International Academic Institute for Science and Technology

International Academic Journal of Science and Engineering
Vol.11, No.1, 2024, pp.247-255.

ISSN 2454-3896

International Academic Journal of Science and Engineering

www.iaiest.com

Programmable Logic Controllers Application in Speed Control of Single-Phase Induction Motor

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Abstract

The current study investigates speed control of a single-phase induction motor using the P.L.C (Programmable Logic Controller). There are several methods to control the speed of a single-phase induction motor. However, this method is one of the most recent methods with its rapid response control, flexibility, adjustment making, etc. Most engines in modern industrial facilities and laboratories are equipped with this technology. Here we have designed an electrical circuit that controls the voltage supplied to the motor and is controlled by a PLC unit to control the motor speed and thus we will benefit from all the possibilities, privileges and special benefits provided by the PLC unit to control the motor speed.

Keywords: Programmable Logic Controller, Single-phase Induction Motor, Programming of P.L.C. Terminal Voltage.

DOI:10.71086/IAJSE/V11I1/IAJSE1128
Received: 17 April 2024/Revised: 02 May 2024/Accepted: 11 May 2024/Published: 16 May 2024

Introduction

The vast development in industry, its growing complexity and accuracy as well as increasing speed of the required response produced what is called Programmable Logic Controller (P.L.C). This technique is small, cost-effective, easy to maintain, and it can be programed in more than one language. Also, it can be modified and updated to keep the workflow or production line, Moreover, it can deal with digital and analogue signals, whether for input or output, identify faults and errors if any, and monitor input and output signals by computer [1]. In addition, it can replace the latch circuit, which is widely used in industrial processes to operate engines, timers and counters of various kinds in the hardware control panels because it is inside the software control unit hence it can be adjusted and treated from inside the program.[Thus, it reduces the connections and units in the main control boards and provides a set of functions such as the set / rest function, the reverse output, and dealing with signals such as the positive edge and negative edge and other functions. This system is available in institutions and factories, which means that we are dealing with a modern industrial system in the labor market, where the control process is considered one of the basic operations and is of great importance in the industry [2]. The rest of this article is organized as follows: Section II talks about the components of the programmed logic controller and the work of each part of it. Section III talks about the method of reading and executing the program from memory and the central processing unit, Section IV talks about updating the entries and exits according to the written program for each step, as well as Section V talks about the methods of programming the programmed logic controller and its details. Section VI talks about the single-phase induction motor and its components, and structure. Section VII, the most important methods used to control its speed. Section VIII, using the programmed logic control technique to control the speed of the single-phase induction motor. Section IX Practical results and advantages of the method used. The conclusion is placed in section X.

Programmable Logic Controller

The following Fig. 1 shows the PLC components. As shown in Fig. 1 the logic controller consists of :Input module, CPU, Programming device, Operator device, Output module and Power supply. The input unit has a set of physical components such as sensors of various types; temperature sensors, weight sensors, liquid level sensors, etc. It also has switches of various types, such as pressure switch, close switch, open switch, and regular switch. The input unit converts these digital and analog signals into logic signals, processed by the logic processing unit. The central processing unit is the brain of the Programmable logic controller unit, and it contains one or more processors (microprocessors). It contains a memory connected to the programming unit and it is the decision-making center. It is the decision-making center whose task is to observe the input devices, read the written program and then transfer it to the output unit as signals according to the required program [3]. The programming unit is connected to the central processing unit and is programmed by writing the required program to be executed in one of the many programming languages. The operator unit displays the information of the various controlled operations and introduces new factors to make adjustment to the factors used. The output unit receives the logic controller instructions received from the CPU and converts them into digital or analog signals to control a variety of devices (actuators). As for the power supply, it provides the power required to operate the electronic units and components, as well as the necessary power to operate the actuators, sensors, etc.

