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Power electronics solar converter model and research using the power grid

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***Streszczenie*— The maximum power point tracking algorithm for a single phase grid-connected photovoltaic converter is provided in this research. High efficiency and good electrical energy output quality metrics define this system. The output inverter that has been developed runs in current tracking controller mode. Reactive power is equal to 0 and the output current (grid current) is almost sinusoidal. A lot of focus was placed on the MPPT algorithm. Its duty is to make sure that, depending on the state of the system, the operating point of PV cells follows the maximum power point. Also presented were some of the findings from simulation and experimental study on an extended solar system.**

I. Introduction

This article introduces developed power electronic converter high voltage power and control structures that serve as a link between the AC power grid and renewable energy sources (RES). This source, in the example at hand, is a collection of photovoltaic (PV) panels. The MPPT (Maximum Power Point Tracking) algorithm, which was used and allows for the system's overall efficiency to be maximised, was detailed.

Additionally, a transistor inverter with a sinusoidal output current was used to supply high-quality energy parameters into the grid. This device also enables the stability of the voltage on the system's DC bus. The paper also provides a simulation model of the converter described with regard to simulating the duty cycle of a photovoltaic cell, which allowed a preliminary evaluation of the proper operation of the implemented MPPT algorithm. This simulation model is based on past investigations allowed a preliminary assessment of the correct functioning of the implemented MPPT algorithm.

Block Diagram and General Idea of Operation of Solar Energy Conversion System

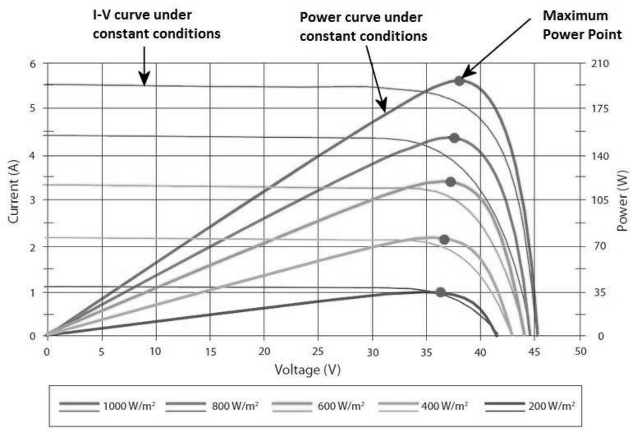
Figure 1 shows the block diagram of the sophisticated system that enables the transfer (and conversion) of energy from a collection of solar panels to the alternating current power grid. In this instance, we may distinguish between the following blocks: namely:

- group of PV photovoltaic panels,
- AC power grid,
- blocks of power electronic transducers acting as a coupling DC/AC, which includes: DC/DC BOOST converter, DC bus circuit, block of the DC/AC grid converter (grid inverter).

Rysunek 1. Block diagram of conversion and transmission system of solar energy.

In the instance being described, it was expected that a set of solar panels would be used, with a band range of output voltage change (depending on temperature, amount of load, and intensity of incident sunlight) of 150 to 450V panels. Fig. 2 [1] illustrates a family of current-voltage characteristics of a photovoltaic PV assembly.

As one can see, the mode of the load has a significant impact on the solar cell's output power. Consequently, the voltage and current levels exist for which the power produced by renewable energy sources is at its highest (ie. The maximum power point - Fig.2). Because of this, the MPPT algorithm for the DC/DC converter was included in the control system to provide the best possible operating conditions for the entire system. Its task is to ensure that the operating point of the cell follows the maximum power point, depending on the actual system conditions (eg. ambient temperature, intensity of the incident sunlight). Developed and implemented MPPT algorithm [2], [3] was presented in subsequent part of this article.



Rysunek 2. Family of current-voltage characteristics of photovoltaic group [1].

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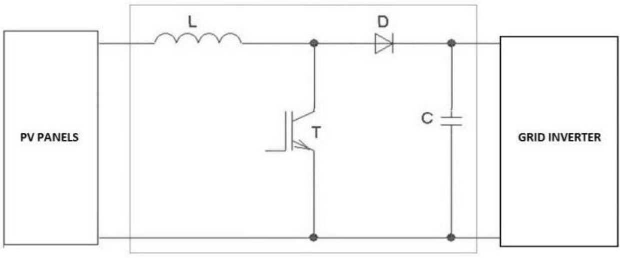


Rysunek 3. Schematic diagram of the DC/DC BOOST converter.

