Power Converter with High Value of Power Factor

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Abstract. Increasing the energy efficiency of using electricity is a current problem. As a modern solution, the development of power equipment based on power electronics was presented. These devices, which absorb relatively large powers from the low-voltage grid, lead to the distortion of currents in the power supply network and to the reduction of the power factor, leading to increased losses in supply networks. The aim of the paper is to develop an innovative solution to increase the power performance of power electronics devices as a result of improving their power factor. The scientific innovation consists in the realization of the technical solution for the fusion of the power factor correction and power conversion improvement in the unique functional block, which has an AC / DC power converter. A simulation model of the AC /DC converter mode has been developed. The efficiency of power factor improvement of the AC / DC converter and operation in switching mode at the zero voltage of the transistor in the primary circuit of the transformer has been demonstrated. It has been experimentally demonstrated the possibility of manufacturing AC / DC converters with cumulative power factor correction functions and output voltage stabilization. The magnitude of the voltage pulses (alternate component) on the rectifier's filter capacitors does not exceed the maximum allowable operating value of the capacitor. This ensures increased efficiency of the converter. The AC / DC converter has an efficiency of 98% and power factor equal $\cos\varphi > 0.985$ for the 1500 W power supply and the 220/12V.

Keywords: converter, zero-voltage-switch, fly-back, forward, mathematical simulations, energy efficiency.
DOI: 10.5281/zenodo.3239218

Convertor de putere cu factor de putere ridicat

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Abstract. Creșterea eficienței energetice a utilizării energiei electrice este o problemă actuală. Ca soluție modernă, în acest context este prezentată dezvoltarea echipamentelor de forță bazate pe electronica de putere. Cu toate acestea, aceste dispozitive care absorb valori ridicate ale puterii reactive din rețeaua de alimentare de joasă tensiune conduc concomitent la injectarea de curenți de înaltă frecvență în rețeaua de alimentare și la reducerea factorului de putere, ce are ca urmare creșterea pierderilor în rețelele de alimentare. Scopul lucrării este de a dezvolta o soluție inovatoare de sporire a indicilor de performanță energetică ale dispozitivelor electronice prin îmbunătățirea factorului de putere. Inovația științifică constă în realizarea soluției tehnice de fuziune a funcțiilor de conversie și de îmbunătățire a factorului de putere în blocul funcțional unic, care prezintă un convertor de energie electrică de tipul AC/DC. S-a elaborat modelul simplicit de simulare a regimului de funcționare a convertorului DC/AC. S-a demonstrat eficiența îmbunătățirii factorului de putere a convertorului de tip AC/DC și funcționarea în regimul de comutație la tensiunea zero a tranzistorului din circuitul primar al transformatorului. S-a demonstrat experimental posibilitatea fabricării convertoarelor de tip AC/DC cu cumularea funcțiilor de corecție a factorului de putere și stabilizarea tensiunii de ieșire. Magnitudinea pulsațiilor tensiunii (componenta alternativă) pe condensatoarele de filtrare a redresorului nu depășește valoarea maximă admisă de lucru a condenatorului de filtrare. Aceasta asigură creșterea eficienței convertorului. Convertorul AC/DC are o eficiență de 98% și factorul de putere egal cu $\cos\varphi > 0.985$ pentru convertorul cu puterea de 1500 W și tensiunea 220/12 V.

Keywords**:** convertor, zero tensiune de comutare, regimurile fly-back, forward, modelare matematică, eficiență energetică.