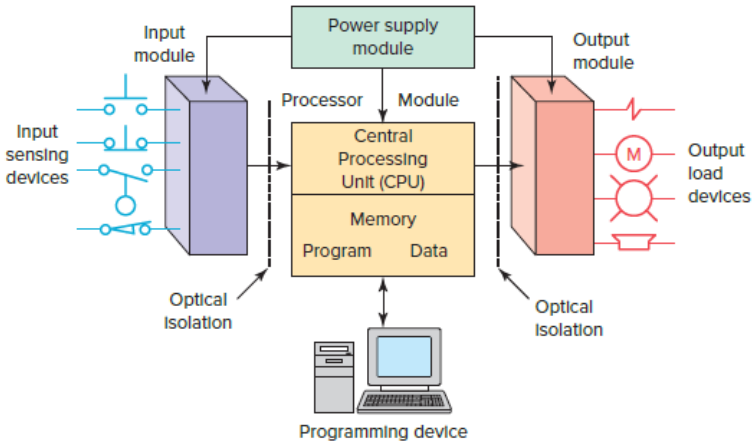


Figure 1: Block Diagram of PLC

The Work of P.L.C. Unit Work

Fig. 2 below shows the diagram of the main steps executed by the Programmable Logic Controller (P.L.C) [4].The PLC unit works by performing a continuous scanning of the written program. The scanning process consists of three main important steps, as follows: Examining the inputs status: the PLC unit checks the status of each input to determine if it is in the (ON/OFF) position. Then it stores the data in the memory to use in the next step. Also, Implementing the program: the PLC unit implements the program after determining the input status and reading the program commands resulting from each case of each input, and then storing the implementation results to use in the next step.

Updating

The PLC unit updates the output status according to the program orders of the second step. After completing the third step, the PLC unit returns to the first step to repeat the same steps continually. One scanning time is defined as the time taken by the PLC unit to implement the previous three steps.



Figure 2: Block Diagram of the Main Steps of a P.L.C

Programming of P.L.C.

Programming is a set of instructions to accomplish specific tasks. There are different ways of programming: Ladder diagram, Statement lists and The function block diagrams. In the first method of programming, it is carried out by drawing a circuit similar to the electrical circuits with a basic difference where the circuit is in a horizontal position rather than vertical. The first line represents the positive voltage, while the second line represents the negative or earth voltage [6]. The following symbols are used in Fig. 3 and Fig. 4. This method is considered one of the most commonly used ways to represent electrical circuits and control circuits in electrical devices of all kinds. In the second method, a statements list is described in which the circuit to be controlled is described by a set of commands expressed by a letter or symbol. which provides the most important abbreviations used in this method [7]. As for the third method, the box diagram depends on the use of basic logic gates using the symbols of the squares that represent each gate, as shown in Fig. 5.

