows any eMSPs or CPOs to explore different options to overcome the issues that might be affecting their current CP management strategy

1. Introduction

There is a need for substantial changes in the transport system of a city in order to achieve the transition to more sustainable and green urban mobility towards reducing city road congestions, direct emissions, noise pollution as well as improving accessibility. Tariff structures define and model the behaviour of charging station users as well as define the main source of income for eMSP's. Despite the fact that in some areas tariff structures are simple due to premature development of EV sector or due to a specific willingness of keeping it simple to users, these can have a large impact in the habits of users and influence the way in which these behave. For this reason, tariff structures play a crucial role in the charging ecosystem. In this direction, the design and establishment of new charging tariffication and incentives schemes for charging in a public charging network should be carefully considered either for the promotion of the e-mobility concept in cities with premature level of EV deployment or to ensure the sustainability of the investment in new infrastructures which will serve the increasing charging needs.

This paper analyses the outcomes of an extended survey, conducted within the framework of the EU project eCharge4Drivers, on charging tariff schemes and e-mobility incentives implemented in the different EU countries (Spain, Greece, France, Belgium, Italy, Luxembourg, Austria) and Turkey. The survey outcomes are analysed and a generic pricing formula which can be adopted by any CPO/eMSP is extracted.

2. Methodology

The survey on the pricing policies and incentives being adopted in different cities and countries was conducted in two stage. Initially, a benchmark analysis conducted to identify the variety of incentive mechanisms for the purchase and the usage of EVs and/or the installation of charging stations implemented in different countries and regions. The incentives depends on national regulations, degree of maturity of the market, cultural values, etc., thus, different practices are adopted at regional level to best serve the charging expectations of local society. Afterwards, a survey was conducted as regards the tariff structures used by the local MSP's and CPO's in the project pilot areas. The scope of this survey was to better understand the motivation of the parameters used to define the pricing schemes and how the CAPEX and OPEX of the charging network is reflected in these pricing profiles.

For the scope of the survey, dedicated questionnaires have been developed and bilateral meeting have been scheduled with CPOs and eMSPs in order to understand and analyse in depth their pricing strategy. The ultimate goal of this analysis is to conclude to a generic formula that any eMSP or CPO is able to define a tariff structure according to their users behaviour, constraints and revenue expectations.

3. Results and Discussion

Regarding the incentive's schemes analysed in the eCharge4Drivers project, the benchmark that was conducted concludes that most countries and cities apply factors to incentivise the purchase and use of EV's. These incentives are based mainly on purchase subsidies, on registration taxes, ownership tax, company tax and in some cases on a reduction of the VAT applied. Despite these are the general incentives mostly applied by states, some other measures have been taken by municipalities such as free kerbside parking, toll reduction or free access to limited traffic zones. Regarding tariff structures in the analysed areas, these depend on several parameters such as subscriptions, type of chargers, average power, initial fees, location of the CP's, types of vehicles, time of the day in which the charging event takes place, minimum charges, and changes in tariffs according to certain thresholds. In some areas, tariffs respond to a need to facilitate and incentivise users to charge instead of generating high revenues to make profit from it. There is a high diversity of opinions on whether energy should be charged per time or per kWh. In any case, most of the accessory tariff parameters that are included aside from the real charging tariff are made to incentive the proper use of charging points. These stand for initial fees, minimum charges, charges for excess of time or energy and others such as differentiating the fee according to the time of the day.

Generalised Formula:

$$C^{s}_{i.j} = C^{cs}_{i.j} + T^{f}_{i.j} + m_{i,j}.max[(d_s - f_d),0] + n_{i,j}.max[(e_s - f_e),0] + p_{i,j}.max[(d_e - f_p),0] + T^{excess}_{i,j}(t,e)$$

$C^{cs}_{i.j}$ is a booking fee that may be charged when booking, $T^{f}_{i.j}$ is the minimum charging (time or energy), $m_{i,j}.max[(d_s - f_d),0]$ where m is the value that determines the cost of the charging session that depends on the time duration, $n_{i,j}.max[(e_s - f_e),0]$, where n is the value that determines the cost of the charging session that depends on the amount of energy charged, Finally, there could be an additional charge regarding the parking time (d_e). As well as for the previous expressions, a minimum parking stay could be charged (f_p).

4. Conclusion

Based on the benchmark analysis of the e-mobility incentives, making incentives available at the time of purchase, appear to be an effective solution to increase EV market share. The current financial incentives should not be removed in the short-term to keep encouraging potential buyers. Another crucial incentive for buyers is the availability of charging infrastructure. Governments should expand the scale of charging points to increase density as a key measure to incentivise EV's. As regards tariffication, all possible tariff structures have been defined through a generalized formula which will be further detailed in the full paper. This formula and the recommendations made, allows any eMSPs or CPOs to explore different options to overcome the issues that might be affecting their current CP management strategy

Keywords electric vehicles, charging tariffs, incentives, tariffication

Acknowledgement

This work is a part of the eCharge4Drivers project. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 875131.

Design of the Community-to-Vehicle-to-Community (C2V2C) for enhanced electro-mobility in photovoltaic energy-sharing building communities

Pei Huang[1,*]

[1]Department of Energy and Community Building, Dalarna University, Falun, 79188, Sweden
*Corresponding author: phn@du.se

Abstract – Both the solar photovoltaic (PV) installation and electric vehicles (EVs) deployment are increasing significantly worldwide. With the large-scale integration of PV and EVs, problems such as the voltage deviations and overloading of components can arise, since the existing distribution grids are not designed to host the large shares of new EV loads and the intermittent PV power feed-in. This thesis investigates a C2V2C (i.e., Building Community to EV to Community) energy flow concept and evaluates how it can improve the power balance performances in communities with both PV and EV integrated in Sweden. Community refers to a group of buildings (i.e., two or more) connected within the same microgrid. It aims to develop a C2V2C model, which utilizes smart charging of electric vehicles to deliver electricity between different communities, for improving the performances at multiple-community-level. A coordinated control of EV smart charging is developed using the genetic algorithm, and its performance is compared with an existing individual control. The control strategy of minimizing the peak energy exchanges with the grid and was considered. Case studies are conducted considering a residential community and workplace community, as well as one EV commuting between them. The study results show that the advanced control achieves a cost reduction of up to 282 % in a summer week compared to the individual control. In a winter week, a performance improvement of up to 13.3% can be achieved using advanced control. The advanced control can also reduce the energy exchange peaks with the power grid of the multiple communities. This study has proven the effectiveness of the C2V2C2 model in enhancing the local power balance at multiple-community-level. It will enhance the resilience and grid-friendliness of building communities, thus paving way for the large PV and EV penetration in the future.

1. Introduction

Literature review shows that the existing studies mostly consider the EV charging in one location, while neglecting its potential in delivering and thus sharing energy in different locations [1,2,3,4]. Despite there are few studies investigating EV power delivering in different locations, the regulation of EVs charging load is isolated and independent in these studies. The EV charging in one location will only consider the power profile of this specific location, without considering the power regulation needs in another location. The EV charging without considering the spatio-temporal power regulating needs of multiple communities in different locations will lead to non-optimal performances at the aggregated level. There is also a lack of a systematic method for balancing the various spatio-temporal power regulation needs in different communities. Therefore, this study develops an advanced control for EV smart charging, with the purpose of improving the performances of multiple communities by using the EV electricity storage and mobility capabilities. The developed control first produces a merged power profile which is taken from multiple communities based on the EV's presence. Then, it conducts a trade- off between the spatio-temporal power regulation needs of multiple communities. After that, it will search for the optimized EV charging/discharging rates in each community to optimize the overall performances of all the communities. Using two building communities located in Sweden as case studies, the developed control is compared with a conventional individual control under different control objectives in different seasons. This is one of the first papers dealing with the C2V2C service, which makes use of EVs for active power delivering between different locations. An advanced control is developed to facilitate and optimize the C2V2C service of EVs to improve the performance of multiple building communities in different locations. The developed control can balance the various spatio- temporal power regulating needs of multiple communities.

2. Methodology

The aim of the developed control is to coordinate the charging /discharging of the EV in multiple building communities to optimize the demand response performances at the multi-community-level. The coordinated control can consider the spatio-temporal power regulation needs of multiple building communities. It consists of four steps. In Step 1, the information related to the community power demand, PV power productions, and EV traveling patterns is collected. For each community, its aggregated power mismatch will be evaluated using the aggregated power demand and aggregated PV power production. The collected EV traveling patterns will include the arrival and departure time in each community, the commuting distances, and the initial and target state of charges (SOCs) in each community. In Step 2, a merged power profile will be generated for multiple communities based on the EV parking period. This merged profile will take power mismatch segments from each community according to when the EV is parked. In Step 3, the objectives for power regulating will be defined. To balance the power regulating needs between multiple communities, a trade-off function is developed. This trade-off function will help build the fitness function for the optimization problem. Step 4 optimizes the charging/discharging rates of the EV in different communities using the genetic algorithm (GA). GA is selected due to its strong ability to find the global optimal solutions. The optimization will take the results from the first three steps as inputs.

3. Results and Discussion

A case study has been studied considering one EV and two building communities (one residential community and one commercial community) located in Sweden. Each of the two communities have renewable energy systems installed. The performances are tested under the control strategy of minimizing the peak energy exchanges with the grid. One summer week and one winter week are selected for testing the performance. The performance of the developed control method is compared with the conventional individual control, which regulate EV charging loads without considering the power regulating needs of another community's needs.

4. Conclusion

Regarding the control objective of minimizing the peak power exchanges, the advanced control produces very similar results to the individual control in the summer week, and it performs better in the winter week. This is because in the summer week the optimization strategy in the individual control (i.e., use more PV power from the workplace community to charge the EV) coincides with the strategy of the advanced control (i.e., take more PV power from the workplace community and delivers to the residential community). While in the winter week, the advanced control conducts a more comprehensive coordination considering both communities' power flow features, and thus it can produce better performances than the individual control i.e., 1%~6% relative improvement.

Keywords: C2V2C; Coordinated Control; Electric Vehicle; Electromobility; Power Balance.

References

[1] Huang P, Zhang X, Copertaro B, Saini PK, Yan D, Wu Y, et al. A Technical Review of Modeling Techniques for Urban Solar Mobility: Solar to Buildings, Vehicles, and Storage (S2BVS). Sustainability. 2020;12.
[2] Usman M, Knapen L, Yasar A-U-H, Vanrompay Y, Bellemans T, Janssens D, et al. A coordinated Framework for Optimized Charging of EV Fleet in Smart Grid. Procedia Computer Science. 2016;94:332-9.
[3] Dorokhova M, Martinson Y, Ballif C, Wyrsch N. Deep reinforcement learning control of electric vehicle charging in the presence of photovoltaic generation. Applied Energy. 2021;301:117504.
[4] van der Kam M, van Sark W. Smart charging of electric vehicles with photovoltaic power and vehicle-to-grid technology in a microgrid; a case study. Applied Energy. 2015;152:20-30.

The Role of EV Parking Lots for Supporting the Distribution System Operation Considering EV Uncertainties

Mahoor Ebrahimi, Mahan Ebrahimi, Miadreza Shafiekhah and Hannu Laaksonen

[1]School of Technology and Innovations, University of Vaasa, Finland
[2]Department of Electrical Engineering, Sharif University of Technology, Iran
*Corresponding author: mahoor.ebrahimi@uwasa.fi

Abstract – Considering the increasing penetration of Electric Vehicles (EVs), the need for EV parking lots is growing dramatically. In this regard, management of EV parking lot operation is of major importance not only to limit the challenges resulting from uncontrolled consumption but also to utilize the potential of EV parking lots acting as an energy storage system for supporting the distribution system requirements. This way, our paper intends to investigate the optimal operation of EV parking lots to support the distribution system needs considering EV uncertainties.

1. Introduction

The need for EV parking lots in different locations is increasing owing to the growing interest in using electric vehicles instead of fossil fuel vehicles. This way, EVs could be parked in a parking lot for several hours while a few hours are needed for full charging them. In addition, there may be the possibility of discharge if the parking lot is equipped with bidirectional EV chargers. Therefore, the EV parking lot could be studied as an energy storage system that can operate in a way that assists the distribution system operator to manage distribution network congestions, voltage level and support power system stability. To mitigate such challenges there is a crucial need for multiple flexibility providers. EV parking lots with the potential for changing the charging (and discharging) pattern could act as an energy storage system for providing flexibility. Some papers have investigated related studies. However, the uncertainty of EV owner behaviour has not been addressed in part of the literature. The other part of the literature that tried to take into account EV owners' uncertainty, deployed a type of modelling that models the parking lot with aggregation of the model of each EV [1] and [2]. This way, the formulation in such studies is so complicated that requires multi-stage approaches with heuristic and metaheuristic optimization algorithms. Such optimization approaches could not usually be employed for large-scale problems due to their high computational burden. Some other papers used an equivalent energy storage model for EV parking lot [3], [4], and [5]. For considering uncertainty, several scenarios are generated that make these approaches hard to deploy for planning studies and large-scale systems with other uncertain parameters such as renewable energy generation and energy price. In this paper, we deal with the mentioned problem with a model which is proper for large-scale systems.

2. Methodology

As discussed in previous sections, we will propose a model for the problem which is suitable for large- scale systems. This way, a virtual equivalent battery energy storage model is deployed to stand for the operation of the EV parking lot, as depicted in Fig. 1. Uncertainty of the EV owners is considered in the characteristics of the virtual battery model. The distribution system constraints will be formulated using a linearized form of a power flow equation that uses equivalent linear equations instead of quadratic constraints. Then after defining the objective function of the distribution system operator, the problem will be formulated as a mixed integer linear programming (MILP) with an acceptable computational burden for large-scale systems. It is noteworthy that, in this work, the problem is formulated assuming that the EV parking lot engaged in the grid-supporting activity is distribution system-owned, or its operation is under the control of the distribution system operator.

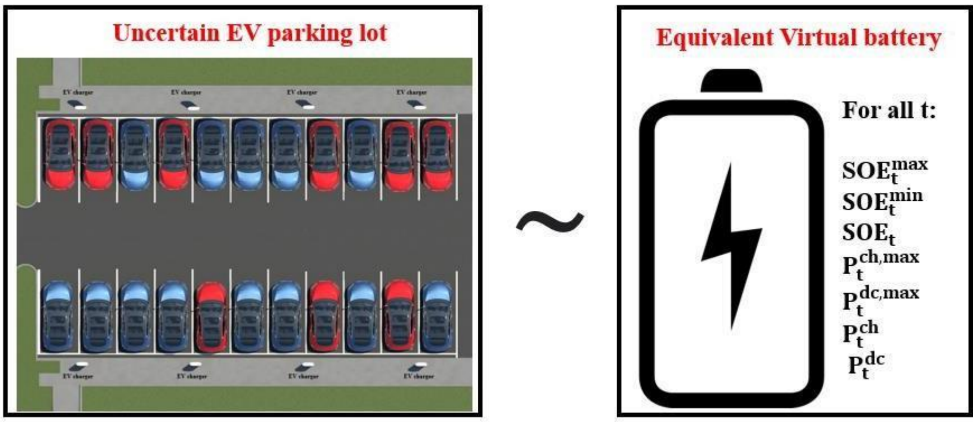


Fig. 1: Equivalent virtual battery model for EV parking lot.

3. Results and Discussion

We will use Python for coding the proposed model. Then, the simulation will be conducted to obtain and investigate the results. Then, the EV parking lot's role in improving the operation of the distribution system will be discussed. Moreover, the further cost imposed on the EV parking lot for providing flexibility for the distribution system operator is evaluated. In addition, the effectiveness of the EV parking lot supporting role based on its location in the network could also be investigated.

4. Conclusion

It is expected that EV parking lots could act similarly to a battery system for providing flexibility to support the distribution system operator. This will reduce the need for investing in battery systems in the distribution system for grid support purposes. However, an EV parking lot could provide less flexibility than a same-size battery.

Keywords Electric Vehicle; Parking Lot; Distribution System management

References

[1] Y. Zheng, H. Yu, Z. Shao, and L. Jian, “Day-ahead bidding strategy for electric vehicle aggregator enabling multiple agent modes in uncertain electricity markets,” Applied Energy, vol. 280, p. 115977, 2020.

[2] I. Sengor, O. Erdinc, B. Yener, A. Tascıkaraoglu, and J. P. Catalao, “Optimal energy management of EV parking lots under peak load reduction based dr programs considering uncertainty,” IEEE Transactions on Sustainable Energy, vol. 10, no. 3, pp. 1034–1043, 2018.

[3] M. Pertl, F. Carducci, M. Tabone, M. Marinelli, S. Kiliccote, and E. C.Kara, “An equivalent time- variant storage model to harness ev flexibility: Forecast and aggregation,” IEEE transactions on industrial informatics, vol. 15, no. 4, pp. 1899–1910, 2018.

[4] Y. Cao, L. Huang, Y. Li, K. Jermsittiparsert, H. Ahmadi-Nezamabad, and S. Nojavan, “Optimal scheduling of electric vehicles aggregator under market price uncertainty using robust optimization technique,” International Journal of Electrical Power & Energy Systems, vol. 117, p.105628, 2020.

[5] M. Nazari-Heris, M. A. Mirzaei, S. Asadi, B. Mohammadi-Ivatloo, K. Zare, and H. Jebelli, “A hybrid robust-stochastic optimization framework for optimal energy management of electric vehicles parking lots,” Sustainable Energy Technologies and Assessments, vol. 47, p. 101467, 2021.

Indicators for Providing Carbon Impact Feedback for EV Users

Nana Kofi Twum-Duah[1,2*], Muhammad Salman Shahid[1], Lucas Hajiro Neves Mosquini[1,3], Frédéric Wurtz[1], Benoît Delinchant[1]

[1] Univ. Grenoble Alpes, CNRS, Grenoble INP, G2Elab, F-38000 Grenoble, France
[2] Univ. Grenoble Alpes, CNRS, Grenoble INP, G-SCOP, F-38000 Grenoble, France
[3] University of Applied Sciences of Western Switzerland, Energy Institute, HEIA-FR, 1700 Fribourg, Switzerland
*Corresponding author: nana-kofi-baabu.twum-duah@g2elab.grenoble-inp.fr

Abstract –The purpose of this paper is to introduce an indicator that evaluates the performance of electric vehicle users in terms of the indirect emissions related to the charging of their electric vehicles. Such an indicator could be essential to influencing the behavior of EV users towards a desired optimal (lowest possible emission) and more flexible behavior. Initial results indicate that indeed there exists a potential (the extent of which is dependent on the energy mix). However, such an indicator should be simple and easy to read and understand, allowing EV owners and fleet managers to adopt their behavior towards a less carbon intense transportation sector.

1. Introduction

The transportation sector is considered to be a major contributor to global warming as it accounts for 23% of global CO_2 emissions (International Energy Agency, 2022). Given this phenomenon, and the collective efforts to reduce greenhouse gas emissions (i.e. the energy transition), a transition towards electric mobility (e-mobility) is considered an important pillar to achieve the energy transition for mitigating climate change. Whilst Electric Vehicles (EVs) themselves have zero direct emissions, the indirect emissions related to the electricity used in charging cannot be ignored.

In this regard, an initial research work is realized to compare the indirect carbon emissions of grid energy mix using the electric vehicle usage data (Renault ZOE) and carbon intensity data of the following countries; India (IN-MH), the USA (US-CAL-SISO), France (FR), the Netherlands (NL), Brazil (BR-N), Germany (DE), and Poland (PL). A linear programming-based optimization is used to compute the best charging scenario for each of the given grids and, consequently, the indirect emissions were compared to that of a high-efficiency internal combustion engine vehicle (a Renault Clio). The results of this study showed that for grids with a low renewable energy penetration such as those of Poland and India (Maharashtra), an electric vehicle, even when optimally charged, can be classified as neither a low nor zero-emissions alternative to normal thermal vehicles (Twum-Duah et al. 2022). This study also showed that there exists a potential to further reduce the indirect carbon emissions related to the charging of EVs.

Thus, the purpose of this paper would be to propose feedback in the form of indicators for EV owners and fleet operators, which would serve as a tool for assessing their performance relative to the optimal case.

2. Methodology

The aforementioned study about the indirect carbon emissions of EVs (which are directly correlated to the energy mix of the grid) is further extended to propose an indicator that allows EV users to evaluate their performance.

For this article, we consider the data from a 2013 Renault ZOE and the carbon impact data of the grids of 7 selected countries. We compare the optimal charging schedule (minimizing the carbon emissions related to the charging of the EV) and the worst-case scenario (maximizing carbon emissions). In this way, we compute the 2 extremes of the indirect emissions related to the EV and compare them with the charging behavior obtained from the EV dataset. 2 optimization strategies are considered; the first, where the daily charging energy requirements from historical data are respected and the second that does not employ this constraint (both respect the discharging energy and times from historical data).

The reference emissions are then compared to the best and worst cases to evaluate how close to the optimal case the reference case is. Based on these three markers (reference, best, and worst case), an indicator will then be devised which can be read and understood by EV users.

Additionally, it is possible to infer the best and worst times to charge from the computed maximum and minimum. Thus a second indicator is proposed which would provide EV users with information on the best and worst times (hours in the day) to charge.

3. Results and Discussion

Figure 1 demonstrates the initial results regarding the CO2 emissions of the reference charging schedule with minimum optimal schedule and maximum optimal schedule for the "Day" strategy. Figure 1 confirms the earlier results about Poland and India (Maharashtra) having higher indirect CO2 emissions and vice versa for France, however, since the day strategy is a more constrained optimization, the results are not as good as that of the annual strategy (better minima). Additionally, Figure 1 provides an indication of how much potential flexibility there exists (generally, the Netherlands and the USA have the highest potential whilst France and India have the lowest potential).

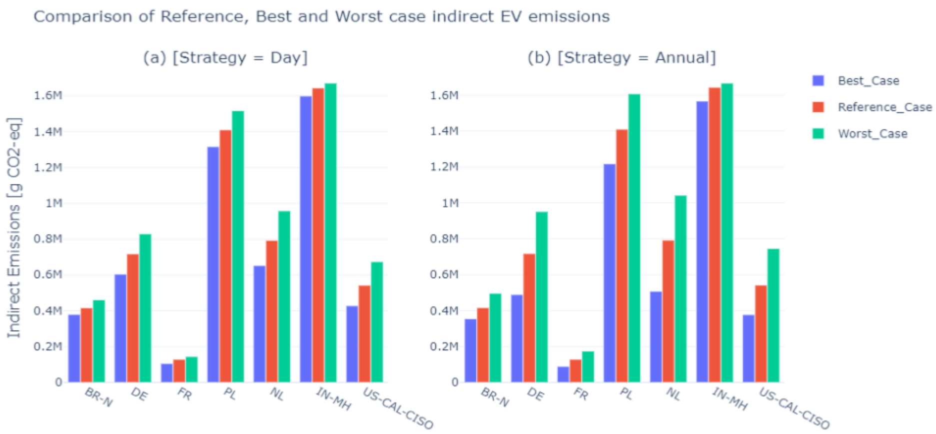


Figure 1. Comparison of CO2 emissions (gCO2-eq/km) of reference charging schedule with minimum optimal schedule and maximum optimal schedule for (a) "Day" strategy and the (b) Annual strategy

4. Conclusion

EVs have an associated operational global warming potential (although indirect it exists), and depending on the grid, there exists a potential to further improve the performance of an EV by potentially giving EV users some feedback.

A further study to evaluate the effectiveness of the proposed indicator and its potential consequence on the behavior of EV users would be required.

Keywords: Electric Vehicle, Energy Transition, Carbon-free grid, energy mix, optimization

Acknowledgment

The authors acknowledge that this study is realized only for academic and research purposes, and has no connection to any commercial interest. This work was partially supported by the ANR project ANR-15-IDEX-02, eco-SESA program (https://ecosesa.univ-grenoble-alpes.fr/), Observatory of Transition for Energy (https://ote.univ-grenoble-alpes.fr/) and a grant from the French government under the PIA, IRT Nanoelec, bearing the reference ANR-10-AIRT-05.