Преобразователь энергии с высоким значением коэффициента мощности

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Abstract. Повышение энергоэффективности использования электроэнергии является актуальной проблемой. В качестве современного решения в этом контексте, представлены результаты разработки силового оборудования на основе силовой электроники. Однако эти устройства, поглощающие высокие реактивные мощности от сети низкого напряжения, приводят к вводу высокочастотных токов в сеть электропитания и уменьшают коэффициент мощности, что приводит к увеличению потерь в сетях электропитания низкого напряжения. Целью данной статьи является разработка инновационного технического решения для повышения энергетических характеристик устройств силовой электроники в результате повышения их коэффициента мощности. Научное новшество предагаемого техничнского решении состоит в объединение несколько функций в процессе преобразования параметров электрической энергии и улучшения коэффициента мощности в едином функциональном блоке, представляющем преобразователь переменного напряжения в рапрчжения постояного тока (AC/DC). Разработана математическая модель в среде SIMULINK для исследования режима коммутации транзистора в цепи переменного тока. Математическое моделирование продемонстрировало эффективность повышения коэффициента мощности преобразователя AC/DC на основе предложенного решения. Экспериментально продемонстрирована возможность изготовления преобразователя AC/DC на основе предложенного инвертора с кумулацией функций в одном блоке. Было продемонстрировано, что импульсы напряжения (переменная составляющая) на фильтрующих конденсаторах выпрямителя не превышают максимально допустимое значение. Транзисторы инвертора работают в режиме переключения при нулевом напряжении. Это обеспечивает повышение КПД преобразователя. Экспериментально установлно, что преобразователя AC/DC с мощностью 1500 Вт при напряжении 220/12 V имеет эффективность преобразования 98%, а коэффициент мощности $\cos\varphi > 0.985$. Разработанный преобразователь AC/DC характеризуется очень низкими индексами массы и объема по сравнению с аналогичным оборудованием, работающим на частоте 50 Гц. Техническое решение может быть использовано для производства блоков питания для компьютеров, телекоммуникационных систем, сварочных аппаратов, систем зарядки аккумуляторов и других приложений.

***Keywords*:** преобразователь, нулевое напряжение переключения, режимы fly-back и forward, математическое моделирование, энергоэффективность.

I. INTRODUCTION

Electricity is the most flexible of all types of energy with is the adapted for long-distance transport, and distribution and final use. Any phase of the process of transformation, transport, distribution and use is accompanied by losses, which lead to the reduction of the energy efficiency of the respective processes. Increasing energy efficiency is now a solution to overcome existing problems in ensuring energy consumers [1, 2, 3-8]. Any consumption is based on energy conversion using different equipment. Performance of the equipment used has a direct impact on energy efficiency. As an example one may indicate at increased energy losses in electric networks due to reactive power flow circulation. Reduction of losses caused by reactive currents is carried by the reactive power compensation [1, 5, 8, 9]. This compensation can be achieved in various ways, including the most effective and reasonable is to compensation on terminals of consumer. As an indicator, which determines the level of compensation reactive power in the circuit is the power factor used. In this context, raising the power factor value for consumers and energy conversion devices used by consumers is presented as an effective solution for the reduction of energy losses.

Power electronics are commonly used to improve the power factor at the consumer's connection point at the power supply network [11 -15]. Power “boost” converters are the most effective solution [8, 10 - 12, 16, 17] for improving the power factor [18 - 21]. The solutions examined are disadvantaged by the fact that the increase in power factor leads to additional losses in the equipment used for power factor correction, which are separate functional blocks

II. PROBLEM IDENTIFICATION

Physical essence underlying the operation of the converter type "boost" consists in dividing the process of increasing the power factor and converting into two different functions. Each functional component of the conversion process is carried out as independent block. As a result, each functional component has its share of energy losses in the working process, affecting the total efficiency of the equipment.

As a technical solution to increase the energy efficiency of electronic power converters, it is proposed to aggregate the conversion factor and power factor correction into a single functional block that will contain the minimum required of electronic elements. This will result in the reduction of the sum of energy losses in comparison with the known solutions for the realization of the power factor correction function. This is the purpose of paper, as the decrease in the number of with energy-loss elements will help to increase the energy performance of the converter.

III. TECHNICAL SOLUTION

Modern power electronics converters include various functional blocks, which are characterized by its own energy consumption during operation of the converter. Their energy performance is determined by the quality of the electronic power components, the control system and the structure of the converter. It is evident that the Power electronics converter performance depends on the number of elements because each element has losses of power.

Merging of various functions performed in separate blocks by a smaller number of functional blocks is an opportunity to increase the energy performance of the converter. In this context, it is proposed the function of increasing of power factor of type "boost" converter to be performed separately. Figure 1 shows the scheme proposed converter by the authors of this paper.

