CHARACTERISTIC FEATURES OF CONTROL METHODS IN ELECTROMECHANICAL DEVICES

G.V.Mamedova
•
Azerbaijan State Oil and Industry University, Baku, Azerbaijan
gulschen98@mail.ru

Abstract

Modern electromechanical devices for continuous process control are used in a variety of industrial applications. A control system or electromechanical device used to control the speed and torque of AC motors by varying the frequency and supply voltage converts alternating current of one frequency to alternating current of another frequency. The power section and the control device are the main elements of the control system. The main elements of a control system or electromechanical device are the power part (electrical energy converter) and the control device (controller). Modern frequency converters have a modular architecture, which expands the capabilities of the device, and also, in most cases, allows the installation of additional interface modules for input-output channels. The control device (microcontroller) is controlled by software and is controlled by the main parameters (speed or torque).

Key words: electromechanical device, control system, frequency converter, control device, power part, modulation method, output voltage, three-phase autonomous voltage inverter, semiconductor device, analog-to-digital converter, controller, comporator.

I. Introduction

Research and development of three-phase autonomous voltage inverters (AVI) are highly relevant. Designing a control system is one of the main stages in the development of AVI. Any control of the power converter ultimately boils down to regulating the time of the open state of the power transistor in relation to the period of its operation. This control method is called pulse width modulation (PWM). Given the tendency to build digital (digital-analog) control systems for power converters, a large number of control methods have been developed for the class of three-phase inverters. When implementing them to solve practical problems that require the formation of an output voltage with increased frequencies (1-2 kHz), the control system must be developed on its own due to the lack of ready-made integrated solutions in the form of three-phase PWM control.

By changing the supply voltage and frequency of electrical equipment to control the speed and torque of AC motors, the applied electromechanical devices or control system provide alternating current of one frequency to another alternating current of another frequency.

As an example of such a device, a frequency converter can be shown, that is, an electromechanical device for ensuring continuous control of the process. Typically, this device relates to the control of speed and torque of equipment (asynchronous or synchronous motors). Such devices are widely used in various fields of industry and transport [1-4,9-13]. Table 1 presents the main control methods used in frequency converters.

Table 1. Basic control methods in frequency converters

Control method	Speed range	Speed error	Period of exceeding mocop	Start howl moment	Meaning	Standard application
Skalyar	1:10	5-10	Inaccessible ny	small	very small	little used pumps, fans, compressors
linear vector	>1:200^2	0	<1-2	big	big	frequently used taps,elevators, transport, etc.
direct control tion with vector field modulation	>1:200^2	0	<1-2	big	big	-------
direct control with nonlinear torque	>1:200^2	0	<1	big	big	--------
direct self-government	>1:200^2	0	<1-2	big	big	high-performance facilities

II. Formulation of the problem

The efficiency of the control system and power section is directly affected by the modulation method. The growth of research in the field of modulation is characterized by the widespread development of power electrical converters, determining economic efficiency and productivity. The main goal of modulation is to achieve the best shape of signals (voltages and currents) with minimal losses. Other additional control tasks such as rectifying DC voltage, reducing input current ripple, reducing overvoltage speed can be solved by using the right modulation method. Modulation methods are divided into IV main groups:

1. pulse width modulation;
2. vector field modulation;
3. harmonic modulation;
4. methods for changing variable frequency circuits.

To generate control pulses using modulation methods, it is possible to synthesize the output voltage with the necessary parameters (shape, frequency, amplitude). Due to the presence of higher harmonics in the output signal, it is necessary to filter the output signal to generate sinusoidal currents.In such devices, the presence of an inductive load (electric motors), if necessary, additional filters are used. The maximum output voltage is determined by the DC link voltage. To effectively apply a heavy load, a high constant DC link voltage is required. However, in practice this voltage is limited by the operating voltage of the semiconductors. For example, low-voltage transistors provide output voltages up to 690 V. In terms of voltage, multi-position converter circuits have been developed to overcome this limitation. Such control modulation devices are complex, but have good power, size, reliability, efficiency and performance. For example, in a three-position converter with a neutral point, the DC voltage is divided by two capacitors, so the phase can be connected to the positive voltage line (by turning on the two upper switches), to the middle point (by turning on the two central switches) or to the negative voltage line (by turning on the two lower switches). Each switch can block only half of the DC link voltage, so the use of semiconductor switches allows you to increase the power of the device. Typically, such devices use high-voltage transistors and thyristors (figure 1).