References

[1] International Energy Agency. (2021). Global EV Outlook 2021 – Analysis - IEA.
[2] Nana Kofi Twum-Duah, Lucas Hajiro Neves Mosquini, Muhammad Salman Shahid, Frédéric Wurtz, Benoît Delinchant, "The Indirect Cost of E-Mobility: Global Warming Impact of Grid Energy-Mix on E-Mobility Using Real-World Data", submitted to "Springer - Environment, Development and Sustainability", Dec, 2022

Application of Solid Oxide Fuel Cells on Hybrid Electric Vehicles Operating in Fleet

Giulia Sandrini[1*], Marco Gadola[1] and Daniel Chindamo[1]

[1]Department of Mechanical and Industrial Engineering, University of Brescia, I-25123 Brescia, Italy (G.S.: g.sandrini005@unibs.it; M.G.: marco.gadola@unibs.it; D.C.: daniel.chindamo@unibs.it)
*Corresponding author: g.sandrini005@unibs.it

Abstract – Solid oxide fuel cells (SOFCs) are well suited to be used with different fuels, including methane and biomethane. Therefore, it may be useful to study their possible application on board hybrid electric vehicles and exploit the fuel cell system, which is characterized by high efficiency, and allow the use of biomethane (a renewable green energy source). Furthermore, there is not yet a consolidated hydrogen distribution network for automotive use, while biomethane makes it possible to take advantage of the existing distribution network and infrastructures of methane. SOFC technology is well suited to be used on vehicles operating in fleets, with a consistent and known mission through the working days, which helps to mitigate SOFCs known limitations such as slow transients and long ignition times. In this work, a model of a fuel cell hybrid vehicle equipped with a SOFC is presented and then used for the sizing of a door-to-door waste collection vehicle. After that, a case study has been carried out considering such a vehicle working on a real-world, door-to-door waste collection mission (maximum around 10h/days shift for 7days/week), showing the entire potential of this architecture in terms of environmental impact.

1. Introduction

Solid oxide fuel cells (SOFCs) are well suited to be used with different fuels, including methane and biomethane. For this reason, it may be useful to study a possible application of the latter on board hybrid electric vehicles.

Hydrogen Fuel Cell technology is already adopted on board vehicles, while the application of SOFC systems to the automotive world is still being studied due to their limitations: slow transients and long ignition times. With SOFC technology it is possible to exploit the fuel cell system characterized by high efficiency and allow the use of biomethane, a renewable green energy source, for which it is possible to exploit the supply infrastructure already present for methane, solving the problem of creating a new hydrogen distribution network.

In the presented work, a model of a fuel cell hybrid vehicle equipped with a SOFC has been realized, taking into account the state of the art of SOFC systems, their characteristics and criticalities. Furthermore, the SOFC model has been integrated into a model for the simulation of the longitudinal dynamics of electric and hybrid vehicles [1]. Considering the slow transient and the long ignition times, the SOFC system is not suitable as a primary energy source. The realized model therefore presents a SOFC system that acts as a generator and it is only suitable for vehicles operating in fleet, with a predefined and known mission. In particular, in order to scale the SOFC system and the battery pack correctly, a specific model was created for a door-to-door waste collection vehicle. Another important criticality of SOFCs is its fragility, it is therefore necessary to find, through future studies and designs, a solution to this problem before the actual realization of a vehicle equipped with SOFC technology.

2. Methodology

The following assumptions have been made for the vehicle model object of this work: use of a solid oxide fuel cell stack to enable biomethane fuelling; SOFC which acts as a constant power generator to charge the battery pack to resolve the problem of slow transient; SOFC system always active, even when the vehicle is off; it is considered a vehicle that works in a fleet, with a predefined mission (a door-to-door waste collection vehicle); during the inactivity phases, the vehicle must be connected to the electricity grid, in fact, once the battery pack has reached the desired SOC (State of Charge), the fuel cell will send power to the grid itself.

The vehicle used in the model is the waste collection vehicle used for what is mentioned as low-performance validation of the TEST model in [1]. The main data of the vehicle is reported in Table 1 of [1], while in Figure 5 of [1] the traction motor torque characteristics is shown. Unlike what is reported in [1], the vehicle in question has SOFC system on board, a total transmission ratio equal to 6.22, a variable mass during the missions (a vehicle empty weight equal to 1900 kg, a driver mass equal to 80 kg and a variable mass relative to the payload carried by the vehicle) and a battery pack system object of sizing.

For the realization of the model 10 speed profiles (with their mass profile as well) have been considered, relating to 10 different daily missions performed by the vehicle every two weeks, acquired through a MoTeC datalogger. For the simulations of the vehicle and its missions, the TEST model described in [1] was used, in particular the latest version of the model [2,3]. For this study, the SOFC system is seen in the TEST model as a sort of "black box", only the constant power supplied by the fuel cell and an efficiency (equal to 90%) relating to the DC/DC converter are considered.

The system has been sized, minimizing the power of the SOFC and the capacity of the battery pack, on the most time-consuming profile, in such a way as to be able to carry out this profile without any stopping. So, a charging stop has been arranged only for the most energy demanding profile rather than the most time-consuming profile.

3. Results and Discussion

After an iterative simulation process for the most time-consuming profile, the best compromise for battery pack size and SOFC power rating have been found as: battery pack capacity equal to 30 Ah; and SOFC power rating equal to 3 kW. Using these values, a SOC field ranging from a maximum of 95.6% to a minimum of 20.6% is exploited for the most time-consuming profile, with an initial SOC equal to 90%. In order for the vehicle to be able to cover even the most energy-demanding profile, it is sufficient to arrange a stop of an hour and a half with the vehicle off, with the SOFC system, always on, which recharges the battery pack. Furthermore, all the recharging times with the vehicle inactive, the periods in which the SOFC system feeds current into the grid, with the vehicle off and connected to the electricity grid, and the relative biomethane consume (231.8 m^3 every two weeks) are obtained.

4. Conclusion

The aim of this study was to investigate the possibility to employ a fuel cell powered hybrid powertrain fuelled by biomethane. This has been done through a model-based design approach, using a consolidated vehicle modelling architecture/tool [1–3]. The system identified features a SOFC as a generator, which is never turned off, and which supplies current to the electricity grid in the event that the vehicle is switched off and the battery pack does not need to be recharged. The model was created and sized for a waste collection vehicle, with a number of predefined missions, which therefore lends itself to SOFC technology. Power delivered by the fuel cell and battery pack capacity have been optimized to values of 3 kW and 30 Ah respectively, adopting the appropriate arrangements in terms of charging stops. The work carried out is repeatable and can be the initial step for future works aimed at exploiting SOFC technology in the automotive sector.

Keywords: mathematical modelling; alternative propulsion; solid oxide fuel cell; vehicle model; energy consumption.

References

[1] G. Sandrini, M. Gadola, D. Chindamo, Longitudinal dynamics simulation tool for hybrid APU and full electric vehicle, Energies (Basel), 14, 2021. https://doi.org/10.3390/en14041207.
[2] L. Zecchi, G. Sandrini, M. Gadola, D. Chindamo, Modeling of a Hybrid Fuel Cell Powertrain with Power Split Logic for Onboard Energy Management Using a Longitudinal Dynamics Simulation Tool, Energies (Basel), 15, 2022. https://doi.org/10.3390/en15176228.
[3] G. Sandrini, D. Chindamo, M. Gadola, Regenerative Braking Logic That Maximizes Energy Recovery Ensuring the Vehicle Stability, Energies (Basel), 15, 2022. https://doi.org/10.3390/en15165846.

Investigating the Impact of Electricity Rationing on Rural EV Charging

Thomas R. McKinney[1*], Erica E.F. Ballantyne[1] and David A. Stone[2]

[1]Sheffield University Management School, The University of Sheffield, UK
[2]Department of Electronic and Electrical Engineering, The University of Sheffield, UK
*Corresponding author: trmckinney1@sheffield.ac.uk

Abstract – The Electricity Supply Emergency Code (ESEC) outlines the process for electricity rationing via a range of scenarios (Levels 1 to 18), should a critical supply incident affect a specific region, or the whole UK country. Given recent global events, the threat of its implementation is currently attracting large mainstream media attention and a genuine concern. With the uptake of Electric Vehicles (EVs) increasing, motorists are ever more reliant on a resilient electrical grid in order to charge their vehicles. This paper aims to investigate the impact on rural EV drivers specifically, should the ESEC be invoked. Focusing on a small rural village in the UK, Bradbourne, located in the Peak District, an EV Charging Model has been designed to incorporate the patterns of various levels of disconnections as laid out in the ESEC. Real concerns arise in the eventuality of the higher level scenarios being implemented.

1. Introduction

Electric Vehicles (EVs) are becoming increasingly popular in recent years, due to their multiple benefits environmentally and lower running costs [1]. It is widely understood that large EV market penetration will lead to increased peak demand causing voltage violations, system losses and a difficulty in optimising power grid operation control [2]. In this electrified vehicle future, a potential major cause of concern is the impact of power cuts due to evermore motorists reliant on an unfailing electrical grid. Recent global affairs have exposed the threat of energy generation difficulties in the UK. This has led to the UK Government considering invoking the Electricity Supply Emergency Code (ESEC) as mitigation, receiving large media attention [3]. The ESEC outlines various levels of disconnections for households in order to ration out available energy during supply/generation issues. This paper aims to investigate the impact that implementation of the ESEC would have on electric vehicles users, in particular those in rural communities. Rural areas are often left behind during large socio-techno transitions [4] and this potential future problem is only compounded by their already typically weaker grid infrastructure [5].

2. Methodology

The small rural village of Bradbourne was chosen as a case study of investigation, this enabled the use of publicly available UK Census data to build a real life scenario upon which to build the required models. Bradbourne is home to 84 vehicles spread across 49 households, which, for this study have been assumed to all be 40 kWh Nissan Leaf's. A custom written python script was used to simulate the EV charging habits which was later adapted to incorporate the power outage schedules laid out in the ESEC. The ESEC proposes 18 levels of disconnections, whereby the houses of the affected region are split amongst 18 groups (A – U). Each disconnection level splits the days of the week into 3hr intervals, with these blocks indicating if the group is to be with or without power. Disconnection Levels 1, 5, 10, 12 & 15 were selected for this investigation to provide a range of results, enabling the analysis of varying levels of impact. Disconnection level 5 is presented in Fig. 1 below as an example, and displays the power rationing schedule for blocks A and B.

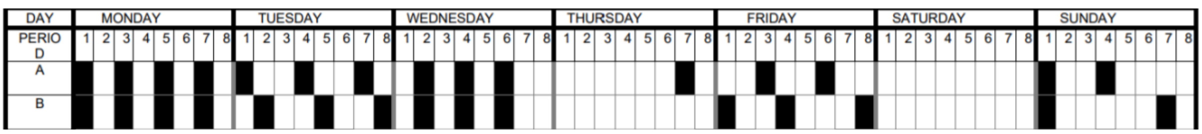


Fig. 1: Disconnection Level 5 (Black squares indicate no power for that block during that 3hr duration)

3. Results and Discussion

Multiple analyses were conducted in order to investigate the impact of these power cuts on the ability to charge this synthetic electric vehicle population, and by extension the ability of Bradbourne's inhabitants to continue to conduct their required travel. As shown in Fig. 2, the impact of the power outage(s) is minimal for the lower disconnection levels, however levels 12 and 15 raise real concerns. These levels lead to an average decrease of 27.4% in vehicle state of charge across the total vehicle population at any one time.

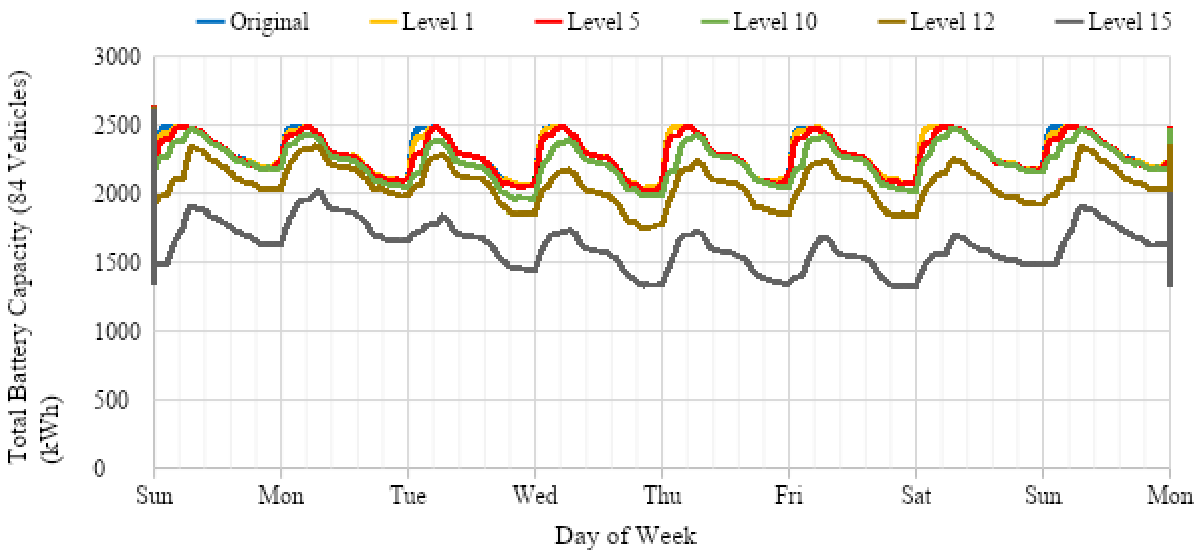


Fig. 2: Example of figure for the extended abstract

The severity of this impact is fully appreciated when considering the individual vehicles. Results indicate a total of 25 out of the 84 vehicles hit 0% state of charge, and for large periods of time do not have sufficient charge to conduct the required travel plans of their owners.

4. Conclusion

There is growing concern of an energy crisis hitting the UK during this or next winter, which has led to the ESEC attaining large media coverage. The impact should this code be enforced, of 5 different disconnection levels of the ESEC, have been investigated for the rural village of Bradbourne's vehicle population. This study highlights real cause for concern should the higher level scenarios be implemented for a fully electrified transport future.

Keywords: Electric Vehicle; EV Charging, Electrical Grid; Power Cuts; Rural Transport.

Acknowledgement

The authors would like to thank the University of Sheffield Energy Institute and the EPSRC FEVER project for supporting this research.

References

[1] Hill, G., Heidrich, O., Creutzig, F., Blythe, P. The role of electric vehicles in near-term mitigation pathways and achieving the UK's carbon budget, Applied Energy, Vol. 251, 2019, p.113111.
[2] Crozier, C., Morstyn, T., McCulloch, M. Capturing diversity in electric vehicle charging behaviour for network capacity estimation, Transportation Research Part D: Transport and Environment, Vol. 93, 2021, p.102762.
[3] Fintan Slye. UK homes can become virtual power plants to avoid outages, The Guardian, 2022.
[4] Williams, F., Philip, L., Farrington, J., Fairhurst, G. 'Digital by Default' and the 'hard to reach': Exploring solutions to digital exclusion in remote areas, *Local Economy*, Vol. 31, No. (7), 2016, p. 757-777.
[5] Western Power Distribution. The Electric Journey, Western Power Distribution., 2022.

Maximizing Wireless Power Transmission for Electric Vehicles with High-Intensity Laser Power Beaming and Optical Orthogonal Frequency Division Multiplexing

Jeongsook Eom[1], Gunzung Kim[2] and Yongwan Park[3*]

[1]Dept. of Multimedia and Communication Eng., Yeungnam University, South Korea
[2] Institute Information and Communication, Yeungnam University, South Korea
[3] Dept. of Information and Communication Eng., Yeungnam University, South Korea
*Corresponding author: ywpark@yu.ac.kr

Abstract – This paper presents a method for determining the optimal power transmission path for wirelessly charging electric vehicles using high-intensity laser power beaming in environments with multiple power transmitters and receivers. The proposed method uses an optical orthogonal frequency division multiplexing system. The power receiver selects the optimal power transmitter and wireless power channel based on the maximum power requirement. The paper also validates the proposed method through simulation and experimentation.

1. Introduction

Electric vehicles (EVs) have been gaining momentum in recent years as a solution to the environmental issues caused by internal combustion engines (ICEs). Still, the widespread adoption of EVs depends on several factors, including the total cost of ownership and charging time, which significantly impact consumer purchasing decisions. An EV with a larger battery capacity can run for more extended periods on a single charge, but this also increases the cost and weight of the vehicle, resulting in lower energy efficiency. Additionally, the current method of plug-in charging can be cumbersome, poses safety concerns, and requires a significant amount of charging time; public charging stations may also be susceptible to damage and negatively impact the appearance of cities. To overcome these challenges, wireless power transmission (WPT) is gaining widespread attention as a potential solution, allowing for the miniaturization of batteries and increasing the maximum range of an EV[1]. WPT for wireless charging is a promising approach that holds great potential to accelerate the acceptance of EVs through users' higher satisfaction, reducing EV cost, and increasing driving range and capability. A WPT system based on high-intensity laser power beaming (HILPB) provides an optimal solution for wirelessly charging electric vehicles from several meters. Still, the problem of optimal path configuration for charging EVs remains unexplored. This paper proposes a method to determine the optimal power transmission path in environments where multiple power transmitters (PTXs) and power receivers (PRXs) are operated simultaneously.

2. Structure and Operation of Wireless Power Transmission based on High Power Laser

We present a novel approach for maximizing the power transfer efficiency (PTE) of HILPB systems by addressing the challenges of accurate receiver positioning. The proposed method utilizes a pairing mechanism based on optical orthogonal frequency division multiplexing (OOFDM) and a Risley prism[2,3]. The system design involves the placement of the PTX on traffic lights at intersections and the PRX on the solar roof of EVs. The EVs are parked and stationary at intersections to ensure safety while waiting for the traffic light to turn green. The PRX-PTX pairing process is executed in multiple steps. The PRX initiates the process by broadcasting a power channel information (PCI) request message, along with its location, via the vehicle-to-infrastructure (V2I) communication channel. Upon receipt of the request, all PTXs scan their own PCI information and use coded laser pilots with a rotating Risley prism to determine the accurate location of the PRX. The PRX then decodes the received coded laser pilots via its solar roof and calculates the maximum power for each received PCI information. After a predetermined period, the PRX selects the optimal PTX and power transmission angle and requests power transmission via V2I. The selected PTXs then transmit the HILPB at the requested angle. Once the traffic light turns green, the PRX requests the PTX to stop transmitting power, and the PTX complies accordingly.

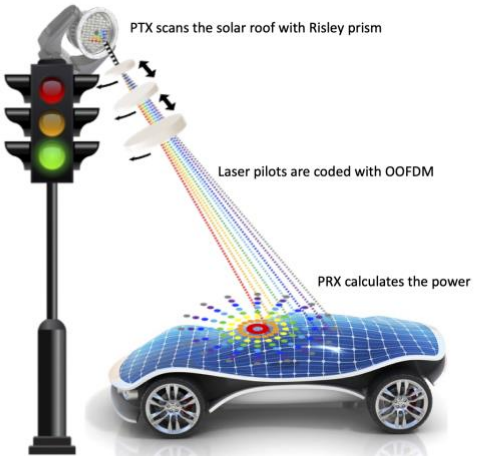


Fig. 1: Operating concept for wireless power transmission based on a high-power laser beam and Risley prism.

3. Experimental Validation and Simulation of Wireless Power Transmission

We adjusted a PV array model and product from MHGP to account for off-centered positioning and electrical output power. To confirm the accuracy of the mathematical model, we conducted experiments using an MHGP PV array and a high-power laser module from Opto Engine LLC. We utilized Synopsys RSoft OptSim to analyze optical characteristics related to the PV array, Risley prism, laser transmission, and reception. Additionally, we used MathWorks MATLAB for encoding/decoding, signal processing, intensity calculation, and distance calculation. The simulation involved placing three PRXs with varying power needs and four PTXs with different power transmission capabilities. We simulated three different PRX-PTX pairing algorithms where PRX R1 to R3 sequentially requested power, selecting the PTX based on the highest, least and best PTE power to meet the energy requirements of the PRX. Results showed that the third algorithm, where the PTX is chosen based on the best PTE power, satisfied the PTE power needs of all PRXs.

4. Conclusion

Our research focuses on decreasing the size of EV batteries and extending their driving range through WPT. Among WPT methods, HILPB technology eliminates interference and simultaneously allows for power delivery from multiple sources. We developed a WPT system and pairing algorithm that utilizes OOFDM and Risley prism to position the receiver precisely. The system was validated through experiments and simulations. This study can potentially improve PTE by reorganizing PV arrays on EVs. Additionally, considering the varying charging time based on an EV battery's residual power, a PTX can continue transmitting power to another PRX while waiting at a red traffic light after completing the power transfer to the first PRX.

Keywords: wireless power transfer; high-intensity laser power beaming; optical orthogonal frequency division multiplexing, multiple transfers and receivers

Acknowledgement

NRF-2021R1A2B5B02086773, NRF-2021R1A6A1A03039493, NRF-2022R1I1A1A01070998

References

[1] X. Zhang, C. Zhu, and H. Song, Wireless Power Transfer Technologies for Electric Vehicles, Springer, 2022.
[2] Z. Ghassemlooy, W. Popoola, and S. Rajbhandari, Optical Wireless Communications: System and Channel Modelling with MATLAB, CRC Press, 2019.
[3] A. Li, Double-Prism Multi-mode Scanning: Principles and Technology, Springer, 2018.

Energy Management Strategy to Limit Battery Degradation in Fuel Cell Electric Vehicles

Christoph Hametner[1,2*], and Alessandro Ferrara[2]

[1]Christian Doppler Laboratory for Innovative Control and Monitoring of Automotive Powertrain Systems, TU Wien, Austria
[2]Institute of Mechanics and Mechatronics, TU Wien, Austria
*Corresponding author: christoph.hametner@tuwien.ac.at

Abstract – This work proposes an energy management strategy to limit battery degradation in heavy-duty fuel cell electric vehicles using dynamic programming to solve the multi-objective optimization problem of battery degradation and fuel consumption. The simulation results show that a Pareto front forms between the two targets because it is impossible to optimize both simultaneously. Nevertheless, selecting a suitable trade-off can reduce battery degradation by 26%, with only a 2% higher fuel consumption than the minimum.

1. Introduction

Research on powertrain technology is essential to ensure that fuel cell electric vehicles meet the durability requirements of conventional ones. In particular, vehicle control systems can mitigate degradation of the individual components through proper energy management, charge control and thermal management.

Focusing on battery degradation, the principal factors affecting degradation are the ampere throughput, temperature, C-rates, and depth of discharge. For example, the cell temperature influences the leading degradation mechanisms, such as solid electrolyte interface growth, lithium plating, and active material dissolution [1].

In hybrid powertrains, multiple power sources work together to satisfy the load demanded by the driver. In particular, fuel cell powertrains usually include batteries to assist the fuel cells during fast load changes, and an energy management strategy is required to distribute the load between the power sources. This additional degree of freedom allows to significantly influence the efficiency and lifetime of the powertrain components through intelligent and predictive optimization [2, 3].

Eventually, this work proposes an energy management strategy to limit battery degradation in heavy-duty fuel cell electric vehicles, using dynamic programming to solve the multi-objective optimization problem of battery degradation and fuel consumption.

2. Methodology

The proposed energy management strategy defines the optimal power-split between the components depending on which optimization target is prioritized. For example, to optimize battery degradation, the strategy defines the power-split between the components so that the battery C-rate, temperature, depth of discharge, and ampere throughput are limited as much as possible.

In particular, the energy management strategy relies on an optimal control problem formulation that considers the multi-objective optimization of fuel consumption and battery degradation. Moreover, the problem includes constraints on battery voltage, C-rate, and SoC operating range to avoid those critical operating conditions that accelerate the degradation.

The optimization problem is solved using dynamic programming, a well-known method in literature to find global-optimal solutions. This method allows good flexibility of the control-oriented models adopted to estimate the optimization targets. For example, this work uses a semi-empirical battery degradation model derived from experimental data of the number of charging/discharging cycles until the end of life [4]. Here, the battery degradation rate depends on the SoC as in Fig. 1, indicating that the least degrading operating condition is around a battery charge of 60%.

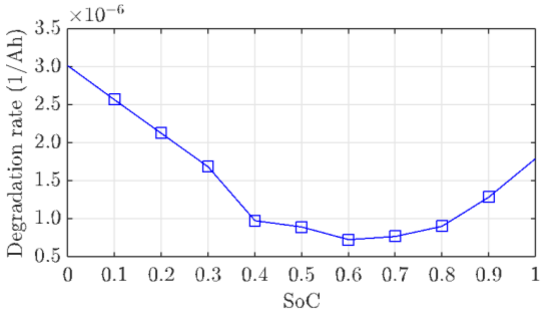


Fig. 1: Battery degradation rate as a function of SoC.

