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Development of contactless switching devices for asynchronous machines in order to save energy and resources

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Abstract. To limit the inrush currents in the stator windings, various schemes for starting an asynchronous electric motor are used. In addition, the existing devices have a complex control system, which creates certain difficulties in installation and operation. But the analysis of scientific literature and materials from certain sources testifies to the insufficient study of this problem. In scientific work, the advantages and disadvantages of a new type of contactless starter are compared with contact and non-contact starters of various types. An original circuit of a new type of thyristor starter with a simplified design has been developed and manufactured, which has the ability to smoothly start and control the power consumption of asynchronous machines. Computer simulation of a new type of contactless starter with pulse-width modulation control in the Matlab Simulink program has been carried out: a pulse current is supplied to the controlled thyristor electrode on the basis of the pulse-width modulation control and the thyristor opens and passes the current, the resistance is set to decrease the input signal level. The design of the proposed starter is based on the combination of a thyristor starter with logical control, which has the ability to smoothly start and remote control of the power consumption of asynchronous electric motors, which has the ability to save energy and resources. Modern methods of implementing a logical control system, a pulse current generator with RLC filters, are proposed, and the task of remote monitoring and control of power consumption of asynchronouselectricmotors is set.

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1 Introduction

It is known that an asynchronous electric motor with a squirrel-cage rotor is the most common electric motor of the medium of other types of electric motors, and is used in all electrical installations of industrial enterprises [1]. The fields of application of asynchronous electric motors are very wide, from the drive of automation devices and electrical appliances to the drive of large mining equipment, conveyors, excavators, mills, crushers, etc. [2]. However, in asynchronous electric motors of medium and high power from 75 kW and above, there are problems with commutation [3]. The start of an asynchronous electric motor with direct connection to the network in the stator winding generates a large starting current 5–7 times higher than the rated current consumption of the motor [4-11]. In addition, the working stator winding heats up, the starting torque changes, a dynamic shock occurs in the drive transmission and can lead to serious technical consequences [12].

In the world, by improving the dynamic modes of operation of technological machines and mechanisms, elements of the electromechanical system with modern control devices, improving the elements of the electromechanical system, using control methods, energy efficient technologies are created, renewable energy in industry [13-21]. The use of such energy-saving technologies saves not only electricity and material resources, but also provides resource-saving [1-2].

Currently, many industrial enterprises use contact and non-contact starters of various types for switching in electrical circuits. But each switching device has its own advantages and disadvantages in terms of structure and power consumption. For example, contactors and electromagnetic starters (MS) use a lot of electrical power, along with this there are large noises in contactors and electromagnetic starters, movable and fixed contacts can stick, and also burn power contacts for sticking [22]. These existing drawbacks will lead to the consumption of excess electrical power and can damage contactors and electromagnetic starters [23]. In addition, the power consumption of the coil of the magnetic starter and the contactor itself increases, depending on the size of the MS and switching processes [24]. To achieve the operation of contact devices silently and less consumption of electrical energy, it is recommended to use non-contact starters using semiconductor elements. Used contactless starters, which are purchased from abroad, are much more expensive [25]. Because of this, it is required to create simple and reliably operating devices for switching induction motors (IM) and other electrical devices.

In foreign contactless starters, various semiconductor elements are used, such as Insulated Gate Bipolar Transistors (IGTB) transistors, thyristors and triacs, or symmetric thyristors that can control a large load. But even in thyristors and transistors there is a trigger effect arising when voltage is applied to the control electrode of the thyristor, and the output signal changes abruptly and will affect the operating mode of the electric motor [25].

The issues of switching have not been sufficiently studied, therefore, the problems of automatic start-up and control of AC electric machines and the development of new contactless starters are more urgent. In addition, it is possible to revise the structure of existing devices, which have a complex control system and create unreasonable difficulties in installation and operation.

Research has shown that modern thyristor and triac soft start and control starters are the most optimal solution to the switching problem [26]. Since non-contact starters have the following advantages:speed, which is very important in case of emergency shutdown;

- the ability to work with strong electromagnetic fields of electrolysis and electric arc production;

- due to the absence of the spark effect, it becomes possible to use contactless starters in fire-hazardous premises;
- simultaneous disconnection of all phases of the supply network;
- significant reduction in power consumption by control circuits;
- protects against short circuits and overload;
- controls the starting current and passes the output signal smoothly;
- reliability, because there are no mechanical moving parts and faults arising from sticking and burning of contacts are excluded.

