ABSTRACT

of PhD thesis on "Research of commutation methods of voltage stages of a multilevel power inverter" submitted for the degree of Doctor of Philosophy (PhD) on speciality - 6D071900 - Radio Engineering, Electronics and Telecommunications

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Relevance of the work.

Ecological problems, global warming and dwindling natural resources had impulses for the development of alternative energy. Climatic conditions of the Republic of Kazakhstan are most favorable for such directions of alternative energy as wind energy and solar energy. Since the electricity obtained from alternative sources needs to be converted for accessibility to the consumer, this sets the task of power electronics, in particular, the development of autonomous voltage inverters.

Modern equipment imposes high requirements on the quality of electricity, which consists in compliance with the parameters of the supply voltage in certain rates. The power supply voltage source must meet the requirements for power, amplitude and operating, i.e. usable, voltage value, as well as the frequency and sinusoidal voltage.

The multilevel inverter has a near sinusoidal output voltage shape. Thus, the output voltage of such an inverter has a much lower harmonic component coefficient, which allows improving the quality of the generated electric power.

In addition, the multilevel inverter has other advantages. For example, a multilevel inverter has much less influence on direct current sources. This is due to the fact that the current consumed during the period increases gradually. Also, the multilevel inverter practically does not require filtering of the output voltage. Since it is not necessary to install low frequency filters, this reduces the size of the converter unit. Moreover, the next important aspect of this is the elimination of time delay due to the absence of filter capacitance elements. The advantages of a multi-level inverter also include the ability to operate at a lower switching frequency of power keys. This, in turn, reduces the energy loss for transients, which means that it provides a high coefficient efficiency of the entire system.

As a rule the multilevel inverter is constructed of a large number of power elements, in particular switching keys, which must be controlled according to a certain law. Since such elements commutate large currents, it is necessary to develop a control system that provides protection against electric shock and failure. In addition, due to the high cost of power semiconductor elements, such a control system should monitor the condition of the converter; prevent emergency situations and operation modes.

Thus, a relevant issue is the study of a power inverter with microcontroller control with an output voltage shape close to sinusoidal. This inverter differs from the known converters in a smaller number of power semiconductor elements. These characteristics will reduce its cost, as well as ensure stable operation, the quality of the converted electricity and the lowest coefficient of non-linear

distortion. To do this, it is necessary to develop a method for calculating the switching time of inverter voltage levels, which allows reducing the coefficient of non-linear distortions and achieving stability of the current voltage value. It is also necessary to improve the topology of the multilevel inverter design in order to reduce the number of power semiconductor elements used.

The development and research of multilevel inverters was carried out by domestic scientists Isembergenov N.T., Taysarieva K.N., Ilipbaeva L.B., as well as their foreign colleagues, in particular: José Rodríguez, Arvind Yadav, Zhiguo Pan, Mamatha Sandhu, Jagdish Kumar, Grain P. Adam, Ebrahim Babaei, Baoming Ge, Pablo Lezana, Byeong-Mun Song, Miguel F. Escalante, Keith A. Corzine, Giuseppe Carrara, Amit Kumar Gupta and others.

The purpose of the dissertation work is to develop and study methods for switching voltage stages of a multilevel power inverter to obtain a sinusoidal output voltage, improve the quality of the converted electricity and reduce the coefficient of non-linear distortions.

The purpose of the dissertation study is to solve the following **problems**:

- analysis of modern topologies of a multilevel power inverter;
- development and research of methods for voltage level commutation of an inverter with a lower coefficient of nonlinear distortion of the output voltage;
- development of microcontroller control system of power inverter providing stability of output voltage, commutation accuracy, protection against failure;
- development of a method for controlling the power switches of an inverter that allows control from a single microcontroller and provides protection against short circuit and electric shock to a person;
- development and research of an experimental installation of a power inverter according to the developed topology and method of level commutation.

Research methods.

The tasks were solved using the methods of system analysis, mathematical modeling, computer modeling using various environments and programs, experiments and other research methods.

The object of the study is an autonomous power inverter with an output voltage close to sinusoidal.

The subject of the study is the topology of constructing a multilevel inverter, strategies for the voltage levels commutation of the inverter, the quality control process of the output voltage of the inverter.

The novelty of the dissertation work is as follows:

- a new method of the voltage levels commutation of the inverter with the lowest coefficient of nonlinear distortion of the output voltage has been developed;
- according to the proposed original circuitry and software solutions, a microcontroller system for controlling a power multilevel inverter and

controlling charging of storage batteries is developed, characterized by high accuracy of switching voltage stages;
- an original galvanic isolation circuit has been developed for controlling an isolated gate of a transistor, characterized in that it allows controlling several bipolar transistors with isolated gates from a single chip;
- a prototype single-phase multilevel inverter up to 3 kW with a stabilized output voltage close to sinusoidal has been developed and tested.

Practical significance.

