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INDUCTION MOTORS IMPROVEMENT FOR A VARIABLE SPEED DRIVE

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New improvement way of induction motors for a variable speed drive when changing mass dimension indices has been proposed. It allows for improvement of energy indices and reduction of running costs. The analysis of simulation results has been carried out and calculation results of economic efficiency of the achieved methods of approach to energy effective induction motors design have been suggested.

Introduction

Energy-saving, or rather production rationalization, distribution and use of all kinds of energy, became one of the main priority trends of technological policy in all developed countries of the world. The potential of energy-saving in Russia is 40...45 % of present energy consumption in the country according to specialists' estimation, that makes 360...430 mln. tons of equivalent fuel. Branches of fuel-energy complex have a third part of this economy potential, another third is concentrated in power-intensive branches and building industry, more than 25 % is in housing and communal services, 7 % is in transport and 3 % is in agriculture [1]. European potential in energy-saving is evaluated at 160 mln.tons of equivalent fuel that is considerably lower than the same index in Russia. Energy intensity of domestic goods is, as a rule, 2,5...3 times higher than in Europe and USA. It gives the reasons to consider Russian potential of energy-saving as a vast resource of economical and social development, concentrated in all fields of practical activity and so far unused properly.

The structure of electric energy consumers in Russia is approximately as follows: electric drive – 60 %, electric transport – 9 %, electrothermics and electrotechnics – 10 %, lightning and other consumers – 21 %. According to the data of European experts, the cost of electric energy, consumed annually by an average motor in industry, is 5 times higher than its own cost. It is obvious that during the motor operating time (tens of years) an energy component is incommensurably higher than the component of capital costs. In this connection, the care of optimization just the energy component is of prime importance.

Modern level of development of power electronics, microintegrated control systems, theory and means of automatic control allow using widely these theoretical and technical achievement for solving tasks of energy- and resource saving. Modern frequency converters provide the quality of control of induction motors (IM) rate being just as good as the quality of direct current drive. The well known advantages of induction squirrel-cage motor such as high reliability, lower cost, simplicity in production and usage, in conjunction with high regulating and dynamic indices supported at present turn the induction variable frequency drive into the dominant type of variable speed drive. Its mass application allows solving not only process tasks, but also energy-saving problems.

Industry gets out of recession and large quantity of electric energy is required now. It may be provided in two ways:

- by introduction of new generating capacity;
- by meeting industry requirements due to energy-saving.

The first way is connected with high capital investments and long period of these capacities introduction, that slows down industry development. The second way may be provided by means of introduction of a variable speed drive with energy-saving induction motors. In this case, while the problem of energy-saving at variable speed drive introduction is sufficiently considered, the problem of manufacturing of special energy-saving IM, operating in electric drive structure, is not practically considered. And it is in IM where the main electric energy losses arising at electric drive operating occur. Therefore, the development of new approaches to IM improvement intended for variable speed drive is required.

The aim of the given paper is the improvement of induction motors for variable speed drive subject to their economical efficiency.

Statement of the investigation problem

The induction motor, as an electromechanic energy converter, is the main device, being a part of electric drive. The objects of our attention are IM with squirrel-cage rotor. The current economic changes have defined the necessity of IM improvement and determined new trends of their development. The main trend of standard IM improvement is the increase of power efficiency [1].

IM power efficiency is characterized by the efficiency level (η) and power factor ($\cos\varphi$). In European Community and Russian Federation the standards for IM efficiency were accepted in 2000. CEMEP euro standards for two- and four-pole IM with the capacity from 1, 1 to 90 kWt three levels of efficiency are provided: normal – EFF3; advanced – EFF2 and high – EFF1 (EFF – efficiency class) [1]. EFF2 and EFF1 standards are partially presented in [1]. Efficiency values lower than EFF2 level are referred to EFF3 level. Standards of SS P 51677-2000 involve motors of all poles in the range of capacity from 1, 1 to 400 kWt. They provide two levels of efficiency, which practically coincide with the levels of euro standards of CEMEP (European Committee of Manufacturers of Electrical Machines and Power Electronics): normal EFF2 and advanced EFF1.

