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The latest generation drive for electric buses powered by SiC technology for high energy efficiency

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Abstract. High energy efficiency and increasing the working frequency of the converter will make it possible to minimize the size of the cooling system and reduce energy consumption. The use of the SiC technology in propulsion drives increases the efficiency of the converter by 1÷1.5%. Simultaneously, higher working frequency reduces losses in the traction motor, significantly lowering the cost of the energy consumed by the vehicle. Auxiliary converters using the SiC technology are a new quality. The reduction of weight and size is very significant (ca. 40÷50%). Higher switching frequency reduces the size of magnetic components (ca. 80%), and higher converter efficiency minimizes the size of the cooling system. The overall efficiency of the converter is extremely high (94÷96%). This paper presents comparison of Si and SiC parameters which are important for modern EV solutions. Paper presents also parameters of SiC traction inverter and auxiliary converter, designed and manufactured as state-of-the-art product for modern electric bus.

1 Technology of silicon carbide components (SiC)

Modern electric buses, which are operated in cities around the world, use traction inverters and static converters to power on board equipment of the e-bus. In the case of modern e-buses, they provide higher power than traditional rotating inverters. This device, commonly used in electrical traction units, is currently designed and manufactured using IGBT (Insulated Gate Bipolar Transistor) transistor technology. By achieving high reliability and electrical efficiency, technology widely used since the mid-1990s is now recognised as a market standard and used by most manufacturers of electronic components [1-13].

According to the predictions of research institutes, vehicle manufacturers and component manufacturers, in the near future IGBT technology will be replaced by SiC technology [14-16].

Power elements based on the new SiC technology are built on silicon carbide semiconductors (Silicon Carbide, SiC), while the current technology is based on silicon semiconductors. Intensive R & D work carried out by component manufacturers has enabled the availability of SiC components with a reliability similar to that of conventional components and has led to a gradual reduction in production costs, which now allow these components to be commercially used in power electronics.

In traction applications where low weight, small size and high efficiency are the most important parameters of power electronics, the new silicon carbide (SiC) semiconductor technology is changing the game rules. The new semiconductor material has significantly better physical properties than silicon (Si), which allows to build on its base the best power instruments: diodes and transistors. It can be noted that compared to commonly used silicon elements, SiC power elements:

- have shorter switching times,
- have lower voltage drops during conductivity,
- can operate at higher joint temperatures.

As a result, power losses in transformer systems designed with the new technology are significantly lower, which allows to reduce energy consumption, but also to reduce the weight and size of cooling systems. You can also increase the switching frequency of semiconductor components and reduce the weight and size of passive components [17-19].

Application of the new SiC technology in drive inverters allows to increase their energy efficiency by 1÷1.5%. At the same time, the higher switching frequency reduces power losses in the propulsion engine, reducing the power consumed by the vehicle [20, 21].

Static converters using silicon carbide components are a new quality – dimensions and weight can be reduced by up to 50%. The higher switching frequency allows to minimize the size of magnetic elements up to 80%, while lower losses reduce the dimensions of cooling systems. The overall energy efficiency of the inverters is very high, ranging from 94÷96%.

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Three types of semiconductor components are now available for traction applications using the new silicon carbide technology (Fig. 1):

- Silicon carbide Schottky diodes
- Hybrid modules (silicon IGBTs with SiC Schottky diodes)
- “Full-SiC" modules (SiC MOSFET + SiC diodes).

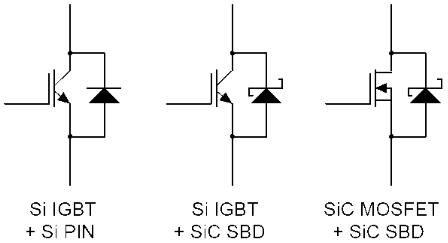

Fig. 1. SiC semiconductor component types – IGBT, hybrid IGBT (transistor with SiC diode), full SiC (SiC MOSFET with SiC diode).

In Fig. 2, a comparison of parameters of IGBT Si and SiC elements for electrical traction power equipment applications is presented.

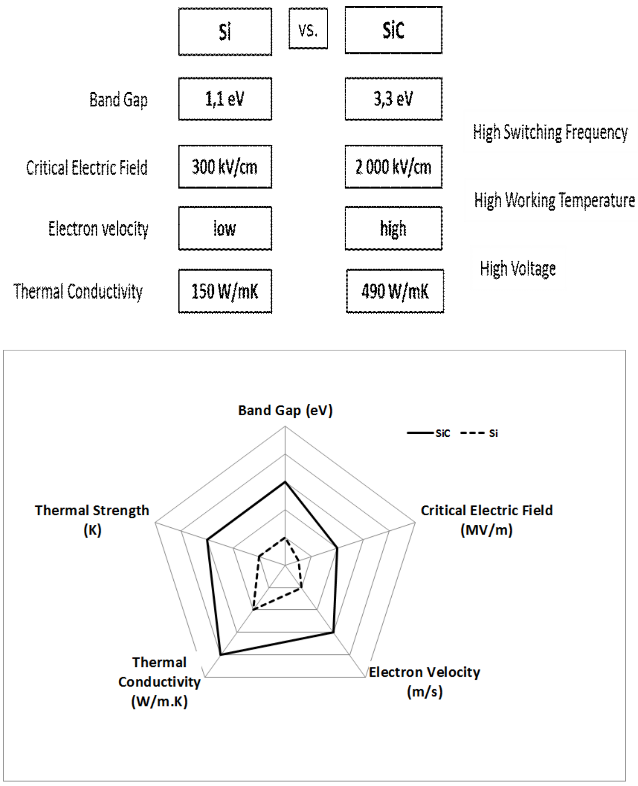

Fig. 2. Comparison of basic parameters of IGBT Si and SiC elements.