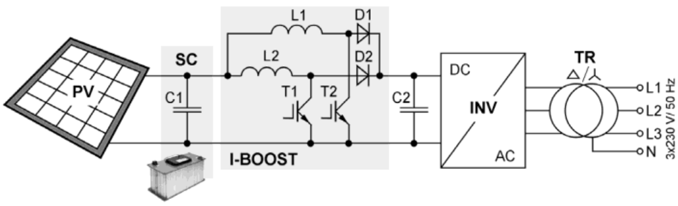
II. DC/DC Direct Current Circuit of Solar System

A. *The Structure of Power Circuit*

The high voltage power portion of the DC/DC converter is based on a system of pulse-type BOOST due to the accepted range of output voltages of PV photovoltaic cells (150V-450V) and the required minimum value of the DC bus voltage, which should be in this case greater than the amplitude of the grid's voltage (Fig.3).

This converter's functions include supplying power to the capacitors in the DC bus circuit and raising the output voltage of the solar panel group. A so-called bypass diode that is used in the target circuit is absent in Fig. 3. This diode makes it possible to use a grid inverter without a BOOST-style system to transmit energy from the PV cells to the input capacitors. However, this scenario is only feasible if the instantaneous value of the output PV cells' voltage is larger than the necessary voltage on the input capacitors of the grid inverter (the capacitors of inverter with sinusoidal current network).

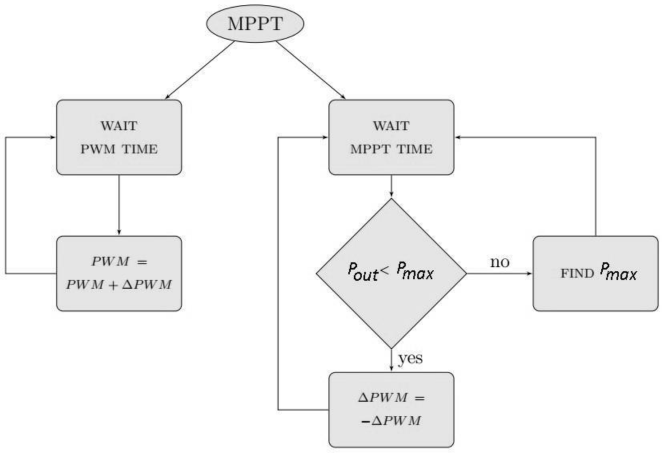
The boost in interleaved mode (I- boost) can be used in cases needing high power, as shown in Fig. 4. Transistors' switching frequency can be lowered in this situation. As a result, switching power losses will be reduced. Supercapacitors (SC) may also be used in DC circuits, as an additional option. As a result, we have extra energy buffer, which comes in very handy when the output voltage of PV cells fluctuates.



Rysunek 4. Boost converter in interleaved mode

B. *Algorithm of Controlling Solar System's BOOST Converter - MPPT Algorithm*

In order to enhance input voltage and supply (recharge) a capacitor group in a DC bus circuit, which powers a grid rectifier, a DC/DC boost converter is used (inverter). In order to reach the greatest level of effectiveness the MPPT algorithm was created and then used in the control system of the BOOST converter to maximise the use of the energy resources of PV solar panels [2], [3]. In Fig. 5, the block diagram was displayed.



Rysunek 5. The block diagram of developed MPPT algorithm (Maximum Power Point Tracking)

The two primary loops of the created method were separated. A key (T) of the BOOST converter power section is activated by changing the duty ratio (PWM) in the first loop (Fig.3). The second loop, which defines the direction of changes in the duty ratio by a constant value defined as (PWM), is what triggers this process, which happens at predetermined indicated intervals (PWM TIME). The second algorithm's loop is tasked with finding the maximum power that can be obtained at a specific system operating point. The control system decides the direction of duty cycle adjustments and searches for a new maximum power based on the comparison between the output power (Pout) for the current operating point of PV cells and a specified maximum value. This comparison is made using a time frame that is (MPPT TIME). duty cycle and looks for a new maximum power. This comparison is performed with a period defined as (MPPT TIME).