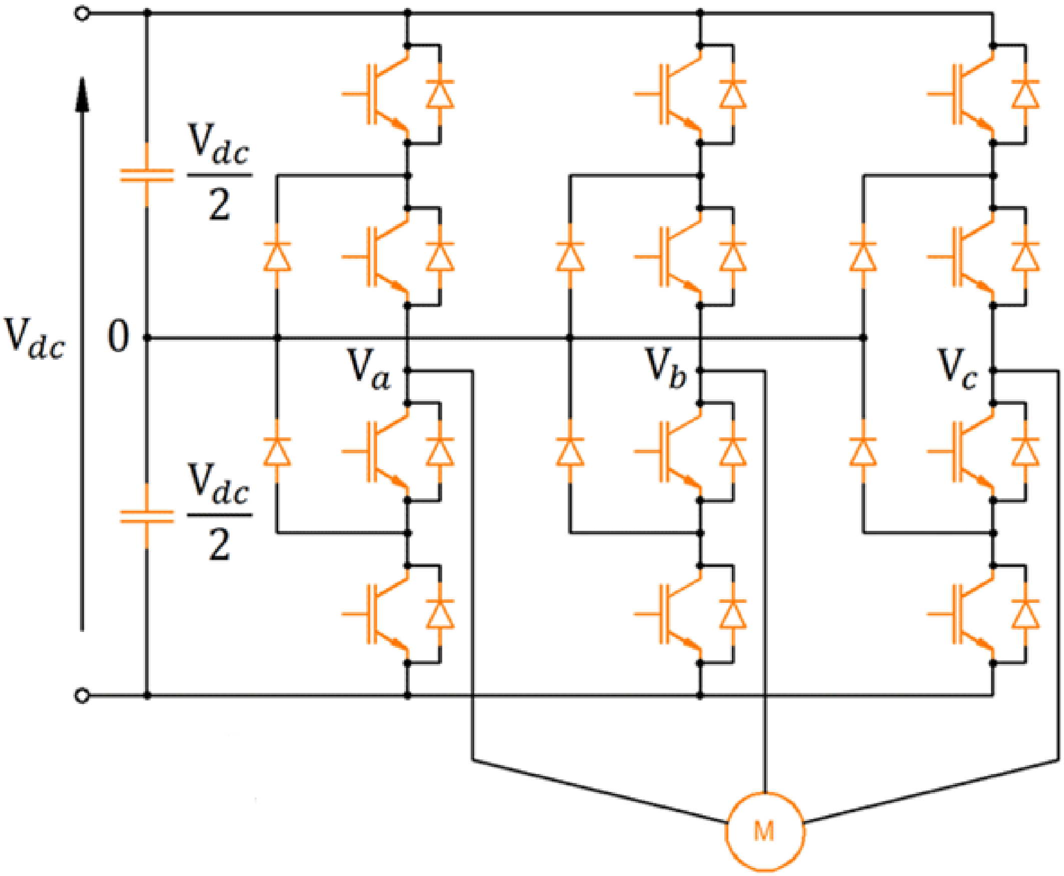


Figure 1. Circuit diagram of a three-position converter with a neutral point

Disadvantages of such devices: imbalance of capacitors created by the asymmetry of the device - this problem is solved by changing the modulation method; uneven distribution of losses - depending on the operating mode, losses from replacing the circuits of central and external keys differ.

The presented converter, in order to achieve an output signal beyond the three-level limit, can be scaled so that by means of capacitors it is divided into more than two values of the DC link voltage. Each of the separated voltages can, using different switches and limiting diodes, be connected to the load. With the increase in power, the advantages of multi-position converters are: power quality, low voltage overvoltage rate and associated electromagnetic interference. Figure 2 shows the voltage dependence of the converter phase [4-6].

Any control of the power converter, ultimately, relative to the period of the operating mode of the power transistor, is driven by the regulation of the period in the open position. As you know, this control method is a method of pulse width modulation. The construction of control systems for power circuits is easily covered by a wide class of industrially produced integrated controllers. In this case, taking into account the trend in the construction of power converters with digital control systems (digital-analog), numerous control methods have been developed for the class of three-phase inverters. However, when solving practical problems, for implementation, which at increased frequencies (1-2 Hz.) requires the formation of an output voltage, the control system is used as a three-phase controller.