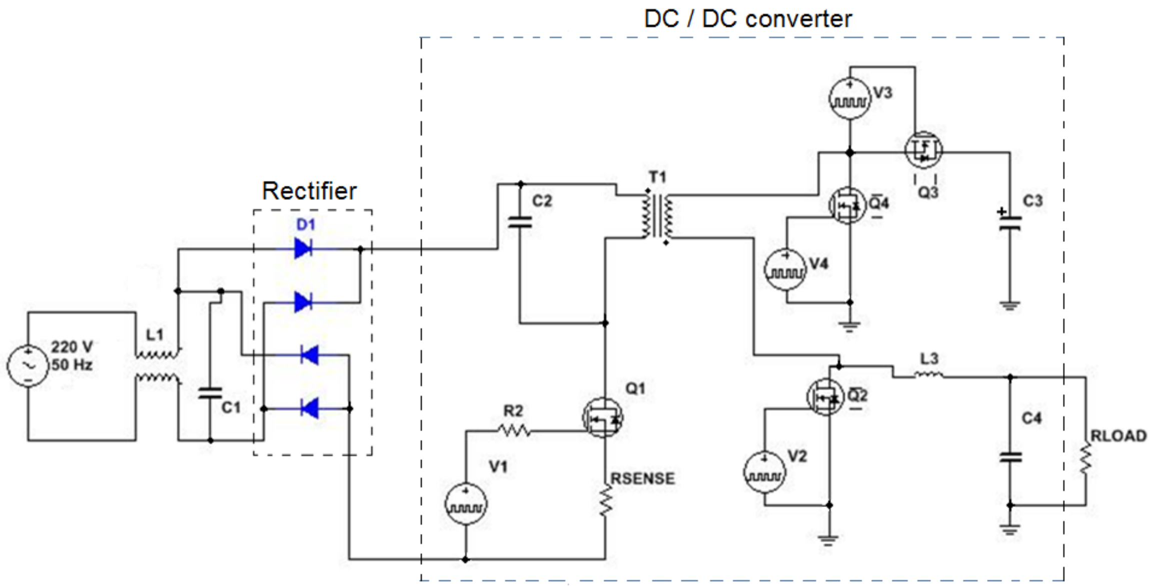

Fig.1. Equivalent circuit of the converter with high power factor value.

The converter is powered by an AC source with the voltage of 220V of industrial frequency. Elements L1 and C1 form a filter circuit for filtering of the higher current harmonics. The higher current harmonics is generated during operation of power electronic device Q1. AC voltage is rectified by the bridge marked "Rectifier" – D1.

The element of fig. 2, denoted as C2, is part of the switching circuit of the electronic device Q1. The use of such a structure, called the switching circuit, provides the "zero-voltage-switched" mode of the electronic device Q1, so the switching takes place at zero voltage.

The use of the ZVS switching mode of the Q1 transistor leads to the reduction of energy losses during the operation of the Q1 electronic device. Electronic device Q1 has the function of connecting and disconnecting the primary winding of the transformer T1 to the supply circuit (to the rectifier terminals D1).

The power transformer T1 is manufactured with air gap of the ferromagnetic core. With this transformer it is realization two modes of transmission of energy from the primary circuit in the load circuit. These operating modes are defined as "fly-back and forward" regimes.

The terminals of the secondary coil of the transformer T1 are connected to the common connection point of the electronic device Q2 and the inductance coil L3 and to the common connection point of the electronic devices Q3 and Q4. The capacitor C3 connects to the secondary terminal of the transformer coil via the Q3 electronic device. The voltages of transformer T1 have phase difference equal to 180 degrees (counter-phase). The electronic device Q4 serves for connect the terminal of secondary coil of the transformer T1 to the ground. The complex load is connected to the secondary coil of the transformer T1 through the inductive element L3. Complex load consists of components C4 and RLOAD. The output of the secondary coil is connected to ground through the electronic device Q2. The electronic devices Q1-Q4 have the diode shunt circuits.

IV. OPERATION OF CONVERTER

The proposed voltage converter is connected to the power supply and to the control device that generates the pulses V1, V2, V4 and V3 (see fig. 2) via the power electronics devices Q1, Q2, Q3 and Q4. In an elementary working cycle, the inverter has three operating modes.

The first mode is ensured by selecting of air gap size the core of transformer T1, **the second mode** is ensured by adjusting the pulse-width control, and **the third mode** by ensured with the pulse-width control V3 were is applied to electronic device Q

A. Fly-back mode

In the first mode converter works as a converter "fly- back" and ensures the regime "Power Factor Compensation" (PFC). Let the control signal is applied to the electronic device Q1 (fig. 1).