The purpose of the article is to model and develop a new type of thyristor starter with a simplified design for soft start and control with the aim of energy and resource saving of power consumption of asynchronous machines.

2 Research methods

Research methods: theoretical - theory of electric drive and transient processes, theory of contactless and contact starters, theory of differential equations in variable loads and severe starting conditions, computer modeling of a thyristor starter with a simplified design, research methods for starting and various operating modes of an electric motor.

Methods for the study of starting characteristics and modeling of physical processes in asynchronous electric motors

To solve this problem, we have developed a new type of contactless switching device, which has a simpler and more affordable price for users of this installation.

In order to eliminate the starting currents of three-phase asynchronous electric motors, we investigated an asynchronous electric motor with a rated power of 160 kW, a voltage of 400 V, and a frequency of 50 Hz. The starting characteristic of an asynchronous electric motor was obtained using the Matlab Simulink program.

3 Results and discussion

In the Fig. 1, the timing diagrams of starting currents of a three-phase asynchronous electric motor is shown, which was made in the Matlab Simulink program. The oscillogram shows the transient process of currents I_a, I_b, I_c before direct start-up by a three-phase system, which has an abrupt inrush of currents relative to each phase and makes an angle of 120 degrees between the phases. In the diagram, with a small inertia of the actuator, the motor speed quickly reaches a steady-state value and the starting current also drops quickly, without causing overheating of the stator winding. But such a significant inrush current in the supply network can cause a noticeable voltage drop in it. In the Figure2, the timing diagram of starting currents and voltage of the stator winding, current and rotor speed of a three-phase IM of an asynchronous electric motor is shown, which was made in the Matlab Simulink program.

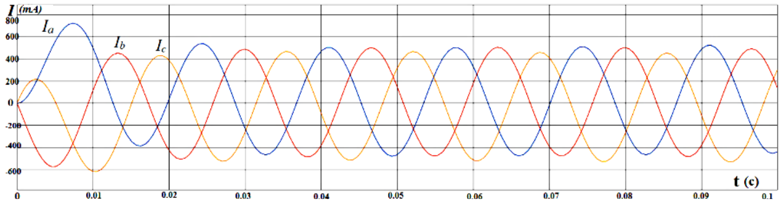

Fig. 1. Timing diagrams of starting currents of a three-phase asynchronous electric motor in the Matlab Simulink program.

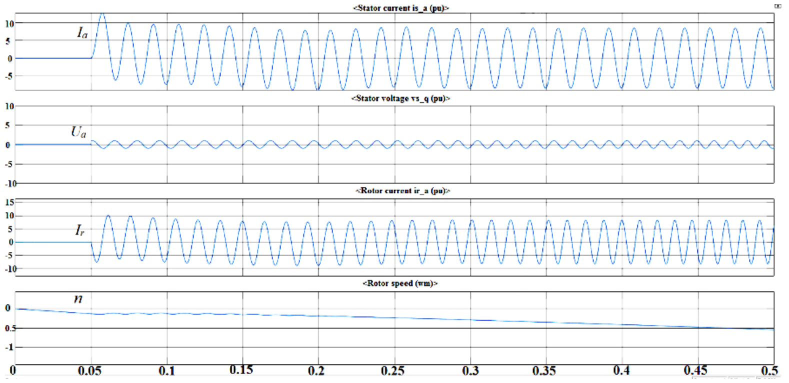

Fig. 2. Timing diagrams of starting currents and voltage of the stator winding, current and rotor speed of a three-phase asynchronous electric motor in the Matlab Simulink program.

In the time period t = 0.15 s, the starting stator current is 5 times higher than the rated value of the stator current, and after a time t = 0.2 s, the transient current value becomes equal to the rated current to each corresponding phase. Since the voltages on the stator winding decrease sharply, and the currents in the rotor winding gradually increase and come to normal after the time t = 0.05 s, and the rotor rotation will reach n = 1450 rpm.

To analyze this energy and resource-saving process using the analytical method, we used the Park - Gorev equations (1), which allows us to study transient processes in an electric drive with asynchronous motors under variable loads and severe starting conditions. According to this equation, the mutual inductions of the rotating magnetic fields of the stator and the rotor are determined in coordinates X, 0, Y, and the study of the electromechanical parameters of an asynchronous electric motor:

