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Trends in High Voltage Inverter Systems

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Abstract

Current EV (Electric Vehicle) technology is effective but where is it going in the future? This paper looks at the current trends in the EV 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. The tends in the market were directly discussed with leading vehicle OEMs, Tier 1 suppliers and research institutions. The clear trend is for the use of silicon carbide power devices with high performance microcontrollers and 6 phase motors with model based tools further in the future.

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

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 enhanced control, high voltage inverter modules in the vehicle.

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2. Methodology

As a semiconductor vendor in the automotive market, there are opportunities to discuss current and future EV concepts with vehicle manufacturers and Tier 1 suppliers. The vehicle manufactures and automotive tier 1 suppliers develop inverter systems for electric vehicles. Discussions were held with their design and research teams during direct meetings to understand future developments. 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.

3.1. 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. GaN based EV traction inverters have not reached production yet with only development modules being announced (Q. Song et al. 2021). There is some work currently underway on GaO (Gallium Oxide) as a possible successor to GaN. Currently there are only single transistors for GaO and it will be a while before high power modules are developed (M. Higashiwaki 2022).

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 Fig. 1. GaN will continue to drive this downward trend providing future switching loss reduction. Most traditional power electronic semiconductor suppliers provide full SiC development processes. This means they can create power semiconductor devices based on their own monocrystalline wafers. SiC powertrain inverters are becoming mainstream.

3.2. Power driver

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:

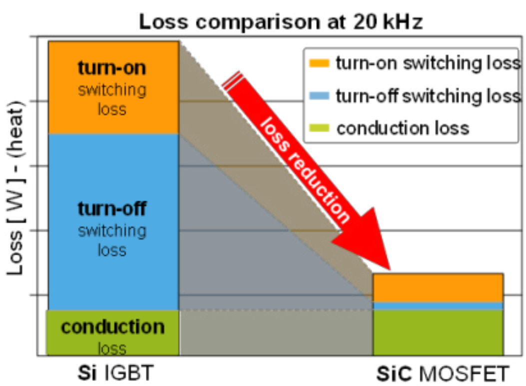

Fig. 1. Switching Loses

- 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.

Something that also needs to be considered in the use of permanent magnets in the motor. Growing market demand for rare elements like neodymium, samarium, cobalt, and other elements needed for permanent magnet production, partially driven by electric mobility, results in a high supply risk for these materials. This is the top reason why manufacturers all around the world are looking for alternative electric machine technologies. Non-permanent magnet technology significantly reduces environmental impact. Switch reluctance (Z. Zhang 2021), and induction machines (R. Thomas et al. 2021), as well as electrically excited synchronous machines (G. Mademlis et al. 2020), are currently under intense development. All of them represent a reasonable alternative to permanent magnet technology and radial PM machine technology.

3.3. 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.

Adding more phases for supporting safety requirements and lowering ripples in speed and torque is not the only significant change in electric motor technology. Another challenge is to create a smaller, faster and more efficient propulsion unit. Electric motors are the heart of the propulsion unit and can be modified to achieve this trend. The target is to increase power density of propulsion units. The most straightforward way to achieve higher power density is to use high-speed motors. Fig. 2 describes a simplified equation for output power ’P’ in the case of electric motors. As can be seen all components in the equation are proportional to each other. The component highlighted in red represents phase current frequency while components in black represent the electric motor cross-section. If the input current frequency is increased and the cross section decreased by the same factor, output power stays the same. By increasing the input current frequency, the volume of the motor can be reduced while output power stays the same. This simple relationship directly affects the MCU’s (MicroController Unit) peripherals and brings several advantages to electric vehicle technology integration.

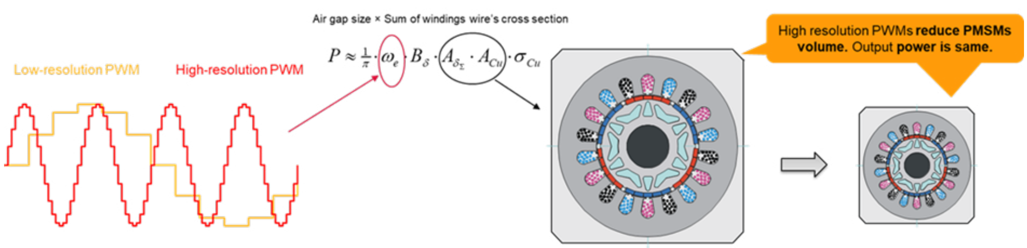

Fig. 2. Power equation

3.4. Position sensing

Currently motor rotor position sensing is dominated by the resolver. It provides very accurate results and is mechanically robust. However, the mechanical components and the processing of the signals are expensive. Inductance position sensors look like possible successors to the resolver as they provide similar features but at a lower cost.