When opens the electronic device Q1 the current I_{Q1} the flowing through the primary winding of the transformer T1. Current that flows through electronic device Q1 and the primary winding provides energy storage in the magnetic field of the transformer T1. Depending on the amount of voltage on the complex load and the voltage loss across the resistor RSENSE, impulse V1 closes the electronic device Q1.

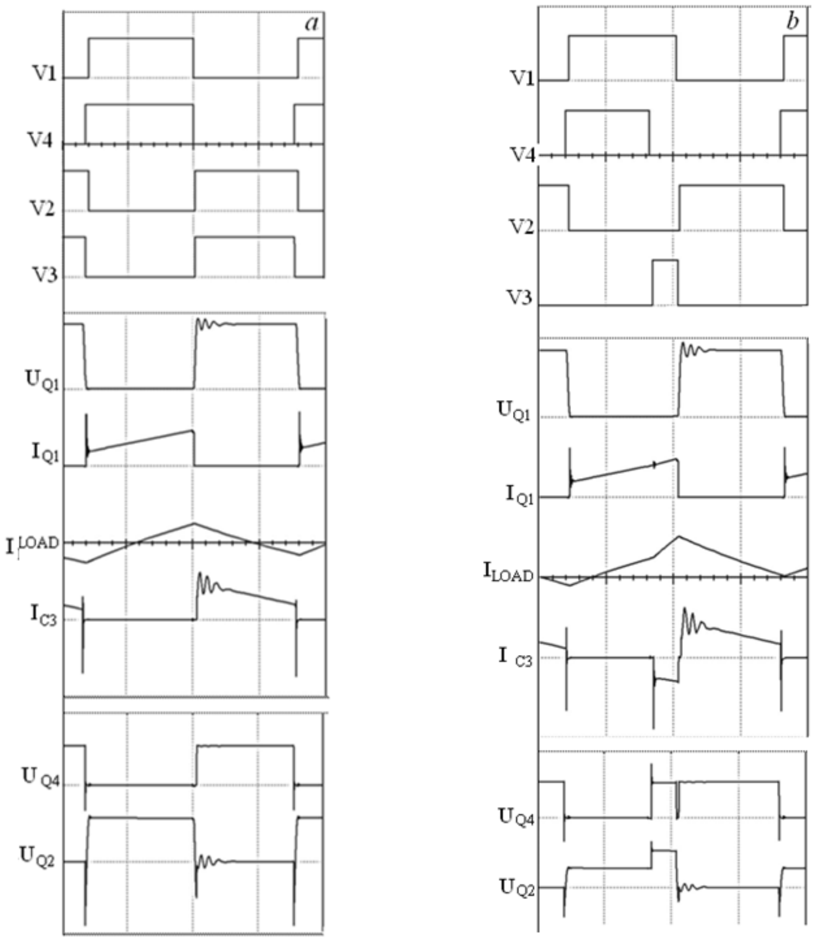

Fig. 2. The work diagrams of the inverter elements when charging the C3 capacitors in the fly-back regime (a) and unloading the C3 capacitor in the forward regime work of the inverter (b).

When closes the electronic device Q1, a new circuit is formed, which consisting of the primary winding of the transformer T1 and the capacitor C2. The electronic device Q1 is shunted and closing, when the voltage drop on it is zero. As a result, when electronic device Q1 closes, the capacitor C2 is charging and storage a small share of the energy of the magnetic field of the transformer T2. At the equalizing condition of the electromotive voltage values of the secondary winding of the transformer T1 and the storage capacitor C3, the inner diode of the electronic device Q2 opens. At this moment, the energy of the magnetic field of transformer is absorbed by the storage capacitor C3 through the circuit comprising the elements: earth - Q2 -Q3 -

C3 - secondary winding, which has the direct connection to earth. To electronic devices Q1, Q2 and Q4 are applied the impulses, that shunts the secondary winding of the transformer T1 before applying a new control impulse V1. At the electronic devices Q1, Q2 and Q4 control pulses are applied and consequently the secondary coil of the transformer T1 is shunted. This state of the circuit is maintained until another V1 control pulse is applied to the electronic device Q1.

