Energy Efficiency of Induction Motor Drives

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Contributor: Plamena Dinolova , Vyara Ruseva , Ognyan Dinolov

Despite activities to introduce low-carbon energy sources worldwide, the share of conventional facilities burning organic fuels remains high. One approach to address this problem is to look for solutions to reduce energy consumption. There are various research projects in the area of energy efficiency that lead to diverse results—such as models, methodologies, new data and theories. On the other hand, induction motor drives are becoming a major consumer of electric power because of their wide range of applications.

electric energy efficiency | induction motor drives | energy

1. Introduction

A number of activities—strategic, political, engineering and other ones—are currently being developed to introduce low-carbon energy sources. Despite the activities worldwide, the proportion of conventional facilities burning organic fuels remains high. This production is inevitably associated with harmful impacts and is characterized by a significant contribution to the observed climate- and environmental changes.

One of the main approaches to address the problem is to look for solutions to reduce energy consumption. Despite systematic efforts in many countries, energy efficiency remains low. In Bulgaria, for example, the Energy Efficiency Act has been in force since 2004. However, a reference to the Eurostat databases for 2019 shows that the energy intensity (units of energy per unit of GDP) of this country is significantly higher in comparison with some other countries. The intensity is 3.32 times higher than the average level for the European Union and 7.78 times higher than the country with the lowest intensity in the Union [1]. These data are revealing. The statistical information is also confirmed by the results of scientific research conducted for specific sites in Bulgaria. In the investigation of some model technological processes, the efficiency coefficient for the electric power consumed by production machines with electric drive is about 30%, decreasing to 1% for some of the machines due to near no-load operating modes [2][3].

2. Energy Efficiency of Induction Motor Drives

Increasing the Energy Efficiency of Induction Motor Drives

The published data [4] show that about 70% of induction motor drives applied in practice do not need speed control. For these cases, opportunities are mainly sought to improve the power characteristics of the drive motors.

In induction motors, constant and variable losses are observed. The methods for their limitation have been studied and analyzed in the literature, where specific solutions for increasing their energy efficiency are also proposed [5][6]. The reduction in losses leads to the creation of energy-efficient motors, the use of which in manufacturing plants is a recommended practice according to a number of authors [7]. The current trends predetermine the motors in the IE4 and IE5 efficiency classes as being energy-efficient according to the international standard IEC 60034-30 [8]. It is considered that there are real opportunities for cage-rotor induction motors to be modernized, to increase their efficiency and to upgrade to a higher energy class according to the mentioned standard [9].

To improve energy efficiency in industry, one of the possible methods is to replace IE1 energy class motors with IE3 motors. In [10], the authors propose a methodology that is based on calculating the possibility of energy savings by performing a prior estimation of the savings and identifying some economic opportunities for the replacement of motors with higher-efficiency ones. The method does not evaluate all the motors in the studied facilities but uses the potential energy savings to select the motors for evaluation. As a result, a full economic evaluation of the final solution is provided based on the discounted cash flow methods.

The induction motor replacement approach is also adopted in accordance with energy efficiency legislation in Brazil. Actions have been taken there to replace motors in the chemical industry with higher-efficiency ones. The multi-criteria model has been used according to the “FITradeoff” procedure [11]. In another developing country, India, it has been found that the electric motors used in industry are mainly of the IE1 energy class or lower-efficiency motors, and the need for their replacement is again reported in order to reduce electricity consumption [12].

Along with the advantages, certain difficulties in the introduction of energy-efficient motors are described. For example, a 2020 study found that under standard operating conditions, some IE4 energy class induction motors have a lower consumption but, in some cases, behave as non-linear consumers and introduce harmonic disturbances to the power grid [13].

In order to improve the energy efficiency of a cage-rotor induction motor, in [14], a field orientation control simulation was performed. One of the effects is the reduction of power losses. On the other hand, it is found that when the thickness of the laminations making up the stator package of a 0.37 kW three-phase induction motor is reduced, the efficiency increases by 1.4% and the power losses decrease [15].

A simplified methodology for the optimization of the magnetic flux between the stator and rotor of induction machines is proposed. The methodology allows for energy-efficient control of the machine to be performed in a dynamic mode [16]. The conditions for efficient electromagnetic conversion in the air gap are also significantly affected by the structure and design execution of the stator winding [4]. In this regard, a method for calculating the phase currents and the magnetomotive force for a given stator winding diagram was proposed in 2021. The method was applied for an asymmetrical “12-zone” stator winding, for which an improvement in the operating energy characteristics of the winding was assumed due to the reduction in the levels of the higher harmonics [4].

Improvement of Induction Motor Drives

In addition to the main component of induction drives—the electric motor—efforts are also focused on all the other components, namely the control and monitoring systems, electromagnetic transducers, conversion mechanisms, etc.

In [17], a generalized control optimization model for continuous transport systems involving descending belt conveyors is presented. The simulation shows that considerable energy savings can be provided through the use of recuperative drives and speed control. The payback period of the investment is less than 5 years. In [18], justification is provided that the recuperative braking process is one of the significant factors for improving the energy efficiency of drives in the mining industry.

Particular attention is paid in the literature to control and management systems. In [19], an energy-efficient scalar control of cage-rotor induction motors that takes total losses into account is presented. The method is based on modifying the stator flux in order to track the operating point with the highest efficiency. The results show an improvement in the efficiency of the drive when the flux is optimized, especially in cases of low loads. The approach is applicable in variable-speed drives such as pumps, compressors and fans.

With the help of an adaptive neural network controller, connected in a circuit with direct control of the torque of an induction motor, the energy efficiency, quality and reliability of the electric drive control in an industrial plant are improved [20].

