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ADJUSTABLE LOAD FOR AUTOMATIC TESTING OF DC POWER SUPPLY

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Abstract—*This article is devoted to the development of adjustable electronic load for direct current power supply testing systems. The structure of the electronic loadunit, which allows to regulate the currents of the tested source and carry out the recovery of energy to the electrical grid, is described in the article. The structure of thisunit includes booster converters, working on a common direct current link, full-bridge inverter, smoothing filter and electrical grid transformer. The basic relationships for element parameters calculation of constituent parts are determined. The control devices of converters and inverter, in which relay current regulation is implemented, are developed. In the Matlab Simulink software environment a model of the proposed electronic load is realized. With the use of developed model researches were conducted, which confirmed the ability of the proposed electronic load to regulate input currents and perform energy recovery.*

Index Terms—Electronic load; energy recovery; testing of power supplies.

I. INTRODUCTION

Direct current (DC)sources are widely used to power a variety of electronic equipment [1], [2]. Essentially such sources are sources of secondary power, which convert the electric power of the industrial grid to electric power of direct current [3]. Power sources that are on the market differ in their purpose, power, output voltage, efficiency factor and many other parameters. But characteristic property of all these devices is the ability to maintain the output voltage or current with given accuracy for a long time while the load could change within the specified limits. Therefore, in the production of such power supplies, it is mandatory to test the finished products to control their characteristics. Similar procedures can be performed at service centers when troubleshooting [4].

For these purposes devices and systems different in complexity and functionality are used. The market now has specialized systems for testing specific power supplies, as well as more versatile equipment that can be configured to test different purpose systems.

For a comprehensive study of DC sources automated testing systems are used [5], the approximate structure of which is shown in Fig. 1.

In addition to the tested device, such a system includes: a voltage regulator, a regulated electric load, a set of measuring and a control units for the entire system. Such complex systems provide measurements of a set of characteristics, among which some should be distinguished:

– output characteristics (output voltage, output current, efficiency, pulsation dispersion, etc.);

– input characteristics (starting current, harmonic current composition, power factor, etc.);

– time and transition characteristics (turn-on and shut-down time, dispersion in transient processes, etc.);

– special characteristics.

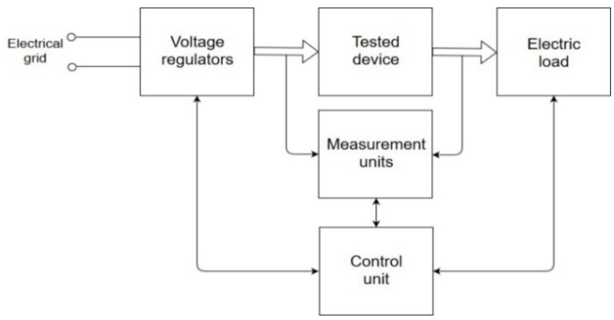


Fig.1. Structure of the automated testing system of secondary power sources

The widespread use of such systems is prevented by its high price, so specialized devices and systems with less functionality are used predominantly.

Considerable attention is paid to the development of systems for testing computer power units, due to their widespread distribution. A characteristic feature of these blocks is the presence of different output voltages, which are divided into several groups. For each of these groups, there is a maximum current for which the voltage should not differ from the specified value by more than 5%.

II. ANALYSIS OF EXISTING SYSTEMS

To study the characteristics of the computer power supply unit different solutions are used [6] – [9]. Mandatory part of these systems is an adjustableelectronic load, without which the correct testing of power supply is impossible.

In article [6] a multi-pin variable resistor is used as such a load module. In articles [7], [8] as a load module set of resistors is used. These resistors connected to the tested power supply trough the electronic keys which are commutated by the control signals. In article [9] electric motor with a voltage regulated module is used as electronic load unit.

Typical drawback of such load units use is their low energy efficiency. This is due to the fact that during testing procedure the energy consumed from the power supply reaches its maximum value, and the time of testing can be quite long. This electric energy isconverted into thermal energy in loadunit, which may need additional cooling system.