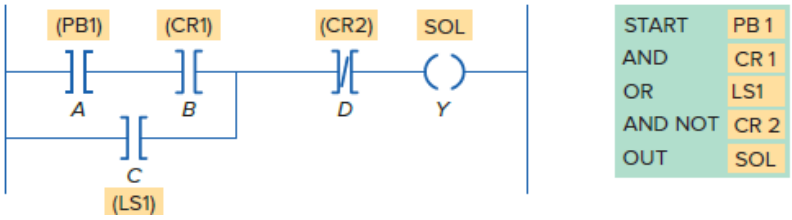


Figure 3: Diagram of the Symbols Used in the Language of the Ladder Plan

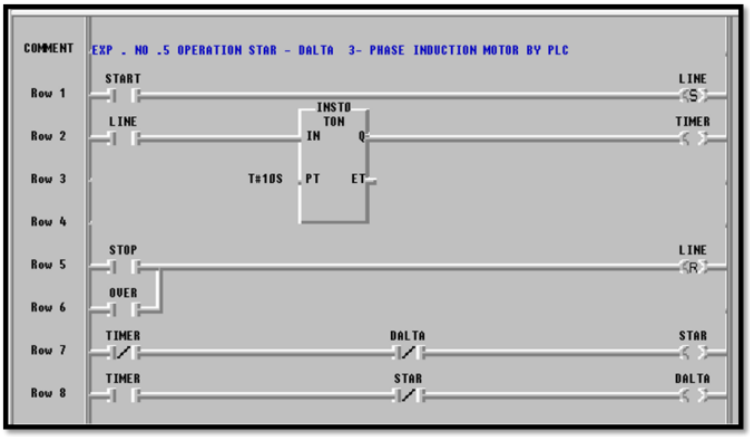


Figure 4: The Ladder Plan of One of the Programs

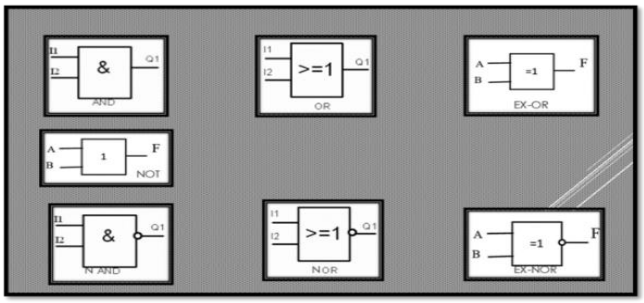


Figure 5: The Logic Gates are Represented by the Box Diagram

Single Phase Induction Motors

An induction motor consists of: 1- The frame: it is a shell made of steel, aluminum or cast iron. It represents the engine body and has a large size so that the gadget sustain the task, as well as the field poles that are fixed to it with screws. 2- The stator: the heart of the stator consists of a bundle of steel plates containing ducts fixing coils, and these ducts are closed or open. The stator is usually made of steel. 3- The rotor: there are two types in the structure of the role member, although the electrical properties between them are almost similar: Slip-ring motors and Squirrel-cage-motors. In Slip-ring motors, the rotor consists of a cylindrical body of iron isolated laminations, containing ducts where the coils are placed, arranged in a similar way as that of the stator and subject to the same rules. The coils of the rotor are connected to sliding rings mounted on the same shaft, hence the name the type of motors are slip rings [8]. In squirrel cage motors, the rotor is made of a cylindrical body of iron laminations and has ducts as in the previous type, but instead of the coil there are copper or aluminum rods. Its ends are connected on each side with a reinforced ring of the same metal as the rods, hence the two rings and rods look like a squirrel cage in its structure, and that's how it acquired its name, as shown in Fig.6.

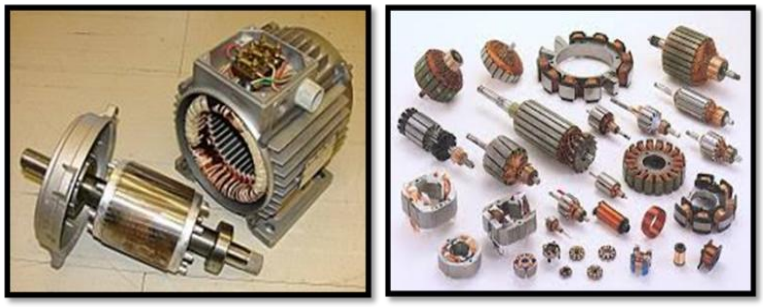


Figure 6: Types of the Rotor

Speed Control Methods of Single Phase Induction Motors

Induction motors are easily maintained and installed, and they are cost-effective and highly efficient in terms of fixed or variable speed compared to other motors. There are some common ways to control the speed of an induction motor such as [9]: 1- Changing the applied terminal voltage.

By the torque equation of induction motor, it is noted to be directly proportional to the applied terminal power.

$$T_t = \frac{1}{ws}.P_t \quad (1)$$

Where: T_t is total torque, P_t is terminal power, and Ws is angular velocity. This method is preferred if the load torque changes with the squared velocity, as is the case with fans. The speed of the motor is determined by the intersection of the torque of the load and the torque of the motor. The motor is in a stable state when the rate of torque change in proportion to the speed of the motor is less than it is in the load at the point of intersection, and on the contrary, the motor is in an unstable state. A certain speed range can be obtained by controlling a corresponding voltage range. This method is suitable for both wound motors and squirrel-cage motors. 2- Changing the number of electrodes. This method is commonly used with squirrel-cage rotor, where a change in number of its electrodes is not needed because it behaves like a stator by self-induction. Changing the number of electrodes does not affect the magnetization current. Hence, the torque is not affected because it depends on the current of the rotor with the flux densities, which do not change by changing the number of electrodes. As for the starting current, rated current, maximum power factor and speed, they are proportional to the number of electrodes. [10]. 3- Changing the frequency of source. Synchronous velocity can be found by the following equation:

$$n_s = \frac{120f}{p} \quad (2)$$

Where: ns represents synchronous speed, f is frequency, p is number of electrodes. By changing the frequency, the synchronous speed changes as well as the motor speed.

The actual impedance of an induction machine depends on both frequency and speed, and therefore it changes the current and flux. If we consider the voltage (E1) as constant, we notice the flux (1) ϕ) to be inversely proportional to the frequency (f), as shown in the following equation:

$$E1 = KW1N1\phi1F \quad (3)$$

Where: E1 represents the induced voltage, KW1is winding modulus, N1 is speed, ϕ1 is the flux and F is frequency

$$\emptyset 1 \ \alpha \ \frac{1}{F_2} \quad (4)$$

Since the torque is proportional to the squared flux:

$$T_e \ \alpha \ \emptyset 1^2 \quad (5)$$

$$T_e \ \alpha \ \frac{1}{fs^2} \quad (6)$$

Thus, the torque is inversely proportional to the squared frequency. However, it is not possible practically to continue decreasing the frequency in order to obtain a high torque, because the flux increases and reaches saturation to maintain the flux. So, when we decrease the frequency, we should reduce the voltage as well. This method is used with wound and squirrel rotor. It is also used with the load whose torque is inversely proportional to the speed, where the motor is stable in the area between the synchronous speed and the speed at the maximum torque. It is preferable to use changing the terminal voltage, especially at low frequencies for a low speed in order to limit the increase of the current and flux.