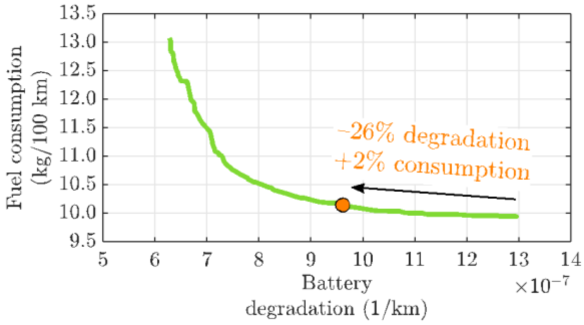


Fig. 2: Pareto front between the optimization targets.

3. Results and Discussion

The proposed energy management strategy is tested for a 42-ton truck with a nominal fuel cell power of 310 kW and a nominal battery capacity of 100 kWh. The vehicle simulations consider a real-world driving cycle on a mountain route with an elevation change of 1500 meters, which is a very challenging driving scenario for energy management strategies.

The strategy is tested considering different priorities for the targets in the multi-objective optimization problem to explore different trade-offs between them. The simulation results in Fig. 2 show that a Pareto front forms between the two targets because it is impossible to optimize both simultaneously. Nevertheless, selecting a suitable trade-off can reduce battery degradation by 26%, with only a 2% higher fuel consumption than the minimum.

4. Conclusion

This paper shows that energy management strategies can limit battery degradation with a negligible impact on fuel consumption. Further research on this topic can potentially foster the market penetration of electric vehicles, especially for heavy-duty long-haul transportation, by overcoming the durability challenges compared to conventional vehicles.

Keywords: battery degradation; energy management strategy; fuel cell electric vehicle; dynamic programming; optimal control theory.

Acknowledgement

The financial support by the Austrian Federal Ministry for Digital and Economic Affairs, the National Foundation for Research, Technology and Development, and the Christian Doppler Research Association is gratefully acknowledged. This work has been created in cooperation with the Austrian research project “FC4HD” (grant no. 885044).

References

[1] J. M. Reniers, G. Mulder, and D. A. Howey. Review and performance comparison of mechanical-chemical degradation models for lithium-ion batteries. Journal of The Electrochemical Society, 166(14):A3189–A3200, 2019.

[2] A. Ferrara, S. Jakubek, and C. Hametner. Energy management of heavy-duty fuel cell vehicles in real-world driving scenarios: Robust design of strategies to maximize the hydrogen economy and system lifetime. Energy Conversion and Management, 232:113795, March 2021.

[3] J. Kölbl, A. Ferrara, and C. Hametner. Impact of Energy Management Strategy Calibration on Component Degradation and Fuel Economy of Heavy-Duty Fuel Cell Vehicles. IFAC-PapersOnLine (pp. 317–322), August 2022.

[4] Y. Wang, Z. Zhou, A. Botterud, K. Zhang, and Q. Ding. Stochastic coordinated operation of wind and battery energy storage system considering battery degradation. Journal of Modern Power Systems and Clean Energy, 4(4):581–592, October 2016.

Design of Hybrid Energy Storage System for Heavy Electric Vehicle

Hanlin Lei[1], Kang Li[2*], Benjamin Chong[1] and Shiyun Liu[1]

[1]University of Leeds, Unite Kindom
*Kang Li: K.Li1@leeds.ac.uk

Abstract – With the requirements of the new era for new energy and Net zero. Electric vehicles are gradually replacing traditional fuel vehicles and becoming the mainstream means of transportation. In terms of small cars, there are already a large number of electric vehicles on the market. Basically all traditional brands are switching to small electric vehicles. But for large cars, heavy trucks, the penetration rate of electric vehicles is not very high. Buses and some oversized vehicles, such as mine trucks on construction sites, are still mainly powered by traditional fuel. This part is an area worthy of study.

Customers currently have basically the same major concerns with large EVs as they do with smaller EVs, such as range. The range of existing battery-electric vehicles depends primarily on the energy density of the battery. But this is not the only method that can be improved. Other methods include improving control strategies, introducing hybrid energy storage systems, and so on.

Hybrid energy storage systems include batteries, supercapacitors, fuel cells, flywheels, etc. The advantages and disadvantages of different energy storage elements are different. For example, the energy density of the battery is high, the power density is small, and the cycle life is short. Supercapacitors have high power density, low energy density and long cycle life. Fuel cells have a high initial cost, but don't take long to recharge. The flywheel has high power density, but the self-discharge rate is high, and all the power will be exhausted within dozens of hours at most. It is important to choose the correct originals to combine. The size calculations and control schemes of these systems are very different from those of pure batteries. (The size calculation includes the mass ratio of each component of the hybrid energy storage system and the ratio of stored energy) The hybrid energy storage system should be installed on the powertrain of the electric vehicle, which requires the selection of the most suitable topology, such as the active topology, passive topology, semi-active topology. The purpose of optimizing the hybrid energy storage system is to allow the electric vehicle to have a longer cruising range, or to allow the car to have a faster start and stop speed under the same cruising range.

This article describes how to apply the most suitable hybrid energy storage system to heavy-duty electric vehicles. Different approaches have been tried and their results will be compared with each other and with conventional pure battery vehicles. After the above comparison, an optimized energy storage system solution based on the above solutions will be proposed.

Keywords : heavy electric vehicle; hybrid energy storage system; control strategy.

A Circular Business Model Innovation Framework for the Electric Vehicle Battery Second Life

Ignat Kulkov*, Koteshwar Chirumalla, Frida Antonsson

The Digital and Circular Industrial Services Research Group, School of Innovation, Design and Engineering, Mälardalen University, Sweden
*Corresponding author: ignat.kulkov@mdu.se

1. Introduction

The second life batteries market presents unique opportunities for electric vehicle (EV) manufacturers to retain the remaining value from the retired EV batteries and to capitalize on the growing demand for reused and recycled materials. It is predicted that more than 85% of all EV batteries are suitable for a second life such as energy storage systems in industrial, residential, and commercial applications and can have a lifespan with a range of 5 to 15 years, depending on the type of second life application [1]. In Europe, several vehicle manufacturers are exploring such emerging market opportunities in partnership with electric utilities as well as specialist third parties, installing used batteries primarily in different kinds of energy storage systems. However, they face several layers of issues and many uncertainties in shifting from traditional linear 'take-make-dispose', business models to the circular business models. Accordingly, the uptake of EV battery circularity has not yet been fully established in the industry, despite being a potential revenue and profit contributor. To address this need, this study aims to identify the required key business model dimensions and develop a business model innovation framework for companies operating in the EV battery second life market in order to maximize their efficiency and profitability. With this framework, we aim to provide companies with a comprehensive understanding of possible alternate choices available to design a new or modify the existing business model to suit to their customer needs and EVs operational context. We believe that the suggested framework is beneficial for companies looking to enter the second life battery market or those already established in the industry. The framework will contribute to the theory of circular business models in general and EV battery circularity more in specific [2].

2. Methodology

The study has been conducted in collaboration with six companies in the EV battery industry following interactive research approach [3]. Data has been collected through a mixed-methods study, eliciting qualitative data via semi-structured interviews, workshops, and multiple case studies. In addition, it includes reviews of existing studies on the second life batteries market, as well as studies of the business models employed by companies. The analysis provides insights into how various companies have structured their business models and the strategies they have employed in order to be successful. Finally, a business model innovation framework was developed and validated with two electric vehicle manufacturers.

3. Results and Discussion

The main result of this study is the development of a comprehensive business model innovation framework to assist companies operating (or willing to operate or expand) in the EV battery second life market, see **Table 1**. The framework considers three key business model dimension of value preposition, value creation and delivery, and value capture [4]. It is designed to help these companies effectively assess their current situation and evaluate the potential choices and alternatives to design the business model scenarios related to the battery second life. Each dimension consists of several key elements, for example the dimension of value proposition dimension includes key elements such as product/service, target customer, novelty, solution approach, and exclusiveness. Similarly, the dimension of value creation and delivery includes key elements such as key activities, customer relations, and ownership. Furthermore, each key element consists of several sub elements. For example, in the key element of product/service, a company can choose product sales, service offer or a mix of these elements. Similarly, in the key element of ownership, a company can choose choices such as manufacturer, customer, battery producer, independent actor, and a joint venture. Choosing elements according to your goals, a company operating in this market can form an individual business model that reflects the specifics of value dimensions. The framework can be adapted to the needs of most companies operating in the market, as well as identify new niches. The framework has been tested with EV manufacturers and led to develop several business models related to the EV battery second life. The paper will present some of these business models.

Table 1. Key dimensions, elements, and sub-elements that form the business model innovation framework for the EV battery second-life market

Value preposition	Product/service	Product sales	Service/solution offer	Mix			
	Target customer (sector)	Industry	Commerce	Residential			
	Novelty	New solution	Addition to existing	Replacement of the existing			
	Solution approach	Single	Customization				
	Exclusiveness	One customer	Multiple customers				
Value creation and delivery	Key activities	Reduce	Reuse	Remanufacture	Recycle		
	Customer relations	Direct sales	Distribution	Franchising	Self-service		
	Ownership	Manufacturer	Customer	Battery producer	Independent actor	Joint venture	
Value capture	Revenue model	Pay per pack	Pay per use	Subscription	Sharing	Renting	State support
	Cost structure	Fix	LIB packs	Logistics	Testing	Repacking	

4. Conclusion

Contribution of this work lies in the development of a comprehensive business model innovation framework for companies operating in the second life batteries market for EVs. The framework provides a valuable tool for companies to assess their current situation and evaluate potential options to design a new or modify an existing business model to meet customer needs and operational context. This framework is important because it considers the unique challenges faced by companies in transitioning from traditional linear business models to circular ones in the second life batteries market.

Keywords: business model innovation; battery second life, EV batteries; circular business models.

Acknowledgement

This research was supported by the RECREATE (Second Life Management of Electric Vehicle Batteries) funded by the Knowledge Foundation (KKS) in Sweden [1602, 2019]. In addition, the work was supported by the Excellence in Production Research (XPRES), a government funded Strategic Research Area (SRA) within manufacturing engineering in Sweden [0219, 2016].

References

[1] Zhu, J., et al., End-of-life or second-life options for retired electric vehicle batteries, Cell Reports Physical Science, 2, 100537, 2021, pp. 1-26.

[2] Wrålsen, B, et al.,Circular business models for lithium-ion batteries – Stakeholders, barriers, and drivers, Journal of Cleaner Production, 317, 128393, 2021.

[3] Sänno, A et al., Increasing the impact of industry-academic collaboration through co-production, Technology Innovation Management Review, 9(4), 2020, 37-47.

[4] Reinhardt, R., Christodoulou, I., García, B. A., & Gasso-Domingo, S. (2020). Sustainable business model archetypes for the electric vehicle battery second use industry: Towards a conceptual framework. Journal of Cleaner Production, 254, 119994.

State-of-Charge Estimation of Li-ion Battery Packs Based on Optic Fibre Sensor Measurements

Shiyun Liu, Kang Li*, Benjamin Chong, and Ye Chen

University of Leeds, School of Electronic and Electrical Engineering, UK
*Corresponding author: K.Li1@leeds.ac.uk

Abstract – Renewable energy plays a vital role in response to the energy crisis and climate change. To address the intermittent nature of clean power and ensure the grid stability between electricity demand and supply, Battery energy storage systems (BESS) are frequently prescribed for the next-generation power grid. Among the numerous types of batteries, Li-ion batteries demonstrate considerable potential in developing the grid-level energy storage systems by virtual of their high energy density, long cycle life, and low life self-discharge rates. Thus, the Lithium-ion battery-based energy storage system is seen as one of the most powerful approaches to a more flexible and stable power system. Due to the manufacturing processes and the working conditions, the inconsistencies between cells in a battery pack are unavoidable. It is very likely to cause the performance of the BESS to deteriorate once a battery pack is operated improperly.

For example, State-of-Charge (SOC) is an important indicator of the residual capacity of a battery [1]. An accurate SoC estimation not only provides reliable remaining power for applications, but also ensures the safety of grid. Assuming that an erroneous SOC estimate is referenced by BESS, batteries might suffer serious abuse, such as overcharge and over-discharge, presumably accelerating the degradation process or causing severe safety hazards. To date, multiple definitions to describe the battery pack SoC have been provided, including the maximum/minimum cell SOC and the average cell SOC. However, the measurements of current and voltage of the aforementioned methods are conventionally corrupted by noise. As one of the main sources of SOC estimation errors, sensor noise significantly affects the accuracy and reliability of SOC estimation.

In recent years, Fibre optic sensing techniques have been attracting a lot of attention, owing to their characteristics of lightweight, mechanical robustness, insulation in nature, resistance to corrosion, being immune to electromagnetic radiation and easy to multiplex [2]. As one of the most popular types of fibre optic sensors, Fibre Bragg gratings (FBGs) have been utilized in battery temperature testing and strain monitoring [2-5]. In this paper, we proposed a strain-based model coupled with an equivalent circuit model to jointly estimate the battery pack SOC. Firstly, a cloud-based strain model has been developed to select the "representative cells" among a pack, i.e., the cell with an upper SOC during charging process and a cell with a lower SOC when discharging. Then, the representative cells' SOC is estimated by a strain model and an equivalent circuit model, respectively. Finally, a fusion algorithm is developed to calculate the battery pack SOC based on the two different monitoring models. The simulation results indicate that the dynamical robustness of the strain and electrical-based approach to various environments, accompanied by a higher accuracy than traditional electrical-based models.

References

[1] K. Liu, K. Li, Q. Peng, and C. Zhang, "A brief review on key technologies in the battery management system of electric vehicles," *Frontiers of Mechanical Engineering,* vol. 14, no. 1, pp. 47-64, 2018, doi: 10.1007/s11465-018-0516-8.

[2] S. Liu and K. Li, "Thermal monitoring of lithium-ion batteries based on machine learning and fibre Bragg grating sensors," *Transactions of the Institute of Measurement and Control,* 2023, doi: 10.1177/01423312221143776.

[3] S. Bandyopadhyay *et al.*, "Machine Learning Model using a Fiber Bragg Grating-based Sensor System to measure Battery State-of-Charge," in *27th International Conference on Optical Fiber Sensors*, Alexandria, Virginia, 2022/08/29 2022: Optica Publishing Group, in Technical Digest Series, p. W4.17, doi: 10.1364/OFS.2022.W4.17. [Online]. Available: https://opg.optica.org/abstract.cfm?URI=OFS-2022-W4.17

[4] L. Zhang *et al.*, "Real-time battery temperature monitoring using FBG sensors: a data-driven calibration method," *IEEE Sensors Journal*, 2022.

[5] Y. Li *et al.*, "A hybrid machine learning framework for joint SOC and SOH estimation of lithium-ion batteries assisted with fiber sensor measurements," *Applied Energy,* vol. 325, p. 119787, 2022.

Novel Loop Heat Pipe System for EV Thermal Management of Batteries: Effects of Ambient Temperatures

Marco Bernagozzi[1], Anastasios Georgoulas[1], Nicolas Miché[1] and Marco Marengo[1,2]

[1]Advanced Engineering Centre, University of Brighton, Brighton, UK
[2]University of Pavia, Department of Civil Engineering and Architecture, Pavia, Italy
*Corresponding author: m.bernagozzi3@brighton.ac.uk

Abstract – Building from previous successful results from the authors, a Loop Heat Pipe based Battery Thermal Management System (BTMS) is investigated over a range of different ambient temperatures (from -20°C to 50°C), thanks to an environmental chamber. LHPs act as thermal vector from the bottom of the battery pack to a remote chiller and graphite sheets allow to achieve a good level of temperature homogenization of the cells surface, whilst minimizing the increased system weight. This design was developed aiming to improve on fast charge timings, all-electric range, reduce costs and complexity, and decrease maintenance requirements. Preliminary studies showed the potential of this innovative BTMS to give better performances than standard active counterparts. The aim of this work is to extend the investigation towards a practical application, by matching experimental results obtained in the environmental chamber with a validated numerical Lumped Parameter Model and extend the results database to different geometries and material/fluid configurations, in order to support the adoption of this technology by automotive manufactures.

1. Introduction

The seemingly unstoppable advance of global warming has motivated organisations worldwide to seek solutions to tackle the problem. Amongst the main solutions, one of the most cited is vehicle electrification, due to the sizeable improvement it can provide in terms of Green House Gases (GHG) emissions reduction, if coupled with a renewable electricity mix [1]. However, despite maximum efforts deployed by researchers, governments and automotive manufacturers, Electric Vehicles (EVs) still represent only the 1% of the global passengers car fleet. Partial reasons for this can be found in the reported motivations that customers have regarding not wanting to purchase an EV, these being high cost, range anxiety (corroborated by limited ranges) and long charging times [2]. These factors can be positively influenced by an efficient, cheaper, long duration Battery Thermal Management System (BTMS), which is how the present work aims to help ultimately increasing EV numbers worldwide.

In fact, one of the several challenges that EVs bring along is the thermal management of the batteries. Temperature is a critical aspect for the performance and operative life of the battery pack. It has been reported that the optimum temperature range for a Li-ion battery is between 25°C and 40°C, with heavy power and capacity losses reported both at higher and lower temperatures. The maximum temperature targets are 40°C for optimum performance, 50°C for acceptable performances and 60°C is set as a safety threshold to prevent the occurrence of disruptive phenomena (e.g., thermal runaway) [3].

In a previous work, a BTMS based on Loop Heat Pipes (LHPs) and graphite sheets was developed [3], aimed at increasing all-electric range of the vehicle and the same time reducing cost and charging time. Thanks to an experimentally validated Lumped Parameter Model (LPM), previous results showed the potential of this passive technology to outperform a standard active liquid cold plate BTMS by reducing the maximum cell temperature by 3.6°C during a 10-min 0.2-0.8 SOC fast charge cycle (up to 4C). Given the positive results, in order to further proceed in the direction of an industrial application, the LHP BTMS was tested in an environmental chamber, to investigate its response to ambient temperature ranging from -20°C to 50°C.

Results showed that the proposed BTMS worked both at very high and very low temperatures, advocating for its operational flexibility. The present work expands on the latter previous results, by replicating them numerically and by means of the validated LPM, reproducing the different geometries and configurations previously investigated by the authors [3].

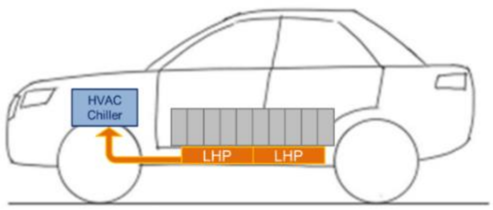
2. Methodology

The proposed BTMS design, illustrated in Fig. 1a, places an array of LHPs at the bottom of the modules forming the battery pack, where they act as thermal vector transferring the excess heat from the cells to a remote chiller (part of the built-in HVAC circuit of the vehicle). Graphite sheets are sandwiched in between the cells to favour cell iso-thermalization and hinder cell-to-cell heat spreading.

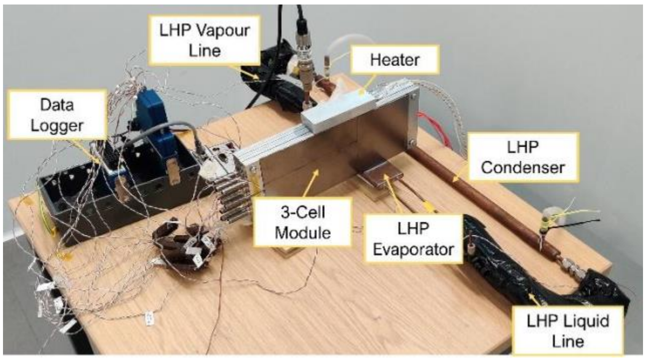
In the experimental set up, for which a schematic is provided in Fig. 1b, the battery module is composed of dummy cells, made from 5083-O aluminium plates with the same dimension as the considered cell type. Using dummy cells is a proven practice that allows to minimize the risk of generating excessive thermal stress to a real battery cell, while still evaluating the efficiency of the cooling methods. Details of the equipment used in the set up shown below are given in previous publications by the Authors [3].

The experiments were performed in climatic chamber (TAS, 4.5x4x3.5m) capable of maintaining temperatures from -40°C to 60°C until 4kW of internal load. The tests were performed in a temperature range from -20°C to 50°C, to respect the operative temperature range of some of the instrumentation for data acquisition. Two different experimental campaigns were carried out, with temperatures higher and lower than 20°C, in order to evaluate the distinct effects of the proposed BTMS on cooling and heating.

These results will be replicated with the experimentally validated Lumped Parameter Model (LPM), which was developed in the open-source software Octave. The structure of the LPM is represented by a series of ODEs, which details can be found in [3].



(a)



(b)

Fig. 1: Sketch of the proposed BTMS design (a) and experimental set-up used for the environmental chamber tests (b).

4. Conclusions

In the full paper the results from the simulations will be shown, where the experimental results will be replicated, further validating the LPM for different ambient conditions. These will allow the investigation of an array of different configurations (shape and number of evaporators, different materials and working fluids, different driving cycles) for practical applications, thus enriching the information database and hopefully eventually leading to the adoption of this technology in the automotive sector.

Keywords: Battery Thermal Management System; Electric Vehicle; Loop Heat Pipe.

References

[1] A. Moro, L. Lonza, Electricity carbon intensity in European Member States: Impacts on GHG emissions of electric vehicles, Transp. Res. Part D Transp. Environ. 64 (2018) 5–14.

[2] L. Noel, G. Zarazua de Rubens, B.K. Sovacool, J. Kester, Fear and loathing of electric vehicles: The reactionary rhetoric of range anxiety, Energy Res. Soc. Sci. 48 (2019) 96–107.

[3] M. Bernagozzi, A. Georgoulas, N. Miché, C. Rouaud, M. Marengo, Novel battery thermal management system for electric vehicles with a loop heat pipe and graphite sheet inserts, Appl. Therm. Eng. 194 (2021).

Data-Driven Multi-Objective Optimisation for Electric Vehicle Charging Infrastructure

Farzaneh Farhadi*, Roberto Palacin and Phil Blythe

Newcastle University, School of Engineering, United Kingdom
*Corresponding author: F.Farhadi2@newcastle.ac.uk

Abstract – This paper focuses on developing a data-driven methodology using simulation and multi-objective optimisation that can integrate large diverse, complex datasets in transportation for implementing the policy commitments with case studies from "electric vehicle charging infrastructure" in Newcastle upon Tyne, United Kingdom. To achieve this aim, we specifically address the following research question: "Could large datasets be used to develop a methodology for efficient implementation of a transport policy commitment?" One of the most important commitments in transport policy of the net zero emission strategy is "to ensure the UK charging infrastructure network meets the demands of its users". The local authorities need to expand the current electric vehicle charging infrastructure in order to ensure achieving this commitment during the transition to zero-emission cars and vans. A baseline simulation of the demand and EV quantities from 2020–2050 developed by the industrial partner, Arup Group Limited, has been used to feed our data-driven solution. We build a multi-objective optimisation approach to optimise the charging point types, charging point locations, charging point quantities, total economic expenditure, and operating hours of the charging points. To demonstrate the approach, we consider four future energy scenarios built on the baseline simulation scenario, and use the demand and EV quantities of the peak years for Newcastle upon Tyne. Our optimisation algorithm suggests optimal plans for the type and location of EV charging points using the simulation model. Through sensitivity analysis of the results, we show that having more diversity in the charging point types can reduce the total expenditure while having similar performance in addressing the charging demand.

1. Introduction

In order to help City Councils and other governmental organisations plan for the EV charging infrastructure, we propose an optimisation method based on genetic algorithm modified by deep learning and neural network architectures. The goal of the optimisation is to consider and optimise charging point type, charging point location, charging point quantity, total economic expenditure, and operating hours of charging points. We use the open-access statistics published officially by the official authorities. We obtain geographic and vehicle data for 175 districts in Newcastle upon Tyne. This data is then analysed using statistical methods and optimised using our designed optimisation model. The results are then further evaluated.

In order to better investigate multiple aspects of EV infrastructure planning at the same time, we choose to use genetic algorithm improved based on the concepts of recurrent neural networks (RNN) and fuzzy logic. The main contributions of this paper are as a follows:

(1) By drawing on recurrent neural network (RNN) architectures, word embedding models, and Long Short-Term Memory (LSTM) networks from machine learning literature, the traditional genetic algorithm is extended and combined with fuzzy logic to design a multi-purpose decision model for multi-objective optimisation problems. (2) We use the developed new optimisation framework to optimise multiple objectives such as economic expenditure, charging point efficiency, and customer satisfaction. (3) The model we have designed removes the need to compress a multi-objective objective function into a single objective function. Instead, the underlying simulation environment is modelled using actual data, enabling a transition from function-driven to data-driven optimisation and evaluation. (4) We provide an efficient implementation of the computations using vector and matrix representations. Matrices provide a compact way of handling large volumes of data and updating values efficiently.