III. Problem Statement

For energy-efficient operation of the automated testing system of computer power units, it is necessary to ensure the transmission of energy consumed from the power unit to the electrical grid. The implementation of such a function of recuperation involves the use of semiconductor energy converters as a load [10]. Considering the need to adjust the load input currents in accordance with the testing algorithm, it would be appropriate to combine these functions in one device.

Therefore, the purpose of this work is to determine the approaches for buildingsemiconductor energy converter acting as a regulated energy-efficient load. This converter should recuperate electric energy to the grid with unity power factor and with minimum harmonic distortion.

IV. Problem Solution

In the computer power supply units, there are groups of output voltages of +3.3 V, +5 V, +12 V, –5 V, –12 V, but in the most modern devices there are no negative voltages. The structure of the proposed energy converter, which can be used as an adjustable load, is shown in Fig. 2.

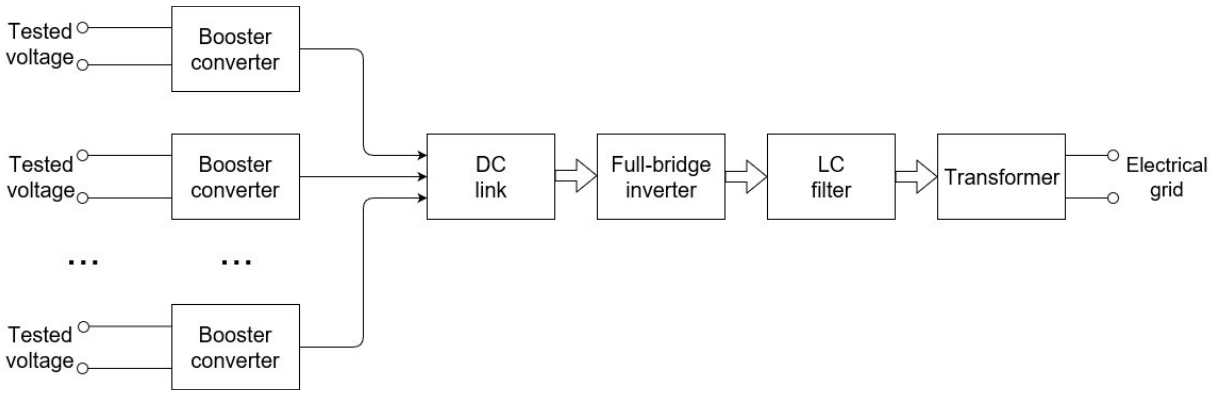


Fig.2. Structure of the adjustable electronic load

It consists of: booster converters, the number of which equals the number of voltage groups of the tested block, the DC link, the output full-bridge inverter, the smoothing LC filter and the grid transformer.

The schematic diagram of the booster converter is shown in Fig. 3.

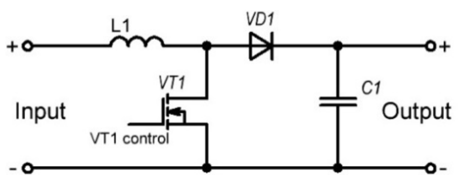


Fig.3. Booster converter

Such converter, depending on the control, can work in the mode of regulation of the output voltage, or in the mode of input current regulation. Based on the purpose of these converters in the system, it will be rational to provide the regulation of the input current. This is achieved by changing the duration of the open and closed state of the transistor at high frequency, which allows to reduce the weight and size parameters of the inductance. Different approaches are used for transistor control, the most common of which is pulse-width modulation and relay regulation. In this case, it would be efficient to use relay control, since such control is the easiest in implementation. This approach involves switching of the transistor at moments of time when the difference between the instantaneous value of the inductance current and the given value exceeds a certain value. The given current value $U_{I\,\mathrm{load}}*$ is set by the control unit and corresponds to the load level for which the testing is performed. Thus, the real value of the load current I_{load} will be constantly located in the "current corridor" ΔI_{load} around the given value. The width of this "corridor" corresponds to the width of the relayelement hysteresis loop. InFigure 4 the structure of a control unit that implements the described approach is shown.