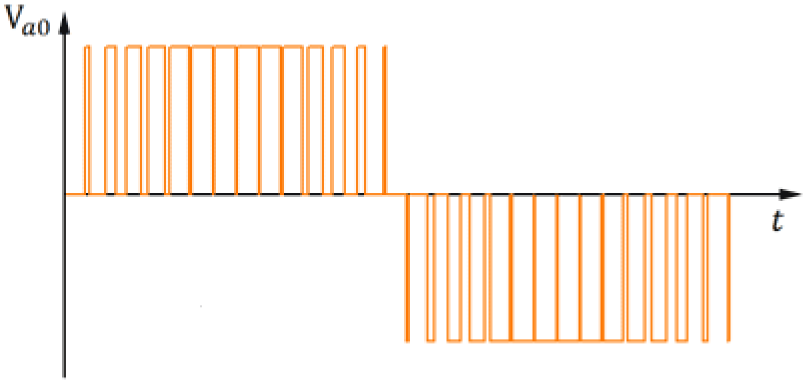


Figure 2. Phase voltage of a three-position converter with a neutral point.

III. Problem solution

Research and development of three-phase autonomous voltage inverters (AVİ) is one of the urgent issues. One of the main stages of the development of AVİ is the design of management systems. Different management of the power converter is adjusted according to the ratio of the time of the power transistor in the open state to its working period. Such a control method is called circular-pulse modulation [1-4]. Numerous control methods have been developed for the classification of three-phase inverters. However, in order to solve practical issues in their implementation, the management system should be developed with special forces.As is known, AVİ is a static converter that converts a constant voltage E_d to an alternating voltage through semiconductor switches (S1-S6). Either field MOSFET-transistors or IGBTs are used as semiconductor switches. Bridge transistors are controlled by the control system . The control of this system is carried out on the basis of existing algorithms in order to provide the load (Z_{load}) with a stabilized alternating three-phase voltage.

Currently, there are three main classifications of IS: analog, digital, mixed (digital-analog). The vector of development in power converters is directed to the application of digital IS [2]. However, the operating speed of modern microcontrollers and analog-digital converters is not so high, 50-100 kHs. and the power converter working at multiple frequencies should ensure the necessary speed of the digital .The most circular-pulse control is characterized by a modulation period, during which the stator winding of the electric motor is sequentially connected to the positive and negative poles of the rectifier. The duration of these states within the impuls modulation period is modulated according to the sinusoidal law. At high clock frequencies of impuls modulation (usually 2.....15kHz.), sinusoidal currents flow in the windings of the motor (due to filter properties). Thus, the shape of the output voltage curve presents a high-frequency bipolar sequence of rectangular pulses. The frequency of the pulses is determined by the frequency of the DIM, the duration (width) of the pulses is modulated according to the sinusoidal law during the period of the output frequency of the AVİ. The shape of the output current (in the windings of an asynchronous electric motor) is practically sinusoidal. The output voltage of the inverter can be adjusted in two ways: the first - by the amplitude method, by changing the input voltage; the second - with impuls modulation, changing the valve rotation program. Due to the development of the modern element base in modern frequency converters (microprocessor, IBGT-transistors), the second method has found wider application.). Such control allows the converter to obtain a high efficiency, equivalent to analog control through frequency and voltage amplitude. Modern inverters are based on fully controlled power semiconductor devices [2].

In the mixed control system, the proportional-integrative-differentiating control operation was performed by means of amplifiers. The linear voltage from the output of the inverter is measured by a voltage transmitter and U_{steady} as a negative feedback signal. the regulation is summed up by the signal of the price. The signal at the output of the impuls modulation regulator is scaled and transferred to a digital series through an analog-to-digital converter, then transferred to a digital pulse generator, which in turn, according to the algorithm, supplies the three-phase AVİ with control pulses using the driver block, is for matching low power control signals with low input resistance of power transistors. According to the structural scheme, the digital pulse shaper is like a prototype of the analog impuls modulation -controller, it forms the control pulses of the function from the sum of the regulation value and feedback signals.

With the development of microprocessor technology, vector impuls modulation algorithms have found wide application. For each phase of the output voltage, there is a period equal to (π/6) in the dual period of the output frequency, and the voltage of this phase is maximal according to the module (figure 4). According to the vector impuls modulation algorithm, the switch corresponding to this interval duration (S1-S6) remains open regardless of the modulation factor K_M. This coefficient is a signal of the adjustment price in relative units U_{steady} and varies in the range of (0-1) (figure 3). According to the vector impuls modulation method, the operating period of each phase of the transistor bridge (2π) is divided into 6 equal intervals (π/3). Using this method, each (π/3) interval is divided into 8 impuls modulation intervals (π/24). Thus, the modulation number of the impuls modulation -transformation is M=48.

