Design and Implementation of Constant Speed control System for the Induction motors Using Programmable logic Controller (PLC) and Variable Frequency Derive (VFD)

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Abstract. This paper presents an automatic speed control system on three phase squirrel cage induction motor using Programming Logic Circuit (PLC) and Variable Frequency Drive (VFD) techniques. The aim of this study is to obtain a constant speed of induction motors when these motors are exposed to variable loads. The required speed of the induction motor can be set as a numerical value by (PLC), while the actual speed of the induction motor can be measured by a tachometer which is equipped with (PLC) ) Through an Analog to Digital Converter (ADC). Then the two speeds are compared to the set point with minimum error to get the required constant speed. The control system designed to be tested with two stator poles number (two and four poles) of induction motors. The results have cleared that in spite of doubled the load 11 and 8 times respectively, but the yield average shaft speeds are almost constant 2891.15 rpm and 1402.45 rpm respectively.

Keywords: Programmable Logic Controller (PLC), Variable Frequency Drive (VFD), Induction motor.

1. Introduction

The methods of controlling induction motors are considered one of the great industrial applications that were and still are the backbone of laboratories, laboratories and industrial workshops. As these applications are directly involved in the processes of controlling the opening and closing of the boiler gates, regulating the speed of filling in the food factories, and in controlling the speed of washing machines with the change of different loads. The traditional methods of controlling induction motors specifically began to appear immediately after the invention of the induction motor by the scientist Tesla in 1889. There are methods that are controlled by the motor starter, for example, control by the number of poles, control by impedance, control by voltage applied, control by frequency change Applied voltages. There are also other classic methods in induction motors of the type of sliding rings, where resistors are added in the form of a curtain to the three-phase routers by means of the sliding loops. It is possible by means of controllable resistors to control the speed or torque with special efficiency during the start of the motor with full load [1] to [3].
The relatively modern methods that appeared after the advent of semiconductor technologies and the invention of the transistor, particularly the Mosfet, especially in the second half of the twentieth century. The invention of the Thyristor at the beginning of the seventies, up to the IGBT device in the mid-nineties, which added important advantages in reaching more efficient and effective methods, such as the method of controlling the voltages and synchronous frequency (V/f), direct torque control method (DTC) , and finally the directed flood control method (FOC)[2,3].

The tremendous technical development in micro-processor technologies at the beginning of the seventies of the twentieth century opened the doors. Nowadays most of industries depend on the automation. By the automation technology those industries have advanced. Factory automation has become very important for any industrial mass production processes. The manual control day by day is going to be reduced due to the growth of industries. This research may contribute to the industrial automation when there is a need for a constant or controlled speed of the induction motor. As for the emergence of technologies of programmable language circuits (PLC), in that period, applied industrial languages began to appear that added high flexibility and inspired researchers to create PLC systems. Currently, PLC systems are used to control three-phase induction motors, especially in the mentioned control methods: V/f, DTC and FOC [4] to [8].

This paper is a design of controlling the required constant speed of the induction motors using (PLC) & (VFD) techniques which they provide the benefits of power savings, reduction of the motor starting current, decreasing the mechanical stresses on the motors especially during starting interval. The main function of the (VFD) is to change the supply frequency that implies to change the speed of induction motors [9]. There are many speed control methods for the induction motors with drawbacks. The first method is the stator voltage method that has the following drawbacks (speed control range is limited, low supply power factor because of the harmonics). The second method is the stator frequency method that has the following drawbacks (reduction in efficiency and torque). The third method is the stator current method that has the following drawbacks (low starting torque, high generation of harmonics). The fourth method is the static rotor resistance method that has the following drawbacks (reduction in efficiency, speed over normal speed is not possible). Using the Variable Frequency Drive VFD to control the speed of the induction motor is called the V/f method [4] to [8].