Utilizing the advantages of the latest generation SiC components also requires a new approach to device design, as shown in Fig. 3.

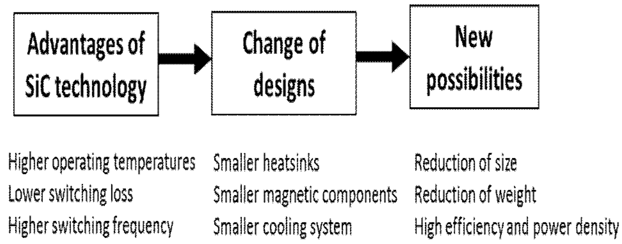

Fig. 3. A new approach to the design of SiCs.

2 Traction inverter integrated with the auxiliary converter with SiC power elements

The FT-160-600 traction inverter is designed for driving electric buses. The inverter is made in full-SiC technology. The drive inverter is controlled by a DSP (Digital Signal Processor) controller using the FOC SVPWM (Field Oriented Control Space Vector Pulse Width Modulation) algorithm. The controller guarantees optimum control of the asynchronous motor and ensures very good traction and high level of driving comfort. The design of the traction inverter allows it to be used for supplying the "classic" traction motor as well as motors integrated with the bus drive axis. The block diagram of the e-bus traction system with SIC inverter and converter is shown in Fig. 4.

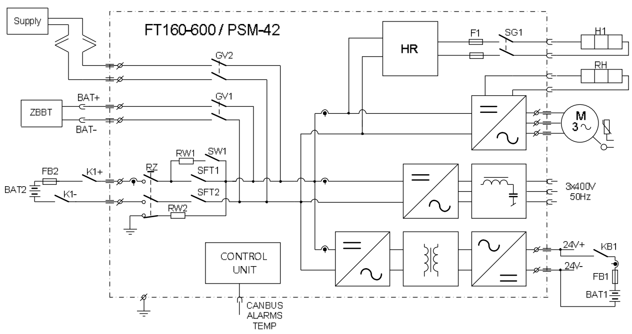

Fig. 4. Block diagram of traction system with inverter and converter FT-160-600 / PSM-42 SiC.

The inverter is equipped with natural air cooling. The system meets all European standards and the requirements of Regulation No. 100 (R100) on safety and radio interference. The system is installed on the roof of the vehicle. It is equipped with an integrated high voltage switchgear connecting the traction battery, buffer power supplies and precharging system in one box. The latest generation of applied elements and advanced diagnostic system guarantee a high level of reliability and low operating costs. The PSM-42 static converter with a power of 30kVA/3x400V AC and 12kW/24V DC is placed in the same box. Fig. 5 shows the device view. The technical parameters of the SiC inverter and SiC converter are shown in Table 1.

Fig. 5. View of the FT-160-600 inverter.

Table 1. Parameters of the FT-160-600 SIC inverter and the PSM-42 SiC converter.

Specification of FT-160-600 inverter	
Input voltage	520 - 750 VDC
Auxiliary voltage	24 VDC + 30%... – 40%
Rated current	300 Arms
Maximum current	500 Arms
Rated power	160 kW
Frequency	0 ÷ 350 Hz
PWM frequency	2 - 6 kHz
Insulation strength	2,5 kV
Cooling	natural, air
Dimensions	1430×990×330 mm

Specification of the PSM-42 converter	
Input voltage	520 - 750 VDC
Auxiliary voltage	24 VDC + 30% – 40%
AC output nominal power	30 kVA
AC output voltage	3x400 VAC +/- 10% (sinus)
AC output frequency	50 Hz
AC output current	43 A
Overcurrent	1.5In/30 sec.
Electronic protection	overcurrent/ overvoltage/ overheating
DC output nominal power	12 kW
DC output voltage	24 VDC
DC output current	500 A
Insulation strength	2,5 kV
Cooling	natural, air
Weight of the set	165 kg

Summary

Electric vehicles are an important part of life around the world, and this is why it is important to save energy. Power elements based on SiC technology allow for significant reduction of energy losses, increasing the efficiency of the inverters. The expected reduction of dynamic losses is approx. 50% compared to IGBT technology. In addition, power elements based on SiC technology have a significantly higher operating speed, which allows higher frequencies to be used, allowing the use of smaller and lighter magnetic components, which can reduce the weight and size of devices by more than 40% compared to traditional designs. Increased switching frequency reduces traction engine losses by lowering the energy cost of the vehicle.

Improvements in efficiency combined with a decrease in the weight and size of equipment is now one of the key improvements sought by electric vehicle manufacturers. Components based on SiC technology reduce the weight of the whole vehicle, reducing energy consumption. The overall efficiency of SiC converter is ca. 94÷96%, SiC technology of inverter gives 1÷1.5% better value compared to IGBT.

An additional advantage, which is particularly important for vehicle passengers, is the reduction of noise generated by devices based on SiC components, allowing for greater comfort of travel.

The use of semiconductor components in SiC technology in the propulsion system and power supply will reduce energy consumption by about 5÷15% compared to traditional silicon technology. The use of SiC technology is a true technological revolution in the design of innovative power electronic devices for public transport.

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