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WYSOKOCZĘSTOTLIWOŚCIOWA PRZETWORNICA DC/DC OPARTA NA TRANZYSTORACH SIC DLA ZASTOSOWAŃ Z ODNAWIALNYMI ŹRÓDŁAMI ENERGII

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***Streszczenie**. Artykuł prezentuje koncepcję budowy, konstrukcji oraz wyniki testów modelu przetwornicy DC/DC typu Buck-Boost o mocy do 1 kW z wykorzystaniem tranzystorów z węglika krzemu (SiC JFET). Przetwornica zaprojektowana została do współpracy z magazynem energii w postaci superkondensatora w układzie stabilizacji napięcia laboratoryjnego wieloźródłowego systemu odnawialnych źródeł energii (OZE). Małe straty przewodzenia oraz mała energia przełączeń tranzystorów Sic JFET umożliwiły zwiększenie częstotliwości pracy kluczy przetwornicy do 500 kHz. Przeprowadzone badania laboratoryjne modelu potwierdziły wysoką sprawność przetwornicy na poziomie 95%.*

Słowa kluczowe: przekształtniki, przetwarzanie energii, przekształtniki impulsowe, sterowanie fazowe, przekształtniki DC-DC, odnawialne źródła energii OZE

HIGH FREQUENCY DC/DC CONVERTER BASED ON SIC TRANSISTORS FOR RES APPLICATION

***Abstract.** The paper presents the concept of the design, construction and test results of the voltage DC/DC Buck-Boost Converter up to 1 kW with silicon carbide transistors (SiC JFET). The inverter is designed to work with the supercapacitor energy storage bank as voltage stabilization system in multi-source renewable energy sources (RES) laboratory stand. Small conduction losses and low switching energy of SiC JFET transistors make possible to increase the operating frequency of the inverter to 500kHz. Conducted laboratory tests confirmed the high efficiency model of the inverter at 95%.*

Keywords: converters, power conversion, pulse inverters, phase control, DC-DC power converters, renewable energy sources RES

Introduction

The paper presents the results of the work related to the development and launch of high frequency DC/DC inverter, using modern silicon carbide (SiC) transistors.

The transistors manufactured using this technology have a significantly better performance than previous solutions based on the silicon. The main advantages are: short switching times, high blocking voltage and low open channel resistance. The low switching losses allow to increase the switching frequency and thereby reduce the dimensions of the entire converter circuit.

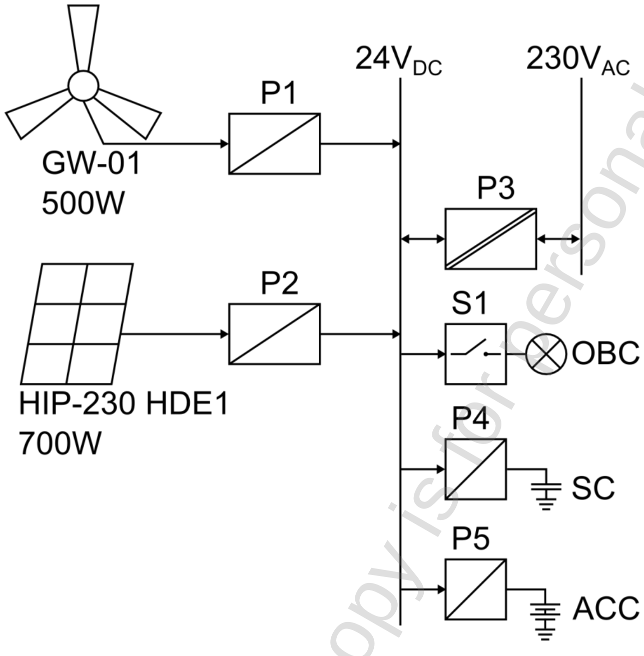

Fig. 1. Micropower RES system with power and energy storage devices

Developed model of the inverter will be tested in the micro system with renewable energy sources as a matching circuit connecting supercapacitor (P4) and battery (P5). The inverter will have the task to stabilize the intermediate circuit voltage at 24 V DC thanks to two-way transmission of energy.