Recently the new trend in creation of energy-saving IM has appeared. It is a design of IM with higher in comparison with base machines of mass-dimensional indices which is realized in the given paper. To create energy-saving IM for working in the system of a variable speed drive the following ways of their design are possible [2]:

- without changing transverse geometry at changing length of starter and rotor cores;
- without changing transverse geometry at changing length of starter and rotor cores, and also changing machine winding data;
- at changing transverse geometry of starter and rotor.

The first two ways of energy-saving IM design were considered in the paper. A mathematical model of economic efficiency estimation at IM design was used for simulation. It covers the main stages of IM design, such as electromagnetic [3] and thermal calculation of a machine [4], and also includes economic calculation allowing us to estimate the optimality of the designed machine at the design stage. The mathematical model of economic efficiency estimation may be used for simulation of any average capacity IM of general industrial performance. Any stage of simulation may be performed separately, and adjustment is also possible at any stage. The advantage of mathematical models is, first of all, the fact that they exclude any physical experiment.

The transverse geometry of base machines is accepted as initial parameters: inner and outer diameter of starter and slot zones, characteristics of applied active, insulator and structural materials. The limiting factors of simulation are the coefficient of slot filling-up and starter winding heating. To calculate the thermal pattern of the machine the method of flow diagram, based on wide use of thermal resistances which are connected into thermal net, imitating real ways of transmission of thermal flows in the machine was used. The method of thermal diagrams became the most widely used due to its simplicity and sufficient accuracy of simulation [4]. In IM of average power the insulation with heat resistance F class possessing 100 °C maximum temperature excess of electric machine parts, at gaseous medium temperature of +40 °C and orthometric height not more than 1000 m is used. Since IM starter is the most heated part of the electric machine at steady-state conditions, the value of an average temperature excess of starter winding ($\Theta_м$) is accepted as the output parameter of thermal calculation. The value of average temperature excess of starter winding allows judging roughly about the reliability of the designed electric machine. It is generally known that the excess of insulator operating temperature by 5...10 °C decreases its service life in two times.

The following energy characteristics are accepted as the output parameters of the mathematical model of economic efficiency evaluation: efficiency and power factor, and also economic indices, such as referred costs $З_m$ of development, introduction, manufacturing and operation of the motor for standard recoupment period and annual costs for active electric energy losses C_a for technical and economic assessment of optimal variant selection

$$З_{т} = C_{д} + \sum_{i=1}^{t_{н}} (C_{a})_{i},$$

where $C_д$ is the total cost of the motor; C_a is the annual costs of active electric energy losses; t_n is the standard recoupment period,

$$C_{д} = C_{м} + C_{т} + C_{вн},$$

where C_m is the costs for materials; C_l is the labor costs; C_{ne} is the nonproductive expenses,

$$C_a = Ц_a t K P_2 \left(\frac{1-\eta}{\eta} \right),$$

where $Ц_a$ is the cost of 1 kW·h of electric energy; t is the number of working hours of the motor per year; K is the load factor; P_2 is the useful power at motor shaft; η is the motor efficiency at actual load.

The lowest referred costs $З_m$ for development, introduction, manufacturing and operation of the motor during the standard recoupmentk period serve as the criterion of economic efficiency at the choice of the best variant [5, 6]. Besides, motor prior cost, which includes motor total cost and also the rate of profit $\rho_н$ of enterprise-manufacturer, is taken into consideration

$$Ц_{двиг} = C_{д}(1 + \rho_{н}).$$

Algorithm of simulation of IM economic efficiency is shown in Fig. 1.