It should be noted that the task of DC/DC converter's control system is not to stabilize voltage in the DC bus circuit. This is a task of the regulator, which has been implemented in the control system of grid converter (inverter).

III. The Structure and Algorithm of Control the Grid Inverter

A. *Grid Inverter Circuit*

A transistor H bridge with an inductive output filter serves as the foundation for the grid inverter, a transistor rectifier working in inverter mode that is directly in charge of transferring energy to the grid. Fig.6 shows a schematic diagram of the system. In order to keep the grid current as close to sinusoidal as feasible and to prevent the creation of reactive power, the system transfers energy from the capacitor battery of the DC bus circuit (rechargeable via the BOOST inverter) to the grid. It should be mentioned that for this to work properly, circuit is possible only if the value of the

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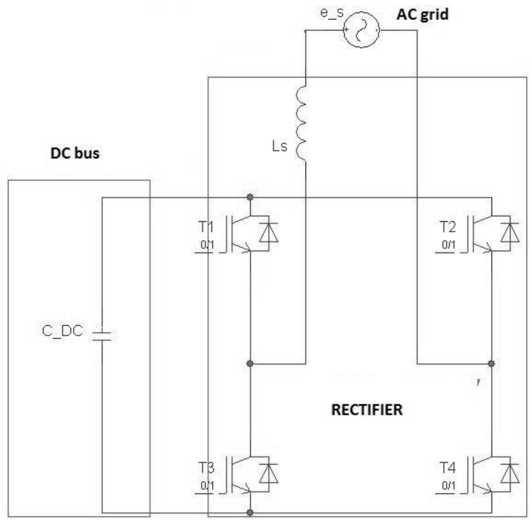
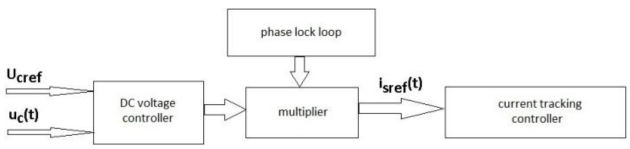


Rysunek 6. Schematic diagram of grid inverter.

The grid voltage's amplitude is less than the instantaneous voltage in the DC bus circuit. The grid inverter's control circuit, which uses a current tracking controller to modify and stabilise the voltage on the capacitors of the DC bus circuit [5], was built based on the definition of the active current [4]. It should be noted that in the example presented, a control system for the BOOST converter, this function does not conform. Only the MPPT algorithm is realised by it.

B. Control Algorithm of Grid Inverter

The DC bus voltage must be stabilised for the system to function properly. Due to her lack, the voltage varies erratically, depending, for instance, on the power provided by PV cells via the BOOST system. This function is carried out in the suggested solution by varying the grid rectifier's preset current's amplitude [5]. As a result, the active power (power sent to the grid) can be changed, which allows the voltage in the DC bus circuit to be stabilised. Fig. 7 presents a block diagram that illustrates how the grid inverter's control system functions..



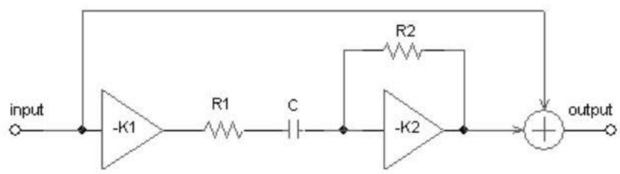
Rysunek 7. Block diagram of grid inverter's control system.

A block in the form of a DC voltage regulator is responsible for determining the am-plitude of the reference grid current $i_{sref}(t)$. The synchronization system of reference signal with the grid voltage signal is based on generator, which is gener-ating sinusoidal signal with phase shift equal to 180 electrical degrees and a unit amplitude. In this way the reactive power was reduced theoretically to zero. The purpose of the next block in the form of a tracking controller of electricity supply to provide grid current generation with a shape as close as possible to the reference signal $i_{sref}(t)$ is

C. Structure of Current Regulator Used in Inverter's Control System

The novel structure of a current regulator based on IIR filters was implemented to ensure proper operation of the grid inverter block known as the current tracking controller (Fig. 7) that is being described. The filters used in the control circuit must adhere to certain requirements. The three criteria for choosing filter architectures and parameter sets were outlined in [5], [6]. The restriction on the slew rate value of the PWM modulator input signal was the first examined criterion. This requirement must be met in order to guarantee the right switching frequency, which must match the frequency of the carrying signal.