1. Construction of the inverter

The expected input and output parameters of the inverter are presented below:

- input voltage range: 15 to 30 V DC,
- output voltage: 24 V DC,
- nominal power: 1000 W.

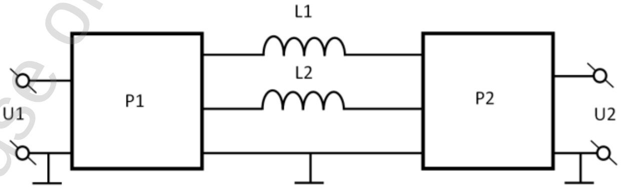

Fig. 2. Structure of the converters system

The device consists of two interdependent systems, constructed of two inverters respectively connected together. The first one is the voltage decreasing inverter, shown in Figure 3a (Buck Converter) and a second one is increasing converter, as shown in Figure 3b (Boost Converter). In addition, to increase the efficiency and output power of the inverter system has been doubled and is connected in parallel with each other as shown in Figure 4.

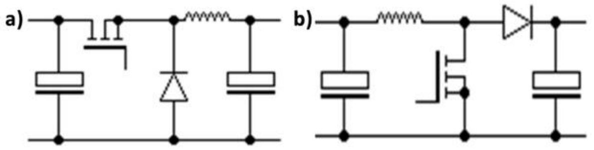

Fig. 3 Converter topology type Buck (a) and Boost (b)

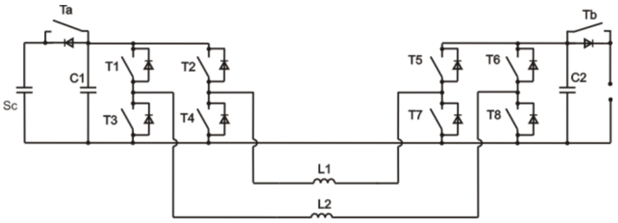

Fig. 4. Part of the energy converter system

The system has been build used IJW120R070T1 power transistors, which are junction field effect transistors JFET built on silicon carbide (SiC) of the NPN type channel. Transistors are switched on when the gate voltage level equals to zero (V_{GS} = 0 V) and blocked with negative gate voltage (V_{GS} = -19 V). As a result of this control pattern it was required to build an additional protection system for eg. power outage control systems, because in this case, all the transistors are in the conducting state, leading to a short circuit capacitive loads, thus destroying the power transistors. The use of such transistors was due to the availability of this type of transistors and their drivers on the market.

The protection against damage is shown in Figure 4. Ta and Tb transistors are switched directly from the auxiliary power supply voltage control circuit. In the event of loss of power transistors security will be introduced first in the state to block off the load from the power transistors. Inverters inductance L1 and L2 are 7 µH in each case.

Current measurements were carried out by means of transducers P1 EL-25 ABB.

For measurements of voltages U1 and U2 resistive voltage divider is used.

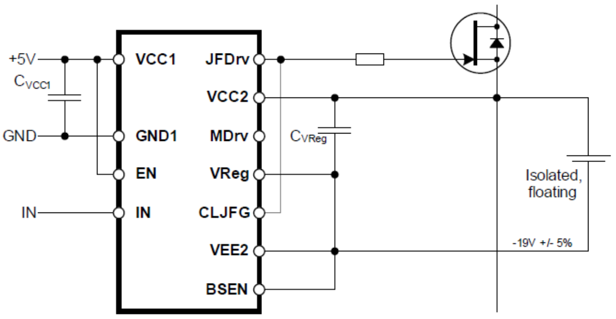

Fig. 5. Work system driver 1EDI30J12CP

To control the power transistors INFINEON company dedicated 1EDI30J12CP drivers have been used in the system as shown in Figure 5. These controllers are characterized by rapid switching transistors and a relatively high current switching IJFDrvH / L = 4.0 A JFDrv output and low power consumption I_{IN} = 30 µA at V_{IN} = 2 V. The driver includes galvanic separation which allows for direct control by the processor without using amplifiers and opto-isolation. Parallel inverter's control is identical with the offset of 180° as shown on Fig. 6. This control allows to maintain continuity of load current, and thus giving better performance of the system.

