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ANALYSIS OF THE USE OF TRANSISTORS BASED ON SiC TECHNOLOGY IN INVERTERS IN THE CONTEXT OF ELECTROMAGNETIC COMPATIBILITY

ANALIZA ZASTOSOWANIA W UKŁADZIE FALOWNIKA TRANZYSTORÓW WYKONANYCH W TECHNOLOGII SiC W ASPEKCIE KOMPATYBILNOŚCI ELEKTROMAGNETYCZNEJ

Abstract

Currently, manufacturers of power-electronic components are trying to introduce the silicon carbide (SiC) technology in their products and MOSFET transistors made with this technology are available on the market. They are characterised by a significantly higher operating frequency, reaching even 100 kHz and low switching losses. The application of this type of devices causes high voltage gradients at the inverter output, which can lead to increased inverter electromagnetic disturbances. This article presents test results and a high-frequency analysis, allowing for a preliminary evaluation of the use of SiC transistors in inverters in the context of electromagnetic compatibility.

Keywords: power electronics, transistors SiC electromagnetic compatibility

Streszczenie

Obecnie producenci elementów energoelektronicznych starają się wprowadzić w swoich produktach technologię węglika krzemu (SiC) i dostępne są w handlu tranzystory MOSFET wykonane w tej technologii. Cechują się one znacznie wyższą częstotliwością pracy, sięgającą nawet 100 kHz oraz niskimi stratami przełączenia. Zastosowanie tego typu elementów powoduje występowanie dużych stromości sygnału napięciowego na wyjściu falownika, co może prowadzić do zwiększenia zaburzeń elektromagnetycznych falownika. W artykule zamieszczono wyniki badań i analiz wysokoczęstotliwościowych umożliwiające wstępną ocenę w zakresie EMC zastosowania w układzie falownika tranzystorów wykonanych w technologii węglika krzemu.

Słowa kluczowe: energoelektronika, tranzystory SiC, kompatybilność elektromagnetyczna

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1. Introduction

Nowadays, power inverters operate at very high keying frequencies, which facilitate appropriate current and electromagnetic torque adjustment in drives. IGBT transistors (insulated gate bipolar transistors), made with the Si technology, are commonly used as switching devices in such inverters. The switching frequency of these devices can reach as high as 15 kHz. Since 2005, power electronic device manufacturers have been attempting to implement the silicon carbide (SiC) technology in their products. There are MOSFET transistors now available that utilise this technology. Such transistors are marked by high operating frequencies of up to 100 kHz as well as low switching losses. The use of such devices results in steep voltage signal rises at the inverter output [3]. It can be expected that this will lead to increased electromagnetic interference in inverters.

Interference produced during energy conversion processes and control processes occurs across a very wide frequency range, from the first harmonic and its interharmonics to higher frequencies generated by control algorithms. Increases in the operating frequencies of power electronic devices have caused high energy disturbances to be shifted to the conducted disturbance frequency range of 9 kHz–30 MHz [1].

Over the recent years, numerous publications have been written on the uses of silicon carbide; however, most of them are articles focussing on current and voltage characteristics of such transistors, with only a few addressing the electromagnetic compatibility issues. Most of these articles only briefly mention that it can be supposed that electromagnetic interference levels will increase due to high switching frequencies. This article presents the results of high frequency tests and analyses, allowing for a preliminary assessment of this technology in terms of EMC.

2. SiC technology

Silicon carbide is also known as moissanite and carborundum. It was discovered by the French chemist Henri Moissan in 1905. Silicon carbide is a solid material composed of silica and carbon in a ratio of 1/1. It occurs very rarely in nature and in small quantities, in places with special geological origins, for example in igneous rock (kimberlite), in meteorites and diamond mines. Commercially available silicon carbide is produced via a chemical reaction [2]. Some properties of silicon carbide are:

- semiconductive,
- high hardness (comparable to that of diamonds),
- chemical inertness,
- resistance to high temperatures,
- resistance to oxidation,
- resistance to harsh environments,
- high thermal conductivity.