For the improvement of the energy efficiency of induction motor drives, a method using artificial intelligence-based controllers has also been proposed in the literature. These are tuned using optimum values of the current, obtained via mathematical calculations [21].

A model of a vibrating centrifugal grain separator with an induction motor was implemented in a MatLab (Simulink) environment [22]. The induction motor is used for vibration transmission, which transmits the motion of the working body without using additional motion transducers. This avoids the control unit for power switching. Stator starting currents are reduced and the system reliability is increased. Using the Simulink tool again, an efficient control algorithm for an induction motor drive of an electromechanical vibration exciter is developed [23]. This algorithm minimizes the effective values of the stator phase currents.

A published article analyzes belt drive transmissions that transfer energy from induction motors to various mechanisms and units [24]. This publication states that many organizations recommend the use of toothed- and V-belts instead of smooth belts for the purpose of increasing energy efficiency. The choice of a cross section and length of toothed V-belts depends on the motor power, and the calculations are time consuming. Therefore, the authors of the article developed a table of standard cross sections and belt lengths with the calculated power.

Energy efficiency and safety improvements in coal mining areas can be achieved by using modernized electric drives on the main machines, thereby also reducing maintenance staff [25]. In the garment industry in some developing countries, more than half of the drives prove to be inefficient due to the use of clutches. In order to save electric power, in [26] a more efficient sewing machine with a single-phase drive with a frequency converter is presented.

With the use of pumps, it is possible to improve the energy efficiency of each component of the drive. In [27], the authors indicate the following options to increase the energy efficiency of induction motor drives of pump units: correct selection of the power rating for the induction motor and the pump; pump speed control via a variable speed drive.

Energy-Efficient Operating Modes of Drives

Increasing the utilization of electric power can be achieved by more than design improvements of drives. Even drives with a high level of design perfection can prove to be inefficient when the operating mode is changed. In many cases, a significant change in the operating modes of induction drives occurs during operation. It may be due to process requirements, climatic factors, environmental conditions, etc. The energy-efficient regulation of the performance or the operating mode, respectively, is the subject of targeted efforts. These efforts mainly refer to changes in the angular velocity of the motor, but there is also a fair amount of research in the area of rational load distribution, torque control, improved starting modes, etc. In the literature, particular attention is paid to low-load modes.

Appropriate load is a measure mostly applied to large electric drives with high annual consumption. To reduce energy losses, an energy-saving method of balancing the load of powerful hydraulic presses is proposed in [28]. The method is based on the analysis of the energy flow characteristics, and the results show that the reduction in electric power consumption can reach 36%. The authors specify a configuration of two presses in which the overload energy of the first press can be used as input energy for the second one. It appears that for some process operations the energy efficiency of the drive system is improved. In a study of other facilities with high power consumption, namely pneumatic systems, methods for the evaluation of the power of these systems are presented and an analysis of the power consumption distribution is performed. This lays the basis for the optimization of the operating modes and energy-efficient design process [29].

In some mining sites, drives with a variable rotational speed powered at medium voltage were installed to achieve energy efficiency in the ventilation systems [30]. In addition to speed variation, torque regulation is also applied.

In order to increase the energy efficiency and improve the performance characteristics of induction motors, a sensorless speed control method was developed, which allows for a symmetrical and balanced mode of motor operation at all operating points in the rotational speed range [31]. A phase-shift algorithm was developed to implement this method. In the same publication, a first-of-its-kind model for continuous start-up of the motor at very low frequencies is reported. The engine simulation shows positive results in terms of the energy efficiency of the proposed method. For dynamic drives with rapidly changing loads, minimization algorithms based on analytical models are also presented in the literature.

In 2018, a team of five researchers proposed an energy-efficient control of the operating modes of variable-speed induction motor drives for pumps, compressors and fans. The results show that if adjustable flow rate pumps are used, a 60% reduction in the electricity consumption of shipboard equipment can be achieved at reduced vessel speeds [32]. The possibilities for savings through frequency control have also been investigated for ventilation systems [33].

Significant savings of electric power at low loads of induction motors can also be achieved with optimum characteristics of the machine magnetic flux. In this regard, the authors propose two methods to determine the optimum flux value, namely loss pattern control and demand control. The Matlab platform [34] is used to verify the results.

Improved Operational Maintenance

The improved operational maintenance of induction motor drives leads to the detection of early signs of failures and facilitates timely troubleshooting actions [35]. It ensures accident-free modes and reduces electric power consumption. It appears that the methods for predictive maintenance, or life cycle assessment of induction motors, respectively, allow for operation under rated loads for longer periods of time [36].

For improvements in the efficiency of electric power consumption, a robust monitoring system was described in the literature to detect faults caused by air gap asymmetry in the induction machine at their earliest stage [37].

In 2019, an action planning algorithm was proposed for the maintenance of induction motors with faults leading to operational losses [38]. The same publication reveals how the monitoring of energy efficiency and motor condition can reduce electric power consumption and carbon dioxide emissions.

Improved Production Technologies

The approaches presented so far are classical ones and require improvements to the drives in terms of their design or mode of operation. In contrast to these approaches, the literature also distinguishes a field where a reduction in electric power consumption while performing the same amount of useful work can be achieved without changes to the drives themselves, but by improving or replacing the manufacturing technology.

In another research project [39], a model for identifying opportunities to increase the energy efficiency of industrial processes using induction motor electric drives is presented and analyzed. The model performs a simplified mapping of energy flows, thereby extending the scope of actions to achieve energy efficiency. To secure the application of the model, an increase in the number of workers in the enterprises is required.

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