All the mentioned methods have drawbacks therefore V/f method for the speed control is the best method because it has the following advantages, lower starting current, and stable torque. According to the V/f method the torque is directly proportional to the voltage and is inversely proportional to the frequency therefore the torque will be stable approximately.

According to the following few researches presented by the researchers [9], M.Deepa [10] that are within the field of speed control system on the induction motors. All the researchers had used the Variable Frequency Drive (VFD) with an additional controller that sends a signal to the VFD to obtain the required frequency, then obtaining the required speed for the induction motors. After studying those papers it was noticed that all the designed control systems designed by those researchers are in the form of open loop speed control systems, while this presented paper introduced a design in the form of closed loop speed control system on the induction motors using VFD and PLC [11].

2. Hardware Components

2.1. Variable Frequency Drive (VFD)

The VFD is a type of motor controller that converts the frequency of the supply voltage into another value therefore the speed of the motor will be changed according to the new value of the frequency. Figure 1 shows the delta variable frequency type, while Figure 2 explains the internal electronic circuit diagram of the VFD [12]. This drive consists of the following stages: Rectifier stage, DC link bus and Inverter stage.
Figure 1. The Delta variable frequency drive.

Figure 2. Electronic circuit diagram for variable frequency drive.

2.2. Programable Logic Controller (PLC)
Figure 3 shows the main components of the programable logic controller (PLC) which are: Input unit, Central processing unit, Memory unit and Output unit.

Figure 3. The Programable Logic Controller (PLC).
The input unit is responsible for receiving the data that may be in the form of analogue signals or digital signals by depending upon the converter’s ADC or DAC. The central processing unit is responsible for the data transfer stored in the memory of the PLC. The memory unit is responsible for storing all types of data (programs or instructions) [13]. The output unit is responsible for sending also digital signals thought relays, contactors, lamps, and sending also analogue signals in the form of DC voltages or currents [14].

2.3. Diagram of the control system
The block diagram of the constant speed control system is shown in Figure 4.

![Figure 4. The block diagram of the speed control system.](image)

This block diagram consists of seven parts. The personal computer is responsible to write the PLC program using a given software, then loaded to the PLC. The PLC is loaded with a ladder program that used to prepare the suitable DC voltage that feeds the VFD to obtain the constant speed after the comparison with the set point stored in the PLC. The VFD is responsible for converting the DC signal coming from the PLC into the equivalent value of frequency. The induction motor is the part that is needed to control its speed. The tachometer is responsible for feeding the (ADC) with the actual value of the motor speed in the form of a low AC voltage, then it will be fed to the (ADC). The (ADC) part is responsible for converting the analogue AC voltage into digital number that is fed to the PLC. The (DAC) part is responsible for converting the digital number coming from the data register (D9900) into analogue signal that will be fed to the VFD.

2.4. The ladder Logic diagram program
The ladder Logic diagram program is shown in Figure 5. It contains three data registers, the first data register (D9900) is a register for storing a digital number responsible for obtaining the output constant speed of the induction motor, where this register is available within the Digital To Analog Converter (DAC), the second data register (D9911) is a register for storing a digital number responsible for actual speed of the induction motor, where this register is available within the Analog to Digital Converter (ADC), the third data register is (D2) for storing the set point digital number which is converted by (D9900) into required constant speed for the induction motor. The ADC and DAC are connected to the Programmable Logic Converter (PLC).
LADDER LOGIC DIAGRAMM

D2 is the data register for set point to the required constant speed
D9911 is data register for the actual speed of the induction motor
D9900 is data register for the control the speed of the induction motor

Figure 5. The ladder Logic diagram program.

Figure 6 shows the hardware implementation of designed constant speed control system on the induction motor. It is noted, the computer is shut down after completing the programming, so it is disconnected.

Figure 6. The speed controller is in operation after uploading the program to the VFD.

