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Increasing efficiency of induction motor by predictive control system

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Abstract. Standard squirrel-cage induction machine is widely used in industrial enterprises due to its advantages in terms of reliability, durability and economic efficiency. However, one of its disadvantages is that it suffers from a power dissipation factor due to its inability to balance active and reactive power consumption. Especially when the SCIM is running at no load condition or during the initial start-up, the power factor or useful operation and performance are drastically reduced. Therefore, improving the power factor of the induction machine is an actual topic for the following article, and has had some interesting solutions for several years. In this thesis, two different induction motor control algorithms (frequency converter and Predictive torque control) are included and a clear comparison between them is given. The main focus of this article is to design an induction motor control system using the two algorithms mentioned above, analyse the performance of different control methods, and experimentally verify these algorithms by comparing simulations and experimental results.

1 Introduction

Electric motors are the main power of our modern and developing society. For this reason, the demand for the variable power induction motor is high, and it is very suitable for the process where the load is not constant. By modern detectors and sensors we can perform our planned work [1, 2]. First of all, working condition of motor should be learned because of several reasons. For instance: in some progress speed of motor is important and in other industrial progress load in the shaft is very changeable, therefore this issue requires certain calculations. According to statistics, almost half of the total electricity produced in industrialized countries is consumed by electric motors Table 1.

Table 1. Explanation of electricity consumption.

Energy Application	% of total electricity consumed by the application	% consumed by the motors in the application
Stand-alone motors	22.6	22.6
Space cooling and air handling	12	11.4
Appliances	12	7.5
Misc. plug loads	11.5	2.3

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Utilities' own use, railways, power authorities	8	6.9
Space heating	7	1.8
Lights	15.5	-
Electrolysis and process heat	6	-
Water heating	5	-
Total	~100%	52.5%

2 Materials and methods

2.1 Mathematical characteristics of induction motors

It is important to understand the basic mathematical relationships that govern the operation of induction motors. Some key relationships used for explanation are given below.

2.1.1 Torque

The torque generated by an asynchronous motor is expressed by the following formula (1):

$$T = \frac{5250 \bullet HP}{N_{rpm}} \tag{1}$$

Where: HP = Horse power rating, hp, N_{rpm} = Operating speed, rpm.

2.1.2 Slip coefficient

The frequency of alternating current represents the speed of rotation of the magnetic field inside the stator. The rotor moves behind this field with a slower rotation relative to the magnetic field in the stator. This difference in speed is called slip [3, 4].

$$\%Slip = \frac{N_S - N}{N_S} \tag{2}$$

Where: N_s = Synchronous rpm, N = Measured rpm.

2.2 Motor load expression in industry

Many induction motor applications currently used in the manufacturing industry are large in size. Calculations made by plant engineers when making engine installation decisions are usually based on the slip method load determination technique. This is the easiest way to determine the motor load. When the load factor falls below the optimal load level of 60-80%, motor efficiency begins to decrease. It can be seen that if the load on the motor shaft is as high as 70%, the efficiency of the motor will be higher [5]. The power factor variation with load and induction motor torque-speed characteristic are given in Figures 1 and 2.

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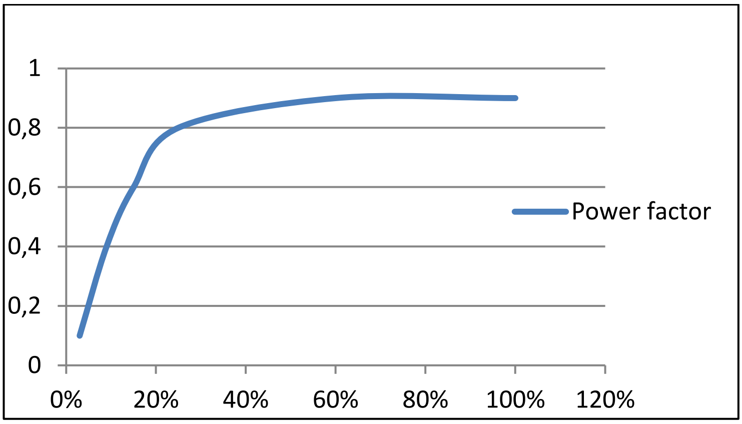

Fig. 1. Power Factor Variation with Load.