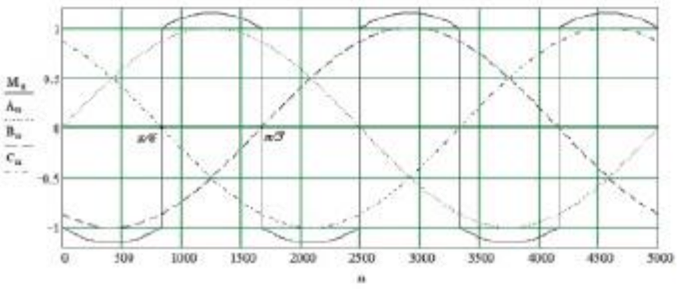
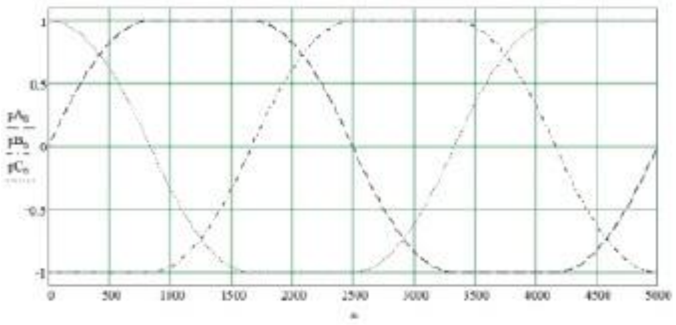
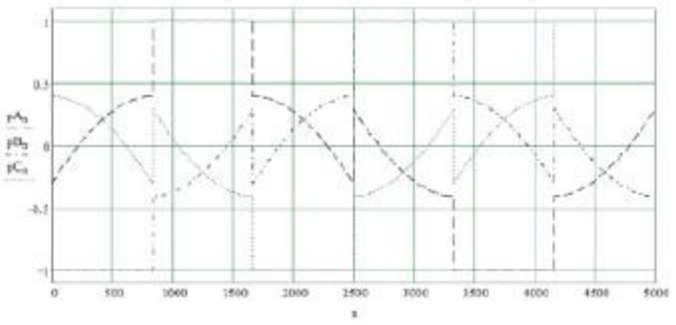


Figure 3. An, Bn, Cn – phase-regulating voltage signals:
Mn – signal to modulation of 3rd harmonics.

If the frequency of the AVİ output voltage (f_{output}) is equal to 1 kHz. Then the switching frequency of power switches: $f_k = M \cdot f_{out.} = 48$ kHz. In this case, impuls modulation period duration: 1/48·103 = 20.833 mks. Practical work experience with modern semiconductor devices shows that the operation at the given frequency in the hard switching mode of the switches is close to the maximum (taking into account the losses of conversions in transistors). That is, to increase the frequency of the output voltage of the AVİ, it is necessary to use transistors with minimal dynamic losses [1].



a)



b)

Figure 4. Control signals: a) modulation signal KM =1;
b) modulation signal KM =0.7.

As is known, the impuls modulation signal is formed by comparing the step voltage with the control voltage through a comparison device. For example, in analog systems - this is an ordinary analog comparator. Due to the fully digital design of the pulse shaping system, the comparison is carried out in digital comparators, a triangular digital opening is used as a two-way impuls modulation opening at the $\pi/24$ interval, and this is provided by a reverse counter. In the implementation of this type of vector impuls modulation, they passivate each phase control twice in the π-difference period of the output frequency during ($\pi/3$) intervals, that is, switching of power switches with the frequency of impuls modulation does not occur. In this case, according to the control algorithm, either the upper or lower phase switch is open. The other two phases are controlled by extending the duration of the pulses according to the sinusoidal law through impuls modulation . Thus, the average switching frequency of each power switch is 1.5 times less than that of the classical impuls modulation, which reduces the switching losses accordingly.