2. Methodology

We have designed a framework for finding the best implementation of policy commitments in transport systems. The following steps are taken in the framework.

(1) Selecting Net Zero Emission policy commitment as a case study. (2) Analysing the policy commitment of providing EV charging infrastructure as a case study by performing a suitable literature review in order to understand the objectives of the policy commitment. (3) Collecting the existing datasets and integrating the datasets from 2012–2020 related to the policy commitment and its objectives. (4) Considering appropriate assumptions for constructing the simulation model to simulate future scenarios. (5) Constructing a simulation model for calculating electric vehicles travel mileage and power demand from 2020–2050. (6) Building an optimisation approach using the simulation model for providing an efficient expansion of EV electrical infrastructure with respect to the charging point quantities, their types, locations, costs, and operating hours.

3. Results and Discussion

We apply our optimisation approach for obtaining the charging locations in Newcastle upon Tyne considering the peak years of the four different scenarios reported in Table 1.

Table 1. Optimisation results for peak years in different scenarios.

Scenario	Leading The Way	Consumer Transformation	System Transformation	Steady Progression
Peak year	2042	2046	2048	2050
Quantity of EVs	134,606	145,345	146,617	160,403
Total number of charging points	4753	5167	5386	5817
Total Cost (£)	8,195,000	8,859,400	9,117,900	9,880,200
Average operating hours of charging points (h)	7.57	7.77	7.81	7.95
Average number of EV charging requests per charging points	35.79	36.17	35.39	35.36

4. Conclusions

In order to study the factors influencing the outcome of the optimisation, a sensitivity analysis was carried out on the number of EVs and the type of charging points. The optimisation results confirms that having more diversity in the charging point types and installing more high power points can reduce the total expenditure while having similar performance in addressing the charging demand.

Our optimisation approach is general and can be applied to any baseline model that provides estimates of the future EV charging demands in any specific area. We hope that in the future, our multi-objective optimisation framework will provide a more scientific and comprehensive support for the EV charging infrastructure in the context of net zero emission strategy.

Keywords Intelligent Transport Systems and Infrastructure, Multi-Objective Optimisation, Electric Vehicles Charging Infrastructure, Implementation of Transport Policy Commitment

Acknowledgement

This work is supported by the EPSRC grant EP/V519571/1 and Arup Group Limited.

Electric Vehicle Charging Flexibility from Representative Mobility Data: The Example of Two Datasets for Passenger and Commercial Transport In Germany

Fabia Miorelli[1*], Hans Christian Gils[1] and Patrick Jochem[1]

[1]German Aerospace Center (DLR), Institute of Networked Energy Systems,
Department of Energy Systems Analysis, Curiestr. 4, 70563 Stuttgart, Germany
*Corresponding author: fabia.miorelli@dlr.de

Abstract – Electric vehicles are a viable option to reduce air pollution caused by the transport sector and reliance on energy imports. Many national governments set ambitious goals concerning the electrification of road transport. Compared to private vehicles, commercial transportation typically has a larger mileage, more meticulously planned routes, and regular driving patterns. Assuming a high share of electrification for future fleets, the scope of this study is to evaluate the electrification potential of commercial transport in German. A particular focus is placed on the significant subset of light commercial vehicles. Based on data from national travel surveys, different vehicle fleet characteristics and economic sectors are evaluated to derivate representative electric vehicle charging and flexibility profiles.

1. Introduction

How plug-in electric vehicles (PEV) will interact with the electricity sector in the future is a topic of great research interest [1]. For the corresponding analysis, different electricity consumption and charging flexibility models exist [2, 3]. They are dependent on relevant input variables, in particular timeseries of vehicle mobility patterns, driving energy demand, grid availability, or grid power demand. The VencoPy model compensates the lack of availability of such data. The model creates customisable timeseries that may readily be used in a variety of model applications. The generated timeseries are based on mobility statistics, the physical characteristics of the vehicle fleet, and other techno-economic scenario assumptions. The tool is used for the generation of representative electric vehicle charging flexibility timeseries for passenger and commercial fleets in Germany.

2. Methodology

The VencoPy model is used to derive characteristic electricity demand and charging profiles (uncontrolled and controlled charging). VencoPy is an open-source Python-based tool [4] that calculates boundary conditions for the charging behaviour and for vehicle-to-grid (V2G) potentials based on mobility data and techno-economic assumptions. This allows for the investigation of the electricity demand increase due to the electrification of passenger and commercial road transport. Figure 1 shows a schematic representation of the model building blocks.

Based on driving profiles, technical data and assumptions about PEVs, boundaries for minimum and maximum states of charge (SoC) of the vehicle batteries are calculated. From this, temporally resolved demands for uncontrolled charging as well as load shift potentials for controlled charging can be derived for different electric vehicle fleets.

The VencoPy framework has been used in different projects [4, 5]. Among others, it was applied to the German transport survey "Mobility in Germany" to investigate the influence of electric vehicles on the future load shifting potential and its impact on the German power system [5]. The framework was applied in a case study involving two recent German national travel surveys to exemplify the implications of different mobility patterns of motorised individual vehicles on the load shifting potential of electric vehicle fleets [4]. Exemplary results of the framework include the distance travelled per hour, the connection availability, and the upper and lower limit for the batteries' SoC. Based on different decision methods, charging and discharging profiles can be calculated.

By additionally including commercial road transport from the "Motorised transport in Germany" dataset, the tool capabilites are extended to commercial fleets, and, in particular, to light-duty vehicles. A sensitivity analysis on different fleet characteristics, vehicle characteristis and commerical sectors is carried out in order to analyse how these parameters infuence the charging operation of the vehicles and how these affect the resulting load profiles.

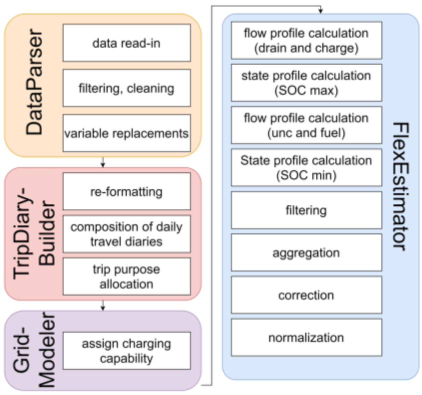


Fig. 1: VencoPy framework workflow components (adapted from [4]).

3. Results and Discussion

Growing PEV fleets can have substantial impacts on the power sector. On the one hand, they increase the electric load, on the other hand, they may also provide temporal demand-side flexibility, which can help in integrating variable renewable energy sources and thus in decarbonising the power sector. The modelling results provide representative PEV load and flexibility profiles with customisable length and resolution for passenger and commercial fleets. Such profiles provide a necessary starting point for modelling PEVs in energy systems models or aggregators in electricity market models.

4. Conclusion

Many model-based analyses to investigate potential power sector interactions of future PEV fleets depend on a realistic representation of mobility patterns of vehicle users. Yet such data are ofen not publicly available and in general empirical data are scarce. VencoPy contributes, among others, to close the gap in PEV charging models to derive relevant timeseries in a flexible way, while including comprehensive documentation, transparency and reproducibility, providing thereby explicit technical flexibility potentials for passenger and commercial fleets.

Keywords Electric vehicles; commercial fleet; charging flexibility; sector coupling.

Acknowledgement

This research is part of the project "SEDOS - The importance of sector integration in the context of the energy transition in Germany - modelling with a national open source reference energy system". It is funded by the German Federal Ministry of Economic Affairs and Climate Action (BMWK) under grant number 03EI1040D.

References

[1] International Energy Agency (2022), *Global EV Outlook 2022: Securing supplies for an electric future*, OECD Publishing, Paris, https://doi.org/10.1787/c83f815c-en
[2] Daina et al. (2017), *Modelling electric vehicles use: a survey on the methods*. Renewable and Sustainable Energy Reviews 68, 447–460, https://doi.org/10.1016/j.rser.2016.10.005
[3] Mwasilu (2014), *Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration*. Renewable and Sustainable Energy Reviews 34, 501–516, https://doi.org/10.1016/j.rser.2014.03.031
[4] Wulff et al. (2021), *Vehicle Energy Consumption in Python (VencoPy): Presenting and Demonstrating an Open Source Tool to Calculate Electric Vehicle Charging Flexibility*. Energies, MDPI. 2021; 14(14):4349. https://doi.org/10.3390/en14144349
[5] Wulff et al. (2020), *Comparing Power-System and User-Oriented Battery Electric Vehicle Charging Representation and its Impact on Energy System Modeling*. Energies, MDPI. 2020; 13(5):1093. https://doi.org/10.3390/en13051093

Unlocking Inter-day Flexibility in Electric Vehicle Charging to Support Future Grids' High Renewable Integration

Siobhan Powell[1, *]

[1]Group for Sustainability and Technology, ETH Zürich, Switzerland
*Corresponding author: spowell@ethz.ch

Abstract - Demand flexibility is of increasing importance to electricity grids to support high amounts of variable renewable energy generation. We explore the use of a simple signal to shift electric vehicle plug-in events from low to high renewable generation days to leverage inter-day flexibility in charging demand. Based on our results for the Western United states, this type of signal can achieve substantial shifts in charging demand. However, these shifts only result in reduced grid emissions when there is curtailment or excess renewable energy generation.

1. Introduction

In countries around the world, the electricity and transportation sectors are undergoing simultaneous, far-reaching transformations to reduce emissions. The two are increasingly coupled by electric vehicle (EV) charging. The grid of the future will depend less on centralized, dispatchable fossil fuel plants and more on renewable energy [1]. Most of this increase will come from wind and solar, two sources of variable renewable energy (VRE). Weather patterns mean that the amount of VRE generation fluctuates on many different timescales, each posing different challenges for the grid.

EV charging is quite flexible, and many researchers have studied the use of controlled charging to improve the grid impacts of charging by supporting grid stability, reducing costs, and increasing the integration of VRE [2]. Charging control includes both automated and behavioural changes. Most existing research implements the ideal, automated case where grid operators have direct control over charging. Real deployments of such centralized technology, however, are very rare.

The most common implementation of charging control today is instead based on electricity pricing. Time-of-use (TOU) pricing plans, for example, typically include peak, shoulder, and off-peak pricing periods, where high, medium, and low prices, respectively, encourage customers to shift their demand to better times of day for the grid. Recent research has studied the design and efficacy of these pricing plans to support VRE integration, e.g. [3]. Though other pricing options like real-time pricing (RTP) are common in simulation, deployments to real electricity customers require much simpler structures [4]. Pricing designs like TOU target hour-by-hour fluctuations in VRE. For example, low midday prices can encourage charging to coincide with peak solar generation.

Day-by-day fluctuations, however, are not targeted by existing price-based controls, despite the massive potential for inter-day flexibility in EV demand. Recent data from California has found that most EV drivers only charge every 3-4 days [5], so moving a charging event a day earlier or later would not inconvenience most drivers. In this paper we examine the use of a very simple control design to target day-by-day fluctuations in VRE generation. We design the signal with just two types of days - high vs. low VRE days - and no within-day pricing variation. We use this framework to address the following two questions:

1. How flexible is EV charging demand day-by-day?
2. How does the value of inter-day control compare between today's grid and the grid of 2035?

2. Methodology

We take the Western United States grid (WECC) as a case study and extend the model presented by Powell et al [5]. We study snapshots of the 2019 and 2035 grid. Fossil fuel generation is simulated using an open-source, reduced order economic dispatch model. The model depends on baseline data from 2019. Generation in 2035 from solar and wind is increased to 3.5x and 3x 2019 levels and we implement announced additions and retirements of fossil fuel units. We calculate a signal which encourages charging on days when renewable generation is above average for the week, and discourages charging on days when it is below average. We use a graphical modeling framework to represent charging demand, where EV drivers are clustered by their past behaviour based on a large dataset of charging from Northern California. We extend the charging model to link subsequent days and track individual vehicles throughout the year. An average charging event frequency is defined for each vehicle from the data. We assume high access to home charging infrastructure based on recent survey data, parameterized on drivers' income and type of housing. In the uncontrolled case, charging occurs on arrival. In the controlled case, on high or low renewable days we increase or decrease the probability with which drivers choose to plug-in by a factor of eta. Once the number of days since the last session reaches the average interval, we assume the driver chooses to plug-in regardless of the grid signal. We focus on a case where 50% of light-duty vehicles are EVs.

3. Results and Discussion

We find this simple control scheme, encouraging drivers to delay charging on days with low renewable generation, can substantially change the timing of EV demand. Fig. 1 shows this effect for a sample week from January 2019. Despite this shift, however, early results do not show a substantial change in grid emissions for periods like January where, even with higher levels of renewable deployment in 2035, there is no curtailment or oversupply of renewables.

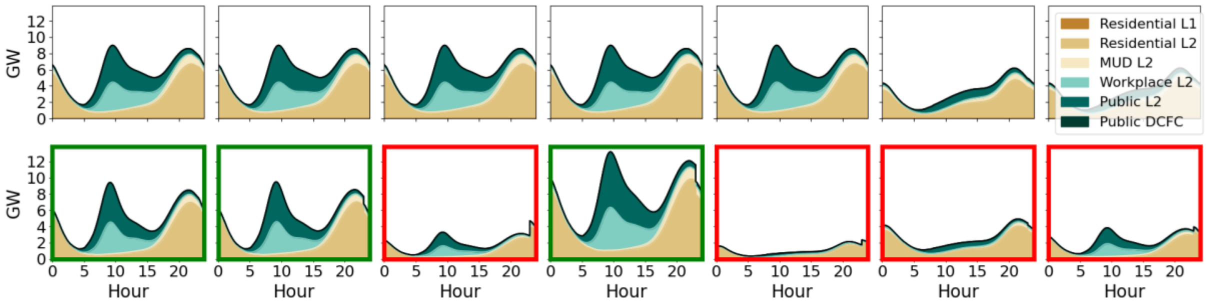


Fig. 1: Charging load profiles for the second week of January, 2019. Row 1 shows uncontrolled weekday and weekend demand. In row 2, the box colour indicating whether it was a high or low renewables day, we see variation in the charging demand and considerably less consumption on low renewable days. Eta=2.

4. Conclusion

In summary, early results show that there is substantial inter-day flexibility in charging, and a simple good vs. bad day signal can unlock meaningful shifts in demand. However, these shifts are most valuable for reducing grid charging emissions only when there is oversupply of renewables. Otherwise, the increase in demand on high renewable days is met in part by other emitting sources.

Keywords: charging; renewable integration; control; rate design.

Acknowledgement

The author thanks Profs. Ram Rajagopal and Inês Azevedo for their support in developing the model. The author acknowledges funding from the SFOE SWEET PATHFNDR project.

References

[1] California Energy Commission, Developing Renewable Energy, State of California, 2023, https://www.energy.ca.gov/about/core-responsibility-fact-sheets/developing-renewable-energy.

[2] Anwar, M.B., Muratori, M., Jadun, P., Hale, E., Bush, B., Denholm, P., Ma, O. and Podkaminer, K., Assessing the value of electric vehicle managed charging: a review of methodologies and results, Energy & Environmental Science, 2022.

[3] Li, X., Jenn, A., Energy, emissions, and cost impacts of charging price strategies for electric vehicles, Environmental Science & Technology, 56, 9, 5724-5733.

[4] Jacobsen, G.D., Stewart, J.I., How do consumers respond to price complexity? Experimental evidence from the power sector, Journal of Environmental Economics and Management, 116, 2022, 102716.

[5] Powell, S., Cezar, G.V., Min, L., Azevedo, I., Rajagopal, R., Charging infrastructure access and operation to reduce the grid impacts of deep electric vehicle adoption, Nature Energy, 7, 10, 2022, 932-945.

Examining EV Drivers' Willingness to Share Personal Information in the Context of Smart Charging: Results of a Five-Month EV Field Trail

Susen Döbelt[1], Madlen Günther[2]*, Bettina Kämpfe[2] and Josef F. Krems[2]

[1]Cognitive Psychology and Human Factors, Chemnitz University of Technology, Germany
[2]Cognitive & Engineering Psychology, Chemnitz University of Technology, Germany
*Corresponding author: madlen.guenther@psychologie.tu-chemnitz.de

1. Introduction

Electric vehicles (EVs) are a promising mobility solution to reduce emissions in the transport sector. However, as EV emissions are still highly dependent on the renewable energy ratio in the electricity grid, a solution should be found that efficiently uses these existing renewables. Smart charging is one approach here. In addition, smart charging contributes to balance the grid in times of energy overload or shortage and promises benefits for different actors. For instance, EV drivers may hope to save money when providing an energy flexibility, suppliers aim at a reduction of operational costs, and operators of the transmission system are interested in a flexible demand side to integrate the growing amount of renewable energy sources [1]. However, this concept requires detailed settings of the EV drivers' consumption demand and the capture of consumption data. By means of a smart data processing, precise indicators of activity patterns arise from energy usage in general and charging information in particular. This provokes a conflict between the usage of sustainable, smart appliances and the protection of individuals' privacy. Thus, privacy concerns may be an obstacle to participate in smart charging [2]. Prior online questionnaire studies indicated differences in the willingness to provide smart charging data of different information levels and consumers reject information provision including threat potential deduced from this data [3]. Accordingly, as research in the smart home context showed [4], the recipient of the data is important to customers. In addition, it has been shown that experience under real world conditions has a significant influence on acceptance [5]. Hence, the objective of the present study was to investigate EV drivers' willingness to share personal information and preferred recipients in the context of smart charging. Further, we examined the influence of real smart charging experience on EV drivers` privacy concerns and their willingness to share personal information.

2. Methodology

The field trail has been conducted in Berlin, Germany and contained two five-month phases. A smart charging station was installed at the participants` home and an electric vehicle (BMW ActiveE) was provided to the participants. Participants' settings (e.g., time of departure, state of charge at the time of departure, safety buffer loaded immediately after plugging in the EV) could be entered via a smartphone application. Furthermore, this smart charging app provided user feedback (e.g., on the amount of charged energy in kWh, the vehicles actual state of charge in %, the financial compensation in € for using the 'smart charging mode'). Smart charging was remunerated during nighttime between 8 pm and 8 am.

Participants have been recruited via newsletter and website announcements of the project partners. Interested participants could apply for the field trial via an online questionnaire and were selected with regard to structural conditions, which allow for the installation of the smart charging system. $N = 20$ participants took part including 18 men and 2 woman. They were on average 48 years old ($SD = 7.94, Min = 31, Max = 60$) and were 'well educated': the majority (70%) holds a university degree.

The field trial started with a baseline of three to ten weeks, were participants should get familiar with the EV and the charging in general. Therefore, the smart charging mode was disabled. Afterwards, the trial period with the enabled smart charging mode started and participants were interviewed after 7 up to 11 weeks (T1) and at the end of the field trail after 21 weeks (T2). Among other things, participants were asked to indicate their willingness to provide smart charging information categorized into three information levels (level 1 - raw data, level 2 - processed long-term data, and level 3 - deduced information) on a 4-point scale (ranging from 1 = *never willing to provide* to 4 = *always willing to provide*). The participants could chose, to whom of the four different data recipients *('aggregator', 'energy supplier', 'grid operator', 'vehicle manufacturer'*), to *'none'*, to *'all four stakeholders'*, or to *'all four stakeholders and third parties'*, they would pass the presented information.

3. Results and Discussion

The results on participants' willingness to provide data showed significant differences between the three data levels ($\chi^2(2) = 30.405$; $p < .000$). Participants were most unwilling to provide level 3-information ($M_{T1} = 1.83$; $SD = .567$) compared to level 2-information ($M_{T1} = 2.79$; $SD = .802$) and level 1- information ($M_{T1} = 2.76$; $SD = .755$). Most unwilling were participants to provide the information: *"if my household is unattended, when I leave it"* ($M_{T1} = 1.15$;

SD = .489*), "what I earn"* (M_{T1} = 1.20, *SD* = .401*)/"who is part of my social network"* (M_{T1} = 1.20; *SD* = .401), and *"that I`m not at home"* (M_{T1} = 1.35; *SD* = .587).

At T1, the majority of participants (64%) chose *"none of the actors",* followed by 22% *"to all 4 actors"* and 13% *"one of the actors"* as preferred recipients to pass level 3 information. If they were willing to pass the information to one of the presented recipients, they chose most often (15%) the aggregator. However, most often the field trial participants chose *"all of the four presented stakeholders"* (42%) to whom they are willing to pass level 1 and 2 information.

To examine the influence of real world smart charging experience on participants` privacy concerns and their willingness to share personal information we compared T1 and T2. However, the overall pattern in terms of serious concerns about deduced information remained stable, the willingness to pass the information to all four possible recipients increased.

4. Conclusion

The strong rejection of sharing level 3 information shows that users recognise a long-term risk potential in the context of smart charging. In order to reduce possible obstacles, we argue that the initial decision for privacy prevention should be anchored top-down from system designers at the beginning of a system design; e.g., by considering *Privacy by Design guidelines*. Subsequently and bottom-up, users can clarify to what extent they want to be informed or control data. Nevertheless, our results also show that (positive) real world experience is an essential factor in increasing the willingness to share personal information and taking part in smart charging.

Keywords: privacy concerns; preferred data recipients; user research; smart charging experience

Acknowledgement

This study was part of the research project "FLOW" funded by the European Union and part of "Gesteuertes Laden V3.0" funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

References

[1] McKenna, E., Richardson, I., & Thomson, M., Smart meter data: Balancing consumer privacy concerns with legitimate applications, Energy Policy, 41, 2012, 807-814.

[2] Kämpfe, B., Zimmermann, J., Dreisbusch, M., Grimm, A. L., Schumann, J. H., Naujoks, F., Keinath, A., & Krems, J.F., Preferences and perceptions of bidirectional charging from a customer's perspective–a literature review and qualitative approach. Electrified Mobility 2019: Including Grid Integration of Electric Mobility, 2022, 177-191.

[3] Döbelt, S., Kämpfe, B. & Krems, J.F., Smart Grid, Smart Charging, Smart Privacy? An Empirical Investigation of Consumers' Willingness to Provide Smart Charging Information, Tagungsband ComForEn 2014, 2014, 29-37.

[4] Yang, H., Lee, H., & Zo, H., User acceptance of smart home services: an extension of the theory of planned behavior. Industrial Management & Data Systems 117(1), 2017, 68-89.

[5] Schmalfuß, F., Mair, C., Döbelt, S., Kämpfe, B., Wüstemann, R., Krems, J. F., & Keinath, A., User responses to a smart charging system in Germany: Battery electric vehicle driver motivation, attitudes and acceptance. Energy Research & Social Science, 9, 2015, 60-71.

Controlled Inductive Charging of Electric Cars has the Potential to Increase the Flexibility and Stability of the Energy System in Germany

Moritz Bergfeld[1], Carsten Hoyer-Klick[2], John Anderson[1], Christine Eisenmann

[1]Institute of Transportation Research, German Aerospace Center, Berlin, Germany
[2]Institute of Networked Energy Systems, German Aerospace Center, Berlin, Germany
*Corresponding author: Moritz.Bergfeld@dlr.de

1. Introduction

The uptake of electric vehicles (EVs) presents challenges to the electricity system. One of the biggest challenges is avoiding too much stress on the energy system from too many simultaneous charging EVs. Since the parking time of most vehicles is much longer than the charging time, smart charging can help shift the charging process within the parking time in order to avoid too many vehicles charging at the same time. However, the frequency EVs are connected to a charging point can also influence the simultaneity in which charging is required. The more frequently EVs are connected to a charging point, the lower is the demand of energy that is needed during that charging process and therefore the peak power of charging demand decreases. Inductive charging can allow EVs to connect to the grid when they are parked without being manually connected by the user. It can therefore be expected that induction charging can lead to higher connection rates of parked EVs, as it might be too cumbersome for users of cable connected EVs to connect their EVs if the battery still has sufficient charge. Therefore, the inductive charging technology can allow EVs connection to the grid whenever an EV is parked on an appropriate parking place. These EVs can be charged with lower power over longer times and may even the distribution of charging demand and therefore ease the power supply. With this contribution we want to analyse the effects on different charging technologies - cable connected charging and inductive charging - on the energy network. Our analysis focusses on the trade-off between cable connected EVs with low connection rates but higher charging demands and inductive charging EVs which are charged more frequent, with lower charging power but also higher charging losses due to the magnetic transmission of the power.