After the application of the new control pulse V1, another C2-T1-C2 circuit is formed and the earthlings circuit of the components Q2 - the secondary winding of the transformer T1 - Q4 - earth, which allows mode of the discharge of the capacitor C2. It ensures the condition that the voltage applied on the electronic device Q1 is zero. This control procedure with the closing and opening process of the electronic device Q1 ensures at the zero voltage switching mode, called ZVS.

B. Forward mode

Second regime presents a system of mode "forward". Let control pulse V1 is applied to electronic device Q1 (fig.1). When opens electronic device Q1 the current flows I_{Q1} through the transformer T1 primary winding (fig. 2). This current forms a magnetic flux in the transformer T1, which provides the appearance of electric voltage in the secondary coil. This current circulates through the circuit formed by the elements "earth - Q4 - the secondary winding of the transformer T1-L3 - C4 - RLOAD - earth". Load elements RLOAD and C4 are connected in parallel. Depending on the voltage that is determined by the complex load C4 - RLOAD is changes impulse duration V1. It is mode, when the power of the source is transferred directly to the load.

C. Stabilization of the load voltage

In the third mode, the voltage on the C4-RLOAD load is stabilized by adjusting the amount of energy transferred from the storage capacitor C3 to the load.

Whether, we have the fly-back mode of operation. Electronic device Q1 is closed. By electronic device Q1 in this time no current flows. Energy stored in the air gap of transformer T1 is transferred to the storage capacitor C3 through the circuit "ground -Q2 - secondary coil T1-Q3-C3-earth". The application of the V1 impulse leads to the electronic device Q1 opening, and the command impulse V3 ensure opens the electronic device Q3, with formation the RLOAD-C4 load voltage stabilization circuit. This stabilization circuit includes the following elements "earth - C3 - Q3- secondary winding T1 - inductance L3- load RLOAD - C4 -earth". When changing the control pulse width V3, which the opens electronic device Q3, we get the opportunity to adjust the amount of energy transferred from the storage capacitor C3 load RLOAD-C4. Therefore, applying this mode of operation of the converter ensures the stabilization of the DC voltage on the load RLOAD-C4.

We mention that there is a main difference on how to perform the exchange of energy in the first mode "fly -back" mode and "forward". In the first case, the amount of energy injected into the storage capacitor C3 in a switching process over work cycle is determined by the size of the air gap of the iron core of the transformer T1 and the pulse frequency value. In the "forward" scheme, the amount of energy injected into the load in an elementary operating cycle of the converter is determined by the inductance value L3 and the pulse width of the constant frequency control of these pulses.

V. MATHEMATICAL SIMULATION MODEL

In fig. 5 presents a simplified version of the mathematical model of the converter, in which the functions of the electronic devices Q2, Q3 and Q4 are assigned to the device denoted as D3. The purpose of these simulations was to verify the converter's impact on the power supply network and the achievement of the goal, which relates to the achievement of the power factor compensation function. The function of stabilizing the output voltage through the injection from the capacitor C3 of the electric energy into the RLOAD load has not been modeled, since these simulations have been performed for the RLOAD = constant regime. For load over time, it is not necessary to achieve the output voltage stabilization function. The AC power supply voltage is used as input parameter to simulation of operating mode of the converter: Um =312 V, f = 50 Hz.

In the equivalent scheme (Fig. 5) are present the numerical values of the passive elements and of the set of components intended for visualization of the parameters of the signals applied to the electronic device (transistors) of the converter voltages and currents.

The simulation of the operating mode of the converter was performed using the SIMULINK software. Since the transfer of energy from the power supply to the load takes place at high frequencies with PWM operation, it was first examined the impact of the converter on AC network. This approach aimed at estimating the curve distortion of the absorbed current from the power supply. At the same time, the angle of phase difference between the voltage of the power supply and the absorbed current was determined, which also determines the power factor of the converter, hence and the effectiveness of the correction of this parameter as a result of achieving the proposed solution.

The switching of the electronic device in the ZVS mode, predominantly of the Q1 element, leads to the reduction of the energy losses in the switching process and to the increase of the energy efficiency indices. The cumulating of several functions, such as power factor correction and converter output voltage stabilization, has also led to improved conversion efficiency.