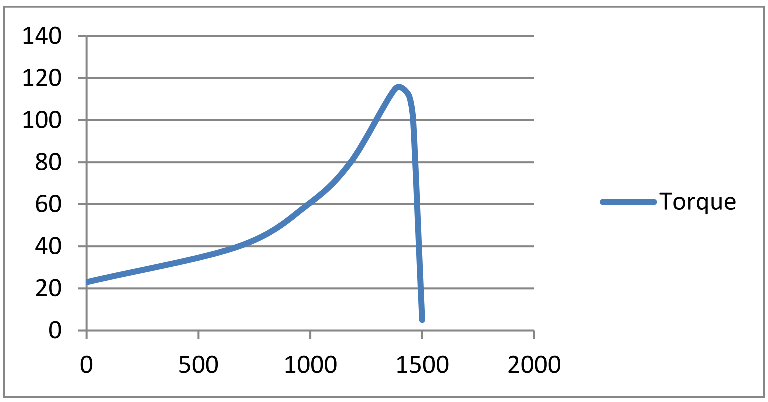

Fig. 2. Induction motor torque-speed characteristic.

2.3 Methods which have been using for improving induction motor efficiency

Induction motor motion control and speed adjustment is a key parameter required in many processes, be it domestic or industrial processes. Systems used for these purposes are called drivers. Electronic drives use various detectors and control algorithms to control the speed of the induction motor using appropriate speed monitoring methods. In general, there are various methods of adjusting the power of an electric motor, and their advantages and disadvantages are still widely used today. One of the main and common methods is power control through a frequency converter, which is used in many cases where it is necessary to change the speed [6].

3 Results and discussion

3.1 Asynchronous motor drive system by frequency converter

Controlling the speed of an induction motor requires the use of variable voltage and frequency sources. Frequency converters that supply power with a frequency of 50 or 60 Hz. To obtain a variable voltage and frequency voltage source, we need to implement a voltage rectifier combined with a controlled voltage source inverter. A rectifier is used to convert AC

(50Hz) voltages into DC voltage, while an inverter is a controlled device that can convert DC voltage into AC variable frequency voltage. The scheme of the used system is shown in (Figure 3).

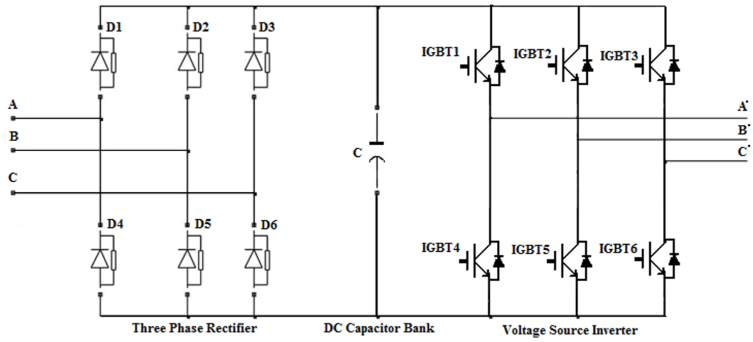

Fig. 3. Veriable voltage and frequency rectifier.

A voltage rectifier is a static power electronic device used to convert alternating current into a direct current source using a set of semiconductor diodes. In a three-phase system, six diodes are used to construct a full 2.5 cycle wave rectifier. The three-phase input sinusoidal graph of the rectifier is described as follows (Figure 4).