The second criterion hinges on ensuring that the shift phase is near to -180 el. deg. and that both the maximum gain value of open-circuit transmittance in useable bandwidth and the minimum value of this increase in bandwidth are present.



Rysunek 8. The simulation model of additional high-pass filter (current regulator).

The last criterion, which has been analyzed during the researches, is the limitation of output signal spectrum due to aliasing effects risk. This limitation is obtained thanks low-pass filter implementation in control system and passive serial inductive filter at the output of inverter. During the simulation and experimental researches, several parameters of low-pass filter were analyzed. Also different additional structures of filters were elaborated. One of these has been filter about structure like in Fig.8.

This block is based on differentiator [5], [6]. The transfer function of presented regulator can be expressed by the following formula:

$$F(s) = \left(1 + \frac{K_1 s R_2 C}{1 + s R_1 C}\right) \frac{K_F}{1 + s T_{FDP}}. \qquad (1)$$

With help of this additional structure, minimization of delay effect in power electronics inverter with PWM modulator has been achieved. Thus, we can increase the resultant gain value of open-circuit transfer function, while the closed feedback loop circuit is still stable. In this way we can improve the quality of output signal of inverter.

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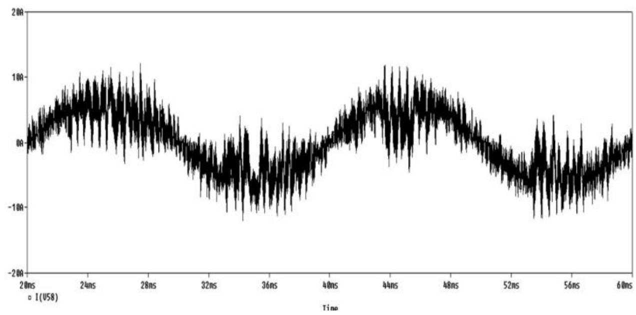
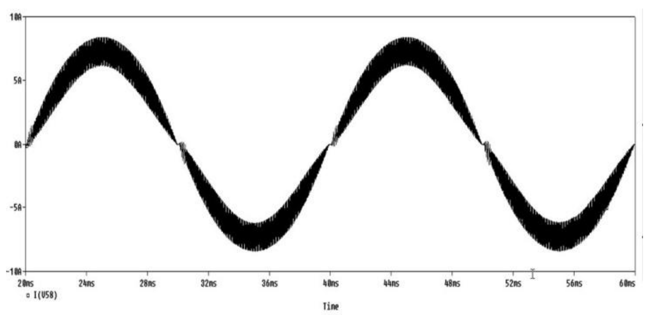
IV. Selected Results of Simulation and Experimental Research

Experimental experiments and preliminary simulations were performed for the system's single-phase version. Utilizing Cadence's Orcad software, a simulation model was created. The proposed solution for the high voltage power circuit and control system of the converter was validated to work correctly based on the simulation results. Figure 10 illustrates a phase current signal from the grid that exhibits low contents of higher harmonics (THD ratio = 1.2 percent) as an example (simulation result). Using the unipolar modulation technique in the grid inverter's control loop (pulse frequency was chosen at level of 12 kHz).

Fig. 9 depicted the grid current in the scenario when there is a leakage current in the circuit. This phenomenon is caused by the presence of the parasitic capacitance between the surface of photovoltaic panels and the surface of the earth. This is a very important issue. It contributes to a distortion of the grid current. Additionally, it causes also danger for human life. One of the ways to eliminate this phenomenon depends on use a energetic transformer between power electronics inverter and the grid. This method was used in presented solution of solar inverter (Fig.10).

