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WOJCIECH MYSIŃSKI, WIESŁAW JAKUBAS*

GATE DRIVER FOR SiC MOSFET TRANSISTORS

STEROWNIK BRAMKI TRANZYSTORÓW MOSFET SiC

A b s t r a c t

As new power transistors, such as SiC Mosfets, are being increasingly used in power electronics systems, it has become necessary to use special drivers. This article compares the parameters of SiC Mosfet, Si Mosfet, and IGBT gate circuits. Differences are discussed with reference to the ways in which these transistors are controlled. Gate circuit parameters of SiC transistors differ slightly from those of common Mosfet or IGBT transistors, and in order to be able to fully utilise the capabilities of these new devices, it is necessary to employ appropriate drivers. This article discusses one such driver for SiC transistors.

Keywords: SiC Mosfet, gate driver

S t r e s z c z e n i e

Ze względu na coraz częstsze stosowanie nowych tranzystorów mocy typu Mosfet SiC w układach energoelektronicznych istnieje potrzeba zastosowania specjalnych układów sterowników bramek. Parametry obwodu bramki tranzystorów zbudowanych na węgliku krzemu są trochę inne niż typowych tranzystorów Mosfet lub IGBT i żeby w pełni wykorzystać właściwości tych nowych elementów, należy zastosować odpowiednie sterowniki. W artykule przedstawiono jeden z przykładów sterowników (tzw. *gate driver*) dla tranzystorów typu Mosfet SiC.

Słowa kluczowe: tranzystor Mosfet SiC, sterownik bramki

* Ph.D. Eng. Wojciech Mysiński, Ph.D. Eng. Wiesław Jakubas, Institute of Electrotechnics and Computer Science, Faculty of Electrical and Computer Engineering, Cracow University of Technology.

1. Primary differences between Si and SiC MOSFETs

Silicon carbide-based power transistors have been around for several years and have been discussed in numerous scientific publications [4–6, 9, 11]. SiC diode and transistor manufacturers continue to add new versions of such transistors to their offering.

Main advantages of SiC MOSFETs, as compared with Si and IGBT MOSFETs, include:

- high switching speed, shorter turn-on and turn-off times,
- lower switching losses,
- lower conduction losses, a lower V_{DS} drop for high voltage devices.

Disadvantages:

- higher gate voltage V_{GS} is recommended in order to achieve low V_{DS} drop, e.g. 20 V,
- costs of SiC devices,
- differences between the performance characteristics of gate circuits in devices made by different manufacturers.

In short, it may be said that converters based on SiC devices exhibit higher efficiency, and their higher switching frequency enables designers to use smaller inductive devices. Unfortunately, high current and voltage rise values can cause electromagnetic interference problems; therefore, the electro-mechanical design of converters needs to be prepared very carefully. Table 1 shows a comparison of the key parameters of gate circuits in SiC Mosfet, Si Mosfet and IGBT transistors for a 25°C operating temperature and similar I_D and V_{DS} values.

One of the major differences between SiC transistors, MOSFETs and IGBTs is their input and output characteristics. Figures 1 and 2 show the output characteristics of the transistors, drain current I_{DS} versus drain-source voltage V_{DS} for various V_{GS} or V_{GE} values in an IGBT. As can be seen, in a SiC Mosfet transistor, the V_{GS} voltage has a significant effect on the drain current and voltage drop V_{DS} across the transistor.

Table 1

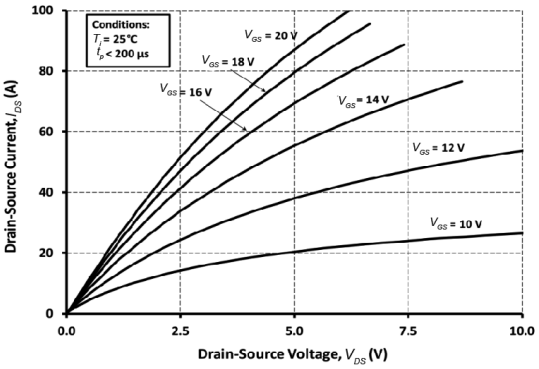
Basic differences between the gate circuits of selected transistors