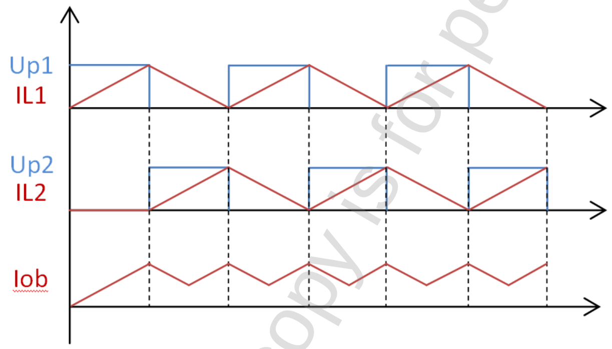

Fig. 6. Currents in the converters

Maximum switching turn-on transistor gate current at R_G = 4R7 is $Ig_{on} = U_{max}/R_G$ = 1.58 A. In contrast, turn-off transistor gate current is Ig_{OFF} = 1.92 A.

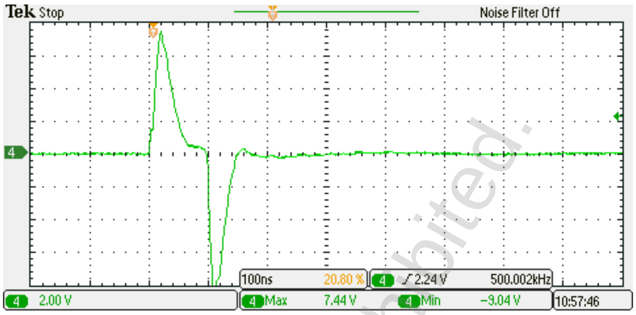

Fig. 7. The course of the gate current on and off the SiC transistor

Due to the possibility of interference introduced by the inverter itself, optional control has been designed using optical fibers. Part of the system is controlled by microprocessor-based processor system TMS320F28335 with programmable ALTERA Cyclone III. PWM signal generation system is realized by a programmable logic device, while the microcontroller creates a supervisory control systems with the regulations. In addition, the work of the control system can be controlled from a PC via USB. Control software for the PC, developed in Gdansk Branch of the Electrotechnical Institute, is equipped with a number of startup and control functions.

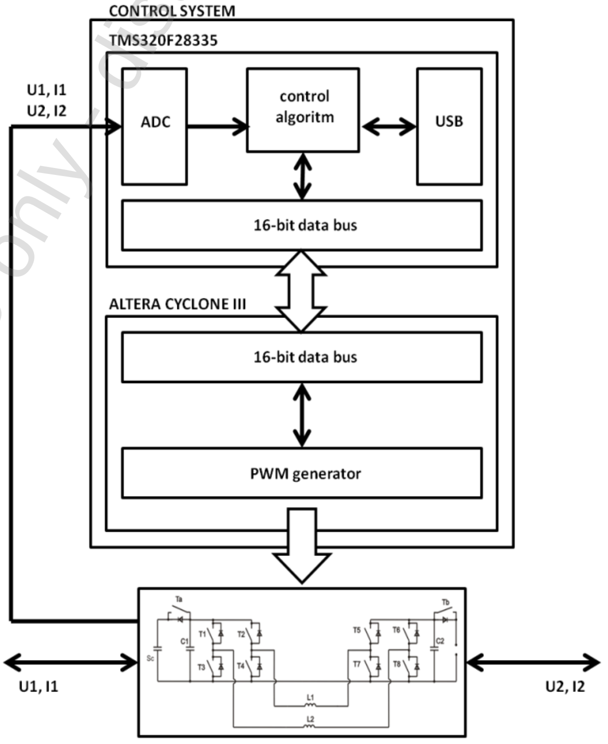

Fig. 8. Microprocessor control unit scheme

2. The simulation results

2.1. Boost converter example simulation waveforms

Boost converter – the duty cycle of transistor TON=39.25 %.