3. Results and Discussion
Tables 1 and 2 shows the measurement of the speed of the two induction motors when they are subjected to variable loads where the load is done as an electrical brake on the induction motors and the two motors are different in the electrical power.
Table 1. The speed measurement with applying variable load to the first motor

| Load Current (Amp) | Speed (rpm) | Frequency (Hz) |
|--------------------|-------------|----------------|
| 0.095              | 1401        | 50             |
| 0.104              | 1405        | 50.2           |
| 0.115              | 1398        | 50.4           |
| 0.130              | 1406        | 50.7           |
| 0.138              | 1402        | 51             |
| 0.152              | 1407        | 51.2           |
| 0.174              | 1402        | 51.7           |
| 0.183              | 1408        | 51.9           |
| 0.223              | 1408        | 52.6           |
| 0.236              | 1395        | 53             |
| 0.269              | 1393        | 53.7           |
| 0.286              | 1401        | 54.1           |
| 0.323              | 1405        | 54.7           |
| 0.350              | 1404        | 55.3           |
| 0.380              | 1402        | 55.9           |
| 0.400              | 1397        | 56.9           |
| 0.432              | 1409        | 57.4           |
| 0.450              | 1402        | 58             |
| 0.466              | 1399        | 58.9           |
| 0.774              | 1405        | 59.2           |

Table 2. The speed measurement with applying variable load to the second motor.

| Load current (AMP) | Speed (rpm) | Frequency (Hz) |
|--------------------|-------------|----------------|
| 0.60               | 2895        | 50.00          |
| 0.63               | 2892        | 50.20          |
| 0.77               | 2891        | 50.70          |
| 0.92               | 2888        | 51.30          |
| 1.26               | 2889        | 51.60          |
| 1.64               | 2884        | 52.00          |
| 1.80               | 2893        | 52.66          |
| 2.55               | 2891        | 53.10          |
| 3.52               | 2890        | 54.00          |
| 4.27               | 2895        | 54.31          |
| 4.45               | 2893        | 54.90          |
| 4.60               | 2890        | 55.30          |
| 4.85               | 2891        | 54.00          |
| 5.00               | 2889        | 54.40          |
| 5.65               | 2888        | 54.80          |
| 5.90               | 2894        | 55.20          |
| 6.22               | 2890        | 55.70          |
| 6.45               | 2894        | 58.30          |
| 6.6                | 2894        | 58.90          |
| 6.7                | 2892        | 59.40          |

According to results shown in Tables 1 and 2. It is noticed that increasing the load current from 0.095 Amp to 0.774 Amp the speed of the first induction motor is about 1400 RPM approximately and the frequency varies from 50 Hz to 59.2 Hz, also we noticed that increasing the load current from 0.6
Amp to 6.7 Amp the speed of the second induction motor is about 2900 RPM approximately and the frequency varies from 50 Hz to 59.4 Hz, that means obtaining the constant speed of the induction motor has been accomplished by this presented design, and this is the aim of this paper.

4. Conclusion
Through the experimental application of changing the speed with shaft loading in the presence of PLC technology. It is noted in the table that despite the change in the load current from 0.095 to 0.77 Amp, that is, the load doubled 8 times, the rate of change in speed remained almost stable on average speed 1402.45 rpm.

In Table 2, a negative feedback system was also applied on another two stator poles (synchronous speed is 3000 rpm) three phase squirrel cage induction motor to keep the rated speed in constant while changing the load imposed on the motor shaft. As for the nominal motor shaft rotation speed, it is about 2895 rpm at no load. The obvious conclusion is from the results in Table 2 showed that in spite of the rising in the load current from 0.6 to 6.7 Amp that means the load doubled 11 times almost, the rate of change in speed remained almost stable on average speed 2891.15 rpm. It is clearly, that despite the wide change in the two cases for the loads, where the load in the four-pole motor was eight times and in the motor with the two poles, the load doubled eleven times, while the speed in both cases remained almost constant. These conclusions demonstrate the effectiveness of the presented speed control system in the current research, and it can be applied in various industrial fields with an appropriate cost.

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