Comparison of Si and SiC based Power Converter Module of 150 kVA for Power System Applications

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Abstract — **The paper deals with the comparison of power semiconductors based on Si and SiC in application of power converters for power systems. These are single-phase voltage-source bridge inverters with nominal power of 150 kVA. Power converters are designed to operate under both active power and reactive power. Mechanical design of the converters is ready for interchange the power semiconductor modules and assess the operation with both, Si and SiC technology.**

Keywords — Si semiconductors, SiC semiconductors, single-phase voltage-source inverter, power converter.

I. Introduction

The power semiconductors converters are increasingly becoming a part of systems in the field of electric energy transmission and distribution. Although this field is rather conservative, where safety and reliability is preferred above all, the trend is expected to continue growing. The grid-connected power converters are used as active power filters, voltage conditioners, for compensation of reactive power, power flow control, or voltage symmetrisation in the grid [1, 2]. Recently, the biggest attention is paid to the transmission technology using HVDC.

Utilization of power semiconductor converters in applications such as the earth fault compensation is also assumed to grow. The compensation of the single-phase earth faults in distribution grids with ineffectively grounded neutral (in the Czech Republic grids of 22 and 35 kV above all) is traditionally provided by passive devices, connected between the neutral point of the distribution transformer and the earth point.

Compensation of a dominant reactive component of the earth fault current is provided by a tuneable inductor (arc suppression coil/Petersen coil), which is tuned to be in resonance with parasitic capacitances of the distribution grid [3]. A new technology based on power converters can bring a lot of advantages and new possibilities to this field, coming from the active character of the device. For example, it is possible to employ the power converters for compensation of the active power and harmonic components of the earth fault current, voltage symmetrisation in the grid, etc.

However, the grid-connected power converters need to meet high requirements for safety, reliability and also power quality. The waveform of the drawn current can be significantly distorted due to the switching frequency. This often results in the need to connect the power converter to the grid via a LCL filter which helps to ensure the quality required.

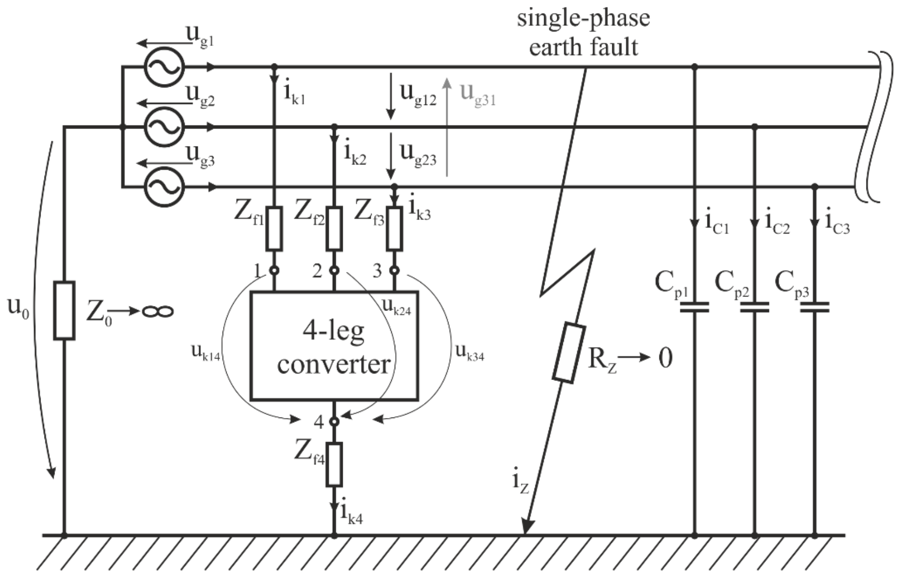

Fig. 1. Compensation of single-phase earth faults in distribution grids with ineffectively grounded neutral.

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II. Power Converter Module of 150 kVA

The power converter which is used as the basic power module for the compensation system is shown in Fig. 2 and Fig. 3. It is a single-phase voltage-source inverter composed of four power modules in the bridge topology. The breakdown voltage of the modules is 1200 V. Each AC output is supplied by two parallel modules, i.e. the power converter is composed of 8 power transistors. Fig. 2 shows the 3D converter design and the final module.