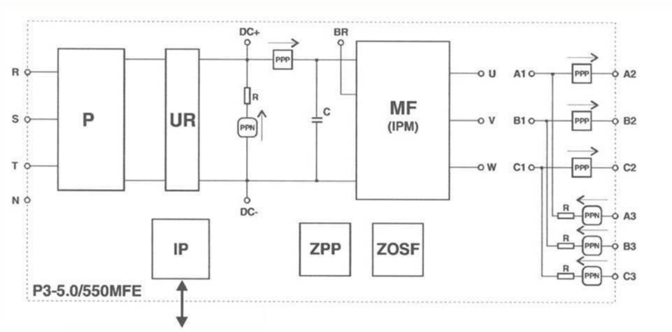


Rysunek 9. Grid current trajectory generated by the inverter with common-mode leakage current



Rysunek 10. Grid current trajectory generated by the inverter without common-mode leakage current

For example, converter type LABINVERTER P3/ 550MFE [7] and DSP development kit ALS-G3-1369 [8] equipped with a floating point digital signal processor were used in experimental experiments of the single-phase version. Devices SHARC ADSP-21369 [9], as well as laboratory DC power supply with adjustable current limit and output voltage (emulating the work of photovoltaic cells). The block scheme of LABINVERTER is shown in Fig.11.

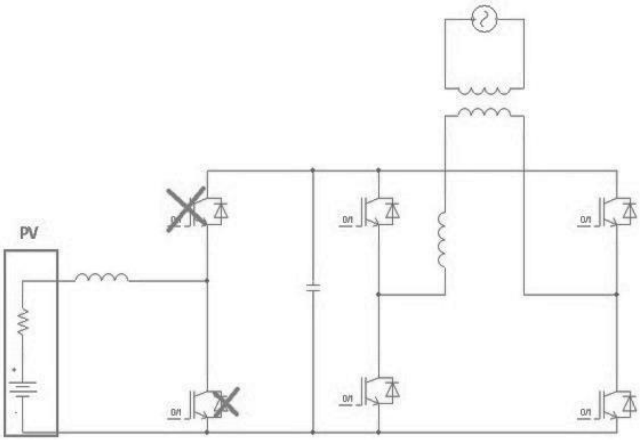


Rysunek 11. The block scheme of LABINVERTER [7]

The functions of each block of this power electronics converter are as follows:

- block (P) represents input diode rectifier (not used in described application),
- block (UR) is used to charging the capacitors imple-mented in DC circuit, when converter is started (not used in presented application),
- (MF) means 3-phase IGBT bridge (with help of this block the power circuits of the BOOST converter and also the output grid inverter were built),
- blocks (PPP) and (PPN) represent the current and voltage measure sensors.

The way of connection in MF module, which was used in presented application of solar converter is presented in Fig.12. The upper transistor and the lower diode are not used in this case.



Rysunek 12. The way of connection used in MF module of LABINVERTER

The block scheme of ALS-G3-1369 digital system, which was used in aim of building control circuit, is presented in Fig.13. It is based on the floating digital signal processor

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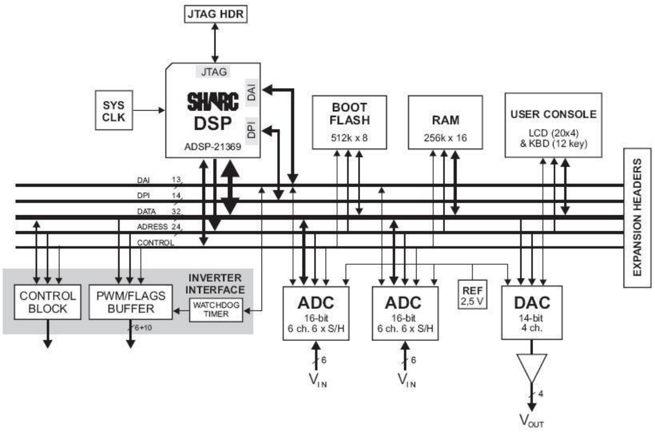
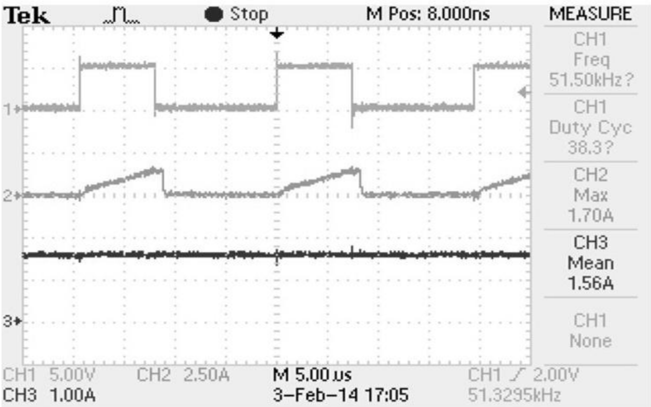
SHARC ADSP-21369, which is equipped with hardware co- processor of PWM (pulse width modulation) [9].