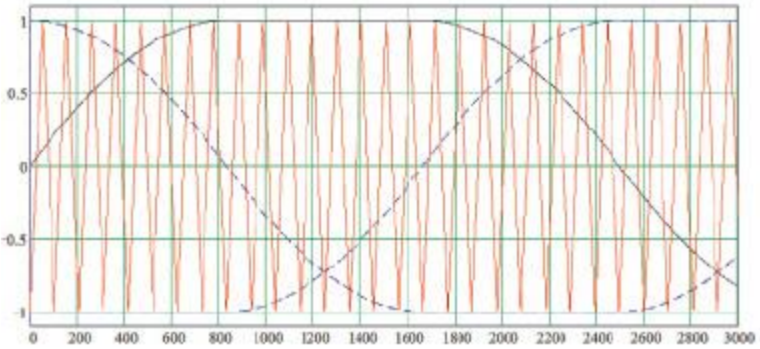


Figure 5. Reference sine functions and signal and shutdowns

Looking at one of the six (π/3) intervals, one switch is fully open and the other two are at 48kHz. they take part in the cycle with the frequency, the width of the pulses in this case changes according to the harmonic law over time. If we take the N/2 opening average of the digital cutting as the conventional level of the zero line of the phase opening (figure 5), then the sinusoidal voltage of the phase opening:

$$U_f = \frac{N}{22} + \left[\frac{N \cdot K_M}{\cos \frac{\pi}{6}} \right] \sin(\theta)\ ,$$

here cos(π/6)- fundamental harmonic amplitude increase factor; θ -initial phase.
And the voltage for this interval:

$$U_f = N - \frac{N}{22} + \left[\frac{N \cdot K_M}{\cos \frac{\pi}{6}} \right] \sin(\theta)$$

The expressions obtained for the second and third phases are identical, only the first phase is shifted by θ(2π/3). After several changes, we get the formulas for calculating the coefficients, which represent the width of the pulses varying with time:

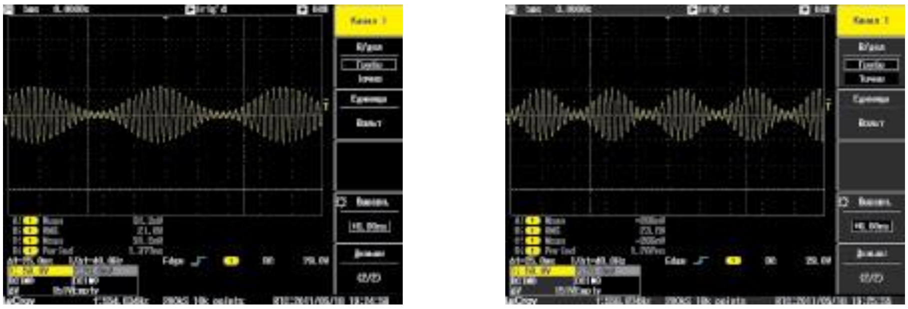
$$A_{1M} = N\left(1 - K \cdot \cos(\theta)\right)$$

$$A_{2M} = \frac{N}{2}\left[2 - K\left(\cos(\theta) + \sqrt{3}\sin(\theta)\right)\right]$$

The calculation of the received coefficients is the same for each (π/3) interval, and their values vary as a function of the modulation coefficient K_M, whose value is determined by the voltage transmitter and the feedback signal received from the digitized analog-to-digital converter. There are two methods of processing received information: calculation of interval coefficients A_1, A_2 (during system operation) and filling of the cells of the coefficients matrix (selection of the numbered line corresponding to the K_M value in the range 0-1), which is divided into a number of values (according to the accuracy of the stabilized voltage). The second option is considered more reliable, because the digital pulse generator consists of a microcontroller and a microcircuit.

In this case, the microcontroller performs the function of initial calculation of the coefficients and filling of the matrix, and the received matrix is used for the selection of subsequent values, in order to transfer them to the inputs of digital comparators. The values of coefficients A_1 and A_2 are calculated according to the formulas and written in the blocks of the matrix. Each block consists of 256 lines. The value of the coefficient K_M =1 corresponds to the maximum value at the output of the analog-to-digital converter. Thus, 16 matrices with 256 rows, 8 matrices for each coefficient, corresponding to the (π/3) sector divided into 8 intervals, need to be created.

The values selected from the corresponding matrix and the digital signal of the cascade opening are given to the digital comparators, at the output of each comparator a rectangular pulse is simultaneously formed. Timed (π/3) sequences consisting of 8 pulses are formed through registers and logic devices. Thus, the received periodic sequences are transmitted to the pulse distribution device. This device, in turn, transmits the necessary control signal to the corresponding transistor according to the logic of the operation of the bridge switches [8-13].



a) b)

Figure 6. Voltage oscillograms at the inverter output (for a given alternating signal):
a-set signal-50 Hz.; b-set signal – 100 Hz.