2. Methodology

We have developed a set of models to investigate future charging scenarios. For this analysis, a model coupling between the energy optimization model (REMix) and the charging demand model (CURRENT) is used, which was first described in [1]. The CURRENT model enables a microscopic view of the charging demand in Germany based on individual passenger car driving patterns over the course of one week. The charging decision is modeled with a utility function, which is based on real world data [2]. Among other things, the electricity price calculated by REMix is an important decision criterion. REMix models the energy system in hourly resolution based on hourly weather data. In addition, it can optimize the controlled charging processes based on the outputs of CURRENT. In order to run the models with inductive charging infrastructure, an adjustment of different model parameters is needed, foremost the connection frequency of EVs and the charging efficiency.

The four different scenarios are shown in Table 1. In the *reference* scenario, inductive charging will not become a mass market and is therefore not an option. In the *home* scenario, inductive charging is especially of interest for home owners with a private parking place as part of their smart home. In the *service* scenario, inductive charging is used as a marketing tool and develops as a service for employees and customers. Charging power is reduced in this scenario due to material usage and energy costs. The *private* scenario, is a combination of the *home* and *service* scenarios. Private parking places at home and at work are equipped with inductive charging technology, since parking time almost always exceeds charging time.

Table 1 : Scenarios for inductive charging

Name	Inductive charging power	Inductive charging availability
ref.	-	No inductive charging
home	normal	Home (private)
service	slow	Shopping and work (private)
private	slow	Home (private) and work (private)

3. Results and Discussion

In this section the model results are compared and analysed. For transport research, the charging behaviour of EVs is of particular interest. Therefore, the charging processes during the week and the state of charge of the EV fleets battery is analysed. Furthermore, the analysis of the occupied charging infrastructure can provide information about how many charging points might be needed in the different scenarios. In terms of the electricity system the flexibility provided by controlled charging is of interest and flexible charging can reduce peak power and stationary storage demand. This information can be used to analyse the electricity mix and compare electricity prices, which is interesting from an economic perspective.

4. Conclusion

The model runs performed have shown that widespread inductive charging has an impact on the flexibility of the electricity system. Therefore, promoting this technology can lead to lower investments in the electricity system and a better utilization of renewable energies. In return, however, the costs for charging infrastructure and energy losses during the charging process would increase. It can reduce renewable power curtailment, the demand in stationary storage and grid extension in transport and distribution grids. In this study the focus was on controlled charging. In the future new technologies like bidirectional charging might enter the mass market. Especially for bidirectional charging, the connection frequency plays a major role. Therefore, the combination of inductive and bidirectional charging could be of particular interest and should be investigated once both technologies are implemented in the model system. In addition, user acceptance and willingness to pay for inductive charging should be investigated in the future and included in the model system.

Keywords Electric vehicles; charging demand; controlled charging; sector coupling, inductive charging

Acknowledgement

This research was funded by the German Aerospace Center in the project DATAMOST (Data and Model-based Solutions for the Transformation of Mobility). The assumptions made regarding composition of the fleet and technical vehicle parameters for the scenario year are based on forecasts from the BEniVer project.

References

[1] Niklas Wulff, Felix Steck, Hans C. Gils, Carsten Hoyer-Klick, Bent van den Adel, and John E. Anderson. 2020. Comparing Power-System and User-Oriented Battery Electric Vehicle Charging Representation and Its Implications on Energy System Modeling. *Energies* 13, 5, 1093. DOI: https://doi.org/10.3390/en13051093.

[2] John E. Anderson, Moritz Bergfeld, Do M. Nguyen, and Felix Steck. 2022. Real-world charging behavior and preferences of electric vehicles users in Germany. *International Journal of Sustainable Transportation*, 1–15. DOI: https://doi.org/10.1080/15568318.2022.2147041.

Modelling-based approach to design a PID controller in electric powertrains

Someshwar Chandrakumar, Temple Agodike, Inderbir Singh, Nitish Konathala, Prabhakar Lalit Penmesta, Pritikesh Bandodkar, Ahmed Rezk*, Yu Jia and Jose Sodre

Department of Mechanical, Biomedical and Design Engineering College of Engineering and Physical Science, Aston University, Birmingham, B4 7ET, UK

Abstract – electrified powertrain is the most promising avenue towards road decarbonisation. PID speed controller is, accordingly, a crucial element of the electric powertrain to meet the demand for vehicle speed for autonomous and human-crewed vehicles. This abstract presents the fundamental operation and modelling of the speed control system using a PID speed controller integrated into a simplified powertrain of F24+ GreenPower Go-cart and employing the NEDC driving cycle. Furthermore, the data obtained is used for controlling the Arduino microcontroller-hardware interface.

1. Introduction

Climate change profoundly impacts people globally in various ways. The increasing vehicle emissions have been proven to directly influence global warming, as the last decade was recorded as the warmest. Moving towards the electric vehicle seems a potential option to reduce emissions impact on the environment. In this study, the NEDC driving cycle was employed to represent the operation of electric vehicles in Europe. NEDC test sequence comprises two parts: urban and extra-urban driving cycle, as shown in Tables 1-2. In this, the PID speed controller integrated into the EV powertrain fitted to the chassis of a commercial F24 go-cart obtained from Greenpower UK was designed and implemented. A Speed controller is a feedback circuit that controls and regulates the speed in an optimum state of an electric motor. An adjustable speed controller also helps with controlled starting current, controlled acceleration, lower power demand on start, and controlled stop. These factors help preserve energy and protect the battery and motor from damage and breakage.

Table 1: Data of urban driving cycle

Average speed (km/h)	18.77
Working time (s)	195
Working time for four cycles	780
Distance(m)	1017
Distance for four cycles(m)	4067

Table 2: Data of extra-urban driving cycle

Average speed (km/h)	62.60
Working time (s)	400
Distance(m)	6956

2. Methodology

A component-based model employing Ricardo Ignite™ software was designed initially to evaluate the physical component matching in a virtual interface. The PID model was then designed. The model has a PID limiter, which obtains one input from the lookup table where the driving cycle data was imported. The feedback on the PID correction will be received from the vehicle speed sensor. In this case study, the PID controller utilised two limiters: the motor speed/power demand and the brake demand. This is to control the powertrain's performance according to the driving cycle.

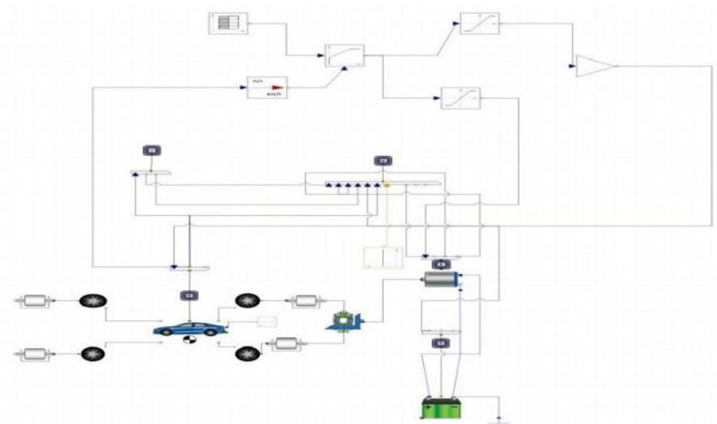


Figure1. Block diagram of electric powertrain integrated with PID.

3. Results and Discussions

After the simulations of the model by considering all the multi-physics concepts needed for the mobility of a powertrain. The optimum motor's speed/power and battery's state of charge were obtained to match the demand by driving cycle and load. It is subsequently providing a larger driving range. The initial parametric study showed the vehicle's range in Figure 2, fulfilling the desired demand. To physically operate the powertrain of the F24 go-cart, the proportional, integral and differential values obtained from the virtual interface are employed in a 4QD board operating Arduino microcontroller interface, as shown in Figure 3.

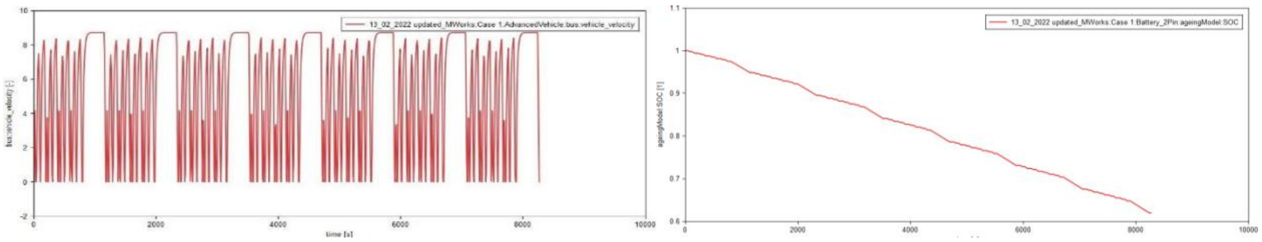


Figure 2. State of charge of vehicle and velocity.

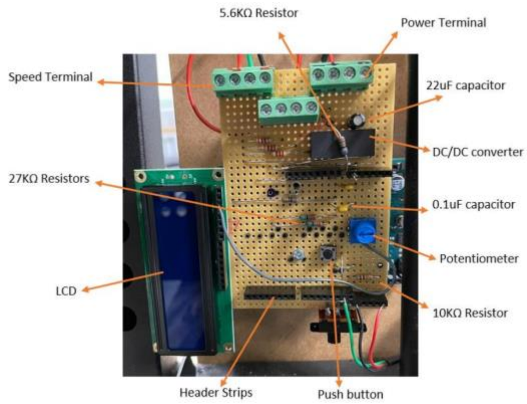


Figure 3. 4QD controller.

4. Conclusion

The speed controller is vital in autonomous and human-crewed cars. The abstract showed a procedure to design and match the PID controller employed into a simplified power train in F24+ GreenPower Go-cart according to a predefined driving cycle, NEDC.

References

[1] Requia, Weeberb J, Mohamed, M., Higgins, C.D., Arain, A. and Ferguson, M. (2018). How Clean Are Electric vehicles? Evidence based Review of the Effects of Electric Mobility on Air pollutants, Greenhouse Gas Emissions and Human Health. Atmospheric environment, [online] 185, pp.64–77. doi: https://doi.org/10.1016/j.atmosenv.2018.04.040.

[2] UNECE Regulation No. 101. Concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be _tted and/or be used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these Prescriptions

Analysis of Axial-Field Flux-Reversal Permanent-Magnet Magnetic-Differential Motors Using Different Iron Materials

Tengbo Yang[1], K. T. Chau[1*], Yao Tang[1], and Zhiwei Xue[1]

[1]Department of Electrical and Electronic Engineering, The University of Hong Kong, Hong Kong, China
*Corresponding author: ktchau@eee.hku.hk

Abstract – This paper analyses the axial-field (AF) flux-reversal permanent-magnet (FRPM) motor using different iron materials for magnetic differential (MagD) application. This AF-FRPM-MagD motor is particularly useful for electric vehicles desiring reliable electronic differential action. Due to the AF structure, the stator and two rotors need to be radially cylindrical laminated to effectively prevent the eddy current if using the laminated silicon steel sheet (LSSS). The soft magnet composite (SMC) material can be an alternative to reduce the structural risk originating from the large axial force between the stator and rotors. However, the SMC material has lower permeability than the LSSS material. Thus, this paper optimizes and evaluates the performances of the proposed motor when using these two different iron materials based on three-dimensional finite element analysis. Finally, a prototype is fabricated to validate the theoretical analysis and simulation.

1. Introduction

As one of the promising solutions to reduce the onboard weight of electric vehicles, the magnetic-differential (MagD) system shows the merits of compactness and robustness. By simply installing a set of magnetic coupling (MC) windings, the MagD motor can realize reliable electronic differential action without adding much copper loss and eliminate the bulky traditional mechanical differential gearbox. Due to the structural diversity of the stator permanent magnet (PM) motor, a thorough comparison of three motor candidates for the MagD system has been presented in [1]. Compared with the flux-switching PM (FSPM) motor, the flux-reversal PM (FRPM) motor can overcome the interaction force on its two rotors when applied to the MagD system. Therefore, the FRPM motor has been selected for further investigation. However, unlike the radial-field (RF) motors, the lamination direction of the AF motors should be radially cylindrical. As to the fabrication, it is made by a whole piece of steel sheet, rolled and glued together like a scroll, and then engraved. And the large axial forces between the stator and rotors risk the steady operation of the AF motors. Apart from the tendency for the stator and rotors to collide and the machine noise mentioned in [2], such axial force may even lead to rotor deformation, especially for the AF-FRPM-MagD motor to be manufactured, since its rotors are relatively thin regarding the motor diameter. On the other hand, the soft magnet composite (SMC) material takes the advantages of low manufacturing cost, isotropic magnetic properties, and low eddy-current loss [3], and an AF-FSPM-MagD motor has been successfully made of SMC parts [4]. However, the SMC material inevitably suffers from low permeability and high hysteresis loss [3], which can hurt the motor output.

2. Methodology

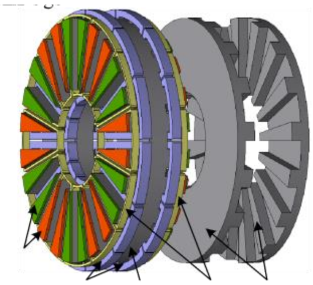
The proposed AF-FRPM-MagD motor is shown in Fig. 1(a). It takes on 12/16 stator teeth/rotor poles combination. Based on the three-dimensional finite element analysis (3D FEA), this paper analyses such motor with the same sizing constraints, i.e., 220 mm of motor outer diameter and 90 mm of motor stack length, using the laminated silicon steel sheet (LSSS) and SMC materials. After the optimization, which aims at high torque and low torque ripple, the motor performances are simulated to provide a comparison between different iron materials. Lastly, given the simulation results and consideration of the manufacturing feasibility, a motor prototype is fabricated to conduct physical experiments to validate the theoretical analysis and simulations.

3. Results and Discussion

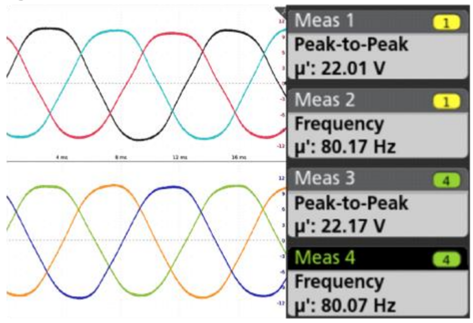
The motor performances based on three types of stator-rotor iron material combinations are shown in Table 1. These three motors have the same rotor speed of 900 rpm, the armature current density of 6 A/mm^2, and the ideal filling factor of 0.6. Due to the high permeability of the LSSS material, the motor taking on an all-LSSS material combination shows the best performance when it is correctly laminated. However, given the fact that the LSSS material is not mechanically strong for two thin rotors, it has to be changed to SMC material to prevent rotor deformation. As one can see, the AF-FRPM-MagD motor with LSSS stator and SMC rotors shows comparable performance with the all-LSSS one and is better than the one with all-SMC parts. The experimental results under the rotor speed of 300 rpm and a filling factor of 0.5 are depicted in Fig. 1(b). As one can see, the peak-to-peak values of the no-load back-EMFs on the left and right rotors are 22.2 and 22.0 V, respectively. And in the simulation, those two values are 22.3 and 22.4 V. The experimental results match well with the simulation results.

Table 1: Motor performances with different iron material combinations

Performances	Stator - LSSS Rotor - LSSS	Stator - LSSS Rotor - SMC	Stator - SMC Rotor - SMC
Peak-to-peak no-load back-EMF (V)	98.9	92.0	83.2
Total torque (Nm)	27.7	26.7	24.2
Torque ripple	6.7 %	7.0 %	8.0 %
Efficiency	88.2 %	87.9 %	87.1 %



(a)



(b)

Fig. 1: (a) Topology of the proposed FRPM MagD motor. (b) Experimental No-load back-EMF waveforms.

4. Conclusion

This paper has analysed and optimised the AF-FRPM-MagD motor using different iron materials. The motor performances have been well supported by theoretical simulations, and verified by experimentation. The novel combination of LSSS and SMC materials into one motor can not only prevent rotor deformation but also maintain good motor performance, which also provides an invaluable guidance for the fabrication of other AF single-stator double-rotor motors.

Keywords: flux reversal; variable flux; magnetic differential; steel sheet; soft magnet composite.

Acknowledgement

This work was supported by a grant (Project No. 17204021) from the Hong Kong Research Grants Council, Hong Kong Special Administrative Region, China.

References

[1] T. Yang, K. T. Chau, W. Liu, T. W. Ching, and L. Cao, Comparative analysis and design of double-rotor stator-permanent-magnet motors with magnetic-differential application for electric vehicles, World Electric Vehicle Journal, Vol. 13, No. 11, 2022, pp. 199.

[2] Q. Wang, F. Zhao and K. Yang, Analysis and optimization of the axial electromagnetic force for an axial-flux permanent magnet vernier machine, IEEE Trans. Magnetics, Vol. 57, No. 2, 2021, pp. 1-5.

[3] C. Liu, J. Zhu, Y. Wang, G. Lei, and Y. Guo, Design considerations of PM transverse flux machines with soft magnetic composite cores, IEEE Trans. Applied Superconductivity, Vol. 26, No. 4, 2016, pp. 1-5.

[4] L. Cao, K. T. Chau, C. H. T. Lee, and H. Wang, A double-rotor flux-switching permanent-magnet motor for electric vehicles with magnetic differential, IEEE Trans. Industrial Electronics, Vol. 68, No. 2, 2021, pp. 1004-1015.

Multiple-Frequency Simultaneous Wireless Power Transmission for In-Vehicle Applications

Hongliang Pang[1], K. T. Chau[1*], Tengbo Yang[1], and Songtao Li[1]

[1]Department of Electrical and Electronic Engineering, The University of Hong Kong, Hong Kong, China
*Corresponding author: ktchau@eee.hku.hk

Abstract – In this paper, a dual-frequency simultaneous wireless power transmission (WPT) system is implemented without any additional inductive devices. Specifically, all the transmitting coils are adopted as inductive elements in high-order dual-frequency compensation topology, thus saving extra space and cost. Meanwhile, in the proposed system, higher harmonics can be utilized to transmit power wirelessly. In addition, the power distribution between dual frequencies can be arbitrarily adjusted according to the requirement of users on board by adopting the proposed harmonic synthesis method. Theoretical analysis and verification are both given to verify the effectiveness of the proposed WPT system.

1. Introduction

Along with the popularity of electric vehicles and the penetration of smart devices, wireless power transmission (WPT) for in-vehicle applications occurs as a unique power-supply solution [1]. However, various standards of different alliances cause troubles on this technique. Hence, multi-frequency simultaneous transmission with the simplest implementation and the lowest cost becomes a critical technical concern [2]. Wherein, most methods transmit the power by the time division approach, which fails to concurrently and simultaneously transmit multiple frequency power [3]. In [4], the multi- frequency power is transmitted simultaneously with high-order compensation, which consumes additional space and costs by utilizing extra inductors. In this paper, in order to solve the aforementioned issues, both full transmitting coil dual-frequency compensation topology and harmonic synthesis method are adopted to wirelessly transmit dual-frequency power simultaneously.

2. Methodology

Fig. 1 (a) depicts the schematic of the proposed WPT system, in which *L1* and *L2* are used as both transmitting coils and inductive elements in the dual-frequency compensation topology. Wherein, *L1* transmits the fundamental frequency of the generated square waveforms and *L2* transmits the third harmonics. Based on the parameter design procedure, *L1* and *L2* can be regulated as the same size with the same value. Meanwhile, the dual-frequency compensation topology can hold two resonant frequencies. Hence, two in-vehicle wireless charging areas with dual-frequency simultaneous transmission can be realized. Besides, the harmonic synthesis method is adopted, namely, a modulated pulse-width modulation (PWM) excitation that consists of the corresponding dual-frequency component with different voltage values is utilized. Wherein, the ratio of the voltage depends on the users' power demand.

3. Results and Discussion

Two cases are conducted to verify the feasibility of the proposed dual-frequency simultaneous WPT system. In case one, as shown in Fig. 1 (b) and (d), the fundamental and third-order harmonics of the square waveforms are utilized to transmit the power simultaneously. The corresponding RMS voltage values and efficiency received by the pickup 1 and pickup 2 are 18.1 V (31.9 W), 17.3 V (2.8 W) and 90.4%, respectively. Similarly, in case two, as shown in Fig. 1 (c) and (e), the modulated PWM excitation is adopted, wherein, both fundamental and third-order harmonics are utilized to transmit the power simultaneously. The corresponding RMS voltage values and efficiency received by the pickup 1 and pickup 2 are 19.7 V (31.7 W), 53.8 V (27.9 W) and 75.6%, respectively. Besides, the voltage curve of pickup 1 holds some distortions, which is owing to the reflected impedance under the operating frequency of the third-order harmonics. Finally, the verification results validate the feasibility of the proposed dual-frequency simultaneous WPT system.

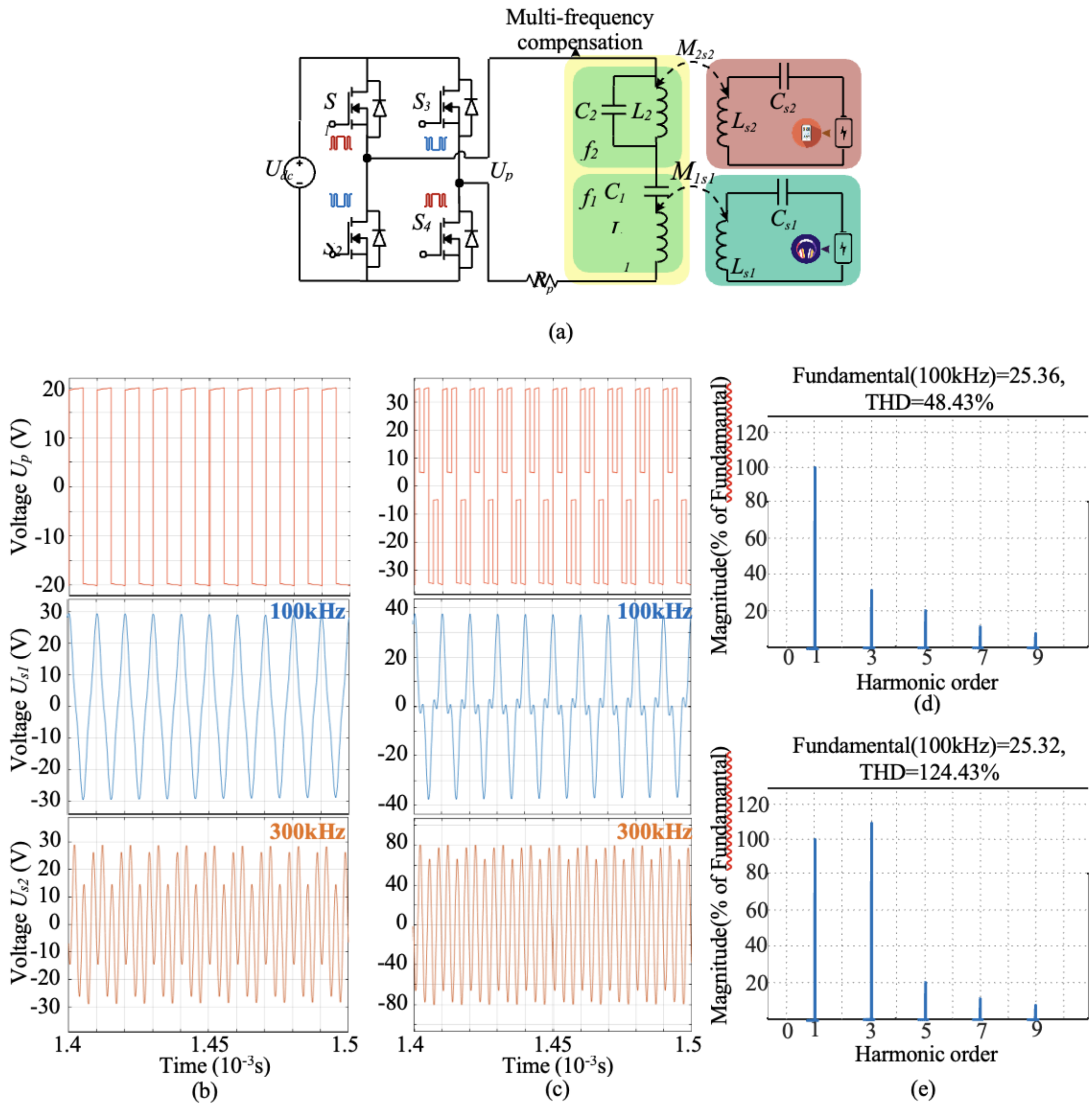


Fig. 1 Schematic of the proposed dual-frequency simultaneous WPT system. (a) System configuration. (b) Voltage waveforms of primary circuit, pickup 1, and pickup 2 under case one. (c) Voltage waveforms of primary circuit, pickup 1, and pickup 2 under case two. (d) FFT analysis of primary voltage under case one. (e) FFT analysis of primary voltage under case two.