Rysunek 13. The block scheme of ALS-G3-1369 digital control system [8]



To simulate the operation of photovoltaic cells, a laboratory DC power supply with an adjustable current limit and output voltage was used in the early stages of the research. Due to the high dynamics of power supplies' power reduction systems, a portion of the research was conducted with the system off, with the supply's output being substituted by a resistor linked in series. As a result, it was feasible to evaluate whether the system's output power value corresponded to the maximum power produced by a cell, confirming the MPPT algorithm's correct operation. Real photovoltaic cells were used to replace the power supply in the last round of laboratory experiments. An illustration of an experiment's findings is shown below:

- the average value of the output voltage of photovoltaic panels: 233V,
- RMS voltage: 230V,
- the value of active power delivered onto the network: 940W,
- determined (maximum) system efficiency of 96% ,
- experimental studies have confirmed proper operation of the system and allowed the time constant tuning of the MPPT algorithm,

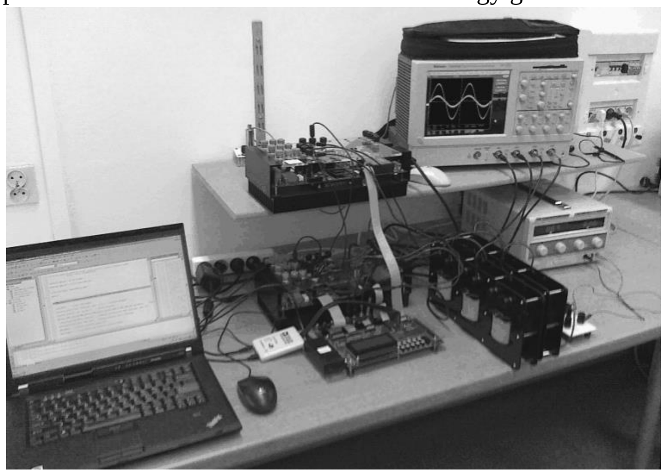
The laboratory system of described power electronics solar converter is shown in Fig.14.

Experimental studies have confirmed proper operation of the system and allowed the time constant tuning of the MPPT algorithm. It should be noted that for the proper functioning of this algorithm, the frequency of the loop responsible for changing the duty ratio should be greater than the frequency of the loop deciding on the direction of changes, which activates a pulse duty factor.

The chosen results of experimental research for boost converter and grid inverter are shown in Fig.15, Fig.16 and Fig.17.

V. Conclusion

Models for the control system and high voltage power circuit were created using simulation and experimentation for the investigation of the DC/AC coupler of a group of photovoltaic PV cells and the industrial energy grid



Rysunek 14. The laboratory system of solar converter with DC power supply emulating photovoltaic cells

Rysunek 15. Bost converter in discontinuous conduction mode. Waveform 1 - pwm signal, waveform 2 - transistor current in boost converter, waveform 3 - boost output current

were developed. The outcomes supported the validity of the theoretical presumptions, enabling compatibility with the whole system. The modification, allowing for, for example, increase of efficiency ratio - notably when system operates with lower power than established - is anticipated throughout the succeeding research phases. Additionally, work on improving the MPPT algorithm's speed and accuracy in calculating the output power of PV cells is anticipated. Additionally, studies are being conducted on, for instance, the elimination or restriction of unwelcome current flow brought on by parasitic capacitance between the surface of the cells and ground.