As a semiconductor, silicon carbide can be used to build power electronic devices with characteristics superior to those of silicon-based power electronics devices used up to now. If compared with silicon, SiC has a forbidden band width three times that of silicon, higher electron mobility, higher thermal conductivity and breakdown voltage rating several times that of silicon. In recent years, manufacturers have launched semiconductor devices – diodes and diode-transistor assemblies – completely based on silicon carbide (SiC). These devices have properties that are far more advantageous than those of identical devices made from silicon. In particular, SiC-based devices exhibit dynamic characteristics, which are very important in the transformation of electrical energy with a high frequency as well as a high semiconductor junction operating temperature. Schottky diodes are being increasingly used as rectifier components, but above all, as anti-parallel diodes in transistor-diode modules with silicon-based transistors (IGBT, CoolMOS). The diodes have a low reverse recovery charge, which reduces the reverse current when a diode is turned off [3].

The transistor and diode modules currently available on the market include MOSFET modules made only from silicon carbide. SiC JFET transistors are the most common type of transistors based on the SiC technology. These transistors offer switching times of 40–60 ns and low drain resistance in the turned-on state. On the other hand, they require the use of quite complex gate control systems. SiC semiconductor devices enable engineers to build power electronic inverters, which, if compared with traditional inverters, offer higher efficiency, have smaller size, higher frequency and smaller passive devices.

Inverters incorporating IGBTs that are currently used operate at switching frequencies reaching more than a dozen kHz, while inverters with SiC-based devices can operate at frequencies 10 times higher. Account should be taken of the fact that voltage rises of several tens kV/us that are steeper than those in IGBTs cause additional phase current harmonics of several MHz.

3. Measurement results

This article presents the results of measurements carried out on two inverters, incorporating Si and SiC devices, respectively. The tests were conducted on a drive that comprised:

- a voltage inverter built using IRFP460A transistors,
- a voltage inverter built using ROHM SCT2160KEC transistors [5],
- the load used was an asynchronous cage motor of type SZJe 340.

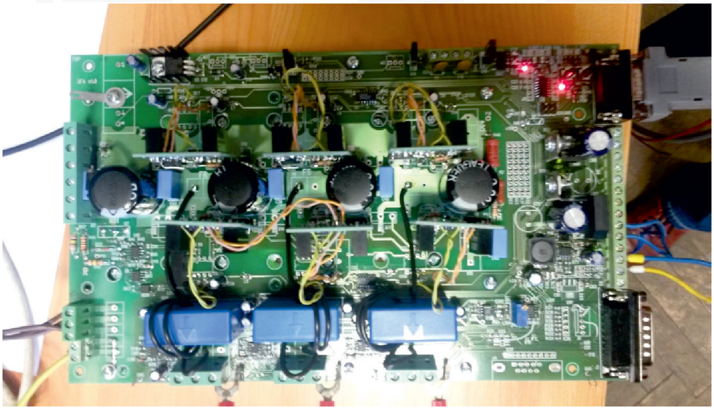

Fig. 1. Inverter with SiC devices

Time domain measurements were carried out using a Tektronix TDS2014 digital oscilloscope, a high voltage oscilloscope probe and a Rogowski CWT1 coil. Frequency characteristics measurements were carried out using an Advantest R3131A spectrum analyser, a SCHWARZBECK MESS – ELEKTRONIK TK9420 high frequency voltage probe and a TESEQ CSP 9160A voltage probe [4]. A sample measurement system for producing spectral characteristics of common-mode disturbance voltages is shown in Fig. 2.