Transistor type	Manufacturer	Nominal parameters V_{DS}/I_D [V]/[A]	Max gate voltage range V_{GS} [V]	Recommended gate voltage range V_{GS} [V]	Recommended gate resistance R_G [Ω]	Drain – source voltage V_{DS} at 25°C and I_D = 40 A, [V]
C2M0040120 – SiC	Cree	1200/40	–10/+25	–5/+20	2.5	1.8
SCH2080KE – SiC	Rohm	1200/40	–6/+22	0/+18	0	3.8
SCT30N120 – SiC	ST	1200/45	–10/+25	–2/+20	6.9	3.5
STE40NC60 – Mosfet	ST	600/40	–30/+30	0/+10	4.7	4
STGFW40V60DF – IGBT	ST	600/40	–20/+20	V_{GE} = 0/+15	10	1.8
RGT80TS65D – IGBT	Rohm	650/40	–30/+30	V_{GE} = 0/15	10	1.65

Maximum drain current I_D can assume significantly different values within the V_{GS} range 10–20 V. The smallest voltage drop V_{DS} (drain-source) across the transistor and consequently, the lowest transistor conduction loss, is achieved for V_{GS} = 20 V (Fig. 1).

Output characteristics of the SiC MOSFET and Si MOSFET and IGBT are different. For Si MOSFET and IGBT transistors, the maximum drain current I_D can be achieved at as low V_{GS} voltage as 10–15 V, and if the voltage continues to be increased further, this will not produce a significant difference in the value of voltage drops across the transistor (Fig. 2). This implies that, with respect to SiC transistors, it is advisable to apply the maximum gate voltage, as recommended by the manufacturer, so that conduction losses should be as minimal as possible. Depending on the manufacturer, the recommended voltage may vary over a range of ca. +18 V to +22 V. It should be emphasised that the maximum allowable gate voltage should not be exceeded, as this will lead to the device being damaged. In such transistors, the maximum positive allowable gate voltage varies over a range of +22 V to +25 V, depending on the manufacturer (Table 1). For a transistor to be turned off quickly, the driver should supply a negative voltage to the gate. In respect of SiC transistors, manufacturers recommend that a negative voltage in the range of ca. –5 V to 0 V should be applied. However, the maximum negative allowable gate voltage V_{GS} varies over a range of ca. –10 V to –6 V, depending on the manufacturer. On the other hand, the maximum allowable gate voltage V_{GE} or V_{GS} for IGBTs and Mosfets varies over the range ca. –20 V to +20 V.

a)



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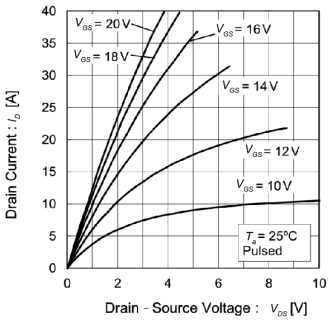

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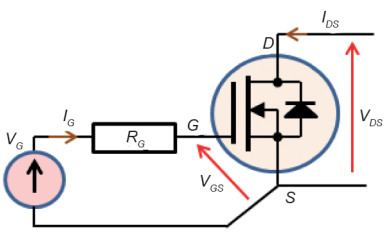

Fig. 1. Output characteristics of a SiC C2M004120D transistor from Cree (a), and of a Rohm SiC SCH2080KE transistor (b) and measurement circuit (c)

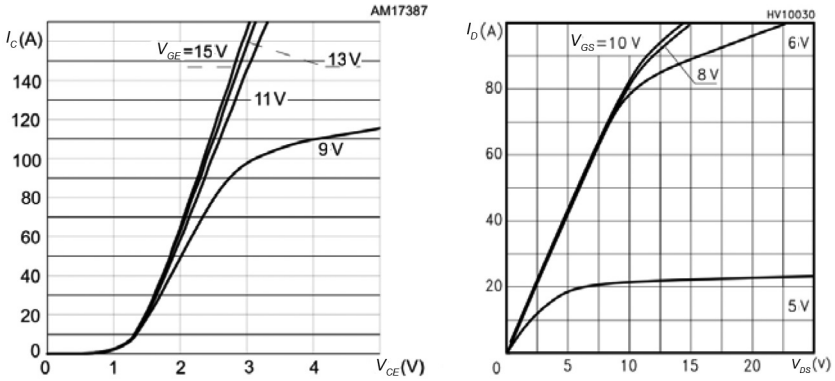

Fig. 2. Output characteristics of an IGBT STGFW40V60DF transistor from ST (a) and of a Mosfet STE40NC60 transistor, also produced by ST (b)