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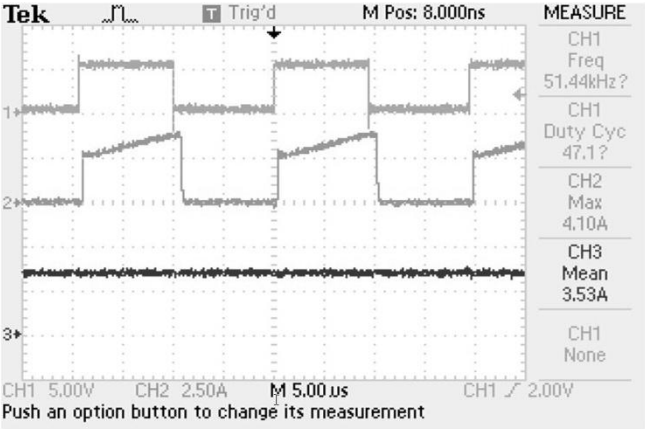
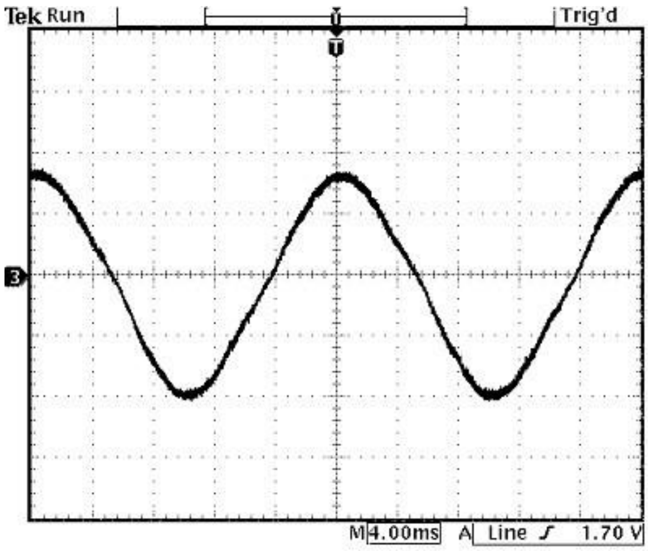


Rysunek 16. Bost converter in continuous conduction mode. Waveform 1 - pwm signal, waveform 2 - transistor current in boost converter, waveform 3
boost output current



Rysunek 17. Experimental results - grid current trajectory generated by the inverter

LITERATURA

[1] (2015,Jan.) Solaris website. [Online]. Available: http://solaris18.blogspot.com/2012/01/panel-fotowoltaiczny-punkt- mocy.html.

[2] M. Krystkowiak and A. Gulczyński, "The construction and control algorithm of power electronic converter implemented in unconventional mini-hydroelectric system dedicated to craft marinas,"*Poznan University of Technology Academic Journals*, Issue 80, pp. 27-34, 2014.

[3] M. Krystkowiak and A. Gulczyn´ski, "Construction and principle of working of an experimental model of a mini hydroelectric units dedicated to yacht,"PES-9, pp. 133-136, 2014.

[4] S. Fryze, "The real power, imaginary and apparent power in electrical circuits with distorted waveforms of current and voltage", Przeglad Elektrotechniczny, Vol. 7 and 8, 1931.

[5] M. Krystkowiak, "Power rectifier with improved indicators working with power electronics current modulator,"PhD thesis, Poznan University of Technology, 2009.

[6] M. Gwoz´dz´, M. Krystkowiak, "Control system of power electronics current modulator utilized in diode rectifier with sinusoidal power grid current", Przeglad Elektrotechniczny, Vol. 7, 2009.

[7] (2015,Jan.) ALFINE-TIM website. [Online]. Avail- able: http://analog.alfine.pl/oferta/produkty-alfine/systemy-uruchomieniowe/84-przeksztaltnik-energoelektroniczny-p3-50-550mfe

[8] (2015,Jan.) ALFINE-TIM. Development board DSP ALS-G3-1369 - technical description Analog Devices, ADSP-2137x SHARC Processor Hardware Refer- ence,A‹DSP-21369 satasheet, April 2013 [Revision 2.2]