Using P.L.C. Technology to Control the Single-phase Induction Motor

In this method, the PLC is used to control the speed of the induction motor by controlling the input voltage and using a multi-transformer (variable) for the output voltage controlled by the PLC, as shown in Fig. 7:

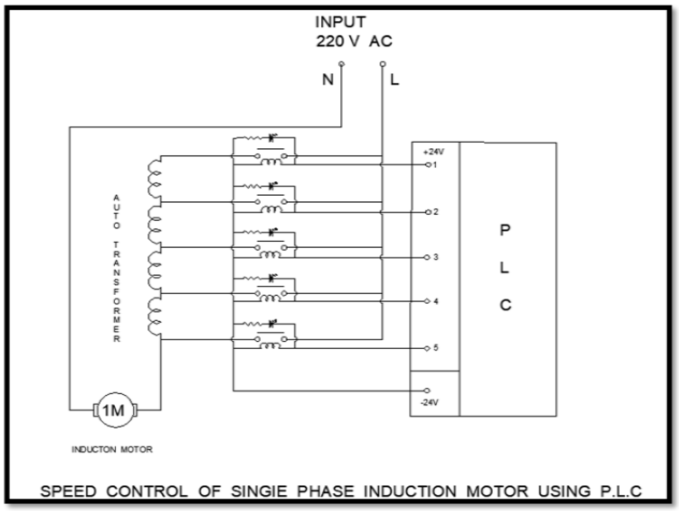


Figure 7: The Block Diagram of Speed Control of an Induction Motor by P.L.C

Table 1. shows the components and the parts used of the circuit and Figure 8 shows the complete circuit.

Table 1: Components of the Circuit Parts

Part no.	Number	Part type
1	5	Relay 30 A- 24V DC
2	1	Tap Transformer
3	4	Resistors 4.7k 1w
4	4	LED 3V
5	5	Conductor

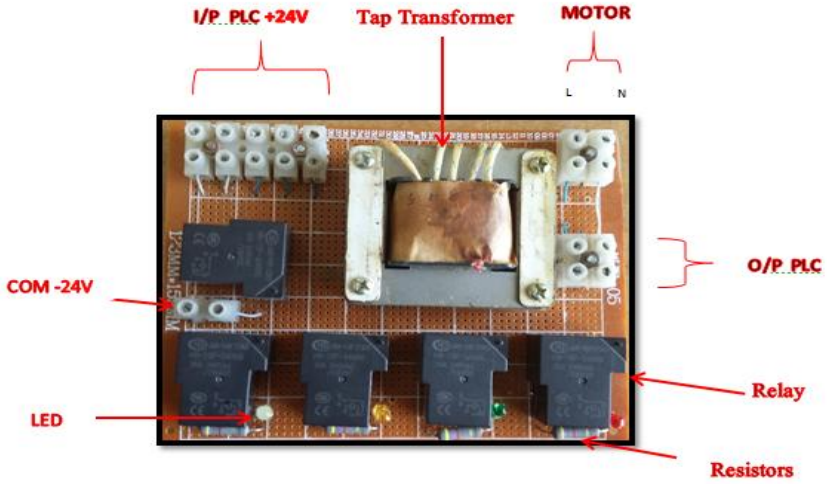


Figure 8: Shows the Practical Circuit Used

In this study, a logic controller type LG-GOLFA of the model GM7U was used, Fig.9 with following specifications: Number of digital input ports is 24, number of digital output ports 16, it works on a continuous voltage of 24 volts for digital input, it works on 220 volts alternating or 24 volts continuous for digital output, extension can be added to the analogue outputs, high speed processor 0.1-0.9 us/step, it can be programmed in different languages, IL/LD/SFC, by the computer through the RS-232C cable. In addition, we used Induction motor is a type of squirrel cage rotor Fig.10. After P.L.C programming and writing adopting the ladder diagram (LD) using the computer and downloading the program to the P.L.C to be stored in the memory, a connection was maintained between the input and the output indicated in the programming. A simulation of the results can be made before implementing the process to spot the errors, if any, which presents.