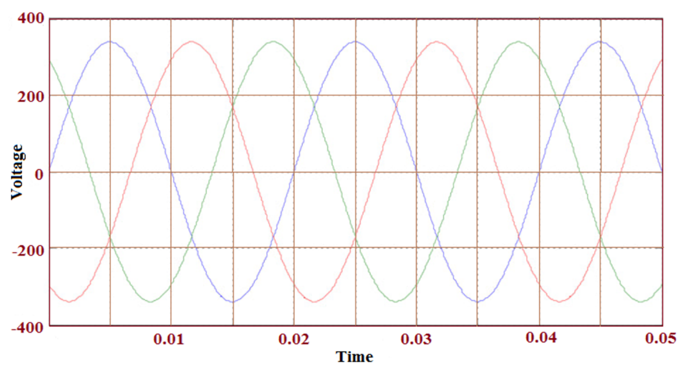

Fig. 4. The three-phase input sinusoidal graph of the rectifier.

The graph of voltage variation in each phase is described by the following line voltage, phase angle and time expression;

$$V_1 = \sqrt{2}V_{rms}\, sin(\, 2\pi f t) \tag{3}$$

$$V_2 = \sqrt{2}V_{rms}\, sin(\, 2\pi f t - \frac{2\pi}{3}) \tag{4}$$

$$V_3 = \sqrt{2}V_{rms}\, sin(\, 2\pi f t + \frac{2\pi}{3}) \tag{5}$$

After the output of the pulsating voltage, it is filtered through a capacitor and a constant smooth graph is formed. The constant voltage output characteristic of the voltage rectifier is shown in (Figure 5).

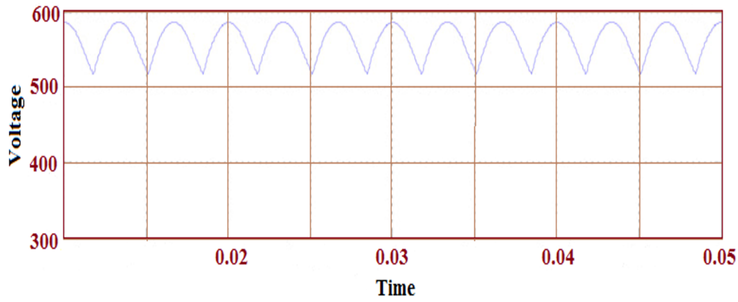

Fig. 5. Full 2.5 cycle wave pulsating voltage rectifier

The conditions for turning on the diodes give the following output voltage from the three-phase voltage curve [7]:

$$V_{out} = \frac{3}{\pi}\left(\int_{\pi/6}^{\pi/2} -(V_1 - V_2)dt + \int_{\pi/2}^{5\pi/6} -(V_1 - V_2)dt\right) - \quad (6)$$

$$V_{out} = -\frac{3V_m}{\pi}[\text{-}1.73\text{-}0.86 + 0.86] \quad (7)$$

$$V_{out} = 1.65V_m = 1.65 \bullet \sqrt{2} \bullet V_{rms} \quad (8)$$

Figure 6 shows the general structure of a three-phase voltage source inverter. As shown, fully controlled switches (IGBT/MOSFETs) connected in anti-parallel with rectifier diodes are used in the above circuit. The principle of operation of the inverter is based on a very fast transition between the positive and negative poles of the direct current source to generate an alternating current, and the speed of this transition depends on the speed of the signal supplied to the base [8, 9].

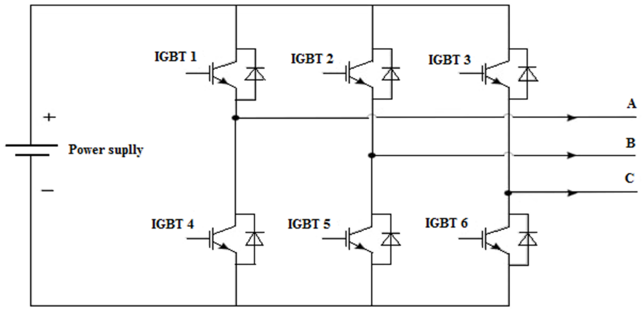

Fig. 6. General structure of a three-phase voltage source inverter.

Current flow in inverter switches (base) is allowed to flow in both directions. This makes it possible to generate AC voltage from a DC source. A constant direct current source can be a battery or a backup capacitor used to power the inverter. The output voltage and current of the power source inverter are shown in (Figures 7, 8).