Keywords: Wireless power transfer; multiple-frequency; compensation topology; simultaneous transmission.

Acknowledgement

This work was supported by a grant (Project No. T23-701/20-R) from the Hong Kong Research Grants Council, Hong Kong Special Administrative Region, China.

References

[1] S. Li, S. Lu, and C. C. Mi, “Revolution of electric vehicle charging technologies accelerated by wide bandgap devices,” Proc. IEEE, vol. 109, no. 6, pp. 985-1003, Jun. 2021.

[2] W. Liu, K. T. Chau, C. H. T. Lee, C. Jiang, W. Han, and W. H. Lam, “Multi-frequency multi-power one-to-many wireless power transfer system,” IEEE Trans. Magn., vol. 55, no. 7, pp. 8001609: 1-9, Jul. 2019.

[3] Y. Zhang, T. Lu, Z. Zhao, F. He, K. Chen, and L. Yuan, “selective wireless power transfer to multiple loads using receivers of different resonant frequencies, IEEE Trans. Power Electron., vol. 30, no. 11, pp. 6001- 6005, Nov. 2015.

[4] H. Pang, K. T. Chau, W. Han, W. Liu, and Z. Zhang, “Decoupled-double D coils based dual-resonating-frequency compensation topology for wireless power transfer,” IEEE Trans. Magn., vol. 58, no. 2, pp. 8000407: 1-7, Feb. 2022.

Feasibility study on Design and Implementation of Electric Motor

Jowyl Fernandes, Ahmed Rezk* and Jose Sodre

Future Vehicle Technologies, Aston University, Birmingham, B4 7ET, UK First
*Corresponding author: a.rezk@aston.ac.uk

1. Introduction.

Countless researchers in the automobile industry investigate low-cost electric powertrain solutions for cleaner and greener vehicles. Robert Anderson, who developed the first electric vehicle (EV) prototype in 1932, never would have anticipated the widespread of electric vehicles nowadays. The Electric Drive or Electric Motor is the heart of an EV powertrain. Its design considers various contingencies like operating environment, terrain, and infrastructure and, not to forget the end user requirement. In this abstract, the light will be shed on the Multiphysics modelling of the system of the EV and the sub-system of the motor.

2. Methodology.

To understand the implications of a drive cycle on an Electric drive in a powertrain, a 0D powertrain model utilising Ricardo Ignite™ computational tool was developed. An open loop circuit attached to the motor helps understand the variation of motor temperature with the power and torque output to match the drive cycle. The target market was Japan, and employing the Japanese 10-15 mode drive cycle was chosen. The input of climatic conditions like pressure temperature and wind density in Ricardo Ignite helped simulate a realistic environment, thereby giving fantastic results.

3. Results and Discussion.

An equivalent Multiphysics model of an automobile propelled by an electric powertrain is developed on Ricardo ignite and shown in fig 1. The circuit beneath the motor and battery denotes the open loop circuit to collect data on the motor temperature. The temperature readings picked up by the thermal circuit are plotted on a graph against the drive cycle and motor speed. This helps us perform a thermal analysis on the motor. It was noted that the temperature is within permissible limits.

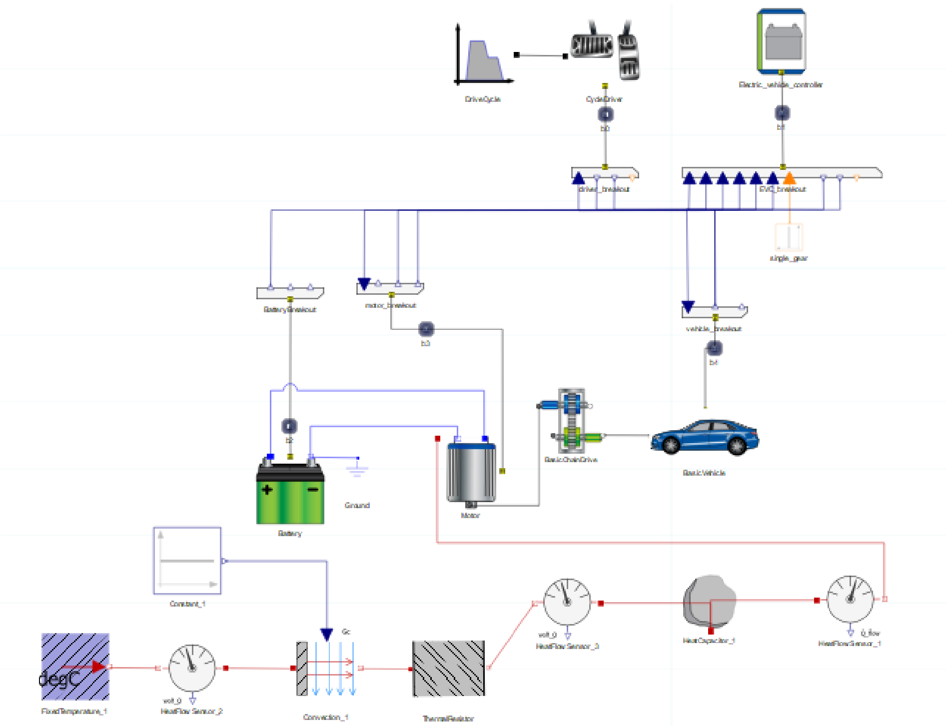


Fig. 1: Multiphysics Model as constructed on Ricardo Ignite.

The advantage of performing a thermal analysis using a Multiphysics modelling system is that it helps us realistically determine the motor's suitability for the end user requirements. In the investigated case, within limits saves us time and money that would otherwise go into developing solutions for cooling or choosing another motor and starting over.

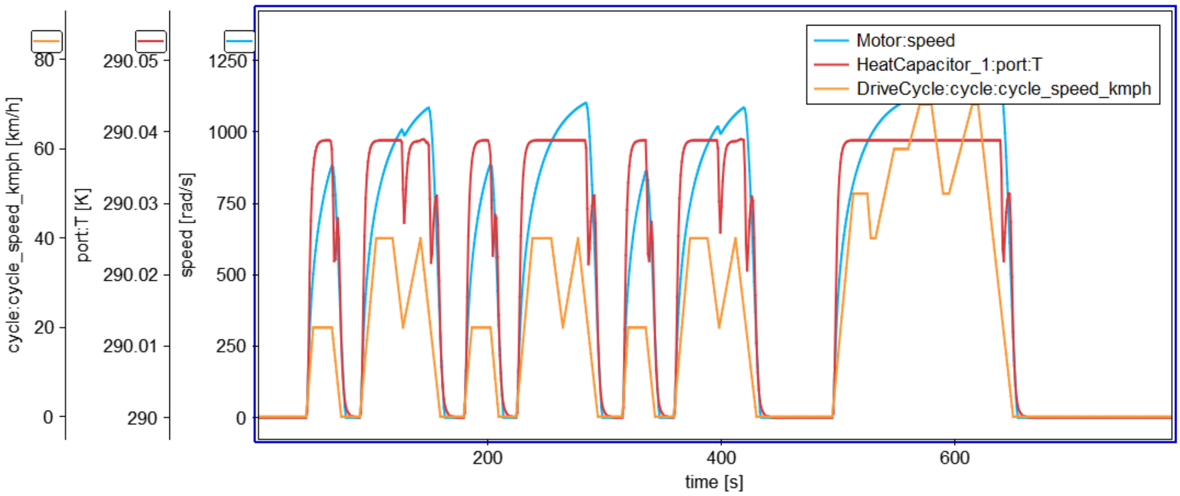


Fig 2: Thermal analysis of motor, temperature variance with motor speed and drive cycle speed.

4. Conclusion.

The motor is one of the critical components in the Electric powertrain. The results obtained from the Thermal analysis of the motor are satisfactory and give an idea of how the motor's temperature varies with the Motor speed and hence the Driving cycle speed. In simple terms, the motor can match the desired powertrain while withstanding the market's operating temperature.

Keywords. Electric Motor, Thermal analysis, PM BLDC motor, Ricardo Ignite, Drive cycle, 10-15 mode, Multiphysics modelling.

References.

[1] www.meti.go.jp. (n.d.). Japan's Roadmap to 'Beyond-Zero' Carbon. [online] Available at: https://www.meti.go.jp/english/policy/energy_environment/global_warming/roadmap/

[2] dieselnet.com. (n.d.). Emission Test Cycles: Japanese 10-15 Mode. [online] Available at: https://dieselnet.com/standards/cycles/jp_10-15mode.php.

[3] Optimising EV Traction Motor Performance from Concept Phase, Considering New Drive Cycles. [online] Available at: https://www.altair.com/newsroom/articles/Optimizing-EV-Traction-Motor-Performance-from-Concept-Phase-Considering-New-Drive-Cycles

[4] Porselv, T. and Student (2017). Selection of Power Rating of an Electric Motor for Electric Vehicles. [online] International Journal of Engineering Science and Computing. Available at: https://ijesc.org/upload/b79d326cd131af0568540ae045c6c49a.Selection%20of%20Power%20Rating%20of%20an%20Electric%20Motor%20for%20Electric%20Vehicles.pdf

[5] en.sekorm.com. (n.d.). PM90-150 / PM90-180 / RE90-146 (rare earth) permanent magnet DC motor. [online] Available at: https://en.sekorm.com/doc/1003046.html

Feedback Linearization Controller Design for Solid Oxide Fuel Cells

Donggil Kim[1], Jaehoon Kim[2], Jisoo Kim[2] And Dongik Lee[2*]

[1]Kyungil University, South Korea
[2] Kyungpook National University, South Korea
*Corresponding author: dilee@ee.knu.ac.kr

Abstract – Electric vehicles have attracted the attention of users because they do not burn fossil fuels and emit zero greenhouse gas emissions. Fuel cells have shown their potential to power vehicles as well. The most common fuel cell types as power sources for automobiles are i) Proton exchange membrane fuel cell (PEMFC) and ii) Solid oxide fuel cell (SOFC). In this paper, feedback linearization controller for solid oxide fuel cells is proposed. And the performance of proposed controller is tested under current disturbances operation condition.

1. Introduction

Electric vehicles have attracted the attention of users because they do not burn fossil fuels and emit zero greenhouse gas emissions. Just as many electric vehicles around the world use batteries as their primary power source, fuel cells have shown their potential to power vehicles as well. The most common fuel cell types as power sources for automobiles are i) Proton exchange membrane fuel cell (PEMFC) and ii) Solid oxide fuel cell (SOFC).

In SOFC, the reaction takes place at the anode and cathode. The ceramic electrolyte will be a good conductor for oxygen ions, not electrons. At the SOFC anode, hydrogen binds with the migrated oxygen ions. It makes water and releases electrons.

The trend in SOFC control is towards developing more efficient, reliable, and cost-effective solutions to meet the challenges of controlling and regulating the output of SOFC stack. This includes developing advanced control systems that can monitor and adjust cell operating conditions in real time to optimize performance. This involves using advanced algorithms and sensors to detect changes in fuel cell environmental and operating conditions and automatically adjust cell performance accordingly. In addition, new technologies are being developed to improve fuel cell durability and life as well as improve efficiency and performance.

In this paper, feedback linearization controller for solid oxide fuel cells is proposed. And the performance of proposed controller is tested under current disturbances operation condition.

2. Methodology

The dynamic model of SOFC which is widely accepted as a benchmark model is used to verify the proposed control method. As shown in equation (1), SOFC system have nonlinearity due to the Nernst`s equation [1, 2]:

$$V_0 = N_0\left[E_0 + \frac{R_0 T_0}{2F_0} ln\, \frac{p_{H_2}(p_{02}\,/\,101325)^{0.5}}{p_{H_2O}}\right]$$

where, the partial pressures can be approximately expressed as the following transfer functions:

$$p_{H_2} = \frac{1/K_{H_2}}{1+\tau_{H_2}s}\left(\frac{1}{1+\tau_f s} q_f - 2K_r I\right),\ p_{O_2} = \frac{1/K_{O_2}}{1+\tau_{O_2}s}\left(\frac{1/\tau_{H-O}}{1+\tau_f s} q_f - K_r I\right),\ p_{H_2O} = \frac{1/K_{H_2O}}{1+\tau_{H_2O}s} 2K_r I$$

Based on benchmark model, feedback linearization controller is designed to regulate SOFC output voltage with current disturbance meanwhile fuel utilization maintains safe range from 0.7 to 0.9 as far as possible (Fig. 1).

The SOFC system is defined with state variable $x = [q_{H_2}\ p_{H_2}\ p_{H_2O}\quad p_{O_2}]$, the output variable $y = V_o$ and input variable $u = q_f$. The control error is defined as followings:

$$e = (\ddot{V}_{0,ref} - \ddot{V}_0).$$

Then, control error dynamics and control gain are designed as followings [3]:

$$(\ddot{V}_{0,ref} - \ddot{V}_0) + K_1(\dot{V}_{0,ref} - \dot{V}_0) + K_0(V_{0,ref} - V_0) = 0, K_1 = 4,\ K_2 = 4.$$

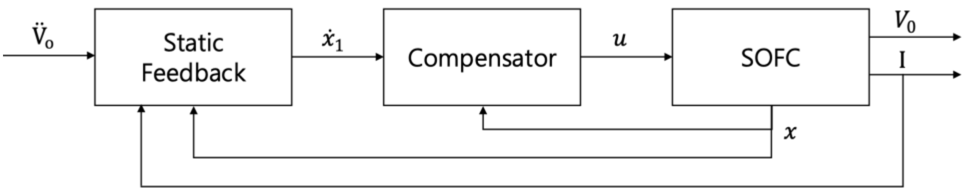


Fig. 1: Feedback linearization control diagram

3. Results and Discussion

To illustrate the effectiveness of the proposed feedback linearization controller, we assume that a current disturbance causes step changes at t=100s, t=200s, and t=300s, respectively. The simulation results are shown in through Fig. 2.

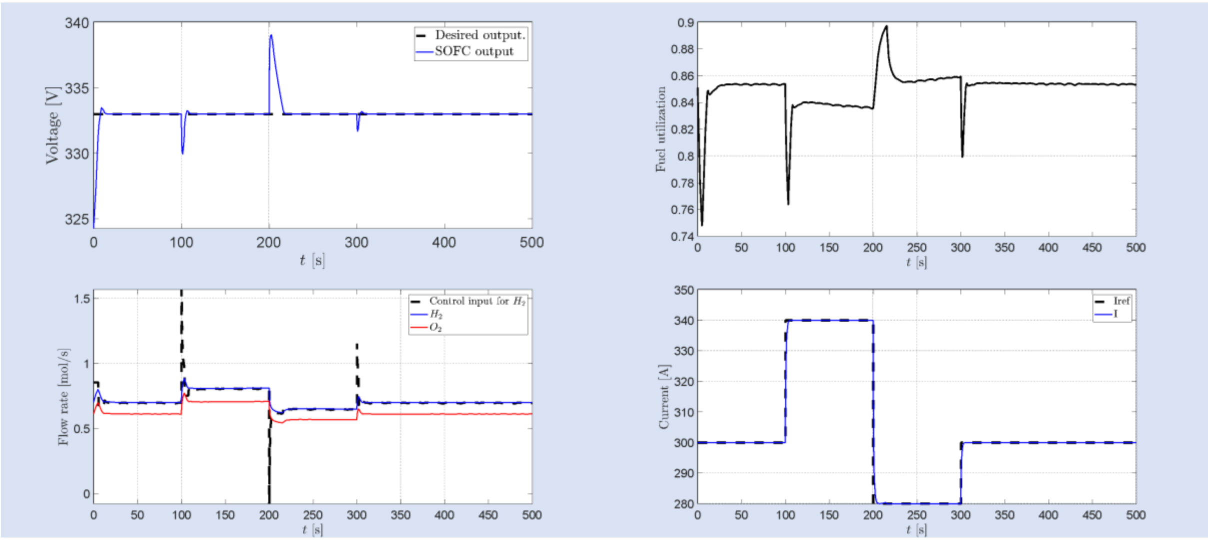


Fig. 2: Simulation results of the feedback linearization control

4. Conclusion

The most common types of fuel cells to power source of vehicles are i) proton exchange membrane fuel cells (PEMFC) and ii) solid oxide fuel cells (SOFC). In this paper, we have proposed a feedback linearization controller for solid oxide fuel cells. Simulation results on the benchmark SOFC system have illustrated that the proposed method can successfully dela with not only output voltage regulate but also fuel utilization under current disturbance.

Keywords feedback linearization; fuel utilization; solid oxide fuel cells.

Acknowledgement

This work was supported under the framework of international cooperation program managed by National Research Foundation of Korea(NRF-2021K1A3A1A78097970).

References

[1] Li, Y. H., Choi, S. S., and Rajakaruna, S., An Analysis of the Control and Operation of a Solid Oxide Fuel-Cell Power Plant in an Isolated System, *IEEE Transactions on Energy Conversion*, vol. 20, no. 2, 2005, 381-387.

[2] Padullés, J., Ault, G. W., McDonald, J. R., An integrated SOFC plant dynamic model for power systems simulation, *Journal of Power Sources*, vol. 86m, no. 1–2, 2000, 495-500.

[3] Kim, J., Kiss, B., Kim, D. and Lee, D. Tracking Control of Overhead Crane Using Output Feedback with Adaptive Unscented Kalman Filter and Condition-Based Selective Scaling, *IEEE Access*. vol.9. 2021, 108628-108639

A Framework to Explore Policy to Support Adoption of Electric Vehicles in Developing Nations: A Case Study of Indonesia

Rachmad Hidayat

Edinburgh Napier University, School of Engineering and the Built Environment, Edinburgh, Scotland
Corresponding author: rachmad.hidayat@napier.ac.uk

Abstract – This presents a summary of the literature review and theoretical framework for policies to support Electric Vehicles (EVs) including Battery Electric Vehicles (BEVs), Plug-in Hybrid Electric Vehicles (PHEVs) and Hybrid Electric Vehicles (HEVs), adoption in developing countries. It is expected that the result of this study can assist in the development of future EVs programmes.

1. Introduction

Global EV adoption is increasing as an alternative to internal combustion engine (ICE) vehicles. However, the transition towards the electrification of transport has not made equal progress throughout the world. The transition from ICE to EVs can help reduce greenhouse gas emissions in terms of global warming, climate change and decrease vehicle environmental impact. EVs may give many benefits not only environmentally but also the technology, experience, and excitement to the users. However, the market penetration is very low, particularly in developing countries. Many questions remain unanswered, such as why EVs are not widely accepted, what policies and regulations should be implemented to encourage their adoption.

This paper is a part of an ongoing study aim at investigating EV acceptance in developing countries using a case study of Indonesia, Jakarta. Indonesia aims to reduce GHG emissions by 29% without international support or by 41% with international assistance. Meanwhile, the role of EVs, which are seen to be one of the keys to reducing GHG emissions, is still missing from Indonesia's National Determined Contribution (NDC). This paper present a systematic literature review to understand the drivers, benefits and barriers of EVs deployment, followed by the main policies and regulations that accelerate EV adoption in Indonesia. This paper proposes the use of Multi-Level Perspectives (MLP) to understand and explain current and future dynamics affecting EV usage in Indonesia. Furthermore, it proposes the Multi-Level Model of Automated Vehicle Acceptance (MAVA) to predict AVs acceptance. Hence, whilst it has a very high degree of commonality with EV adoption.

2. Methodology

Systematic literature reviews were done to acquire a base for knowledge and future research agenda for studies on users' acceptance of EVs (BEV, HEV and PHEV) and policy implementation. the literature search employed the following database: ABI/INFORM, ScienceDirect, and Google Search. The collected data study was limited to articles published in international peer-reviewed journals written in English and published from 2010 – 2022. A total of 133 documents were examined and included in this review using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) four-phase flow diagram.

3. Results and Discussion

As this research aimed to understand the main and contextual factors of Jakarta's citizens toward intention to adopt EVs and examines the impact of policy instruments designed to promote the adoption of EVs. The theoretical framework introduced in the literature review includes higher and individual level factors shown in Figure 1. On the higher level, the socio-technical transition of EVs will be used to understand and explain current dynamics as well as explore the factors impacting the transition to EVs to analyse the affecting EV usage in Indonesia at three analytical levels: niches, socio-technical regimes and socio-technical landscape (Geels, 2002). Individual level, the MAVA developed by Nordhoff et al. (2019) will be applied to predict EVs acceptance and Unified Theory of Acceptance and Use Technology (UTAUT2) (Venkatesh et al., 2016) as the structural foundation for MAVA. This study uses a mix-methodology, sequential exploratory design implies collecting and analysing qualitative then quantitative data in two consecutive phases within one study. Both will be conducted in Greater Jakarta, after analysing the qualitative data, new factors and constructs will be added to revise the theoretical framework. Subsequently, the hypotheses from the literature review and the preliminary qualitative study will be evaluated using questionnaires for citizens in Greater Jakarta. By analysing and synthesising the qualitative and quantitative findings, the researcher will revise and compare the understanding of acceptance factors between higher-level contextual factors (government and stakeholders) and individual contextual factors (citizens) to explain the phenomena examined and generate recommendations for future implementation of the electric vehicle

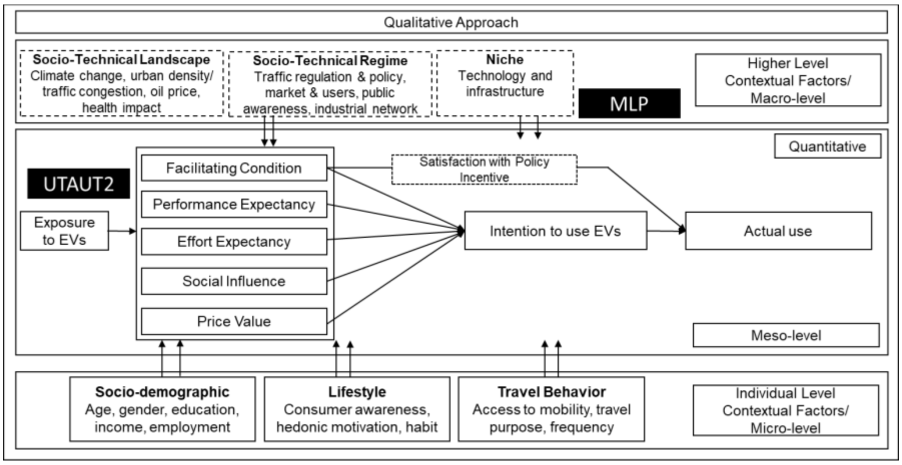


Figure 1: Theoretical framework adapting MLP and UTAUT2

4. Conclusion

Many theories have been widely used to understand the intention and acceptance of EVs. For instance, the Theory of Planned Behaviour (TPB), Diffusion of Innovation (DOI), and Technology Acceptance Model (TAM). Nevertheless, the application of UTAUT is lacking. Hence, this study proposes the use of UTAUT2 model to study the adoption intention of EVs in Indonesia. This model is selected as a theoretical basis for understanding the relationships between factors that influence user acceptance. However, there may be other many insights from the government and citizens' perspectives that can be used to enrich this model. These insight might include incorporating satisfaction with policy incentives in the adoption intention of EVs. Policy implementation, financial and non-financial incentives are two regulations commonly used by the government to promote large-scale EV adoption. In general, financial incentives are often coupled with other non-financial incentives (e.g., road priority and traffic restriction) to attract more users. However, not all countries provide non-financial incentives to promote EVs, even though it is a focal point in EV policy discussion. In geographical coverage, a review of South East Asian countries particularly Indonesia, would have been ideal since these are directly relevant. However, consumer preference and EV usage tend to be more empirically supported in countries with large markets. Most of the studies took place in Europe and North America, while Asia, predominantly China and India, came up with the highest number of research articles. This study has provided a systematic review on higher and individual factors that affect EV adoption and propose a multi-level model to predict electric vehicle acceptance, building on MLP and UTAUT2.

Keywords Electric vehicles; transport policy; public acceptance; multi-level model; multi-level perspective.

References

[1] Geels, F. W. 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research policy,* 31**,** 1257-1274.
[2] Nordhoff, S., Kyriakidis, M., Aarem, B. V. & Happee, R. 2019. A multi-level model on automated vehicle acceptance (MAVA): a review-based study. *Theoretical Issues in Ergonomics Science,* 20**,** 30.
[3] Venkatesh, V., Thong, J. Y. L. & Xu, X. 2016. Unified Theory of Acceptance and Use of Technology: A Synthesis and the Road Ahead. *Journal of the Association for Information System*, 17**,** 49.