$$\left.\begin{aligned}
\frac{d\Psi_{x1}}{dt} &= U_m\omega_0\alpha_s^{'}\Psi_{x1} + \omega_0\alpha_s^{'}k_r\Psi_{x2} + \omega_0\Psi_{y1};\\
\frac{d\Psi_{y1}}{dt} &= -\omega_0\alpha_s^{'}\Psi_{y1} + \omega_0\alpha_s^{'}k_r\Psi_{y2} - \omega_0\Psi_{x1};\\
\frac{d\Psi_{x2}}{dt} &= -\omega_0\alpha_r^{'}\Psi_{x2} + \omega_0\alpha_r^{'}k_s\Psi_{x1} + \omega_0 s\Psi_{y2};\\
\frac{d\Psi_{y2}}{dt} &= -\omega_0\alpha_r^{'}\Psi_{y2} + \omega_0\alpha_r^{'}k_s\Psi_{y1} - \omega_0 s\Psi_{x2};\\
M &= \frac{3}{2}p\omega_0\frac{k_r}{r_1}\alpha_s^{'}(\Psi_{x2}\Psi_{y1} - \Psi_{x1}\Psi_{y2});\\
\frac{ds}{dt} &= \frac{p}{J\omega_0}(M_{\text{с}} - M_{\text{д}});\\
i_{x1} &= \omega_0\frac{\alpha_s^{'}}{r_1}(\Psi_{x1} - k_r\Psi_{x2});\\
i_{y1} &= \omega_0\frac{\alpha_s^{'}}{r_1}(\Psi_{y1} - k_r\Psi_{y2});
\end{aligned}\right\} \quad (1)$$

Where $\Psi_{x1}, \Psi_{y1}, \Psi_{x2}, \Psi_{y2}$ − projections of the stator and rotor flux linkages on the X and Y axes;

U_m − amplitude of the phase voltage of the supply network;
ω_0 − angular frequency of the supply network;
$\alpha_s^{'} = \frac{r_1}{x_{s\sigma}}$; $\alpha_r^{'} = \frac{r_2}{x_{r\sigma}}$; $k_s = \frac{x_0}{x_s}$; $k_r = \frac{x_0}{x_r}$;
M_c − moment of resistance of the driven mechanism;
M_∂ − electromagnetic torque of the motor;
x_0 − inductive resistance of mutual induction;
$x_s(x_r)$ − synchronous reactance of the stator (rotor) winding;
$r_1(r_2)$ − active resistance of the stator (rotor) phase;
p − number of pole pairs of the stator winding;

$J -$ moment of inertia of rotating parts of the electric drive;
$s -$ slip of an induction motor (IM);
$\sigma -$ dissipation factor, $\sigma = 1 - k_s k_r$;

The resulting systems of differential equations (1) can be solved using computer technology. However, the coefficients of these equations, which are not given in the reference data on electric motors, are difficult to establish.

For a relative analysis of the transient process of the IM of an asynchronous electric motor (in the Figure 3), we set the Block constant to obtain 5 times the electromechanical load. This type of unit is used for the production of variable loads and severe starting conditions in the IM of asynchronous electric motors.

It should be noted that the presented Park - Gorev differential equation serves to select thyristor starters, RLC filters, Block constant, which create a variety of electromechanical loads in electric motors. Based on the differential equations of Park - Gorev, a new type of contactless starter has been assembled.

Simulation of the physical process and characteristics of the control device for a three-phase asynchronous motor.

For modeling the processes of non-contact devices based on thyristors, the most preferable is the MATLAB environment combined versions of the Simulink and SimPower Systems packages.

The main advantage of Simulink and SimPower Sistems is the ability to create models of complex electrical devices and electromechanical systems based on simulation and functional modeling.

The use of these models makes it possible to check the operability and efficiency of the starters at the lowest cost, to evaluate the parameters of the IM, the nature and magnitude of its load, the adopted circuit solutions when building a start control system.

To construct and experimentally study models of thyristor starters, Figure 3 shows a simulation of the control circuit of a three-phase IM with a power of 160 kW, with thyristor starters in the Matlab Simulink program.

This circuit consists of one Three-Phase programmable Voltage Source AC alternative current block connected to a star, simulating a three-phase voltage source, one three-phase RLC block of resistance Three-Phase series RLC branch, of two Step signal blocks, from two ideal switches Ideal Switch, six blocks Thyristor 1 ... Thyristor 6, connected in phase antiparallel, modeling thyristors, from two pulse generators Pulse Generator (a logic device producing a pulse signal or a pulse transformer) (Fig. 3.), measuring and recording equipment for monitoring the parameters of the electric motor during start-up and control of AM with a squirrel-cage rotor.