Table 2

Gate circuit parameters – recommended V_{GS} and R_G values for a SCT2160KE transistor, from Rohm

Parameter	Symbol	Conditions	Values			Unit
			Min.	Typ.	Max.	
Transconductance	g_{fs}	V_{DS} = 10 V, I_D = 7 A	–	2.4	–	S
Input capacitance	c_{iss}	V_{GS} = 0 V	–	1200	–	pF
Output capacitance	g_{oss}	V_{DS} = 800 V	–	45	–	
Reverse transfer capacitance	g_{rss}	f = 1 MHz	–	7	–	
Effective output capacitance, energy related	$c_{0(er)}$	V_{GS} = 0 V V_{DS} = 0 V to 500 V	–	71	–	pF
Tum – on dalay time	$t_{d(on)}$	V_{DD} = 400 V, I_D = 7 A	–	23	–	ns
Rise time	t_r	V_{GS} = 18 V/0 V	–	25	–	
Tum – off delay time	$t_{d(off)}$	R_L = 57 Ω	–	67	–	
Fall time	t_f	V_G = 0 Ω	–	27	–	
Tum – on switching loss	E_{on}	V_{DD} = 600 V, I_D = 7 A V_{GS} = 18 V/0 V R_G = 0 Ω, L = 500 µH E_{on} included diodereverse recovery	–	126	–	µJ
Tum – off switching loss	E_{off}		–	55	–	

On their data sheets, transistor manufacturers provide information on the recommended gate voltage ranges as well as gate resistance, so that optimal switching parameters could be achieved (Table 2). The proper selection of a series resistor for the gate circuit has a significant effect on the switching time parameters of the transistor.

One could use either a single resistance value or two different values; the latter option will have a greater effect on transistor turn-on and turn-off delay times. This, in turn, will have an effect on the rate of current and voltage rises in the power circuit as well as switching losses (Fig. 3). On the one hand, increasing the value of a resistor will slow down the switching of the transistor and will lead to higher switching losses; on the other hand, it helps to avoid oscillations in the gate circuit and the power circuit, which, in turn, reduces EMC interference generated by the transistor.

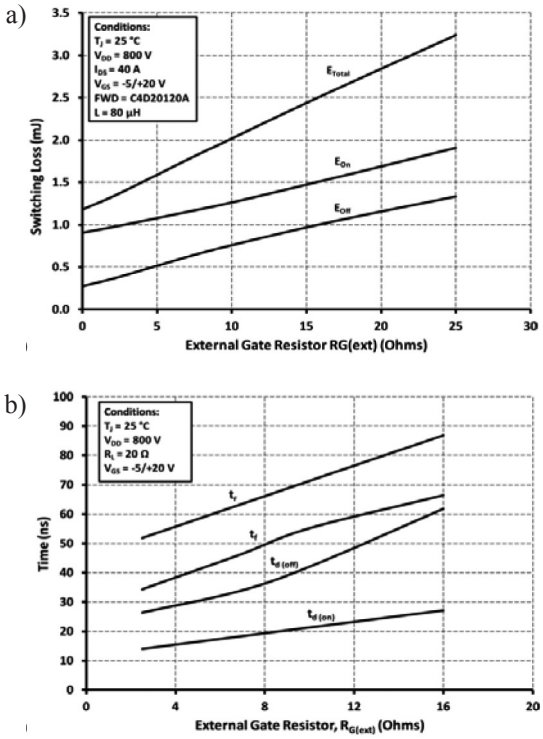

Fig. 3. Effect of the gate resistor R_G on switching losses (a) and switching times (b), for a SiC C2M0040120D transistor from Cree

2. Gate drivers for SiC transistors

At present, manufacturers offer many ready-made integrated circuits that are used as drivers for unipolar transistors and could also be used to drive SiC transistors; however, care needs to be taken to ensure that the device used can supply an output voltage within the range ca. +20 V to +22 V. Not all integrated circuits on the market meet this requirement. It is also possible to build a driver using discrete devices, such as those shown in Figures 4 and 5.