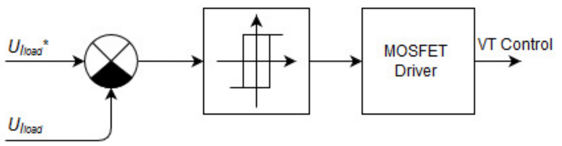


Fig. 4. Structure of booster converter control unit

With a constant input current of the booster converter, the electric energy will accumulate in the capacitance of the DC link, which will lead to the voltage increase. Returning of the accumulated energy to the power grid is carried out by the inverter. Its functional purpose is the formation of the output current I_{out}, the shape and phase of which must coincide with the shape and phase of the electrical grid voltageU_{grid}, and the amplitude $I_{out.max}$is regulated depending on the DC link voltage. In this case, the power factor is almost equal to 1, so the recovery of the electric energy will not negatively affect the power grid. Figure 5 shows the scheme of the output part of the regulated load, which includes afull-bridge inverter, a smoothing filter and a grid transformer.

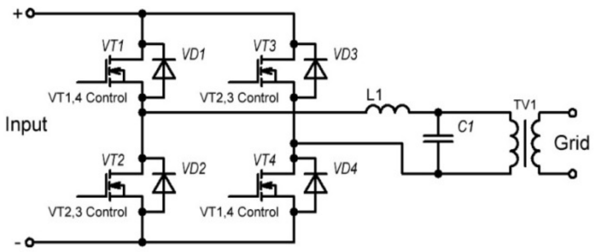


Fig. 5. The scheme of the output part of the regulated load

Regulation of the inverter output current I_{out} is carried out by alternating pairwise switching of transistors VT1, VT4 and VT2, VT3. For this purpose, it is also rational to use relay control. The form of the output current set value $U_{I\,out}$* must coincide with the electrical grid voltage form, and the amplitude must depend on the DC link voltage U_C. The more energy is accumulated in the link, the greater the voltage and the greater the amplitude of the output current would be. The structure of the control unit that implements the described approach is shown in Fig. 6.

The input signals are the sensor signals of the following values: grid voltageU_{grid}, inverter output currentU_{Iout}, DC link voltageU_{Uc} and given value of DC link voltage signalU_C*. To form the set signal of the inverter output current $U_{I\,out}$*, subtraction blocks, regulator (proportional controller in this case), and multiplication unit are used. At the output of the subtraction block, the difference signal ΔU_C is generated. This signal is fed to a proportional controller, which serves to determine the amplitude of the output current. Next, by multiplication of the amplitude signal on the signalU_{grid}, the signal$U_{I\,out}$*is generated. Transistor control signals are generated using a relay element, on the input of which the difference between the $U_{I\,out}$* signal and the $U_{I\,out}$ signal is given, which in turn is formed by the second subtraction block. The opening of transistors VT1, VT4 should occur at a high level of the relay element output signal, and transistors VT2, VT3 –at low. To distribute control signals an inverter is used.

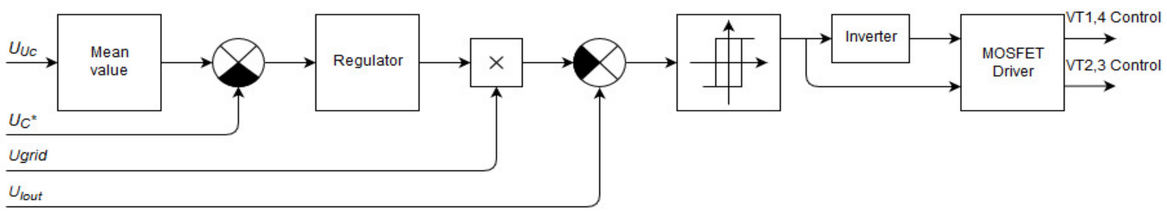


Fig. 6. Structure of full-bridge inverter control unit

During operation, the increase of load currents will increase the voltage in the DC link, which automatically will increase the output current. Thus, the tasks of transmitting energy from the tested power supply unit to the network with a unitary power factor and voltage stabilization in the DC link is automatically solved. Usage of a proportional controller for formingU_{Iout}* causes a U_C adjustment error. But taking into account that for controlling current relay control is used, this error will only lead to a change of the current pulsations frequency.