The power converters are designed for replacement of power modules based on Si (Infineon FF450R12KT4, see Tab. I) and SiC (Cree CAS300M12BM2, see Tab. II). Besides interchangeability of the modules, special attention has been paid to reverse diodes, whose dimensioning in many types of modules often does not correspond to the parameters of its transistor; usually, the converter is expected to operate in the dominating active power mode, where the transistors are much more strained compared to their diodes. However, in applications related to power systems, the reactive power mode is often dominating, and thus, the diode dimensioning must be taken into account.

For the optimal power loss distribution, it is critical to ensure an even distribution of the current flow, and thus, the parallel connection of the power semiconductor modules is designed to be ideally symmetrical.

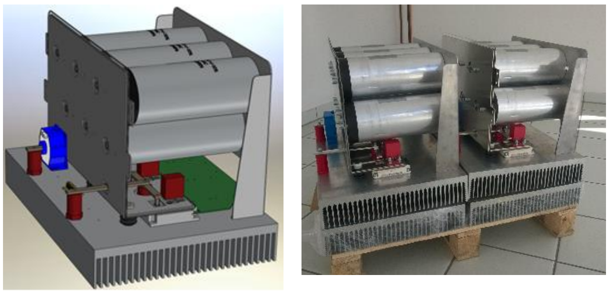

Fig. 2. 3D design and final module of the single-phase voltage-source inverter with rated power of 150 kVA.

TABLE I.
Basic Parameters of Si-based Power Module FF450R12KT4

Si transistor FF450R12KT4		
Collector – emitter voltage	V_{CE}	1200 V
Transistor continuous DC collector current	$I_{c\ nom}$	450 A
Diode continuous DC forward current	I_F	450A
Turn-on energy loss per pulse	E_{on}	30 mJ
Turn-off energy loss per pulse	E_{off}	40 mJ
Diode recovered charge	Q_{rr}	80 µC
Max temperature under switching conditions	T_{max}	150 °C
Package		62 mm
Technology		Si IGBT4 Si HE diode

TABLE II.
Basic Parameters of SiC-based Power Module CAS300M12BM2

SiC transistor CAS300M12BM2		
Drain – source voltage	V_{DS}	1200 V
Continuous DC drain current	$I_{D\ nom}$	285 A
On state resistance	R_{DSon}	5,7 mΩ
Turn-on energy loss per pulse	E_{on}	6,05 mJ
Turn-off energy loss per pulse	E_{off}	5,95 mJ
Diode recovered charge	Q_{rr}	3,2 µC
Max temperature under switching conditions	T_{max}	150 °C
Package		62 mm
Technology		SiC MOSFET SiC Schottky

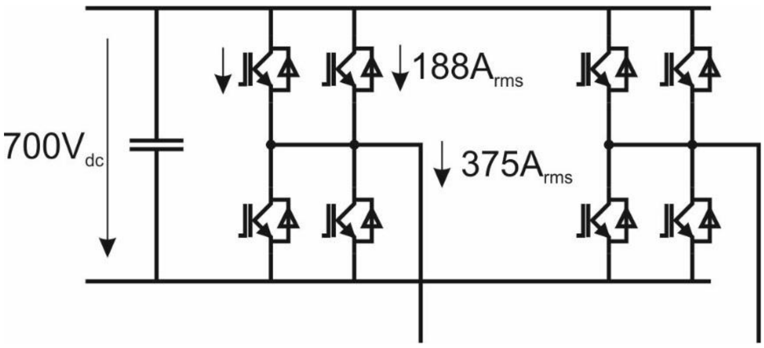

Fig. 3. Basic diagram of one block for the single-phase bridge inverter with rated power of 150 kVA.

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III. EXPERIMENTAL MEASUREMENTS

A special laboratory stand was built for experimental measurements and testing of the designed power converters (rated power 150 kVA). In order to provide full power of 150 kVA, the converters were interconnected in back to back topology with sinusoidal LCL filter.

Both power converters were interconnected on their DC sides to interchange the active power. At the same time, the AC sides have been connected via an LCL filter which enables to interchange both, active and reactive power. The used topology is shown in Fig. 3.