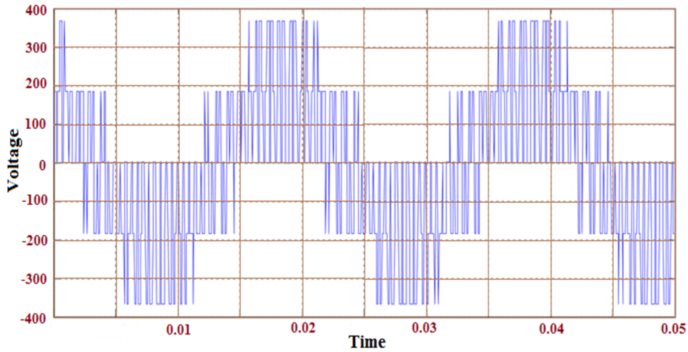

Fig. 7. The output voltage of the power source inverter.

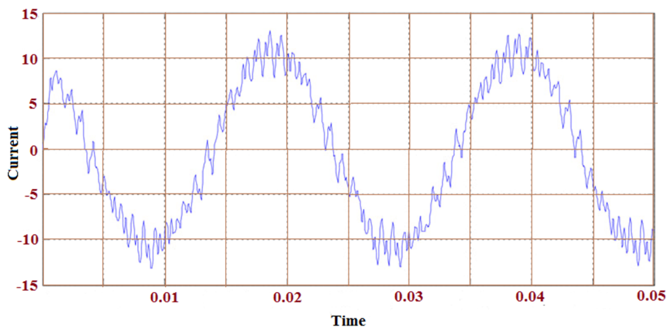

Fig. 8. The output current of the power source inverter.

The speed control system of the induction motor driver indirectly through the artificial neural network torque control scheme is shown in the figure. In the circuit diagram below, it can be seen that the speed of the shaft changes as a result of the load on the rotor of the induction motor. The analysis of the speed change is transmitted to the controller and analyzed, and as a result, the operating current i_{qs} generated in the current controller transmits a logic signal to the inverter on what frequency to generate accordingly. From this it can be understood that the change of speed in the loading effect does not affect this process. It should not be forgotten that an excessive increase in the torque on the shaft will cause a sudden increase in the supplied frequency, and may cause an increase in the current in the stator and damage. Therefore, it is absolutely necessary to take protective measures [10].

Computer simulations of IM control through FCS-MPC are performed on the basis of MATLAB/Simulink software. The simulations are tested based on the above program as a preparatory step before the implementation phase in the experimental state. The simulation experiment is illustrated in Figure 9 above. The general approach for the simulation phase should be to model the system and the predictive controller as closely as possible and be based on exact values. In the simulation, the exact IM parameters used in the experimental implementation are set for the induction motor model. A 2L-VSI model with realistic switches is used, as the focus is not on inverter efficiency, but on quality in control performance. Control action is performed under a subsystem called "MPC-model predictive control".