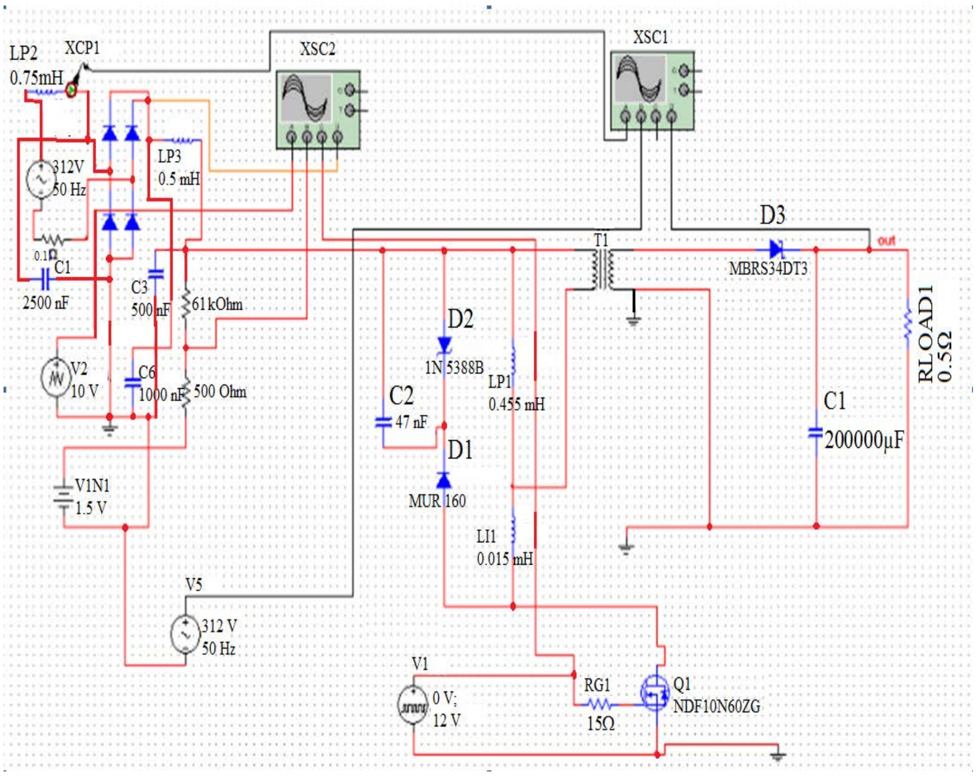

Fig. 5. Simple simulation model of the ZVS mode of the AC / DC converter.

The results of the simulation work the electronics device (transistors) mode of inverter at the instantaneous change of the input voltage of this inverter is shown in fig.7. The voltage applied to the inverter input is a characteristic curve for the signals with industrial frequency.

Based on the results of the mathematical simulations, a laboratory sample of the converter with the power factor correction was designed and manufactured (fig.6).

The topology of the proposed converter can provide a high power factor. Thus, the power factor of the proposed converter has a value of 0.98. The laboratory functional sample of the converter had a power of 1500 W. The input voltage for the laboratory converter allowed variation of the AC voltage across the range 160-240V and the output voltage was 12V DC.

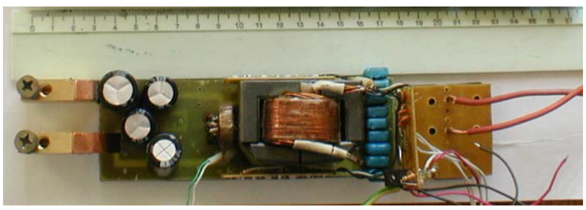

Fig. 6. AC / DC converter with 1500 watts and 220 / 12V voltage.

In fig 8 we show the instantaneous voltage on the filtering capacitor C1 the upper harmonics, as a result of the operation of the converter, and in fig. 9 there is presented the curves of the input voltage and of the current absorbed from the network.