On the other hand, it should be taken into account that transferring of energy from the DC link to the grid has a pulsating nature. Since I_{out} coincides with the shape of the grid voltage, its energy will be changed with double frequency. At the same time, current and energy consumption from the tested power supply unit is constant over time. The difference between these energies is compensated by the electric field energy of the DC link, which leads to the appearance of U_C voltage fluctuations. The smaller the capacitance would be in DC link, the less amount of energy can be stored, and therefore the amplitude of U_C pulsations will be greater. PossibleU_C voltage drop can lead to a loss of controllability of load currentI_{load}. Neglecting the value of losses, we can assume that the input power is equal to the average output power on the period.

The deviation of the voltage in the DC link from the mean value is characterized by the pulsation coefficient $K_P = U_{Cm}/U_{Cd}$, U_{Cm} is the amplitude of the voltage pulsations in the DC link, U_{Cd} is the average voltage value in the DC link. The value of the capacitance is determined by the expression:

$$C = \frac{P_d}{2\omega \cdot K_P \cdot U_{Cd}^2}, \qquad (1)$$

where P_d is the average energy of the period, ω is the circular frequency of the current transmitted to the grid.

To ensure controllability of the load current, it is necessary that the voltage U_C would be greater than the highest voltage of the power supply unitbeing tested, that is equal to 12 V. Therefore, the proper average voltage value of U_{Cd} and the magnitude of its U_{Cm} pulses should be selected. Obviously, when testing a power supply unit of a given power for reduction of the DC link capacitance, it is rational to increase the U_{Cd}. But such increase of U_{Cd} voltage would also lead to increase of the power transistors switching frequency, which is determined by the expression:

$$f = \frac{1}{\dfrac{L_{\text{load}} \cdot \Delta I_{\text{load}}}{U_T} + \dfrac{L_{\text{load}} \cdot \Delta I_{\text{load}}}{U_{Cd} + U_{Cm} - U_T}}, \qquad (2)$$

where U_T is the output voltage of the tested power supply unit; L_{load} is the input inductance of the booster converter.

Therefore, when designing a regulated load of a given power, all the above-mentioned factors must be taken into account.

It should be noted that since voltage U_C is used to generate the $U_{I\,\text{out}}$* signal, then the presence of pulsations will cause distortion of the output current, and change the power factor. To avoid this, when calculating the $U_{I\,\text{out}}$* signal, the mean value of voltage U_{Cd} should be used.

To test the performance of the proposed approach for building a regulated load with the possibility of energy recovery, its visual model in the Matlab Simulink [11] software environment was composed (Fig. 7).