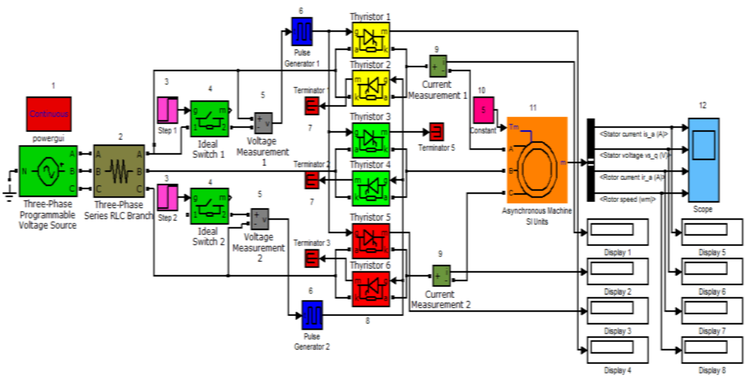

Fig. 3. Simulation of the control circuit of a three-phase IM with a power of 160 kW, with thyristor starters in the Matlab Simulink program.

The power supply to the motor begins by applying voltage to the Three-Phase Series RLC Branch 2 resistor RLC unit. An active resistance is supplied in each phase to reduce the input signal level and to protect the thyristor unit 8 from reverse voltage. The AC output signals are routed to the thyristor unit 8 and at the same time voltage is supplied to the pulse generator Pulse Generator 6, through the ideal switch Ideal Switch 4. When the button of the ideal switch 4 is pressed, the pulse generator generates pulse currents from 1 mA to 100 mA to the control electrode of the thyristors and the thyristor opens. Thyristor units are connected in a circuit in anti-parallel fashion to pass alternating currents in two half-periods 8, and it is controlled by a pulse generator 6 (with a logic converter of current, voltage and frequency) generating a pulsed DC ripple current.

The power thyristor units are opened with the help of pulse current generators Pulse Generator 6, and a voltage of 400 V is applied to the terminals of the asynchronous electric motor. As a result of this process, the motor receives power and begins to rotate.

In the Figure 4, the output characteristic of the thyristor starter with the change of currents, voltage and speed on phase A in the start of the 160 kW electric motor is shown.

As can be seen from the signal characteristics, the starting current of the motor is set at the level of the allowable one after 0.05 seconds, which is typical for the IM.

In the process of modeling, the modes of starting the stator winding in each phase I_a, I_b, I_c of the electric motor were investigated, the voltage of the stator winding Ua, the starting currents of the rotor winding Ip were obtained, the rotational speed of the short-circuited rotor n was taken. Curves of changes in current and voltage begin as early as 0.05 s, the electronic keys open and a voltage from 0 to 400 V is supplied to the electric motor. Accordingly, when the electric motor uses an electric current I_a, the voltage Ua in electric motors drops sharply. Since, the starting current of the rotor winding reaches a value in the negative direction of about 3 A, and in the positive side of 4 A, and the electric current gradually increases with the help of a contactless starter. The speed of the short-circuited rotor goes down to the negative side and the rotor rotates n = 1450 rpm.

In the Fig. 5, the starting shown characteristic of the current in phase A is shown, which is at the input of the starter when the motor is started.

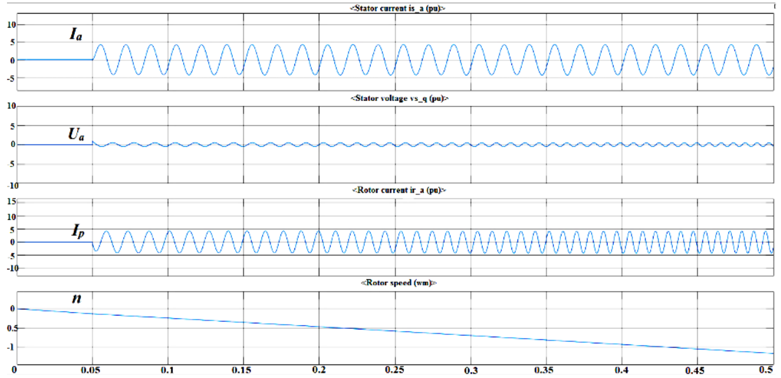

Fig. 4. The output characteristic of the thyristor starter with a change in currents, voltage and speed on phase A, in the start of the electric motor 160 kW.

From the graph of the data of the Matlab Simulink program, it can be seen that the value of the starting current reaches a value in the positive direction of about 1.8 A, and in the negative direction of about 1.8 A. The onset of a stable mode of operation begins already in 0.05 s. From the starting characteristic, it can be seen that the thyristor starter opens from 0.05 s to 0.5 s, and the AC voltage of the asynchronous motor reaches the maximum opening.