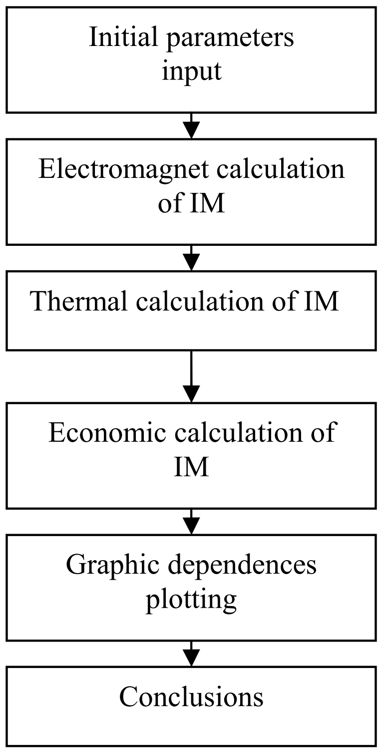

Fig. 1. *Algorithm of calculation of IM economic efficiency*

The task of simulating is to determine economic efficiency at machine running, being guided by its specified geometry, and to make a decision on the appropriateness of the realized direction in IM improvement.

The analysis of simulated results

IM AIR112M2, AIR112M4 with squirrel-cage rotor were taken for simulating. AIR112M4 was selected as the most widespread IM with stable parameters at manufacturing, and AIR112M2 is used more often in housing and communal services. The following ways of energy-saving IM design, used in this paper, may be singled out:

- the increase in length of starter and rotor cores (l) without changing the number of turns of starter windings (w_1);
- the increase in length of starter and rotor cores and decrease of starter winding number of turns.

The change of length of starter and rotor cores of the machine was taken in the range from 100 to 130 % of gauge length, and the change of starter winding number of turns in the range from 100 to 85 % from the base value.

The dependences of the complex efficiency index, representing the product of power factor and efficiency of the designed motors at changing winding data and the length of starter and rotor cores are shown in Fig. 2. As it is seen from the Figures, at IM weight increase the improvement of energy indices occurs due to electric losses reduction, falling at starter and rotor winding. In this case, the complex efficiency index turns out to be higher than the index of the base motor for the variants with simultaneous change of the number of turns in the starter phase winding and the length of starter and rotor cores. The best complex efficiency index results from number of turns decrease in starter phase winding by 10 % from the base value.

The dependences of annual costs for active losses of electric energy depending on the length of starter and rotor cores at the change of number of turns in the starter phase winding are presented in Fig. 3. The decrease of annual costs for active losses of electric energy which are the main item of expenses at IM service occurs due to the energy indices improvement. The least value of electric energy active losses occurs at the decrease of the number of turns in the starter phase winding by 15 % from the base value.

The dependences of the referred costs for the development, introduction, manufacturing and operation of IM for the standard recoupment period at the change of winding data and the length of starter and rotor cores are shown in Fig. 4. The referred costs for the development, introduction, manufacturing and operation of a motor for the standard recoupment period and the annual costs for the active losses of electric energy are minimal at the decrease of the number of turns of starter phase winding by 15 %. The decrease of the referred costs for the development, introduction, manufacturing and operation of IM for the standard payback period occurs due to the decrease of annual costs for active electric energy losses. In this case, minimal values of the referred costs fall at the variants of simulation at the simultaneous change of core length and the number of turns in the starter phase winding.