The common, interconnected DC bus of both converters is supplied by the three-phase grid and three-phase diode bridge rectifier. However, the main power (150 kVA) is circulated through the DC and AC terminals between both power modules, and thus, the three-phase power supply covers only the power losses of the whole installation. The interconnection of inverters on the AC side is realized via the LCL filter, transmitting the AC power of 150 kVA and filtering the harmonics. In order to ensure safe operation, all terminals of the LCL filter contain inductors, so the common DC part is not short-circuited when switching. At the same time, to ensure the system controllability with a single PWM synchronous control unit, the LCL filter terminals are crossed at one side.

Fig. 5 shows the employed control diagram, which was implemented in real-time environment using floating-point DSP TI TMS320F28335. Every single power converter is controlled by one PWM unit. The power converter #2 is controlled to generate the target AC voltage of 400 V_{rms}. Therefore, its control sine waveform directly enters the PWM block and no current controller is employed.

In case of the converter #1, the sine wave current reference is compared to the actual current measurement and the difference enters the proportional-resonant controller, which ensures the current control directly in $\alpha\beta$ coordinates. The output of the controller is a difference between voltage generated by the converter #2 and the voltage needed to reach the current reference. Sum of the u and Δu signals enters then the PWM block. Thus, using the current control, various converter operation can be tested and measured, e.g. active and reactive power mode as well as inverter and rectifier mode, all at various power rates.

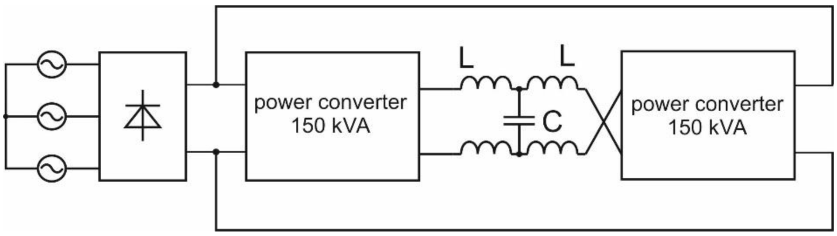

Fig. 4. Diagram of laboratory stand of two power converters interconnected via LCL filter.

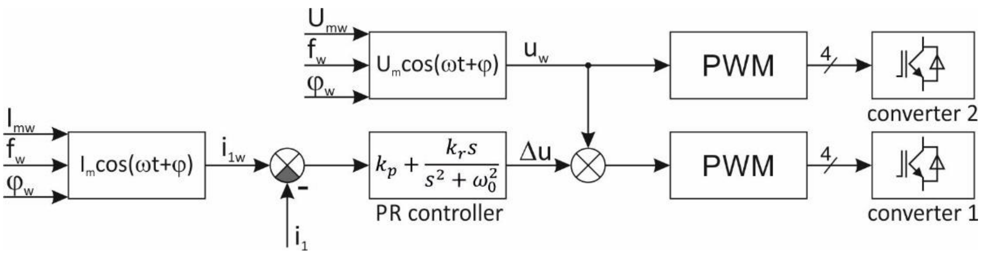

Fig. 5. Diagram of the implemented control algorithm employing proportional-resonant controller for current control.

IV. EXPERIMENTAL MEASUREMENTS

Fig. 6 shows the output voltage and currents of both AC inverters in the active power mode, i.e. operating at the power factor cos φ = 1. The DC link voltage is rather constant (700 V). The rms value of the output voltage (1st harmonic component) is 400 V and the output current reaches 390 A_{rms}. In this operation mode, first power converter operates as a power source, in the inverter mode, and the second one as a load, in the rectifier mode. The corresponding current waveforms of both power converters can be seen in Fig. 6, while their voltages are of opposite polarity. It corresponds to the active power flow; the 1st converter is controlled as a power source and the 2nd one as a load.

The peak to peak ripple of the current reaches 60 A at the applied switching frequency of 20 kHz (current switching frequency). The switching frequency of the power transistors is 10 kHz.

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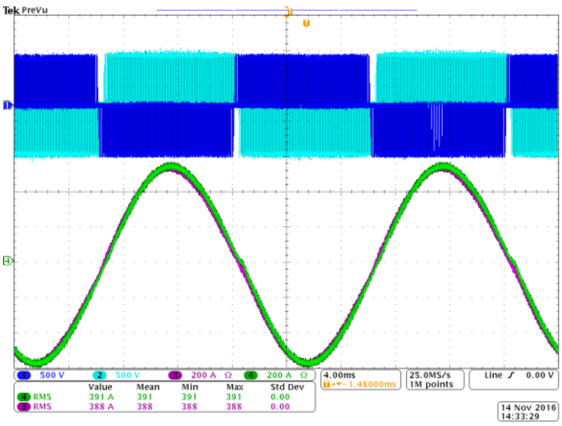

Fig. 6. AC currents and voltages of both power converters interconnected via the LCL filter.

