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INCREASING ENERGY EFFICIENCYOF ASYNCHRONOUS ELECTRIC DRIVE BY OPTIMIZATION OF SWITCHING FREQUENCY IN FREQUENCY CONVERTER

Asynchronous electric motors are widely used in various industries and transport – from rolling mills to rail transport. Frequency converters that work with sinusoidal or spatial-vector pulse-width modulation are most often used to control the speed and torqueof induction motors [1, 2].

Improving theenergy efficiency of an asynchronous electric driveis an important areaof development of electrical engineering and electromechanics [3, 4]. Theincreasein theefficiency of induction motors is associated with an increasein the poles of induction motors, a decreasein the resistanceof the windings and an increasein the power factor. In addition, toensure the maximum efficiency of theinduction motor, it is rational to usean induction motor with full (nominal) load (Fig. 1).

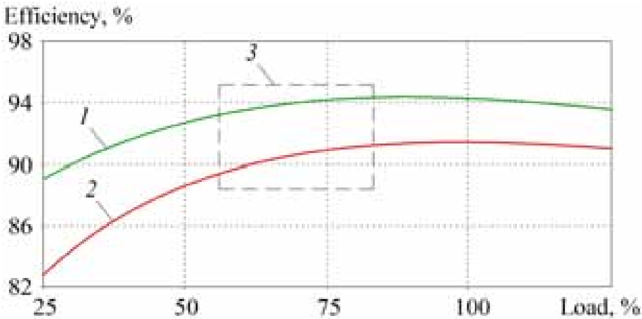

Fig. 1. Efficiency at full and partial loading of theengine:
1– high-efficiency electric motor; *2*–inefficient electric motor;
3– fixed zoneof normal speed

It is alsoimportant toincrease theefficiency of frequency converters in an asynchronous electric drive [5, 6]. Types of power losses in power switches and possible methods of reducing these losses are given in Table 1.

Table 1 – Structural and circuit methods to reduce power losses in the power switches of theinverter

Type of losses	Components of losses	Causes of losses	Possible methods to reduce losses	Disadvantages
Static	– losses in the leading state; – leakage currents	– depending on theamount of current and voltageon the device	– changeof an internal design of a power switch for decreasein voltage drop	– high cost of switches based on silicon carbide
Dynamic	– transistor switching losses; – losses on switching off the transistor; – diode recovery losses; – losses in drivers	– theamount of current and voltage during switching; – duration of switching; – number of switches	– soft switching methods; – improved driver designs; – reducing the switching frequency	–complications of device circuitry; – increasein cost; – reducing the quality of theoutput current of theinverter

Reduction of power losses and, accordingly, increaseof efficiency in the system "frequency converter –asynchronous motor", in addition to design methods, can beachieved by algorithmic methods, ie features of thealgorithm of control systems, or modeof operation [7].

Most common frequency converters (such as Siemens, OWEN, Danfoss and others) have theability to configureand set the modulation frequency. The switching frequency affects the following factors. As the modulation frequency increases, the power losses in the power switches of the stand-aloneinverter increase. At the same time, as the switching frequency increases, the sinusoidality of theinverter phase current improves, as a result of which additional power losses in the windings of induction motors from higher harmonics are reduced. Oneof the ways toimprove theenergy efficiency of an asynchronous electric drive with a frequency converter is tooptimize the switching frequency of power switches. Thereis a dilemma, the higher the switching frequency of the transistors, the greater the power loss in the power switches, but the higher the sinusoidal current of theinduction motor and, accordingly, the smaller the power loss in theinduction motor from higher harmonics. The theoretical dependences of power losses in an induction motor and a frequency converter inverter are shown in Fig. 2.

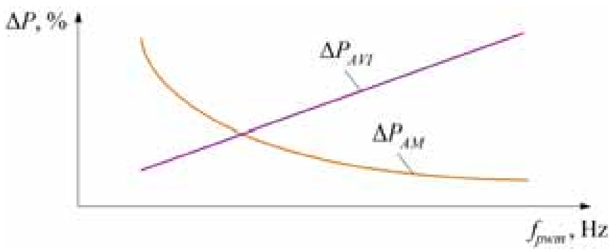

Fig. 2. Theoretical dependences of power losses in the motor$P_{AM}$and inverter P_{AVI} on the modulation frequency

Thus, thereis a theoretically possible switching frequency at which the total power loss in the motor and inverter will be minimal.

Power losses in power MOSFET or IGBT modules consist of power losses in the transistors themselves and power losses in the reverse diode. In this case, the power losses are conventionally divided into static power losses – losses in the conductivestate, and dynamic power losses – losses when turning on and off the transistor. Determination of power losses in the power switches of theinverter can be determined, for example, by calculation in specialized programs from manufacturers of power transistors, namely programs MelcoSim, SemiSel, etc.

A method for determining additional heat losses in the windings of electric motors of alternating current from higher harmonics, which are uniquely determined based on the resulting valueof the coefficient of harmonic distortion of the motor current. This method can be used in the case when theeffect of the skin effect on the resistanceof the windings of motors with a limited rangeof higher harmonics of the current is insignificant. In this case, theadditional losses in the windings from the higher harmonics can be calculated based on theincreasein the root mean square value (*RMS*) of the current relative to the valueof the first harmonic, and hence theincreasein square losses depending on the RMS valueof the current. Theeffective valueof alternating (or constant pulsating) current is equal to the valueof such direct current, which for a timeequal toone period of alternating current, will do the same work (thermal or electrodynamic effect) as the considered alternating current.

Simulation of system "autonomous voltage inverter – asynchronous motor operation is performed at nominal engine load (nominal constant torqueand nominal speed). During the experiments, only the PWM modulation frequency and, accordingly, the switching frequency of the power switches changed. According to the simulation results, the valueof the first harmonic of theoutput voltageand output current does not change due to the changeof modulation frequency, but the content of higher harmonics decreases with increasing PWM frequency, as a result of which the rms valueof phase current.

During theimplementation of an autonomous inverter, a power transistor of the PS21A79 typeand a typical asynchronous electric motor with a pull of 3.7 kW with an optimal modulation frequency in PWM a frequency of 1200 Hz. At the same time, it means that in the rangeof frequencies from 1 kHz to 2 kHz, the total volumeof theeffort does not grow. In the frequency ranges below 1 kHz and more than 2 kHz, it is difficult to grow.

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ЗАГАЛЬНА ІСТОРИЧНА ОЦІНКА КОЕФІЦІЄНТА КОРИСНОЇ ДІЇ ЛОКОМОТИВІВ

Локомотивобудування має досить довгу та цікаву історію. Перший прототип паровоза було збудовано ще у Франції в 1769 році інженером Ніколя-Жозе Кюньо. Перший рейковий паровий локомотив було розробив у 1801 році британець Ричардом Тревесік. З того часу було розроблено досить багато типів локомотивів, які мають суттєво різні технічні показники.