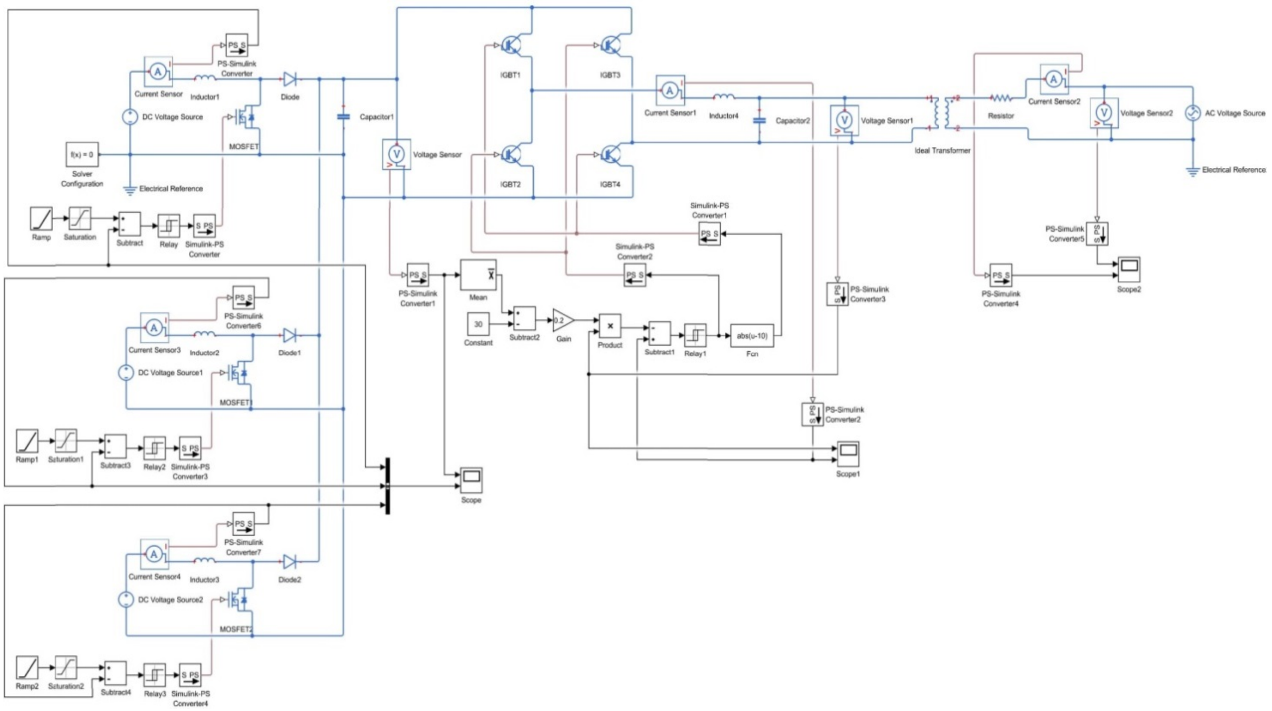
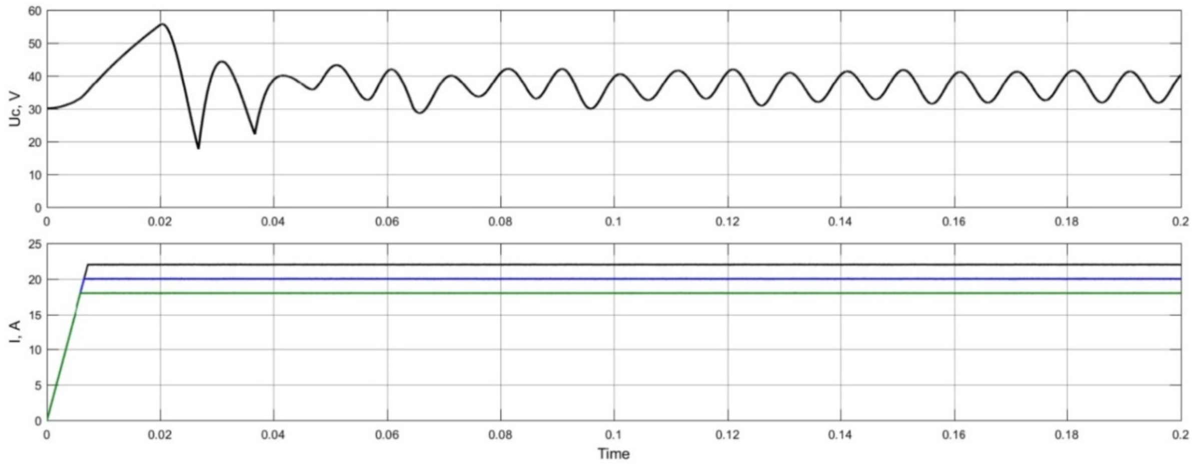