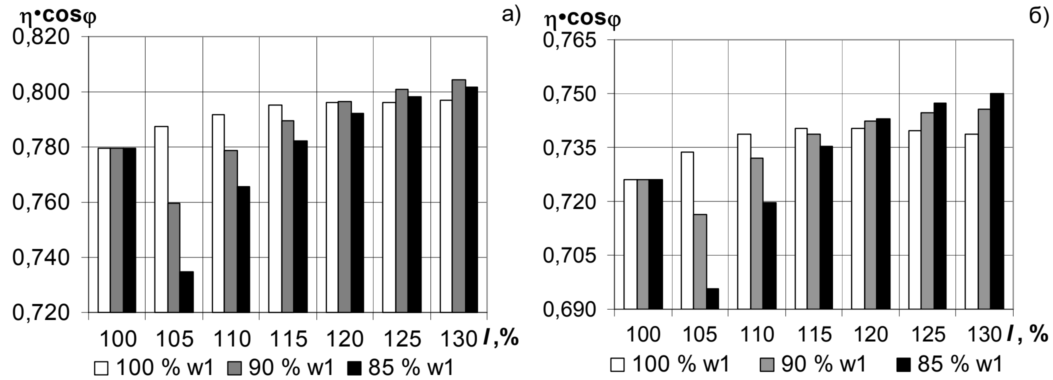

Fig. 2. *Complex efficiency index η·cosφ depending on the length of starter and rotor cores at change of the number of turns in starter phase winding for: a) AIR112M2; b) AIR112M4*

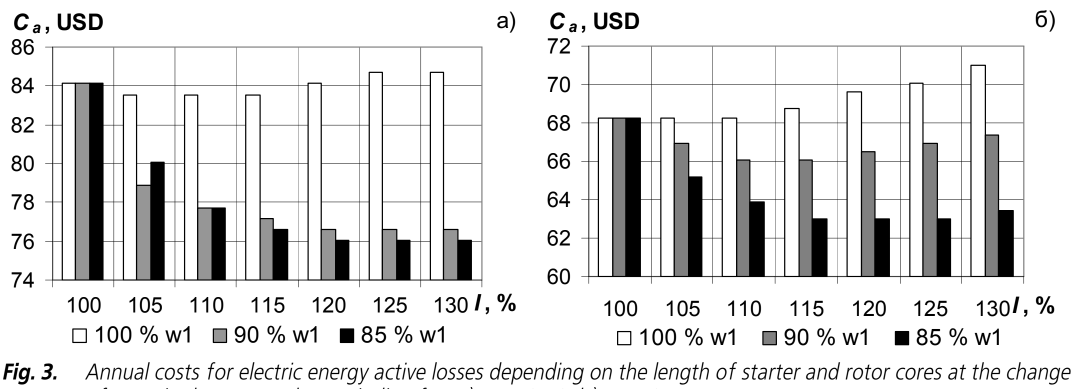

Fig. 3. *Annual costs for electric energy active losses depending on the length of starter and rotor cores at the change of the number of turns in the starter phase winding for: a) AIR112M2; b) AIR112M4*

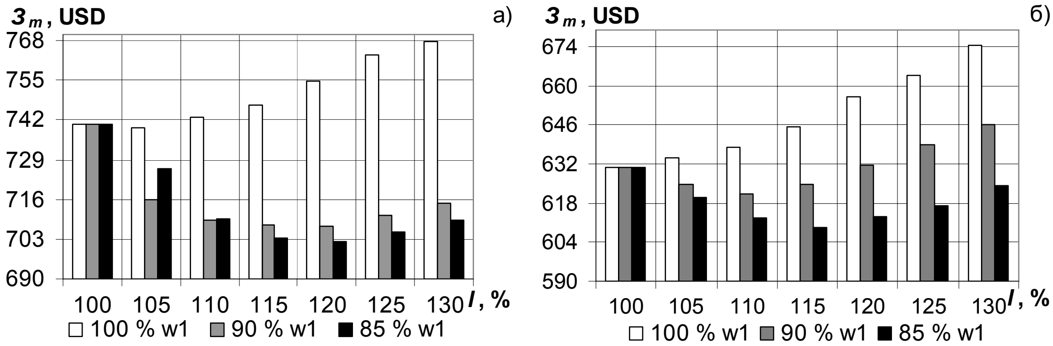

Fig. 4. *The referred costs for the development, introduction, manufacturing and operation of induction motor for the standard recoupmentk period depending on the length of starter and rotor cores at the change of the number of turns in the starter phase winding for: a) AIR112M2; b) AIR112M4*