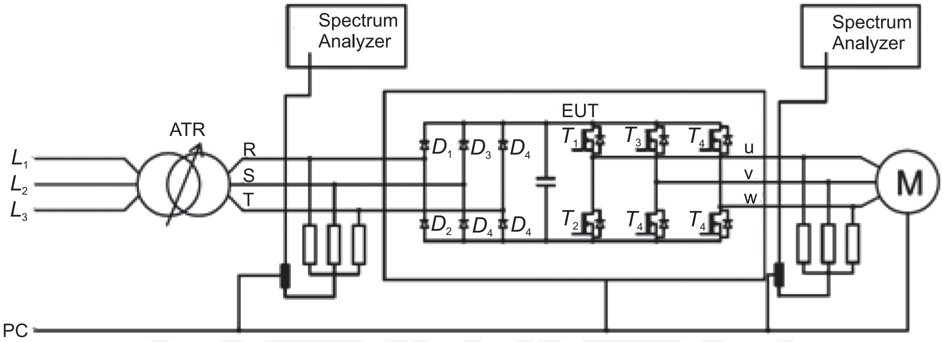

Fig. 2. Measurement system for determining common-mode disturbance voltages

During the tests, the authors recorded selected time waveforms for current and voltages as well as frequency spectra of characteristic electromagnetic interference waveforms.

3.1. Time domain measurements

Fig. 3 shows a time waveform of common-mode disturbance voltage, occurring across the output of an inverter based on Si technology (transistors of type IRFP460A). The waveform shape depends on the control algorithm adopted. Fig. 4 shows a time wave form representing common-mode disturbance current across the output of the inverter.

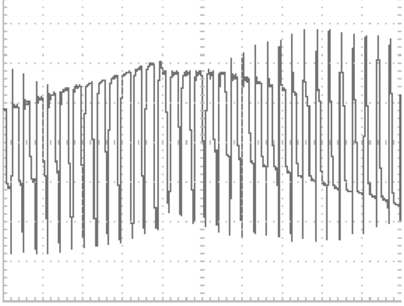

Fig. 3. Waveform representing common-mode disturbance voltage with the Si technology

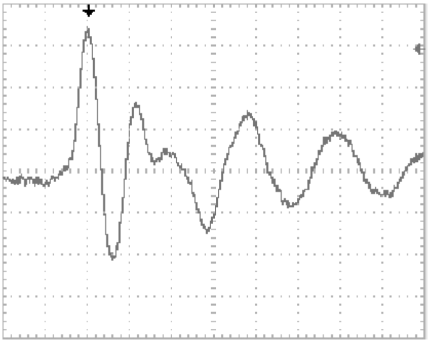

Fig. 4. Waveform representing common-mode disturbance current with the Si technology

The above oscillogram shows a special asymmetrical current shape, which is a damped waveform. The waveform indicates that an estimated maximum current is $I_{p\text{-}p} = 2.7$ A, the period of the component being damped slowly is $T = 210$ ns, the dominant frequency is 4.7 MHz.

Similar results were obtained for an inverter based on the SiC technology (SCT2080KEC transistors). Fig. 5 shows a waveform representing common-mode disturbance voltage, while Fig. 6 shows a waveform for common-mode disturbance current. Both signals were also measured across the output of the inverter.

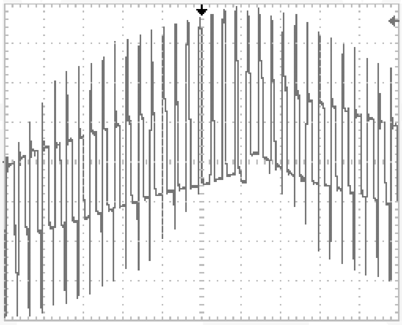

Fig. 5. Waveform representing common-mode disturbance voltage with the SiC technology

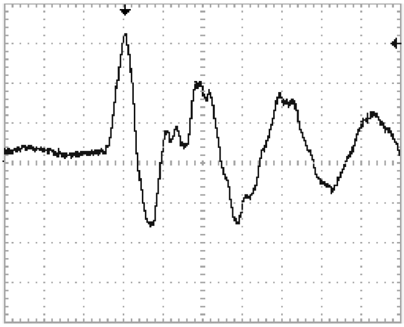

Fig. 6. Waveform representing common-mode disturbance current with the SiC technology

The above waveform shows a special asymmetrical current shape, which is a damped waveform. The waveform indicates that an estimated maximum current is $I_{p\text{-}p} = 5$ A, the period of the component being damped slowly is $T = 220$ ns, the dominant frequency is 4.5 MHz.