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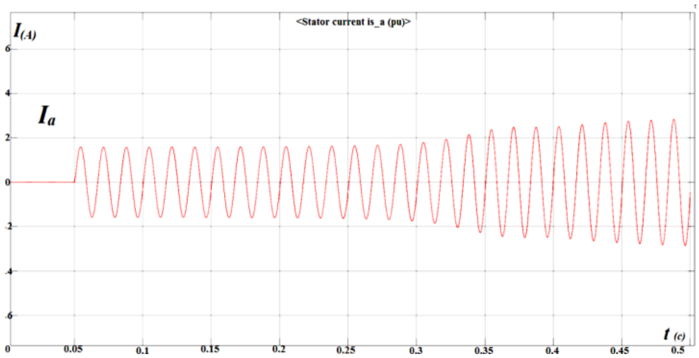

Fig. 5. Starting characteristic of current in phase A.

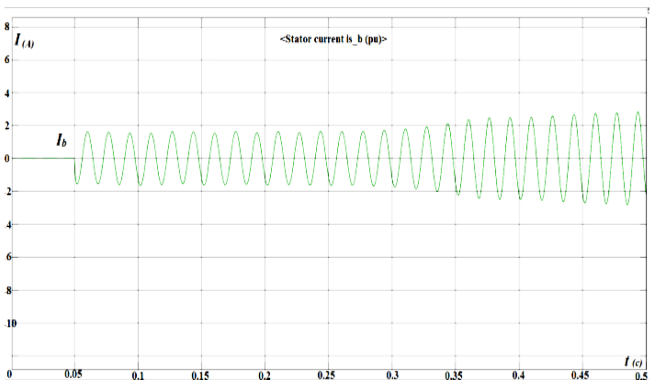

Fig. 6. Starting characteristic of the current in phase B.

In the Figure 6, the starting characteristic of the current in phase B is shown. The starting current in phase B reaches a value of about 1.8 A in the negative direction and 1.9 A in the positive direction, and the electric current is gradually increased by means of a contactless starter.

It should be noted that by regulating the value of the control voltage supplied to the thyristors, it is possible to smoothly start the motor. This will make it possible to limit inrush currents and thereby increase the service life of the electric motors.

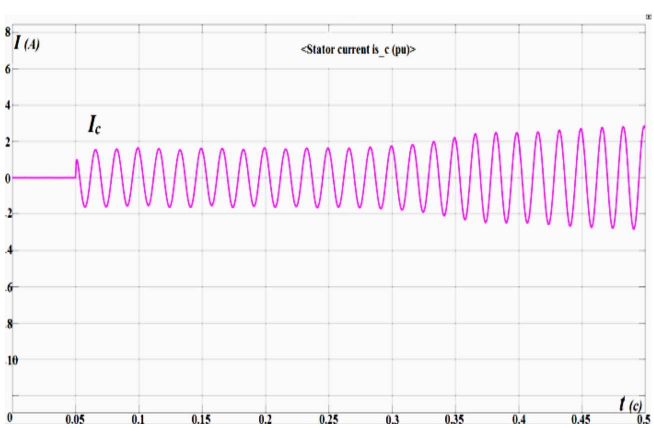

Fig. 7. Starting characteristic of the current in phase C.

In the Fig. 7, the starting characteristic of the current in phase C is shown. The starting current in phase C begins to pass an electric current with half a positive half-cycle of 1.8 A, and in the negative direction about 1.8 A, the electric current increases smoothly and continuously using a contactless starter. Since, the process continues, and the IM asynchronous electric motor works reliably and stably.

Thyristor starters are made of semiconductor elements and will be different depending on the type. The complexity of the starter control system is one of the factors that hinders the widespread use of such switching devices.

The desire to improve the starting properties of asynchronous squirrel-cage motors has led to the creation of a contactless starter with a simplified design.

4 Conclusion

Our proposed circuit of a non-contact thyristor starter has a simpler control circuit that has all the advantages of non-contact starters based on semiconductor elements.

Thus, the new non-contact three-phase thyristor starter can be used as a switching device for starting electric motors and technological equipment at industrial enterprises.

It should be noted that contactless starters of this type will be very useful for two-speed motors with pole-switched windings, where a large number of commutations are required with frequent starts, transitions from one speed to another, and braking.

The use of non-contact switching devices has great prospects, at present they are used in vector control of asynchronous electric motors, in the most complex automation systems and other applications where high performance is required.

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