Social Acceptance and Sustainability Assessment of Light Electric Vehicles in Ghana

Frederick Adjei[1], Eric Mensah[2], Tobias Pflug[1] , Oskar Bauer[1*] and Semih Severengiz[1]

[1]University of Applied Sciences Bochum, Germany
[2]The Palladium Group, Ghana
*Corresponding author: oskar.bauer@hs-bochum.de

Abstract – The demand for transportation in Ghana has seen an increase in recent times with a non-corresponding increase in transport infrastructure. An opportunity is created to introduce sustainable modes of transport such as light electric vehicles. The researchers use a mixed methods approach to evaluate the factors that would increase the social acceptance of such devices in Ghana. The researchers evaluate the sustainability of such devices by means of a criteria catalogue. It was found that factors such as cost, noise and range ranked high for respondents whiles environmental considerations ranked low for a mobility switch. Results of the sustainability assessment are as well presented in a graphical manner.

1. Introduction

The demand of reliable transportation solutions is increasing in Ghana because of the urbanization and population growth experienced in the country in recent decades. This increase of demand is seen in the challenges of the infrastructure conditions in Ghana clearly with an increase in vehicles from 6.7million in 1960 to 30.8million in 2022 as showed by Ayetor et.al [1]. Devices deployed in Ghana by the researchers are an e-moped, two-wheeler and three-wheeler e-cargo bicycle. It is necessary to identity what factors contribute to the social acceptance of such light electric vehicles in the local environment to inform entrance strategies for business models using light electric vehicles in environments such as Ghana. Finally, a catalogue of criteria needs to be selected and assessed in the local environment to prove the sustainability of the products introduced. A product clinic held on the Don Bosco Tema Ghana campus set out to answer the following research questions:

I. What factors influence the social acceptance of light electric vehicles and their sharing systems in Ghana?
II. How can the sustainable offer of light electric vehicles used in Ghana be assessed by means of a criteria catalogue?

2. Methodology

To achieve the objectives of the product clinic, a mixed approach which includes focus group discussions and track testing in various terrain are used. A mixed methods approach allows the use of qualitative and quantitative questions and hence is well-suited to the research questions [2]. Using the theoretical framework of Schäfer et.al, the social acceptance of LEVs were assessed as part of the overall sustainability assessment using the criteria catalogue. Acceptance infers that someone (acceptance subject) accepts something (object of acceptance) within the respective or initial conditions (context of acceptance) [3]. The overall sustainability assessment was derived using the framework of Goedkoop et.al[4]. To evaluate the sustainability performance qualitatively and quantitatively, a multi-criteria evaluation based on a selection of key figures and indicators is required. A simplified reference scale was developed and converted to a three-stage evaluation.

3. Results and Discussion

3.1 Factors influencing social acceptance of LEVs

In evaluating factors that influence social acceptance of Light Electric Vehicles (LEVs) in Ghana, respondents were asked to rank factors important to them when using a sharing system and e-mopeds on a Lickert scale. Respondents had e-mopeds as well as e-bicycles on site and hence could familiarize themselves with the use of both devices. The factors for influencing the adoption of e-mopeds are therefore similar if not the same for the adoption of e-bicycles. The factors influencing the social acceptance of e-mopeds and sharing systems are elaborated in the tables below following statistical analysis using Kendall´s Coefficient of Concordance.

3.2 Sustainability Criteria Catalogue of LEVs in Don Bosco Ghana

The results from surveys and interviews were used to populate a criteria catalogue to assess and provide a larger overview of the sustainability of the product system installed on the campus of Don Bosco. The criteria catalogue is provided below in a figurative form.

Table 1: Ranking of factors important to respondents in the purchase and use of e-moped and the use of sharing systems

Factors	Mean Score	Rank
Acquisition Cost	5.31	1st
Low Noise	5.32	2nd
Range	5.34	3rd
Weight Capacity	5.37	4th
Safety	5.38	5th
Repairability	5.46	6th
Power	5.53	7th
Environmental sustainability	5.57	8th
Maintenance Cost	5.77	9th
Design	5.95	10th
Ranking of factors important to respondents in using the sharing system		
Location	2.89	1st
Easy Usage	2.94	2nd
Availability	2.95	3rd
Price	2.97	4th
Variety	3.26	5th

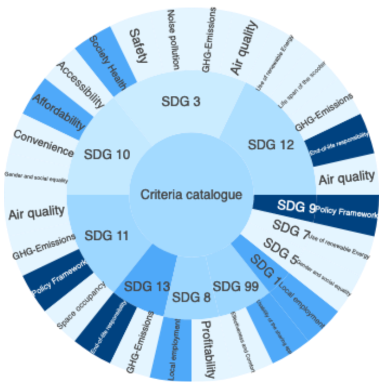


Fig 1: Overview of criteria catalogue in relation to SDGs. Ranking of 1 indicates sustainability while -1 indicates non-achievement of sustainability goals and 0 indicates a neutral impact.

4. Conclusion

It is clear that environmental sustainability is not the driving factor for a switch to a more sustainable transport mode for the given society from its 8th rank in factors affecting social acceptance. An entry strategy for future suppliers would need to focus on the core needs or purposes for transport as opposed to an inference to planet protection or climate change. Cost appears to be the main factor and this is reflective of the current economic conditions in the country. On sharing systems, location of pick-up points, easy usage of software applications, availability, price (cost), and variety of devices were ranked as significant to potential users. With the aid of criteria catalogue, it is possible to prove the sustainability of the product system across economic, ecological and social dimensions. With these insights, it is possible to device entry strategies to transitioning economies such as Ghana for light electric vehicles and their sharing systems.

Keywords: electromobility; sustainable transport; sustainable development goals

References

[1] G. K. Ayetor, R. Opoku, C. K. K. Sekyere, A. Agyei-Agyeman, and G. R. Deyegbe, "The cost of a transition to electric vehicles in Africa: A case study of Ghana," *Case Stud. Transp. Policy*, vol. 10, no. 1, pp. 388–395, 2022.

[2] P. F. Wu, "Journal of the Association for Information A Mixed Methods Approach to Technology Acceptance Research," *J. Assoc. Inf. Syst.*, vol. 13, no. 3, pp. 172–187, 2012.

[3] M. Schäfer and D. Keppler, "Modelle der technikorientierten Akzeptanzforschung: Überblick und Reflexion am Beispiel eines Forschungsprojekts zur Implementierung innovativer technischer Energieeffizienz-Maßnahmen," *Zent. Tech. und Gesellschaft*, no. 34, p. 87, 2013.

[4] M. J. Goedkoop, D. Indrane, and I. M. de Beer, "Handbook for Product Social Impact Assessment - 2018," *Amersfoort, Sept. 1st, 2018*, no. November, 2020.

Disaggregation of Fast Charging Stations for Energy Management System Using a Single Point Sensing

Sami M Alshareef[1]

[1]Department of Electrical Engineering, College of Engineering, Jouf University, Saudi Arabia
*Corresponding author: smalshareef@ju.edu.sa

Abstract – The aim of this paper is to apply the load disaggregation using a single point sensing on fast charging stations aiming to managing the system's energy by proposing a machine learning-based method for detecting and classifying four fast charging stations with capacities of 50 kW, 90 kW, 150 kW, and 350 kW. The proposed method in this work utilizes turn-on/off transient waveforms to identify fast chargers and analyze their characteristics. The main data in an non intrusive load monitoring system are the voltage and current of aggregate loads received from the point of common coupling (PCC) at the utility service entrance. The turn-on/off transients of the fast chargers were simulated by the Power Systems Computer Aided Design (PSCAD). Wavelet transform is a mathematical technique used to analyze and represent signals in a different domain called the wavelet domain. The wavelets are chosen to be localized in both time and frequency, which allows for a more detailed analysis of the signal than traditional Fourier transform techniques. Once the features of the main data have been extracted by Wavelet functions, they will be used in a machine learning model for load disaggregation.

1. Introduction

With the globally increasing electricity demand and desire to reduce CO2 emissions, the world has shifted from fossil fuels to renewable and sustainable energy resources in the past three decades. Due to this, the proliferation of grid-integrated renewable energy sources dominated by wind energy and solar energy is increased in the low and medium-voltage utility grids to meet the energy demand in the future smart grids. These multi-energy integrations have promoted the efficient operation of energy systems and reduced carbon emissions significantly. On the other hand, excessive greenhouse gas emissions from conventional internal combustion engine vehicles have also worsened climate change and have arisen as a global issue. This climate change issue has encouraged governments worldwide to seek alternative solutions to reduce their carbon footprint. One way to address this issue is to electrify transportation. Therefore, electric vehicles are an excellent replacement for internal combustion engine vehicles. It is forecasted that a large number of EVs will be adopted into the market in the near future. According to the US Energy Information Agency, CO2 emissions from the transport sector have been higher than those of the other sectors. However, these numbers show a decline in areas with higher EV penetration rates. Charging stations are critical in facilitating increased EV penetration. Further, integrating charging technology with renewable energy and storage can synergize with electricity supply infrastructure, i.e., the power grid, to increase environmental benefits and improve energy efficiency. However, the interconnection of high penetration of electric vehicles into the power grid can alter the operation of the existing network. The interconnection of high penetration levels of EVs could overload the components of the power grid, such as transformers and cables. Furthermore, the fast charging mechanism of electric vehicles worsens the situation as this charging drains high power from the power grid, thus stressing the local power grid.

2. Methodology

The aim of this paper is to apply the load disaggregation using a single point sensing on fast charging stations aiming to managing the system's energy. To minimize the drawbacks of steady-state signatures that was followed in past research, this paper identifies a new analysis method for identification of fast charging station using nonintrusive load monitoring (NILM) system. From literature it has been observed that the traditional non-intrusive load monitoring system operates considering P and Q as power signatures. However, false identification arises when the power of a certain load matches the total power of the other loads in the NILM system. To curb this issue, the proposed method in this work utilizes turn-on/off transient waveforms to identify fast chargers and analyze their characteristics. The main data in an NILM system are the voltage and current of aggregate loads received from the point of common coupling (PCC) at the utility service entrance. The turn-on/off transients of the fast chargers were simulated by the Power Systems Computer Aided Design (PSCAD). Wavelet transform is a mathematical technique used to analyze and represent signals in a different domain called the wavelet domain. It is a time-frequency representation that can be used to decompose a signal into its different frequency components, while also preserving the temporal information of the signal. The wavelets are chosen to be localized in both time and frequency, which allows for a more detailed analysis of the signal than traditional Fourier transform techniques. One of the main advantages of wavelet transform is its ability to provide a time-frequency representation of a signal, allowing for the detection of both frequency-localized and time-localized features. Once the features of the main data have been extracted by Wavelet functions, they will be used in a machine learning model for load disaggregation.

3. Results and Discussion

This paper considers the IEEE 4 bus test system to validate the proposed technique. The IEEE 34 bus test system is a widely-used benchmark system in the field of power systems and it is a realistic representation of a medium-sized power distribution system. The IEEE 4 bus system is modeled in PSCAD/EMTDC Software. Four fast charging stations with capacities of 50 kW, 90 kW, 150 kW, and 350 kW were connected and simulated. The voltage and current measurements were then used. The single-line diagram of the IEEE 4 bus system is shown in Figure 1 below:

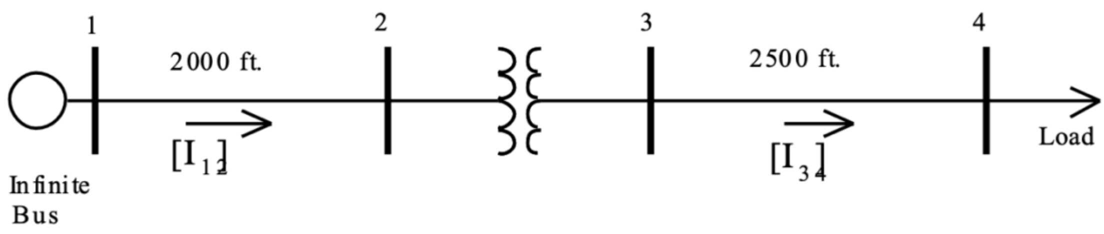


Fig. 1: IEEE 4 Node Test Feeder

References

[1] Distribution Test Feeder, Distribution Test Feeder Working Group, IEEE PES Distribution System Analysis Subcommittee [online].Available: https://ewh.ieee.org/soc/pes/dsacom/testfe eders/.

Modelling the Intensity of Electric Vehicle Arrivals at Charging Points

Yvenn Amara-Ouali[1]
[1]EDF R&D, FRANCE
*Corresponding author: yvenn.amara-ouali@universite-paris-saclay.fr

Abstract – With Electric Vehicles' (EV) market adoption surging in recent years, the smart grid paradigm requires accurate forecasts of EV arrivals at charging points. One efficient way to model these arrivals is to use Point Processes. In this paper, we introduce an additive model using both spline and wavelet effects for fitting the intensity of a non-homogeneous Poisson process applied to EV arrivals at charging points. Our key contribution is a novel estimation procedure inspired from backfitting which is illustrated by a case study on real-world EV arrivals at charging points. We show that this approach can help better capturing EV arrival peaks.

1. Introduction

Recently, additive semi-parametric methods have raised ample interest for estimating the intensity of non-homogeneous Poisson Processes (NHPPs) [1]. An important focus has been given to spline basis for additive models and many theoretical and experimental results are available. In the meantime, progress has also been made on regression with additive wavelet effects. In this work we consider an additive model of the intensity function of a NHPP of the following form:

$$log\ log\ \lambda(t) = \beta_0 + \sum_{l=1}^{L_p} \beta_l x_l^p(t) + \sum_{l=1}^{L_s} s_l(x_l^s(t)) + \sum_{i=1}^{L_w} w_l(x_l^w(t)) \qquad (*)$$

with, β_0 the intercept, $(\beta_l)_{l\in\{1\dots L_p\}}$ the coefficients of the linear component, $(s_l)_{l\in\{1\dots L_s\}}$ and $(w_l)_{l\in\{1\dots L_w\}}$ respectively spline and wavelet basis expansions. In addition, $x(t) = \left((x_l^p(t))_{l\in\{1\dots L_p\}}, (x_l^s(t))_{l\in\{1\dots L_s\}}, (x_l^w(t))_{l\in\{1\dots L_w\}}\right)$ is the vector of covariates evaluated at time $t \in [0, T]$ ($T \in R^+$ being the final time at which we observed the NHPP).

Essentially, this model decomposes the intensity of arrivals into linear, smooth and irregular components [2]. That is to account for both general trends as well as sudden changes in the arrival rate. Furthermore, we chose the additive structure to have an interpretable model with the contribution of each component made clear for analysis.

2. Methodology

We propose two algorithms which can be used to successfully fit model (*). The first one is referred to as **OBO** which stands for "One-By-One"'. We start by fitting the linear part, then the splines components to finally end with the wavelet effects. Apart from the linear component, which is fitted all at once, each non-parametric component is fitted separately. The idea behind this algorithm is to move from the lowest frequency (linear part and splines with not too many degrees of freedom) to the highest frequency of the signal (wavelet basis of relative high order).

Unlike **OBO**, the **BAC** algorithm does not involve an a priori on the order in which the different effects should be fitted. In practice, effects are fitted in a random order. Each time an effect is fitted, the rest of the model fitted up until this iteration is subtracted from the target response. So only the residuals of the current model iteration are fitted at each step. Like backfitting, this procedure is repeated multiple times until convergence. Convergence is reached when the L^2-norm of the difference between the parameters' estimate at the previous and current iterations for each effect is less than a certain tolerance threshold ϵ. In fact, **OBO** could be seen as one iteration of **BAC** however set in a particular order.

3. Results and Discussion (Times New Roman, Bold, 11pt)

The dataset in the scope of this case study gathers charging session information in the United Kingdom (UK) during 2017 [3] Figure 1 shows the boxplots of performance with regards to the mean absolute error (MAE) and root-mean squared error (RMSE) for variations of the **BAC** and **OBO** algorithm including splines (s), wavelets (w) and both (sw). The **BAC** approach seems to perform significantly better on this fitted data and we can also see that the *sw* variation is the most performant overall.

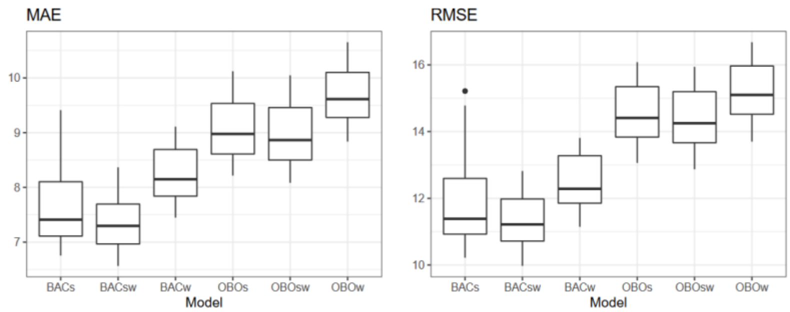


Fig. 1: Example of figure for the extended abstract (Times New Roman, Regular, 10pt)

Figure 2 represents a fitted **BAC** approach for a random week. On this fit it is interesting to note that the benefit of the wavelet effect can be clearly observed on four out of the five peak estimates. The benefit of wavelets is marginally seen on the ascendant and descendant part of the curve. Essentially, we can see that most of the work is done by the linear and splines part but the wavelet really seems to meet the intended aim, namely, enhancing the performances on peak estimates.

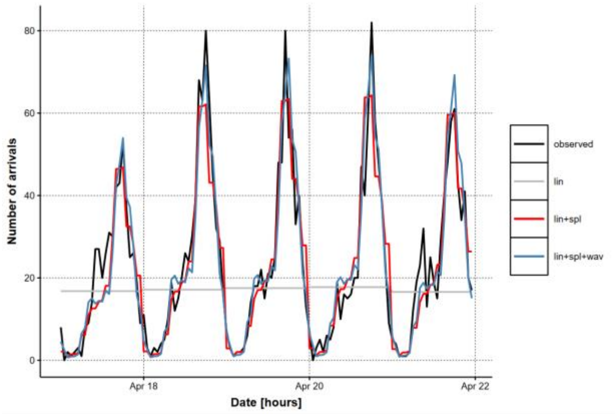


Fig. 2: Example of figure for the extended abstract (Times New Roman, Regular, 10pt)

4. Conclusion (Times New Roman, Bold, 11pt)

In this paper we have studied an additive model with both wavelet and spline components for estimating the first-order intensity function of NHPP applied to EV arrivals at charging points. Two algorithms were proposed, **OBO** and **BAC**. **BAC** performs better with the use of both splines and wavelet components on the fitted residential data. Furthermore, we observed that there could be some benefit to use a model with additive spline and wavelet effects to capture peaks which is a crucial component of the smart grid paradigm.

Keywords smart grids; point processes; peak forecasting; additive models; wavelets

References

[1] Youngman, Benjamin D., and Theodoros Economou. "Generalised additive point process models for natural hazard occurrence." Environmetrics 28.4 (2017): e2444.

[2] Amato, Umberto, et al. "Forecasting high resolution electricity demand data with additive models including smooth and jagged components." International Journal of Forecasting 37.1 (2021): 171-185.

[3] UK Department for Transport, “Domestics Chargepoint Analysis” (2017)

Power Electronics Converters for an Electric Charging Station: Description and Experimental Evaluation

Moacyr A. G. de Brito, Anderson S. Volpato, Edson A. Batista and Ruben B. Godoy*

Electrical Engineering Department, Faculty of Engineering, Architecture and Urbanism and Geography - FAENG, Federal University of Mato Grosso do Sul - UFMS, Campo Grande-MS, Brazil
*Corresponding author: ruben.godoy@ufms.br

Abstract – This paper presents the power electronics converters of an electric vehicle charging station that works as a DC microgrid with AC grid interface. The interface converter is an interleaved bidirectional DC-AC converter that enables the V2G (Vehicle-to-grid) application. The control methodology and experimental results from the proposed system with focus on the interface converter are presented. In the final version, the function of the remaining converters will be addressed.

1. Introduction

For many years, humans have extracted resources from Earth without thinking about environmental concerns. The conversion of combustion automobiles fleet into electric vehicles (EVs) may reduce the arising issues. In addition, EVs open new possibilities such as vehicle-to-home (V2H), vehicle-to- vehicle (V2V), and vehicle-to-grid (V2G). Among those approaches, V2G allows vehicles to be charged by the grid or supply energy to it, enabling EVs not only to assist in transportation but also to act as controllable loads and distributed energy sources, enabling possibilities for pricing and strategies for peak demand mitigation [1, 2].

Inside the V2G electric vehicle charging station, there are some power electronics converters. Among them, the bidirectional DC-AC converter allows the correct power flow among VEs and the grid. Its main function is to regulate the DC bus to allow proper operation of the microgrid. From this point of view, this converter must be prepared to inject and/or absorb power from the grid respecting standards and maintaining energy quality aspects. Thus, this converter has to be controlled accordingly and for that sense, it is applied a multi-loop current control strategy in the dq axis [3]. This paper presents the analysis of the bidirectional converter exchanging power to the grid being supplied by a PV source and a stationary battery bank. The analysis of all microgrid converters and their functions will be better addressed in the final paper's version.

2. Methodology

The proposed electric charging station is a type of DC microgrid with an AC grid interface as shown in Figure 1. Energy sources are the PV system, a stationary battery bank, and mobile battery banks (results from the e-bikes). The e-bikes account for 10 vehicles and each e-bike is charged through its own wireless power converter. The PV system has its own DC-DC converter that tracks the maximum power point and increases the voltage for the connection with the DC bus. Interfacing the stationary battery bank with the DC bus is a bidirectional current DC-DC converter.

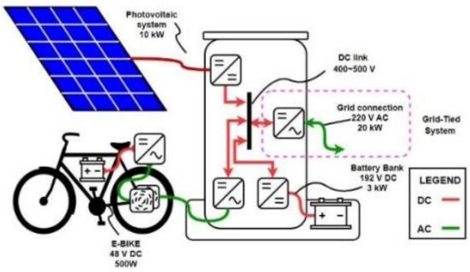
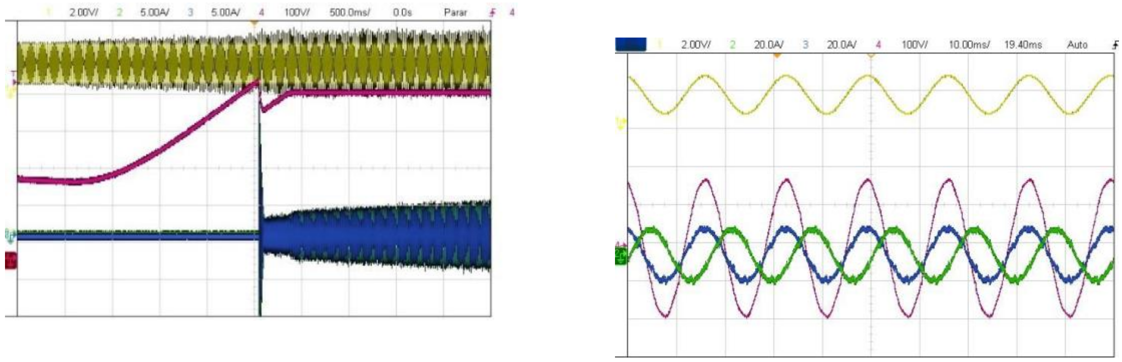


Fig. 1: Proposed microgrid.

The grid-tied converter has 2 parallel voltage source inverters that can handle until 10 kW each to reduce the current over the grid coupling filters. Each converter act as separate current sources connected to the same DC bus. Both inverters have their own current control loop using a synchronous reference frame strategy, where the current controllers can follow the references for injecting or absorbing active or reactive powers. The outer control loop is for voltage regulation. According to the changes in the DC bus voltage (e.g., power injection from the other converters), the controller updates the reference for the current components which is equally divided between the grid-tie converters. The proper regulation of the DC bus allows the remaining converters to properly exchange power with the DC bus. For grid synchronization, it is used a positive sequence phase-locked-loop [4]. The interface converter can work with an L or LCL filter, in interleaving, and this will be discussed properly in the final paper´s version.