Fig. 7. Structure of a regulated electronic load model

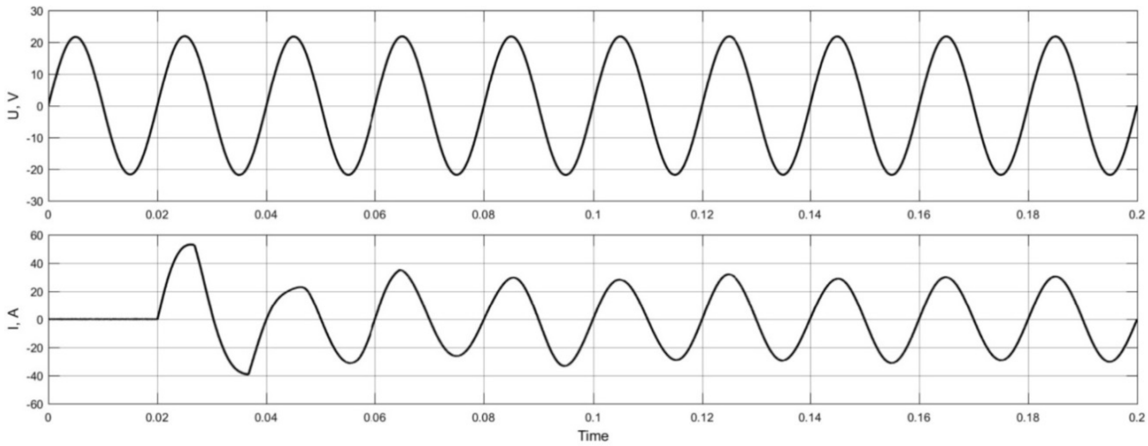
In the developed model, three booster converters with independent input current control are implemented. The number of such converters should correspond to the number of voltage lines in the tested power supply unit. But for this analysis we will consider their limited number.

As a tested power supply, threeEMF sources of voltages 3.3 V, 5 V and 12 Vare used. The signals of the given load currents$U_{I\,\text{load}}$* are linearly variable with saturation at 22 A, 20 A and 18 A for each EMF source, respectively. For collecting data of currents and voltages instantaneous values, ideal current and voltage sensors are used. Inductance of input reactors is equal to 0.5 mH, 1 mH and 2 mH for different voltage lines, capacity of the DC link 5 mF. The parameters of the LC filter are set to 3 mH and 100 μF which corresponds to the resonance frequency of 290 Hz. Transform coefficient of the grid transformer is equal to 0.07. The results of the simulation are shown in Fig. 8.

As can be seen from these graphs, the input load currents follows the given values $U_{I\,\mathrm{load}}$*. So the proposed approach for controlling the these currents ensures their direct regulation.



(a)



(b)

Fig. 8. Modeling results: (a) are graphs of load currents and voltage in the DC link; (b) are graphs of the output voltage and current of the inverter

During the first period of the grid voltage, the output current of the inverter is not formed – this is due to the need to determine the mean value of voltage U_C. During this time, the capacity of the DC link is charged and the voltage on it reaches 55 V. After the first period, the inverter output current increases and the transient process begin, which ends in four periods of the grid voltage.In the quasi-steady state, the amplitude of the output current remains unchanged, and the current shape coincides with the voltage shape. Power factor is equal to 0.999. Total harmonic distortion is equal to 1.2%. This confirms effective recuperation of energy consumed from the tested power supply back to the grid.

V. Conclusion

The features of constructing an adjustable electronic load for computer power supplytesting systemsare studied in this article.The structure of such load is proposed, in which the booster converters are used for the regulation of input currents, and for the energy recovery a full-bridge inverter is used. The correctness of the proposed structure operation is confirmed by the research carried out using the developed model.