3.5. 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 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 performance 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) in the EV powertrain, reducing overall size, complexity, and weight of the system. (Chatelain et al. 2018). MCUs are integrating more features to reduce external components which drives cost reduction in the Bill of Materials. Functionality, such as the external resolver position decoder, can be moved into the MCU by using a combination of MCU features and software.

The S32K396 from NXP, shown in Fig. 3, is a new MCU 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.

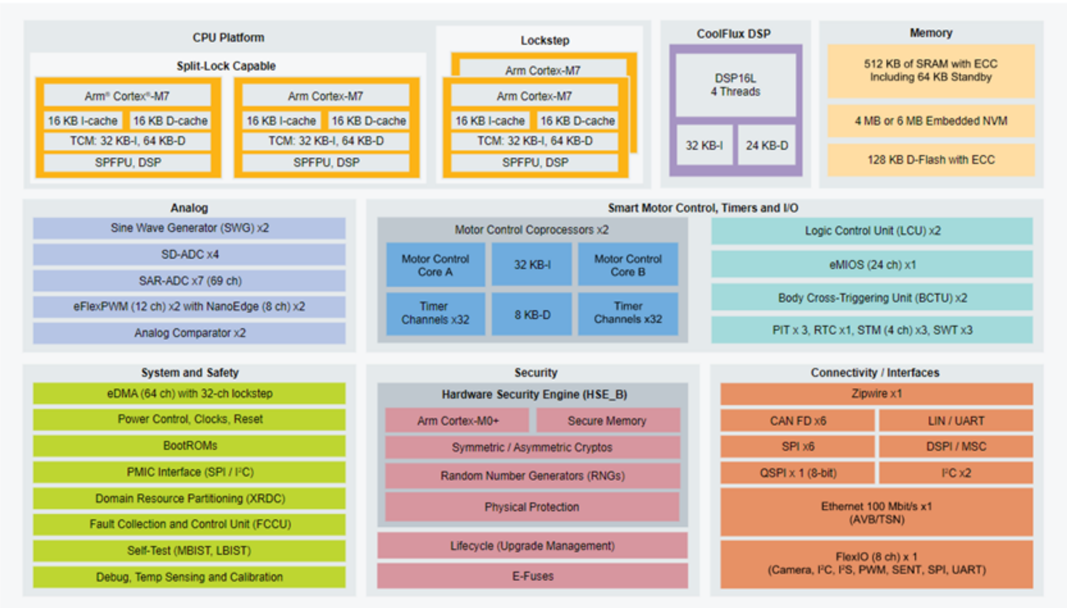

Fig. 3. NXP S32K396 MCU

3.6. Control and programming

With the growing number of modules in vehicles and the functionality of these modules rising, the amount and complexity of software for vehicles is rapidly increasing. The requirement of increased additional safety to support autonomous driving applications is also contributing to the complexity of software. It would not be sustainable to continually increase the size of software teams to support the increasing requirements. The solution is to move to model-based design software development. Model-based software design uses high level modelling tools, like MATLAB and Simulink to develop the software. This has the advantage of reducing software development resources while also reducing cost and development time. The only disadvantage to this solution is that the code generated by the modelling tools is larger and requires more computation performance to execute it.

New features that are being added are preventative maintenance and aging monitoring. Using algorithms to identify conditions that could cause problems, so they can be repaired before a failure, provide for increased reliability. Monitoring the aging of the system could allow the lifetime of the vehicle to be extended based on actual usage rather than estimates. These new features can provide real benefits to vehicle owners, however like model-based design they will require more computational performance to implement them. This is why new, more powerful devices, like the NXP S32K396 are being used for these types of advanced inverter applications.

3.7. 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 Miles Per Gallon (MPG) by 4.5 %. (Cavanimim Majecki et al. 2022)

4. Conclusion

To allow a comfortable 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. Current trends indicate that future, higher efficiency systems will use 6-phase, axial flux motors driven by GaN power devices with inductance based feedback requiring advanced MCUs like the NXP S32K396 to control them.

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