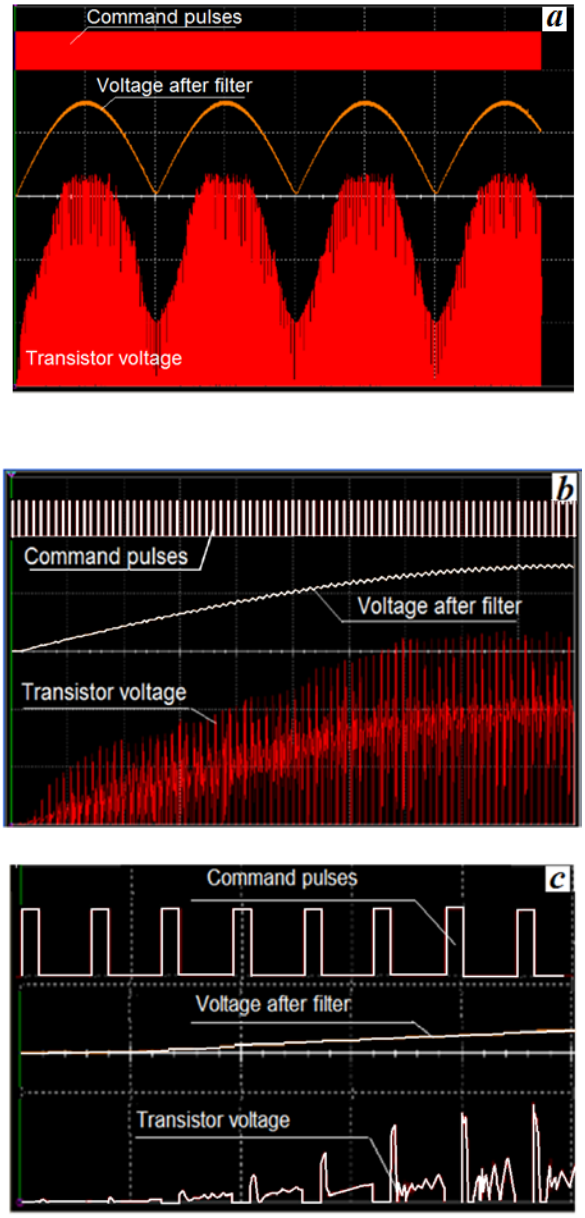

Fig. 7. Control pulse diagrams, transistor voltages and voltage curve on after rectifier (shown in different scale sizes to elucidate the process, scale *a*< scale *b*<scale *c*).

Since the transfer of power from one circuit to another circuit is made at high frequency, the harmonics of the current generated in the conversion process are high frequency and for their good filtering it is not necessary to have the high capacitance and inductance of the elements L1 and C1.

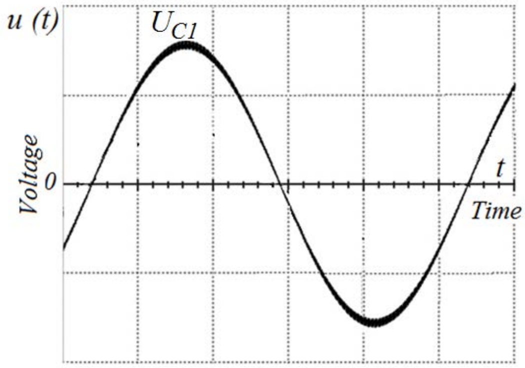

Fig. 9. Voltage curve on the filter capacity C1 = 2500 nF.

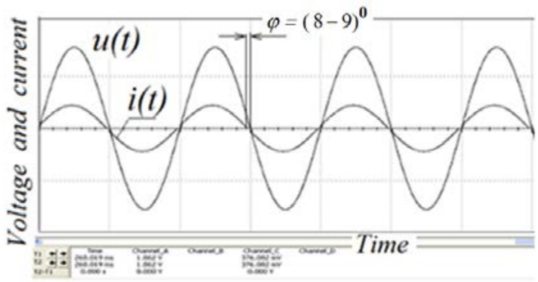

Fig. 8. The phase difference angle between the voltage and the current of the converter with the correction of the power factor.

CONCLUSIONS

1. The proposed solution of the converter is robust. Simulation results confirm that the operating ZVS mode, when the electronic device Q1 opens and closes occurs at zero voltage on the electronic device and ensure to reduction of switching losses.
2. Correction of the power factor of the device with the power of about 1500W ensure of the value to 0.98 and has a capacitive character. The reducing the capacitor value C1 leads to higher power factor PFC and increased voltage pulsation on the capacitor C1. Visible distortions were not detected of the shape of current and voltage of converter in laboratory tests.

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