Prototype of single-phase multilevel inverter with stabilized output voltage close to sinusoidal voltage is developed. At the same time, the sinusoidal voltage reduces the losses associated with the presence of alternative current harmonics.
The power of the power inverter according to the proposed topology and the developed switching method is limited only by the capacity of the switching keys and at the moment can reach more than 30 kW. The prototype multilevel inverter is developed according to the proposed circuitry and software solutions, which provide protection against failure, human electric shock, short-circuit protection and allow extending the service life.

Provisions of the dissertation submitted for defense:

- design topology of a multilevel power inverter, characterized by the use of fewer power semiconductor elements;
- the strategy of the voltage levels commutation of the inverter, characterized by a lower coefficient of nonlinear distortion of the output voltage, as well as the strategy of the voltage levels commutation of the inverter based on the equality of areas, which allows you to get not only a smaller coefficient of nonlinear distortion of the output voltage of the inverter, but also the ability of the inverter to maintain the current voltage value at a given level;
- a model of a multilevel inverter based on an H-bridge and a voltage stage commutation;
- the structure of a multilevel inverter based on an H-bridge and a voltage stage commutation with a control system.

Approbation of the work.

As a result of theoretical and experimental studies, a single-phase multilevel inverter with a power of 3 kW with a stabilized output voltage close to sinusoidal was obtained. The main results of the research were reported and discussed at the International Scientific and Practical Conference "Achievement of high school - 2013" (Sofia, Bulgaria, 2013), the 10th International Scientific and Practical Conference "Strategiczne pytania swiatowej nauki - 2014" (Przemysl, Poland, 2014), International Satpayev readings "The role and place of young scientists in the implementation of the strategy "Kazakhstan-2050", dedicated to the 80th anniversary of KazNTU named after K.I. Satpayev (Almaty, 2014), International Scientific and Practical Conference "Current issues of energy saving and new technologies in science and education of the Republic of Kazakhstan" (Petropavlovsk, 2014), International scientific and Practical Conference

"Integration of science, education and production - the basis for the implementation of the National Plan" (Karaganda, 2016).

Publications.

According to the results of the dissertation study, 19 publications were published, including 7 in scientific publications recommended by the Committee for Control in the Field of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, 3 in the journal included in the Scopus database, 5 in the materials of conferences, including 2 - foreign, 2 - innovative patents of the Republic of Kazakhstan for the invention.

The author's personal contribution.

The author independently obtained the main results of theoretical and experimental studies. In published scientific works as part of the team of co-authors, the applicant is the main contributor in receiving, summarizing and analysing the achieved results.

Structure of the dissertation.

Dissertation work consists of an introduction, four chapters, a conclusion and a list of sources used. The work is set out on 109 pages, contains 64 drawings, 18 tables and a list of literature from 88 titles of publications by domestic and foreign authors.

Results of the research.

As a result of the dissertation research, theoretical and experimental results were obtained that contribute to improving the quality of electricity generated by autonomous power inverters, due to greater stability and sinusoidal output voltage, as well as conversion efficiency, increased power and reliability. The tasks have been completed in full. The main results of the study are the following:

The analysis of the existing topologies of multilevel power inverters is completed. In accordance with the analysis, the topology of an autonomous power inverter based on a multi-winding transformer has been developed. The analysis revealed the advantage of the topology of a multilevel power inverter based on a level switch and a bridge inverter, provided that the output voltage of the inverter is at least three levels. Based on this topology, a method for implementing a multi-level power inverter is proposed, in which the voltages from the converters are sequentially switched, forming a stepped shape, and inverted by a bridge inverter. This principle has been successfully implemented in practice in a prototype of an autonomous voltage inverter, which has a significant advantage in terms of weight and size compared to analogues.

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A computer model of the output voltage of the inverter and a computer model of the power inverter itself have been developed. These models were used to study various strategies for switching voltage stages of a multilevel inverter, including strategies based on pulse width modulation. The dependences of the coefficient of nonlinear distortion of the output voltage of the inverter on the strategy, the number of stages and other parameters are obtained. The results obtained by computer simulation are confirmed by the results of the experiment.

A technique based on the geometric approximation of the output voltage of the inverter to a sinusoidal shape is proposed. Unlike other switching techniques, the developed technique allows not only to reduce the harmonic components, but also to keep the current voltage value stable.

A galvanic isolation method is proposed for controlling multiple insulated-gate bipolar transistors from a single microcontroller that uses an optorele and a voltage converter with a galvanically isolated input and output. This scheme is suitable for controlling most types of IGBT and is used to develop a multilevel power inverter assembled on the basis of IGBT modules 2MBI200L-060 and transistors with an isolated gate G7PH42UD. Special attention is paid to the development of a microcontroller control system for a power inverter, characterized by high switching accuracy of the inverter stages due to the high frequency of the clock generator. In addition to inverter control, the developed system monitors the output voltage, current strength, power, as well as the temperature of the substrate of transistor modules.

Prototype of single-phase multilevel inverter with stabilized output voltage close to sinusoidal voltage is developed. The power of the power inverter according to the proposed topology and the developed switching method is limited only by the capacity of the switching keys and at the moment can reach more than 30 kW. This inverter was used to experimentally investigate the capabilities of switching keys, microcontroller control system, switching strategies, etc.

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