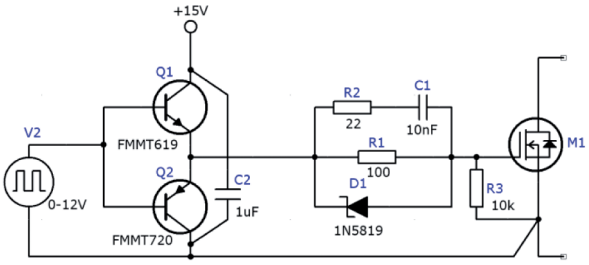

Fig. 4. Sample driver circuit based on discrete devices [10]

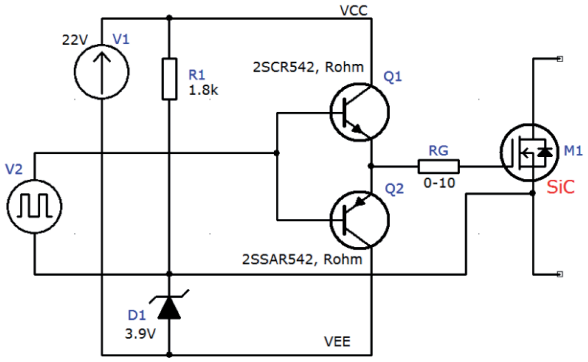

Fig. 5. Another driver produced by Rohm [11]

By simply using a diode in the gate circuit (Fig. 4), the value of series resistance in the gate can be changed; series resistance can take on different values upon the transistor being turned on and turned off. That is a very common solution employed in driver circuits for transistors, both SiC and Mosfets as well as IGBTs.

3. Designing, building and testing a driver

In order to build a driver for a SiC transistor, the authors used product documentation developed by the Cree company, which kindly made available articles on an isolated driver [3, 8]. Using the materials provided, after making certain modifications, the authors designed and built a driver for which a schematic is shown in Figure 6. An IXDN609SI integrated circuit, intended for use with IGBTs, MOSFETs and SiCs, is employed as a key device in the driver (*U*1).

Key parameters of an IXDN609 integrated circuit from IXYS:

- maximum peak output current (source and sink) $I_{OUT} = \pm 9$ A,
- wide supply voltage range $V_{cc} = 4.5$ V to 35 V,
- operating temperature range of –40°C to +125°C,

- input voltage range $V_{IN:}$ –5 V to V_{cc}+0.3 V,
- rise time t_f = 22 ns, fall time t_f = 15 ns, on-time delay t_{on} = 40 ns, off-time delay t_{off} = 42 ns for V_{cc} = 18 V and C_{obc} = 10 nF,
- quiescent supply current 10 μA,
- low output impedance R_{OH} = 0.6 Ω, R_{OL} = 0.4 Ω.

In order to provide galvanic isolation for the entire driver, isolated DC/DC converters have been used and the so-called digital isolator – an ADUM1100 isolator from Analog Devices for transmitting a signal driving the transistor. Thanks to the current efficiency of circuit U1, the driver can be used to drive both individual transistors and high power transistor modules incorporating several transistors connected in parallel.

The circuit that the authors designed and built has the following features and characteristics:

- full galvanic isolation in respect of power supply and control,
- driver power supply voltage +5 V,
- a TTL input signal (+5V), a logic '1', active state,
- voltage across the transistor gate, on-state –5 V, off-state +20 V,
- switching times are the same as U1 (IXDN609), and they are additionally determined by the resultant gate resistance value upon transistor turn-on, and a separate resistance value upon transistor turn-off.