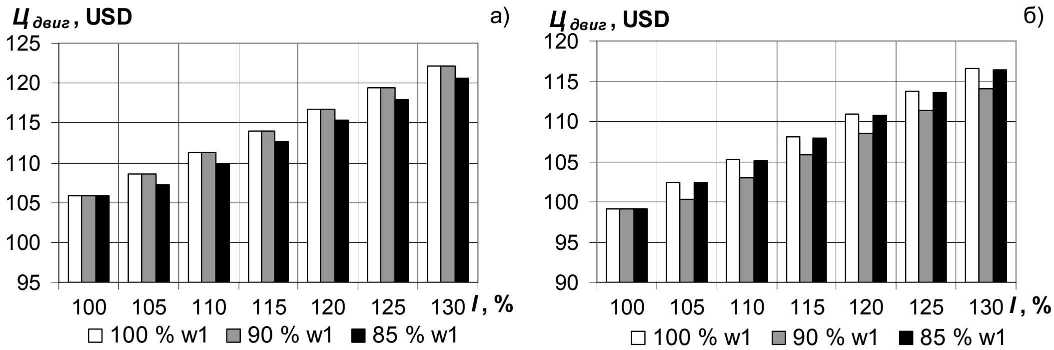

Fig. 5. *The cost of a squirrel-cage IM depending on the length of starter and rotor cores at the change of the number of turns in starter phase winding for: a) AIR112M2; b) AIR112M4*

The dependences of squirrel-cage IM cost at the change of winding data and the length of starter and rotor cores are presented in Fig. 5. As it was expected IM turns out to be rather expensive than its analogue due to the increase of costs for the materials, which are the main expenses, included into the prime cost and also due to the growth of labor costs. The growth of IM cost occurs linearly; it is connected with the fact that the costs for materials grow proportionally to the increase of core length. But a certain growth of IM cost due to the increase of active materials consumption is compensated due to decrease of annual costs for electric energy active losses.

Conclusion

The realization of the suggested trend of IM improvement for the variable speed drive, connected with the increase of mass-dimensional indices of IM, allows designing the machine, possessing the advanced energy characteristics and lower costs, during the operation life. In this case, the best energy indices are obtained at the simultaneous change of cores length and the number of turns in starter phase winding. The designed IM possesses the energy indices which correspond to the increased efficiency level according to the CEMEP EFF2 euro standards and to the normal efficiency level according to the SS P 51677-2000.

Energy indices turn out to be higher for the variant of simulation at the reduction of the number of turns of starter cores by 10 % at relative value of core length of 125 %. The referred costs for the development, introduction, manufacturing and operation of the motor for a standard recoupment period and annual costs for the active electric energy losses are lower for the variant at the decrease of the number of turns in starter phase winding by 15 % and relative value of core length of 115 %. It confirms once again the fact that optimal induction motor should be chosen for the specific operation conditions.

Improved energy indices allow reducing the costs during the operation life that compensates the increase of induction motor cost. Minimal value of the referred costs for the development, introduction, manufacturing and operation of the induction motor for the standard recoupment period is at the decrease of the number of turns in starter phase winding by 15 % and relative value of core length of 115 %. Thus, the designed motors are economically the most profitable.

The induction motor cost for any variant of calculation is higher than the cost of the analogue, due to the increase of active materials consumption as well as the growth of labor costs. But a certain increase of the cost of the designed induction motor is compensated by the reduction of costs during the operation life for the variants of simulation with the decreased number of turns in starter phase winding. The analysis of simulation results shows that the increase of core length over 115...120 % from the base length is not reasonable.

The realization of the trend of IM improvement, connected with the design of energy-saving IM at the change of starter and rotor transverse geometry, is further expected. It allows turning to the high efficiency level according to CEMEP EFF1 euro standards and higher efficiency level according to SS P 51677-2000. However, it demands carrying out additional scientific research.

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