3.2. Frequency domain measurements

The spectral measurements were carried out in respect of both inverter systems, just as the time measurements. The authors selected signals that occurred at the input of the inverter (on the mains side) and output signals (on the motor side). The inverters operated with identical power supply parameters, with a carrier frequency of 6,7 kHz and an output frequency of 49 Hz. The figures below show a comparison of the two inverters, with the black graph representing the inverter incorporating Si-based transistors, and the olive coloured graph representing the inverter incorporating SiC transistors.

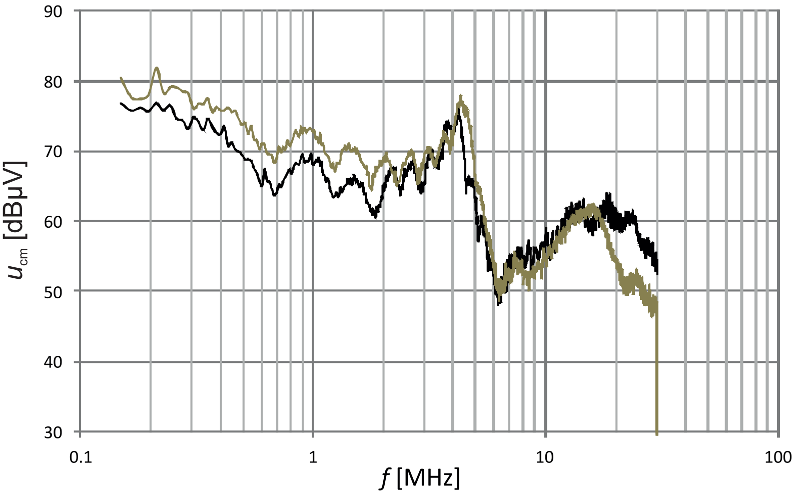

Fig. 7. Common-mode disturbance voltage spectrum on the inverter output side (black is for Si)

As it can be seen, the system based on silicon carbide transistors generates, in the frequency range 150 kHz – 6 MHz, a slightly higher amount of common-mode disturbances. An opposite situation occurs for frequencies exceeding 17 MHz (Fig. 7).

The results obtained show that both inverters generate higher common-mode disturbance voltages on the mains side. The spectral characteristics indicate that the system based on silicon carbide transistors generates a slightly higher common-mode disturbance level at the output, in the frequency range up to ca. 5 MHz. An opposite situation occurs for frequencies exceeding 10 MHz (Fig. 8).

The disturbance current spectra obtained indicate that the system based on silicon carbide transistors generates, in the entire frequency range, a slightly higher amount of common-mode disturbances (Fig. 9). Higher disturbance current levels, just as in the case of voltages,