Table 1. Simulation parameters of Boost Converter

Vin_{min} = 15.0 V	Vin_{max} = 24.0 V
Vin = 15.0 V	V_{out} = 24.0 V
Iout = 20.0 A	freq = 500 kHz
L = 894.3 nH	ΔIL for Vin_{min} = 13.17 A

2.2. Buck converter example simulation waveforms

Buck converter – the duty cycle of transistor T_{ON} = 75.50 %.

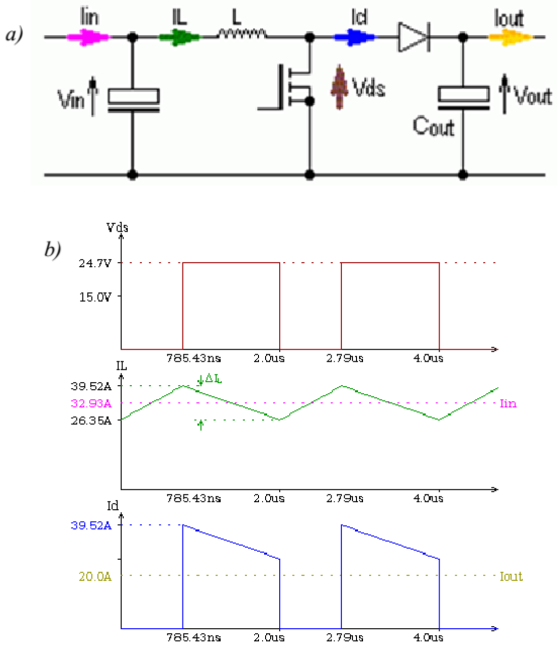

Fig. 9. Diagram (a) and output waveforms (b) of the Boost converter

Table 2. Simulation parameters of Buck Converter

Vin_{min} = 24.0 V	Vin_{max} = 32.0 V
Vin = 32.0 V	Vout = 24.0 V
Iout = 10.0 A	freq = 500 kHz
L = 894.3 nH	ΔIL for Vin_{min} = 13.51 A

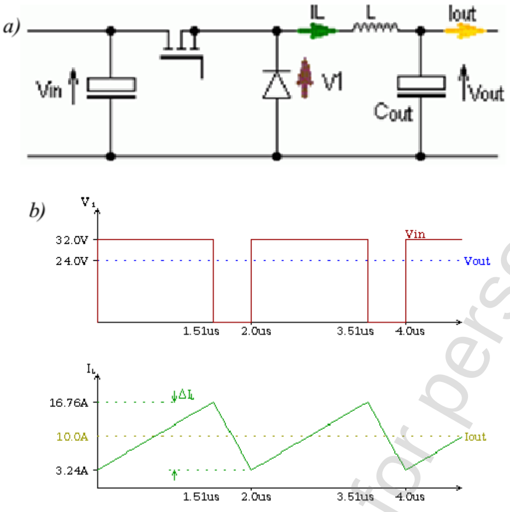

Fig. 10. Diagram (a) and output waveforms (b) of the Buck converter

All active states of inverter for reducing voltage (Buck inverter) and increasing voltage (Boost inverter) for one way energy transfer are presented on Figure 11.

3. The results of experimental studies

Efficiency coefficients has been identified for different pulse widths, to determine the efficiency of the widest possible range of the inverter power. Tests were conducted for duty factor of transistor equal successively 5%, 10%, 20%, 30%, 40%, 50%.