References

[1] V. Shakhnov, O. Berezin, A. Skripko, and V. Kostikov, *Design of power supplies for electronic equipment*. Moscow: Knorus Prospekt, 2013, 532 p. (in Russian)

[2] A. V. Vasil'kov, *Power sources*. Moscow: Forum, 2015, 400 p. (in Russian)

[3] V. V. Podgornyy, *Sources of secondary power supply.* Moscow: Goryachayaliniya-Telekom, 2013, 150 p. (in Russian)

[4] A. P. Kashkarov, *Pulsed power sources. Circuit design and repair*. Moscow: DMK Press, 2014, 184 p. (in Russian)

[5] A. Shadeyko, "Universal test benches for testing secondary power sources and voltage converters, "*Silovaya elektronika*, no. 2, pp. 84–85, 2012.

[6] Stand for testing power supplies or excitation units: Pat. RU 87034 U1: MPK G09B 23/18. No. 2009107684/22; declare 03/03/2009; publ. 20.09.2009, Byul. no. 26. 6 p.

[7] Stand for examination, testing and analyzing computer power supplies: Pat. RU 2548577 C1: MPK G01R 1/00. No. 2013158598/28; declare 12.27.2013; publ. 04/20/2015, Byul. no. 11, 10 p.

[8] Power supply testing system: Pat. US 8330448 B2: MPK G01R 1/00, G01R 31/40, G01D3/00. Appl. No.: 12/765, 588; Date of Patent: Dec. 11, 2012.

[9] Power supply unit testing system: Pat. US 2013/0249576A1: MPK G01R 31/40. Appl. No.: 13/726, 150; Date of Patent: Sep. 26, 2013.

[10] V. I. Meleshin, *Transistor Conversion Technology*. Moscow: Tekhno sfera, 2006, 632 p. (in Russian)

[11] S. G. German–Galkin, "Computer modeling of semiconductor systems in Matlab 6.0," *Proc. allowance*. St. Petersburg: KORONA print, 2001, 320 p.

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О. В. Стаценко, Д. С. Недашківський. Регульоване навантаження для автоматичного тестування джерел живлення постійного струму

Дану статтю присвячено розробці регульованого електронного навантаження для систем тестування джерел живлення постійного струму. Розглянуто структурублоку електронного навантаження, яке дозволяє регулювати струми тестованого джерела та здійснювати рекуперацію енергії до електричної мережі. До складу цього блоку входять перетворювачі підвищуючого типу, що працюють на спільну ланку постійного струму, мостовий інвертор, згладжуючий фільтр та мережевий трансформатор. Визначені основні співвідношення для розрахунку параметрів елементів складових частин. Розроблені пристрої керування перетворювачами та інвертором, в яких реалізовано релейне регулювання струму. В програмному середовищі Matlab/Simulink реалізовано модель запропонованого електронного навантаження. З її використанням проведені дослідження, які підтвердили здатність розробленого навантаження здійснювати регулювання вхідних струмів та рекуперацію енергії.
Ключові слова: електронне навантаження; рекуперація енергії; тестування джерел живлення.

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А. В. Стаценко, Д. С. Недашковский. Регулируемая нагрузка для автоматического тестирования источников питания постоянного тока

Данная статья посвящена разработке регулируемой электронной нагрузки для систем тестирования источников питания постоянного тока. Рассмотрена структура блока электронной нагрузки, которая позволяет регулировать токи тестируемого источника и осуществлять рекуперацию энергии в электрическую сеть. В состав этого блока входят преобразователи повышающего типа, работающие на общее звено постоянного тока, мостовой инвертор, сглаживающий фильтр и сетевой трансформатор. Определены основные соотношения для расчета параметров элементов составных частей. Разработаны устройства управления преобразователями и инвертором, в которых реализовано релейное регулирование тока. В программной среде MatlabSimulink реализована модель предложенной электронной нагрузки. С ее использованием проведены исследования, которые подтвердили способность разработанной нагрузки осуществлять регулирование входных токов и рекуперацию энергии.

Ключевые слова: электронная нагрузка; рекуперация энергии; тестирование источников питания.

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