3. Results and Discussion

For the grid-tie converter control, it was used the Launchpad F28379D. Figure 3 shows the results of injecting active power into the grid. In Fig (a), one may see the instant of connection to the grid – in yellow, the PLL signal, in purple, the DC bus voltage – the injection of power occurs with 450 V, and in blue and green, the injected currents. In Fig (b), it is displayed the steady state waveforms – in purple, phase A voltage and in blue and green, phase A and B currents. All grid injected currents are with reduced harmonic content.



(a) (b)

Fig. 3: Waveforms for grid-connection. (a) Instant of connection. (b) Steady state.

4. Conclusion

The bidirectional power converter is the key converter to allow the V2G technology. This paper proposes an interleaved topology for this objective. In the final version of this paper, it will be discussed the purpose of each power electronics converter and more experimental results for different points of operation. Discussions about the usage of an L or LCL filter for grid connection will be also inserted.

Keywords Electric vehicle charging station, power electronics converters, renewable energy source.

Acknowledgement

The authors would like to thank Federal University of Mato Grosso do Sul – UFMS and the Research and Development Project-P&D ANEEL. PD-06961-0010/2019.

References

[1] C. Liu, K. T. Chau, D. Wu and S. Gao, Opportunities and challenges of vehicle-to-home, vehicle- to-vehicle, and vehicle-to-grid technologies, Proceedings of the IEEE, vol. 101, no. 11, pp. 2409--2427, 2013.

[2] X. Li, Y. Tan, X. Liu, Q. Liao, B. Sun, G. Cao, C. Li, X. Yang and Z. Wang, A cost-benefit analysis of V2G electric vehicles supporting peak shaving in Shanghai, Electric Power Systems Research, vol. 179, p. 106058, 2020.

[3] J. C. U. Pena, L. P. Sampaio, M. A. G. de Brito and C. A. Canesin, Robust Control of Three-Phase VSI with LCL Filter for Distributed Generation Power Quality Improvement, Journal of Control, Automation and Electrical Systems, vol. 31, pp. 1051--1062, 2020.

[4] Se-Kyo Chung, A phase tracking system for three phase utility interface inverters, IEEE Transactions on Power Electronics, vol. 15, no. 3, pp. 431--438, 2000.

Sliding Mode Control Design Using PWM Modulation Method for Induction Motor Speed Control

Rohullah Rahmatullah[1,] *, Necibe Fusun Oyman Serteller [2], and Ayca Ak[3]

[1,2] Marmara University, Faculty of Technology, Electrical and Electronics Engineering, Istanbul, Türkiye
[3] Marmara University, Vocational School of Technical Sciences, Department of Electronics and Automation, Istanbul, Turkiye
*Corresponding author : rohullahrahmatzai@yahoo.com

Abstract – The sliding mode control method can be successfully applied in the control of high- dimensional nonlinear systems operating under uncertain conditions due to its high accuracy and simplicity of application. In this Matlab/Simulink-based study, a proportional-Integral-Integral Sliding-Mode Control (PI-ISMC) method is developed for the mechanical speed control application of a three-phase squirrel-cage induction motor. For this purpose, the modelling of the induction motor and the design of the proposed controller has been made in the qd0 reference plane. Uncertainty and asymptotic velocity tracking under different loading conditions are guaranteed by the parameter adjustment of the developed PI-ISMC controller. The stability of the proposed controller under parameter uncertainties and load disturbances is provided by using the Lyapunov stability theory. In addition, to evaluate the success of the sliding mode control topology in the induction motor control application, the field-oriented control method (FOC) has been applied on the same motor and its performance has been compared with the sliding mode control method.

1. Introduction

Induction motors (IMs) have been used for a long time in industrial applications where mechanical energy is required due to their robust structure and easy adaptability to various operating modes in a dynamic state. Recently, the use of IM has become more effective with the diversification of power electronic devices used in control technology and the advances in microprocessor technology. Due to the complex structure of IMs, position and speed control is more difficult and complex than DC machines. Obtaining a smooth and effective electromagnetic torque from IMs used in industrial systems requires asymptotic speed monitoring and control methods to prevent deterioration. Sliding mode control (SMC), which is built on the variable structure control (VSC) algorithm, provides the desired conditions for the system to be controlled despite external and internal disturbing factors and uncertainties. SMC technique, which is one of the non-linear control methods, has become the focus of research in the literature as it gives successful results in IM control application operating under complex and uncertain conditions due to its strong robustness, fast response and simple software and hardware application. In the study [1], the basic concepts, mathematics, and design aspects of variable structure systems and sliding mode control method were discussed, the derivation of mathematical models for high-dimensional nonlinear systems operating under uncertainty conditions and the sliding mode control design philosophy was summarized and its applicability to the control of electric motors of different structures is elaborated.

In this study, it is tried to fix the mechanical rotor speed of the IM by using the IP-ISMC method to prevent asymptotic speed tracking and steady-state error and distortions in speed control applications of IMs. During the controller design process, FOC theory is applied to achieve fast dynamic performance. In addition, suitable SMC parameters were selected to solve the chattering problem and eliminate the steady-state error. FOC performances were compared with the proposed SMC control method under and different loading conditions.

2. Mathematical Model of Induction Motor

Models to be developed for fault diagnosis and control of faulty IM must be of a form that will accurately reflect all behaviours of the motor, but such a model will have an overly complex structure. Therefore, for simplicity, some assumptions are considered.

3. SMC Control Design

The block diagram of the proposed control method is given in Figure 1, as it can be seen in the figure, the stator phase currents measured from the stator windings are converted into ids and iqs currents components with Park and Clark transformations. The currents ids and iqs will be responsible for magnetizing rotor flux and electromagnetic torque respectively.

4. Simulation Results

The proposed model of IM for investigating the effects of SMC controllers in the speed control applications and to evaluate the performance of SMC and FOC is given in Figure 1.

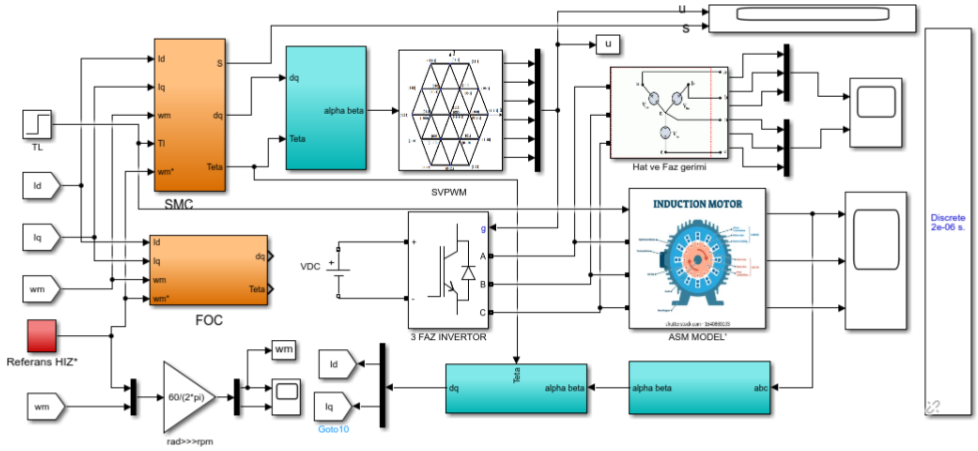
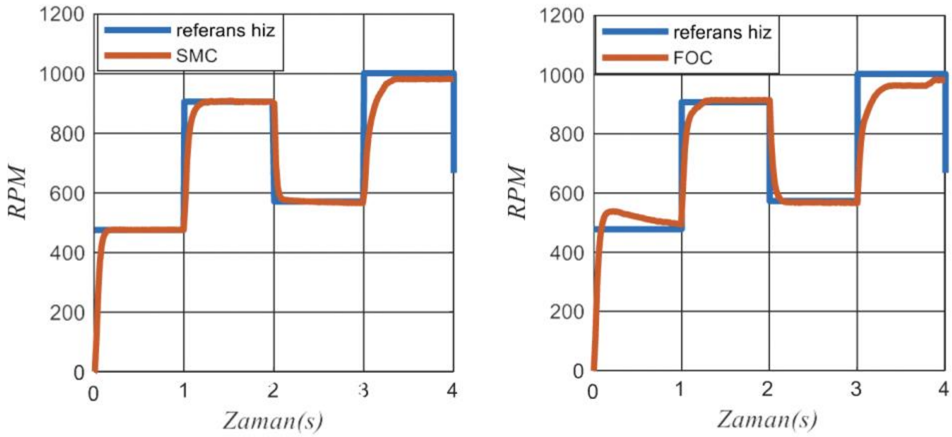


Fig. 1: Simulink Model of SMC and FOC controlled induction motor.

Figure 2 shows the rotor speed obtained for reference speed applied as a step function of [50 95 105 94] r/s to the motor within [1 2 3 5] sec under SMC and FOC control… will be added in the final manuscript.



(b) (c)

Fig. 2: After 2 seconds under full load motor speed: (a) under the SMC Method, (b) Obtained by the FOC Method

4. Conclusion

In this study, IP-ISMC was applied to the IM to regulate rotor mechanical speed and eliminate load distortions and parametric changes. IM speed was successfully controlled using SMC and FOC control methods. According to the simulation results, it can be observed that SMC operates more effectively than the FOC controller in controlling the speed of the IM due to advantages such as asymptotic speed tracking, no steady-state errors and overshoots, and faster settling time.

Keywords: Induction Motor , SMC Control, FOC Control, dq0 Reference Systems, Matlab/Simulink

References

[1] Utkin, V. I. (1993). Sliding mode control design principles and applications to electric drives. IEEE Transactions on Industrial Electronics, 40(1), 23–36. doi:10.1109/41.184818

Real-Time Comprehensive Condition Monitoring Technique for SiC MOSFET-Based Inverters in EV Application

Javad Naghibi[1*], Kamyar Mehran[2] , and Martin P. Foster[3]

[1,2] School of Electronic Engineering and Computer Science, Queen Mary University of London, UK
[3] Department of Electronic and Electrical Engineering, The University of Sheffield, UK
*Corresponding author: s.naghibinasab@qmul.ac.uk

Abstract – High density compact inverters based on Silicon Carbide power MOSFET devices can address high density and high power requirements of next generation power electronics applications. Reliable performance in long-term operation, however, is still a challenge. In this paper, a comprehensive condition monitoring technique is proposed and validated which covers both package-related and chip-related failure modes of SiC MOSFETs in a 3-phase inverter circuit used for EV applications.

1. Introduction

Inverters, also known as motor control units (MCUs), are widely adopted in automotive industry. The existing trend is to design MCUs with higher power density [1]. Silicon carbide power MOSFETs have paved the way to achieve high power density designs in MCUs. This is mainly because of SiC MOSFET capabilities in high frequency operation and lower conduction and switching losses in comparison to their Silicon-based counterparts [2]. As these devices are newly adopted, there are extensive research efforts to characterize the device to assure reliable performance.

Condition monitoring (CM) has been introduced as a technique to assess the device health in different operation conditions. Depending on the category of failure (package-related or chip-related), different CM precursors have been introduced in the literature. Changes in the gate threshold voltage (V_{TH}), on-state voltage ($V_{DS,on}$), device thermal impedance, on-state drain-source resistance (R_{DS-on}), and dynamic changes of the gate current are introduced as package-related failure precursors [2],[3]. Similarly, for the chip-related failure modes, changes in V_{TH} , Miller plateau voltage (V_{GP}) during the turn-on process, etc. are introduced as the failure precursors [4],[5].

In all the above-mentioned precursors, the proposed CM method is specialized for a specific failure mode. For example, V_{TH} has shown good potential to indicate gate oxide degradation level. However, this parameter cannot represent any implications about the health status of the device in package level. In circuit-level CM of MCU, the main challenge is to have a comprehensive CM method which can detect both major package-related and chip-related failure modes.

In this paper, with a concentration on real-time capability, a practical CM technique is proposed and validated for assessing SiC MOSFET health status in MCU circuit. Gate oxide degradation monitoring and wire bond fatigue are monitored using the proposed CM technique.

2. Methodology

V_{TH} and V_{GP} are measured and employed as the chip-related failure indicators. The devices in the inverter circuit are undergone high electric field stress mechanism, which is basically an accelerated degradation process for inducing gate oxide degradation in the device. In Fig.1, it is shown that V_{GP} is changed from 72ns to 112 ns.

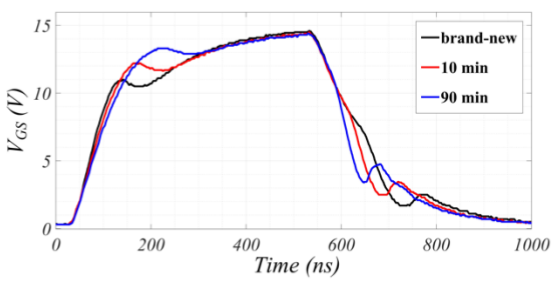


Fig. 1: V_{GP} changes during the gate oxide accelerated degradation process

Wire bond lift off failure mode accounts for most of the package-related failures [2]. On this basis, the focus of this paper is to use CM precursors to detect wire bond lift off. R_{DS-on} is used for indicating this failure mode. For the six modules in the inverter, this measurement is done and the captured data are sent to the control section of the proposed CM system, as shown in Fig.2.

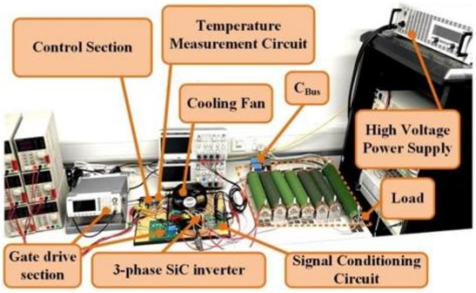


Fig. 2: Experimental set-up of the SiC-based 3-phase inverter

3. Results and Discussion

The case study circuit is a 350V/2kW three phase inverter which is used for a BLDC motor drive application (see Fig.2). All the six SiC MOSFETs in the inverter are undergone through high electric field stress test to induce gate oxide degradation. The results showed that in t_{stress} = 90 min, the low side switch in phase A failed. This is basically due to the more harsh effect of trapped charges on low side switches in the inverter.

Power cycling is chosen as the strategy of accelerated degradation for inducing wire bond lift off. All the six modules were subject to identical power cycling parameters. The results showed that after 4200k cylces, the high side switch in phase B failed. This instance was detected by the diagnosis section of the proposed CM technique.

4. Conclusion

Being focused on inverter application, a comprehensive condition monitoring method was developed in this paper. Real-time capability, detecting both package-related and chip-related failure modes, and simplicity are the main advantages of this method.

Keywords: Condition Monitoring, Inverter, Silicon Carbide power MOSFETs, Reliability

References

[1] Z. Ni, X. Lyu, O. P. Yadav, B. N. Singh, S. Zheng, and D. Cao, “Overview of real-time lifetime prediction and extension for sic power converters,” IEEE Transactions on Power Electronics, vol. 35, no. 8, pp. 7765–7794, 2020

[2] J. Naghibi, S. Mohsenzade, K. Mehran and M. P. Foster, "Gate Oxide Degradation Condition Monitoring Technique for High-Frequency Applications of Silicon Carbide Power MOSFETs," in IEEE Transactions on Power Electronics, vol. 38, no. 1, pp. 1079-1091, Jan. 2023, doi: 10.1109/TPEL.2022.3198291.

[3] W. Chen, L. Zhang, K. Pattipati, S. Joshi, and E. M. Dede, “Data-driven approach for fault prognosis of sic mosfets,” IEEE Transactions on Power Electronics, vol. 35, no. 4, pp. 4048–4062, 2020.

[4] U. Karki, N. S. Gonzalez, and F. Z. Peng, “Effect of gate-oxide degradation on electrical parameters of silicon carbide mosfets,” IEEE Transactions on Electron Devices, vol. 67, no. 6, pp. 2544–2552, 2020

[5] J. Naghibi, S. Mohsenzade, K. Mehran, and M. P. Foster, “Evaluation of drain-source voltage in switch transient time intervals as gate oxide degradation precursor of sic power mosfets,” in 2022 24th European Conference on Power Electronics and Applications (EPE’22 ECCE Europe), pp. 1–9, 2022.

Gear Design of Electric Vehicle Powertrain

Zaid Alkhatib, Stelvio Silvia, Fazle Rabby, Dhananjay Singh, Ahmed Rezk* and Jose Sodre

Future Vehicle Technologies, Aston University, Birmingham, B4 7ET, UK First
*Corresponding author: a.rezk@aston.ac.uk

Abstract – Power transmission analysis by coupling 3D finite element modelling and powertrain 0D modelling is crucial in electrified powertrain development. Therefore, this abstract investigates a power transmission via sprocket/chain assembly as part of a simplified electric power train under dynamic loading and according to a predefined drive cycle, European Driving Cycle (NEDC). Within the predefined operating range informed by NEDC, minimum and maximum strain varied from 2.5399×10^{-10} to 1.2357×10^{-6} mm, which was used to assess the safety limits to operate the system in a simplified powertrain drives GreenPower F24 car.

1. Introduction

An attachment mechanism for a chain is a sprocket, a wheel with several teeth/slots. A socket is any wheel with radially directed engagement projections and is passed over by a chain. Because it does not mesh directly with a gear, a sprocket differs from a pulley and has teeth, making it a different gear. Such a simplified speed reduction mechanism is commonly used in electrified powertrains to transmit rotational motion between two shafts in machines such as motorbikes, cars, tracked vehicles, or other machines. When the car accelerates and the transmission transitions between gears during dynamic events, the tooth count of the sprocket is a significant factor. Sprockets are designed to use the linear force generated by the drive chain to generate rotational energy to rotate the differential (Rohan Rai, 2020). Therefore, matching the parameters of an electric vehicle's powertrain is vital to improve its performance and driving range. This abstract aims to demonstrate the principle and procedure of parameter matching for EV powertrains, which is likely used in more complicated powertrain configurations. The designed EV is developed based on analysing the vehicle's dynamics. (Gong, X.W., at., al, 2013)

2. Methodology

A meshed geometry replicating sprocket was developed using the finite element analysis computational tool ANSYS by changing the teeth count and measuring its stress and strain. The front sprocket rotates the rear sprocket. The boundaries of the simulated sprocket and the dimensions are 12 Tooth 06B Simplex Pilot Bore Sprocket for 3/8-inch Pitch Chain. The front sprocket is to be rotated by the output shaft connection from the gearbox output. It will constantly rotate based on the electric motor output as a part of the GreenPower F24 simplified electric powertrain. Data and parameters have been integrated into ANSYS from the powertrain matching software Ricardo IGNITE™, from power, torque, driving speed, and time.

3. Results and Discussion

As a standard driving cycle widely used, European Driving Cycle (NEDC) was used to test the power performance of the designed vehicle. Figure 1 shows the strain distribution on 12 teeth sprocket by applying the dynamic loadings acquired from the powertrain 0D model developed by Ricardo IGNITE™: power and torque with driving speed. Minimum and maximum strain can vary from 2.5399×10^{-10} and 1.2357×10^{-6} mm, which means it is safe enough to be employed in the EV under the parameters and the driving conditions of the area and the weight of the car. Figure 2 shows three lines: the minimum, maximum, and average strain. All these results are under maximum power of 510 W and maximum torque of 1.3 Nm.

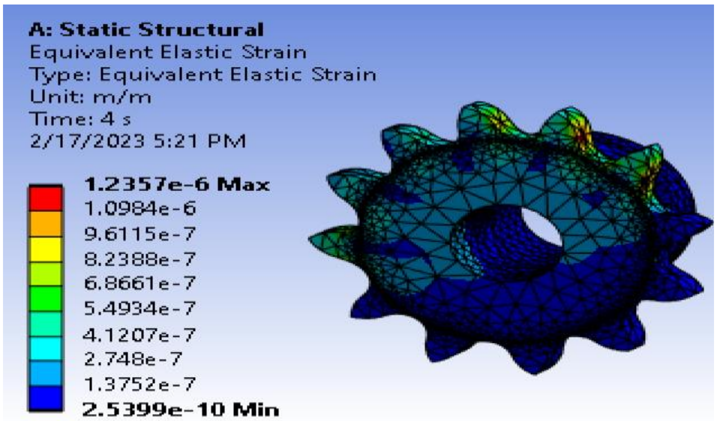


Fig. 1: Strain distribution.

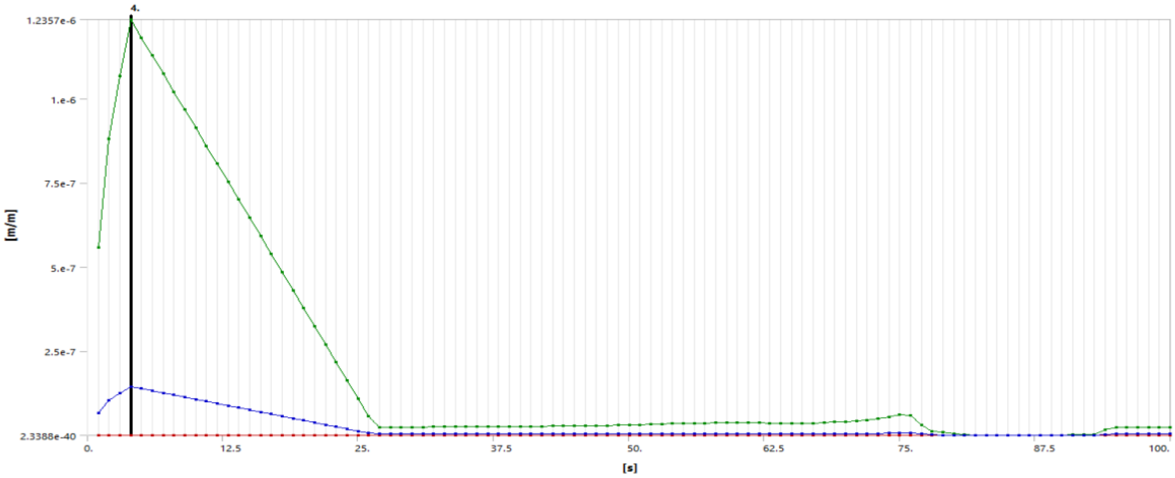


Fig. 2: Minimum, Maximum, and Average Strain against time.

4. Conclusion

A design methodology of powertrain parameters matching for electric vehicles using IGNITE, aimed at finding the optimal torque-speed profile for the electric driving system based on vehicle dynamics to be applied on the sprocket. Parameter matching was achieved through 3D computational modelling coupled with 0D powertrain modelling. The simulation with NEDC driving cycles demonstrates that the design of powertrain parameters can meet the design specification of the vehicle's power performance. Therefore, this methodology can be used to design other EVs. Further, the analysis of the sprocket was undertaken in terms of Static Structural.

Keywords. Powertrain matching, sprocket.

References

[1] Rohan Rai (2020). Designing and Validation of a Sprocket Wheel for a Formula Student Vehicle. International Journal of Engineering Research and, V9(05).

[2] Gong, X.W., Wu, D.J. and Ma, J. (2013). Matching Design and Simulation of Powertrain Parameters for Electric Vehicles. Advanced Materials Research, 655-657, pp.596–602.

EVC2023

COMMITTEE MEMBERS

ORGANIZING COMMITTEE

CHAIR
Dr. Efstathios-Alexandros Tingas

CO CHAIR
Dr. Firdaus Muhammad-Sukki

EDITOR / PUBLICATION CHAIR
Dr. Firdaus Muhammad-Sukki (Chief Editor)
Dr. Efstathios-Alexandros Tingas
Dr. Nurul Aini Bani

LOGISTICS & PUBLIC RELATIONS SUPPORT
Yvonne Lawrie
Gary Wright

TECHNICAL PROGRAMME COMMITTEE

Dr Alexandros Nikitas
University of Huddersfield, United Kingdom

Dr Chenghong Gu
University of Bath, United Kingdom

Dr Colin Axon
Brunel University London, United Kingdom

Dr Daniel Auger
Cranfield University, United Kingdom

Professor Emma Kendrick
University of Birmingham, United Kingdom

Professor Haiping Du
University of Wollongong, Australia

Professor Kang Li
University of Leeds, United Kingdom

Professor Liana Cipcigan
Cardiff University, United Kingdom

Professor Miadreza Shafiekhah
University of Vaasa, Finland

Dr Nurul Aini Binti Bani
Universiti Teknologi Malaysia, Malaysia

Dr Patrick Jochem
DLR, Germany

Dr Safak Bayram
University of Strathclyde, United Kingdom

Dr Shawn Ou
Oak Ridge National Lab, United States

Dr Vahid Vahidinasabn
Nottingham Trent University, United Kingdom

Professor Yulong Ding
University of Birmingham, United Kingdom

Dr Zhenhong Lin
South China University of Technology, China