For a demonstration of the inverter's work in an application similar to the target, the tests were made for supercapacitor battery charging. The battery consists of six serial LSUCMH46367 type capacitors with a rated voltage of 2.8 V and capacitance of 3000 F, which gives battery voltage of 16.8 V and capacity of 500 F. Adjustable current limit was set at 10 A, caused the battery loading time as 600 s.

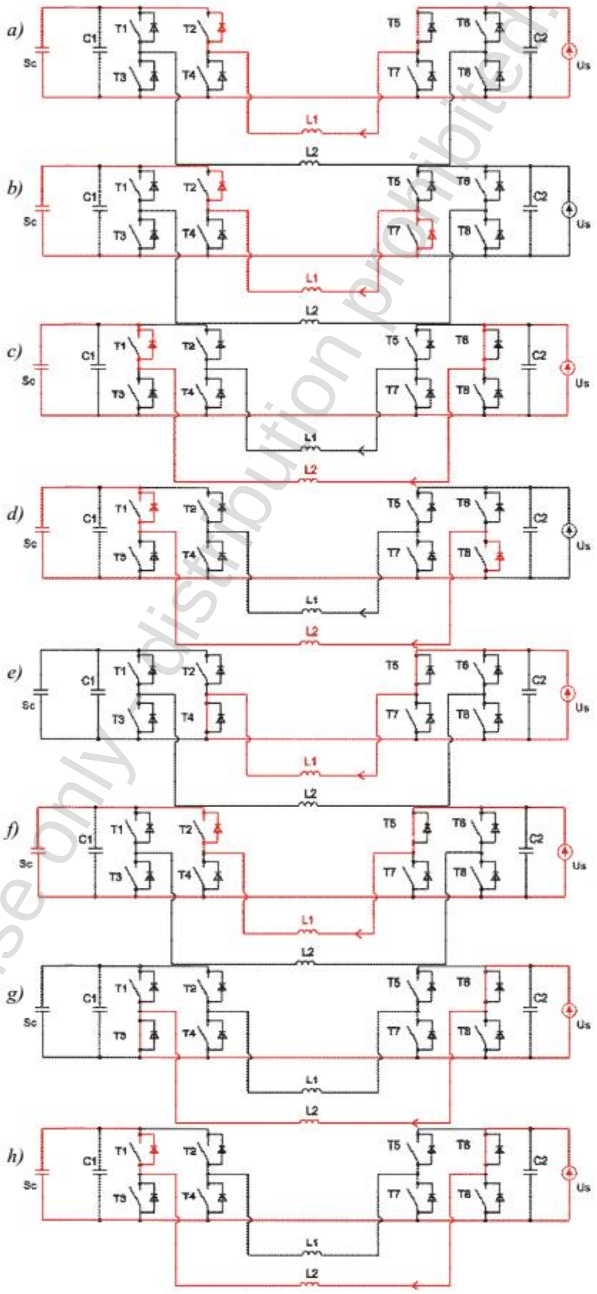

Fig. 11. Active states and current flow for Buck converter: (a) (b) (c) (d) and Boost converter: (e) (f) (g) (h)

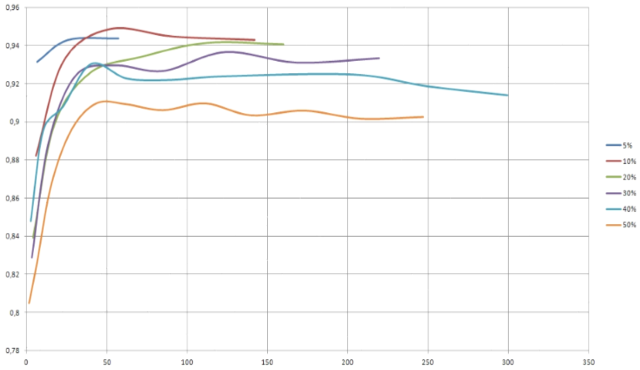

Fig. 12. Selection of the waveform of the inverter efficiency as a function of output power for filling successively 5%, 10%, 20%, 30%, 40%, 50%