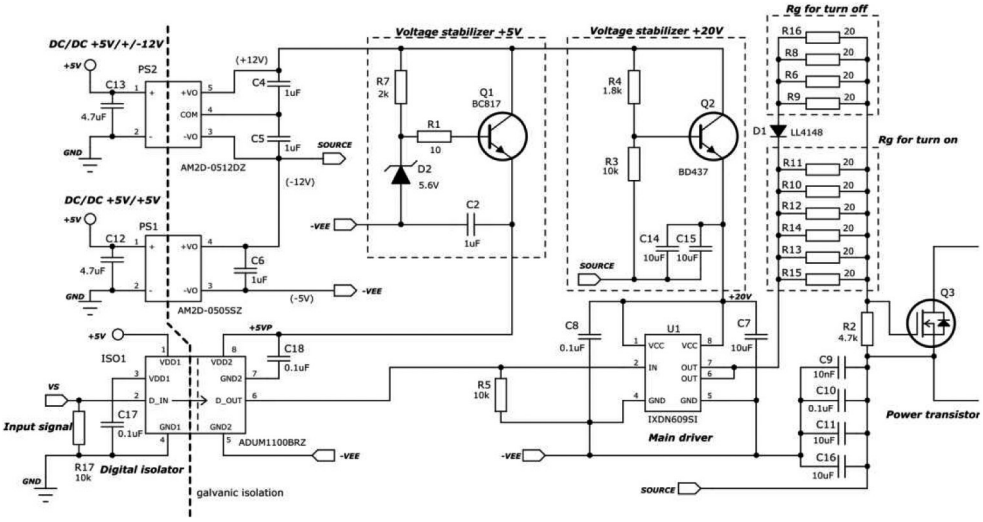

Fig. 6. Schematic of the driver for a SiC Mosfet transistor

Compared with the original circuit incorporating the materials [3], the actual circuit built was modified by replacing the ACPL-4800-300E optical coupler with the ADUM1100 digital isolator and adding an extra voltage linear stabiliser, so that gate voltage of +20 V could be achieved. The driver output voltage values (–5 V, +20 V) were adapted to a SCT2160KE transistor, made by Rohm.

For the entire circuit to operate, it is necessary to provide a number of supply voltages. Voltage of –5 V for turning off the transistor is supplied by the isolated DC/DC converter (+5

V into +5 V) (PS1). Voltage of +20 V for turning on the transistor is supplied by the isolated DC/DC converter (+5 V into ±12 V) (PS2). The output of converter PS2 provides +24 V (if load connected to the converter is small, output voltage can be as high as +26 V), so in order to achieve +20 V, a linear stabiliser circuit was added across transistor $Q2$. To enable digital isolator ISO1 to operate, the authors used a +5 V linear stabiliser across Zener diode D1 and transistor $Q1$. The driver module is installed on a 50×40 mm double-sided printed circuit board, with the devices mounted on both sides of the PCB (Fig. 7).

The output of $U1$ comprises parallel resistors and diode $D1$; these devices allow the user to set the resistance level required to turn on and turn off the transistor. Peak gate current values can reach several amperes and that is why the gate resistor needs to have a sufficient power rating to allow for dissipation of power as heat that will be emitted, particularly at high switching frequencies. It is imperative that the so-called coupling capacitors should block +20 V and –5 V supply voltages in close proximity to $U1$ and the SiC transistor. These capacitors should have low internal resistance. The connection between the driver and the transistor should be kept as short as possible in order to minimise connection inductances and thus to minimise oscillations in the gate circuit [3–5].

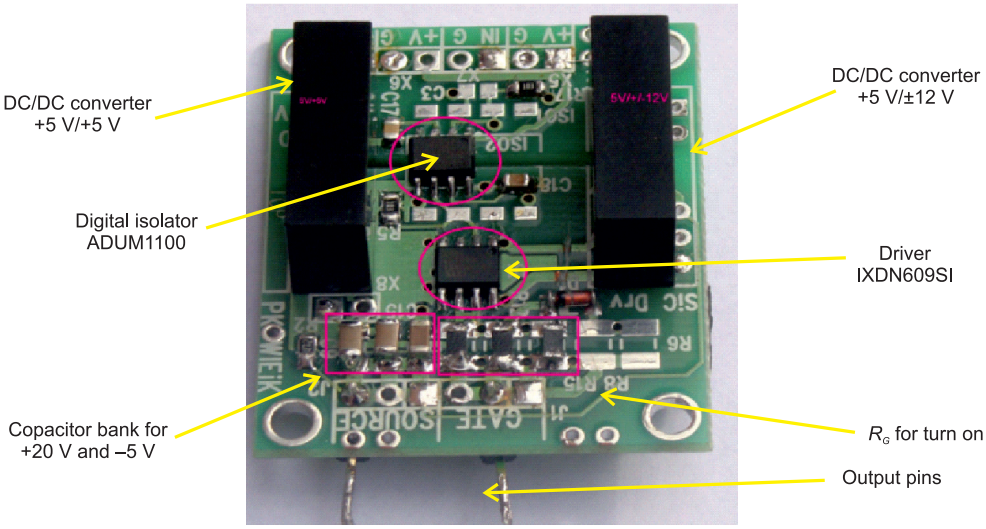

Fig. 7. PCB used to build the driver

The 2 W DC/DC converters and the digital isolator provide galvanic isolation of up to 1.5 kV, so the driver can be used for circuits supplied with voltages up to 600 V. If the inverter is to operate at higher voltages, it is necessary to use converters designed for isolation voltage of 3 kV.