Figure 9: The Adopted Programmable Logic Controller



Figure 10: Single Phase Induction Motor is a Type of Squirrel Cage

Practical Results

The first stage begins with writing the required program and selecting the appropriate programming language, where the ladder diagram method is used. This method is characterized by simple and easy specifications and can be implemented and simulated easily to correct the errors, if any. After programming the PLC using the calculator, the program is downloaded to the PLC and stored in memory.

After downloading the program to the logic controller, the inputs specified in the program are connected to the input of the PLC and the same applies for the output of the PLC as in Fig. 11 then the RUN command is given to the logic controller used. The input and output will be linked to the programmable logic controller and to the practical circuit used to control the engine speed.



Figure 11: Connecting the Inputs and Outputs with the P.L.C

Thus, the (start1) key is pressed, which represents the first speed located in the PLC (IX0.0.1), the central processing unit in the PLC will feed the first relay with the appropriate voltage (24VDC) and thus will connect (pick) the first coil of the transformer rotating the motor located in the PLC (QX0) 0.0) according to the input voltage through the first relay at a slow speed. Fig.12.When the (stop) key is pressed in the PLC (QX0.0.0) the motor will stop rotating. To get the second speed, the (start2) key is pressed, which represents the second speed in the PLC (IX0.0.2). The central processing unit will equip the second relay with feeding (24VDC) and thus the relay will pick the second coil of the transformer, the motor will rotate according to the voltage of the second coil at a faster speed than the first Fig.13. The same process goes for the rest of the motor speeds (the third, fourth and fifth) noting that it is not possible to switch from one speed to another except after pressing the (stop) key. Table 2. shows the different motor speed control situations.

Table 2: Motor Speed Control and its Location in the PLC

OUTPUT PLC	INPUT PLC 24 V	SPEED RPM
74V QX0.0.0	IX0.0.1	442 START1
110V QX0.0.1	IX0.0.2	670 START2
160V QX0.0.2	IX0.0.3	950 START3
185V QX0.0.3	IX0.0.4	1100START4
220V QX0.0.4	IX0.0.5	1425START5
0V	IX0.0.0	STOP

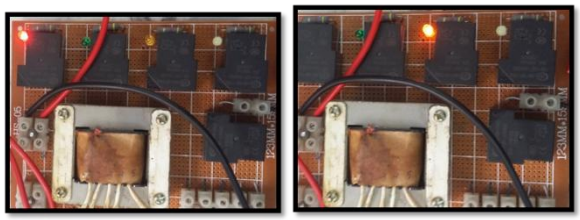


Figure 12: The Control Cases for the Operation of the Relays and Coils Converted



Figure 13: The Response of the PLC Unit to the Programming

After obtaining the practical results, Table 2. we can draw the form of the relationship between the motor speed and the applied voltage, and we get Fig.14. Among them, we note the form of the relationship, which is linear, and the engine torque is constant and stable.

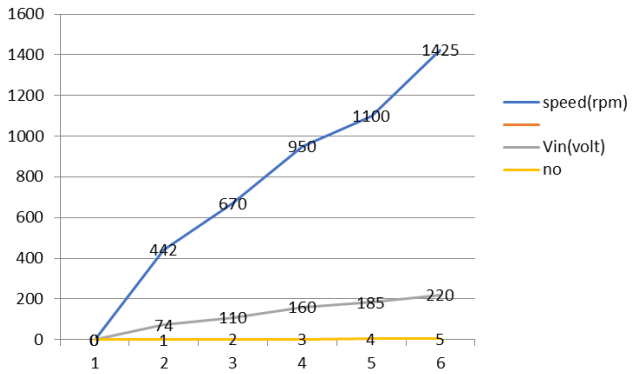


Figure 14: The Relationship between Speed and Output Voltage

Conclusion

In this study, a new method was presented to control the speed of single-phase induction motors, by PLC. This method is characterized by excellent specifications in this field in terms of motor speed control. Also, making any modifications in the performance of the motor speed such as adjusting the speed as required is more convenient than the classic method. This is what all laboratories, factories and modern facilities need. Moreover, the important feature is the monitoring, operation and shutdown of the engine and the control of its speed change, which is done through a calculator or a screen that attaches to the showing all the required data. Here, a simple method was used to control the motor speed by means of a voltage converter. The required speed is tested by selecting the appropriate voltage controlled by the automatic control. Any alteration or adjustment of the speed can be made through work and setting the appropriate speed for the specific purpose.

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