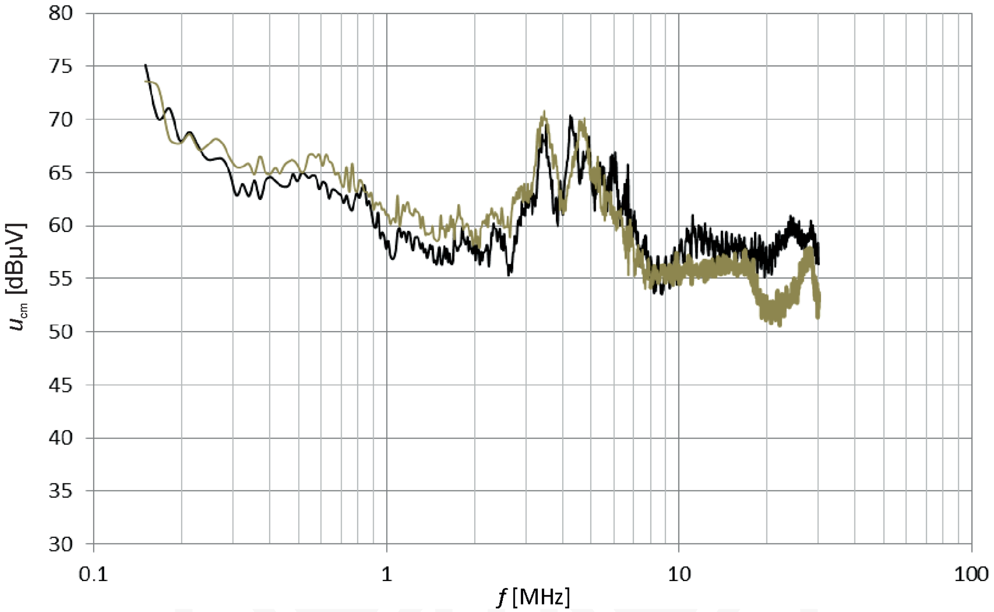

Fig. 8. Common-mode disturbance voltage spectrum on the inverter output side

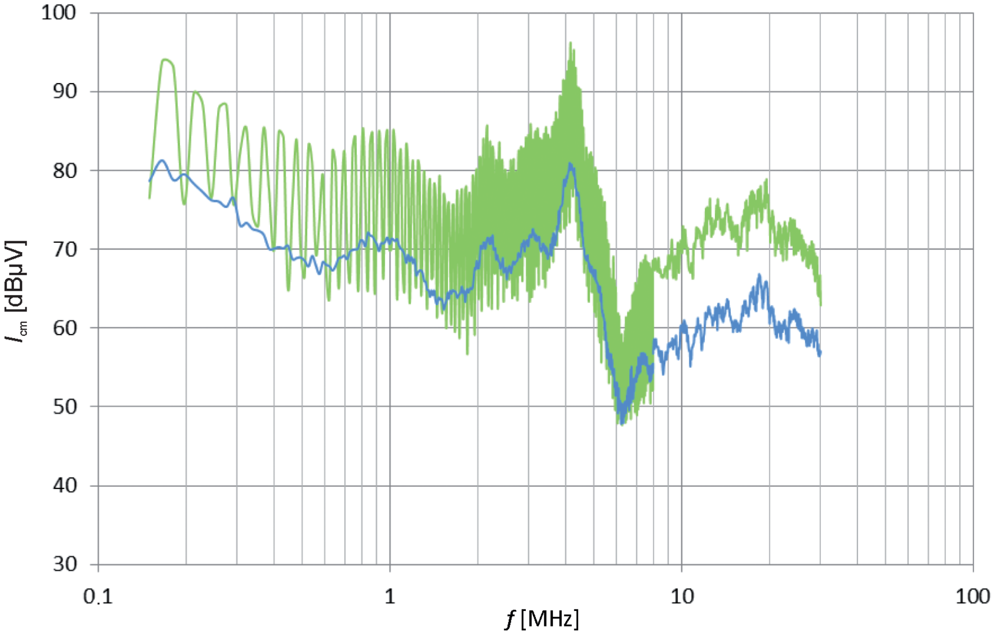

Fig. 9. Common-mode disturbance current spectrum on the inverter input side

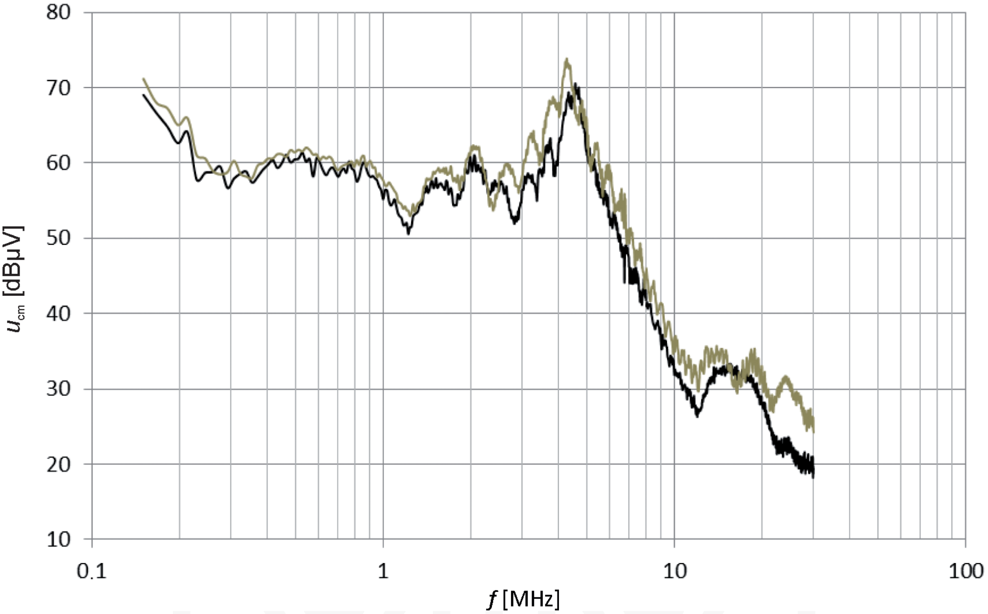

Fig. 10. Common-mode disturbance current spectrum on the inverter output side

have been recorded in the output circuit of the inverter (Fig. 10). Both the voltage spectra and the current spectra results indicate that in terms of disturbance emissions, the inverter with Si devices performs slightly better than the other inverter.

3.3. Effect of control parameters

When the Si inverter and SiC inverter operated with identical power supply and control parameters, slight differences were noticed in terms of the conducted disturbance emissions. The results obtained for various carrier frequencies are shown below. The basic assembly under test operated at a frequency of 67 kHz, which was subsequently increased to 56 kHz.

Increasing the frequency of the carrier waveform (Fig. 11, green colour) resulted in far higher common-mode disturbance levels being generated. As it can be seen, the common-mode disturbance level in the entire range rose by ca. 15 dBμV.

Increasing the carrier waveform frequency resulted in far higher common-mode disturbance levels being generated, as was the case with the spectrum of the input disturbances. As it can be seen, the common-mode disturbance level in the entire range rose by ca. 20 dBμV (Fig. 12), while the largest difference occurred in the 3-4MHz and amounted to ca. 30 dBμV.

Common-mode disturbance current, in the system with an increased carrier frequency across the entire frequency range, is at higher levels both at the input and output of the inverter (Fig. 13 and Fig. 14). The spectrum across the entire frequency band is increased by ca. 15dBμA.