IV. Conclusions

Autonomous voltage inverter (AVI) using semiconductor switches is a static converter of direct voltage into alternating voltage. MOSFET or İGBT field-effect transistors are used as semiconductor switches. The transistors are controlled by the control system according to a given algorithm, providing a stabilizing alternating three-phase load voltage (Z_{load}). Currently, there are three classes of control systems: analog, digital, mixed (digital-analog). Analogue control systems have an advantage over mixed ones; the vector of development in power converters is aimed at the use of digital control systems. The three-phase autonomous voltage inverter with the vector modulation method has a digital-analog control system with a frequency (1-2kHz), high-speed response for the necessary stabilization and formation of the output voltage, with improved weight and dimensions, it can be used for various three-phase voltage inverters with symmetrical loads. The practical implementation of the developed method is carried out by a device consisting of an analog-to-digital converter controller and a microcircuit. A digital pulse shaper is directly designed in this device.

In order to check the performance of the system, a sinusoidal signal of various frequencies is transmitted to the input of the converter (figure 6) and we have oscillograms at the output of the inverter. As can be seen from the presented oscillograms, the control system has stability and good dynamic feature.The power part (electricity converter) and the control device (controller) are the main elements of a control system or electromechanical device. An example of such devices is a frequency converter, that is, an electromechanical device that provides the control process. The control device of the control system (microcontroller) runs software and controls the main parameters.

References

[1] G.S.Kerimzade, L.Ya.Qurbanov.“ Control and modulation methods in electromechanical devices triplets”,Baku. 2019. “Energy Problems”, №1. pp.94-98.

[2] G.S.Kerimzade, L.Ya.Qurbanov.“Three-phase autonomous inverter control system with vector pulse width modulation”,Baku. 2019.“ScientificWorks”, №2. pp.167-172.

[3] G.S.Kerimzade ”Calculation of parameters of control induction support”, PRZEGLAD Elektrotechnich niczny Publishing house of magazines and technical literature SIGMA-NOT.ISSN 0033-2097,R.100.NR.05/2024. Warszawa.. pp.219-222.

[4] G.S.Kerimzade. ”Method for determining the overall dimensions of an induction control support”, PRZEGLAD Elektrotechniczny Publishing house of magazines and technical literature SIGMA-NOT.ISSN 0033-2097, R.100.NR.06/2024. Warszawa.. pp.235-237.

[5] G.S.Kerimzade. ”Structure of the monitoring and tracking electromechanical control system”,PRZEG LAD Elektrotechniczny Publishing house of magazines and technical literature SIGMA-NOT.ISSN 0033-2097, R.100.NR.07/2024. Warszawa.. pp.295-297.

[6] G.S.Kerimzade, G.V.Mamedova. ” Research of electromechanical devices with levitation elements in control systems”, Journal “Realibility: Theory & Application”. ISSN 1932-2321. Volume 19.№ 2(78). Yune 2024.pp.85-90.

[7] G.V.Mamedova, G.S. Kerimzade.”Design parameters for electromechanical devices with a levitation element”, PRZEGLAD Elektrotechniczny Publishing house of magazines and technical literature SIGMA-NOT.ISSN 0033-2097,R.100. NR 09 / 2024.Warszawa. pp.175.

[8] A.Q.Yudinsev . Three-phase inverter control systems with vector pulse width modulation. Basic Research // - 2015.

[9] M.P.Belov . Technical means of control and automation. Study guide.2009.

[10] A.D.Pozdnev. Electromagnetic and electromechanical processes in frequency-controlled asynchronous electric drive. Cheboksary. Chuvash University.2000.

[11] R.T.Chreyner. Mathematical modeling of an AC electric drive with a semiconductor frequency converter.- Ekaterinburg . 2000.

[12] Rahul Dixit, Bindeshwar Singh, Nupur Mittal. Adjustable speeds drives. Review on different Invertertopologies.-// Sultanpur, India. International Journal of Reviews in Computing, 2012.

[13] Marian P. Kazmierkowski, Leopoldo G.Franquelo, Jose Rodriquez, Marcelo A.Perez, Jose I.Leon “High-Peromance Motor Drives”. // IEEE Industrial Electronicsd, vol.5