Fig. 7 shows the power flow in a common interconnected DC link between both converters operating in the active power mode where the mean current value is 230 A. In case of the reactive power operation mode the mean current is close to zero.

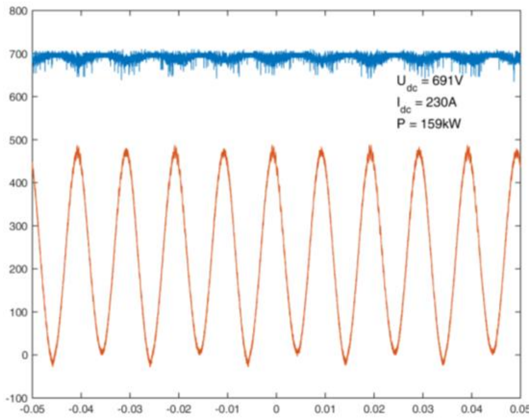

Fig. 7. Power flow in the common DC link in the active power mode.

A comparison of the Si and SiC technology can be made based on Figs. 6 and 7. Both temperature measurements show the hottest point, measured at the base of the power module. Measurement taken with Infineon FF450R12KT4 modules (Si technology) can be seen in Fig. 6. When the inverter is fully loaded (~160 kW), the maximum temperature reaches 105 °C. A corresponding measurement has been taken with the Cree modules CAS300M12BM2 (SiC technology), shown in Fig. 7. Due to significantly lower switching losses with SiC technology, better results have been reached compared to Si modules. The point of the highest temperature reaches a maximum of 48 °C.

Conclusion

Comparison of the Si- and SiC-based power modules has been made using power converters of 150 kVA designed for power systems and energy distribution applications, being specific by dominant operation in reactive power mode. Experimental results show a significant difference of maximum surface temperature reached at the transistor switching frequency of 10 kHz. The temperature difference is nearly 60 °C. It can be seen, that the SiC technology offers space for increasing of the switching frequency, which is beneficial regarding the LCL filter dimensioning, whereas the Si technology reaches its operation limit on the installed heat sink. On one hand, the SiC power modules increase the costs compared with Si modules, reducing the current ripple, on the other hand, has a significant impact on savings in design of the LCL filter.

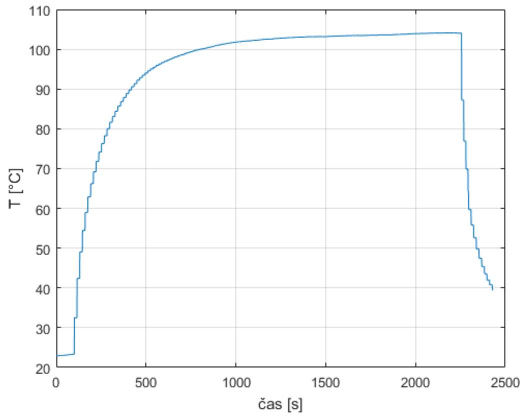

Fig. 8. Temperature curve during testing with Si Infineon FF450R12KT4 transistors.

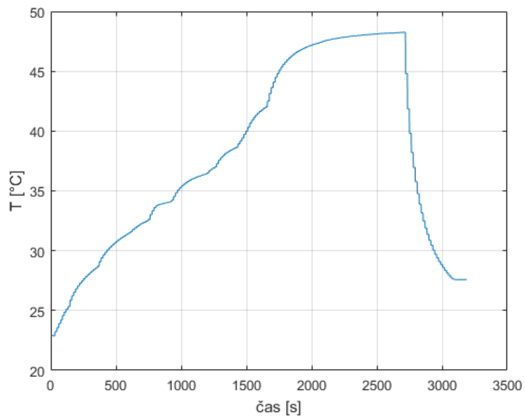

Fig. 9. Temperature curve of converter during testing with SiC CREE CAS300M12BM2 Transistors.

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