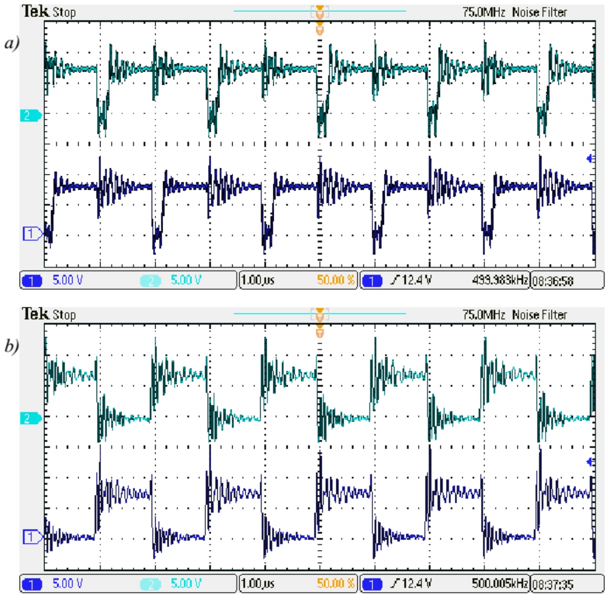

Fig. 13. Voltage transistors T1 and T2 gating while completing 10% (a) and 50% (b)

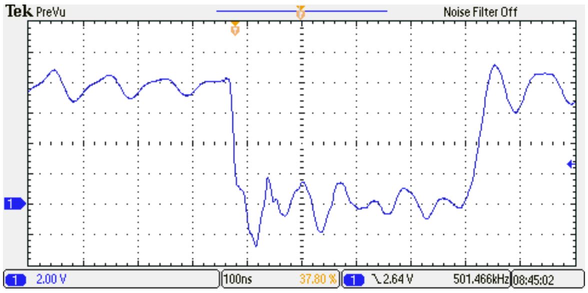

Fig. 14. The voltage across the transistor during the on and off

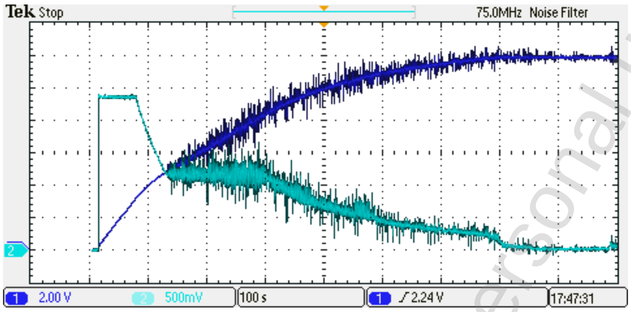

Fig. 15. Voltage output waveform (1) and output current (2) of the inwerter, while charging supercapacitor. Scale 1 V – 10 A

4. Remarks and Conclusions

Using the experience concerning transformer inverter with silicon carbide transistors the transformerless inverter model with the function of increasing and decreasing voltage has been developed. The previous structure with SiC transistors operating in bridge circuit, allowed a one-way flow of energy, and reached a stable switching frequency of 700 kHz. Such a high frequency made possible a significant reduction of the inverter size.

The proposed structure, comprising two converters operating in parallel with a phase shift control, provides two-way flow of energy in a wide range of voltages, while maintaining high quality output power and high efficiency. The efficiency of the system over a wide range of voltages reached over 90%, and the best result achieved was 95%. Transistors used in a model system allowed us to achieve switching times of 20 ns for the turn-on, and less than 40 ns for a turn-off. The frequency of operation of the system is currently 500 kHz in each of the parallel converters, which gives the results-frequency operation of the system at 1 MHz.

The study confirmed the correctness of the concept design of the inverter using silicon carbide transistors thus allowing a new experience in the high-frequency switching systems. The proposed structure will enable the development of future commercial DC/DC converters for special applications in the so-called prosument small power plants associated with local renewable energy sources.

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