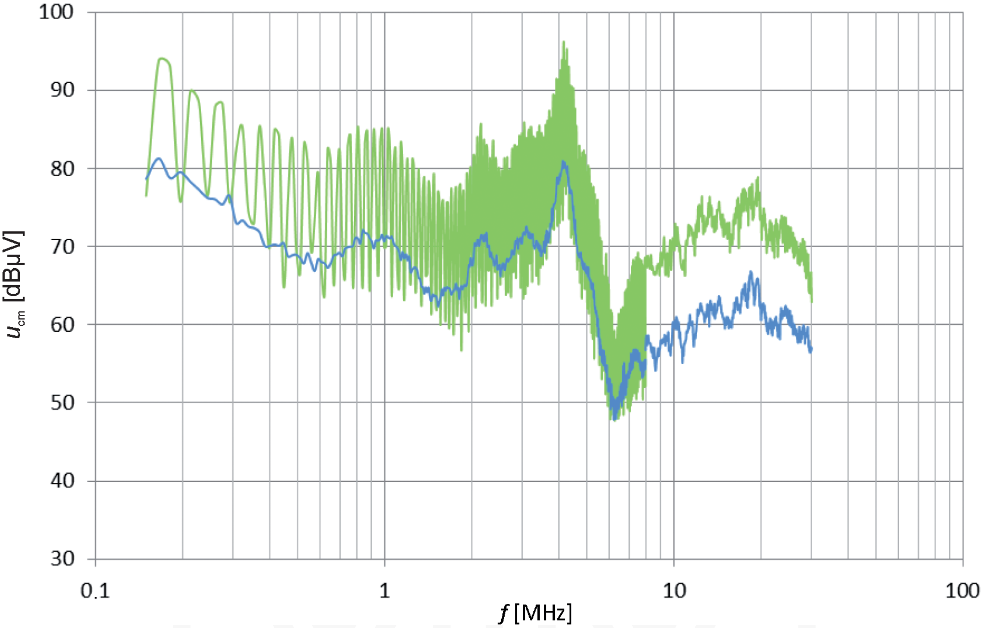

Fig. 11. Common-mode disturbance voltage spectrum on the inverter output side

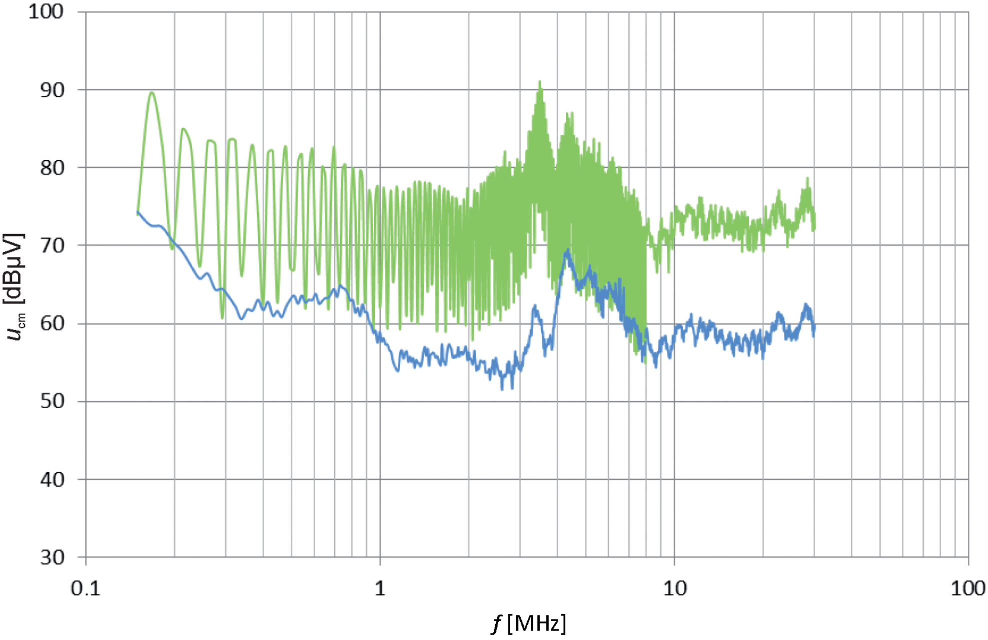

Fig. 12. Common-mode disturbance voltage spectrum on the inverter output side

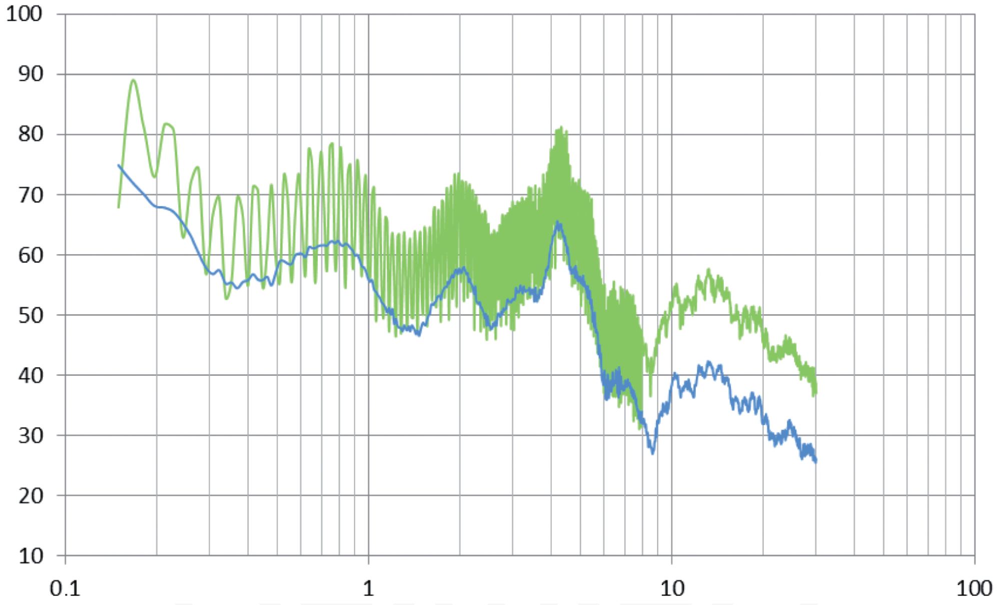

Fig. 13. Common-mode disturbance current spectrum on the inverter input side

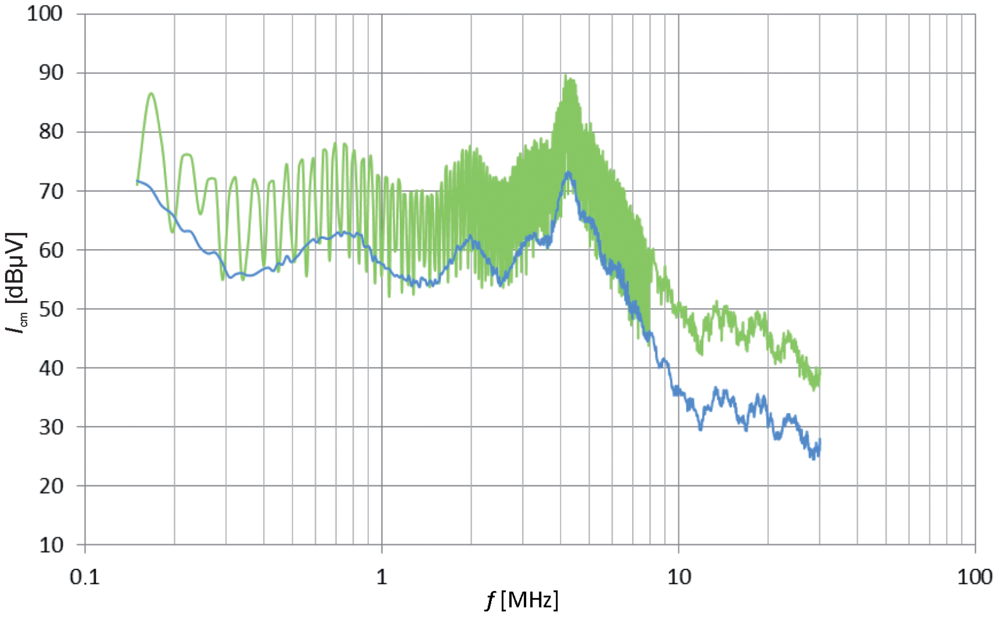

Fig. 14. Common-mode disturbance current spectrum on the inverter output side

4. Conclusions

When comparing the disturbance levels for the inverter based on the Si technology with the inverter incorporating SiC devices, it was found that the inverter with SiC transistors, operating at the same circuit parameters as the Si inverter, generated slightly higher disturbance levels.

When the carrier waveform frequency was increased from 67kHz to 56kHz, the conducted disturbance levels rose by ca. 15 dB. The change of this parameter did not bring about changes in the resonance frequency .

Silicon carbide technology allows engineers to build power electronic inverters that, when compared with those based on traditional Si technology, offer high efficiency (thanks to low losses on transistors), smaller dimensions, smaller passive devices and higher thermal tolerance. In terms of electromagnetic compatibility, these devices pose a larger threat to the electromagnetic environment. During the tests, it was found that electromagnetic interference levels were significantly higher, particularly in cases where the carrier frequency was increased when PWM control was being used. Increased conducted disturbance levels on the inverter power supply side may render it difficult for the inverter to meet applicable prescriptive requirements and may be harmful to equipment connected to the same mains network. On the other hand, an increased disturbances occurring at the output of the system may cause problems in ensuring the so-called internal compatibility. The test results show that engineers are going to have to use both input and output filters in order to reduce conducted electromagnetic disturbances.

References

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