Figure 9 shows the results of laboratory tests on the driver. The waveforms represent control voltage V_S (Ch1), gate-source voltage V_{GS} (Ch2) and gate current I_G (Ch4). An SCT2160KE transistor was connected without the load; drain current $I_D = 0$ A and drain-source voltage $V_{DS} = 0$ V.

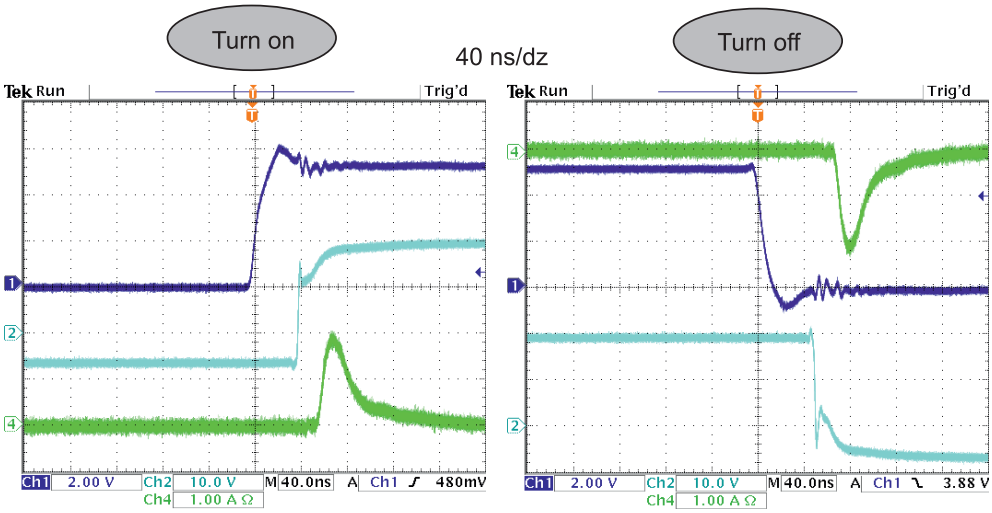

Fig. 8. Control voltage V_S (Ch1 – 2V/div), gate voltage V_{GS} (Ch2 – 10 V/div), gate current I_G (Ch4 – 1A/div). Gate voltage V_{GS} –5 V, +20 V, R_G = 3.3 Ω

As can be seen, the turn-on delay time is 40 ns, and the turn-off delay time – 43 ns. These values were measured without any load connected to the power circuit of the transistor. Figure 9 shows 6 drivers incorporated in a test model three-phase inverter.

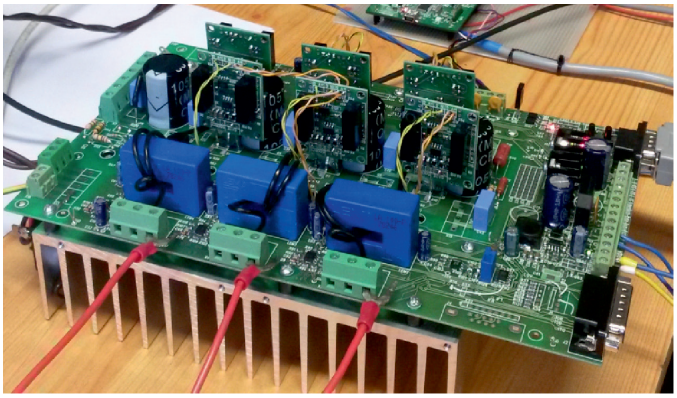

Fig. 9. Inverter incorporating transistor drivers

4. Conclusions

The driver designed by the authors delivers the required performance and has been used in tests of a three-phase inverter. The use of SiC transistors requires specially designed drivers. That is why standard drivers used to drive MOSFETs and IGBTs are not always suitable for use with SiC devices.

The driver built by the authors is designed only to turn on and turn off transistors; a complete driver should also provide overcurrent protection. The output circuit of the driver exhibits sufficient current efficiency to control a SiC transistor module that, for examples, has a maximum drain current $I_D = 100$ A. Where devices have lower power ratings, integrated circuits having lower output current can be used. A comparison of the characteristics of the gate circuits of SiC MOSFET transistors from a number of manufacturers shows that there are differences between these devices in respect of the recommended control voltage.

In order to fully utilise the capabilities of SiC transistors, the maximum gate voltages recommended by transistor manufacturers should be used.

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