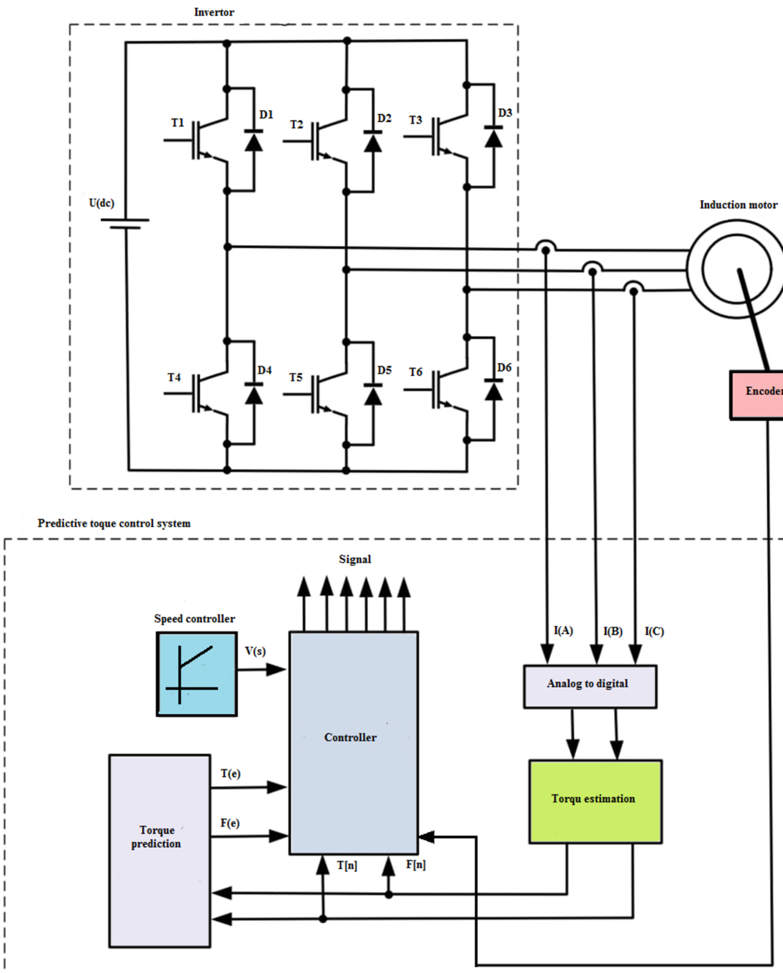

Fig. 9. Predictive artificial neural network of torque controller.

The MPC unit is modeled as an actuated subsystem that controls the process based on a predetermined or programmed control cycle. Thus, speed and load are evaluated in proportion to each other, and current flow and power consumption are under constant control. For satisfactory numerical accuracy, the simulation step size or speed is set to 1 μs. Because the transmission of information about the process to the controller in idle state causes some problems in the work process, for example, the effect on the speed of the motor due to a sudden change in the load on the shaft [11].

It is important to relate the value of the motor current and the load to each other in order to apply the following procedure. This is because we all know that an increase in load causes an increase in the value of the current. Therefore, it is necessary to constantly monitor the current value. Through the following equation, we can see the connection between the two main parameters, the stator current I_s and the load on the shaft T_{sh}.

$$I_S(k+1) = (1 + \frac{T_{sh}}{\tau_\sigma}) \bullet I_S(k) + \frac{T_{sh}}{\tau_\sigma + T_{sh}} \bullet \frac{1}{R_\sigma}((\frac{k_r}{\tau_r} - k_r \bullet j \bullet w(k)) \bullet \varphi_r(k) + v_s(n)) \quad (9)$$

Where: $\tau_\sigma =$ time, $R_\sigma =$ resistance, $k_r =$ inductance coefficient, $\tau_r =$ rotor time, $w(k) =$ rotor speed, $v_s(n)$ = voltage vector, $\varphi_r(k)$ = rotor flux.

If the information about the load change on the induction motor shaft does not reach the controller at an unspecified time, a sudden change in the current in the stator will occur. Therefore, in this experiment, the accuracy of the encoder detector, torque sensor, and sensors that analyze current, voltage, and power factor changes, as well as the speed of their signal transmission to the controller, are extremely important [12-13].

4 Conclusion

In conclusion, it should be said that the methods of controlling induction motors through frequency changer and predictive load controller are common, and it is possible to achieve high efficiency through both methods. Of course, the use of these methods depends on the operation of the motor. But in some processes, the value of the load on the motor shaft changes constantly. As a result, the motor operates in three different no-load, nominal and load modes of operation. In this mode of operation of the motor, the generalized view of the frequency changer and load controller allows to obtain effective results. This means that if the load on the shaft of our induction motor increases, the exact analysis result is transmitted through the sensors and the information is analyzed through the controller, and then the command is transmitted to the inverter through the output signal. As a result, we get a number of advantages, for example, reduction of excitation current, partial limitation of excess active and reactive power consumption, a slight increase in power factor, speed control and a number of protection functions, which can be obtained by this method.

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