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Monitoring and Control of a Variable Frequency Drive Using PLC and SCADA

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Abstract— Programmable Logic Controller (PLC) and Supervisory Control And Data Acquisition (SCADA) are two new approaches to control a Variable Frequency Drive (VFD) whose output is fed to a three-phase induction motor and driving a conveyor belt. The conveyor belt has three sensors are inputs which senses a passing object and carries out the necessary instructions programmed in ladder logic programming of the PLC through the medium of a personal computer (PC). The SCADA software installed in the PC in turn enables the human operator to control the entire operation away from the plant and just by using the virtual inputs designated on his computer screen. The results have been verified with a validating experiment.

Keywords- *Variable Frequency Drive, Programmable Logic Controller, Supervisory Control And Data Acquisition, RS-Logix, Intouch Software 9.5*

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I. INTRODUCTION

A. Variable Frequency Drive (VFD)

A Variable Frequency Drive is used for applications wherein speed control is of an essential importance due to load changes wherein the speed needs to be increased or decreased accordingly. Traditional methods in existence have addressed this issue, each with their own drawbacks such as high motor starting current, lower power factor, energy losses, etc. To address these problems, VFD provides a flexible approach as compared to traditional methods of speed control especially for certain applications which do not require a constant speed at all times. To name an example, a pump delivering cooling liquid supply may require peak load operation only for a requisite period of time and may require only much less amount during the remainder of the day. VFD will allow the speed of the pump to run at a lower rate in such case thereby enabling energy saving benefits.

B. Programmable Logic Controller (PLC)

With the advent of technology and availability of motion control of electric drives, the application of Programmable Logic Controllers with power electronics in electrical machines has been introduced in the manufacturing automation systems. The use of PLC in automation processes increases reliability and flexibility and also reduces production costs. To obtain accurate industrial electric drive systems, it is necessary to use PLC interfaced with power converters, personal computers and other electric equipment.

A PLC based control system was set up comprising of an Allen-Bradley PLC, an Allen-Bradley PowerFlex 4M Variable Frequency Drive, a three-phase induction motor and workstation) has been delivered, configured and integrated together for the monitoring and control of a motor driving a conveyor load.

Various control schemes have been used to operate the induction motor in speed and position control modes of operation using PLC programming developed on the workstation.

C. Supervisory Control And Data Acquisition Systems (SCADA)

SCADA is a system which exercises supervisory control of a particular device from a remote location and the human operator is able to monitor and control the device from his computer screen without being physically present near the device.

A PLC based control system was set up comprising of an Allen-Bradley PLC, an Allen-Bradley PowerFlex 4M Variable Frequency Drive, a three-phase induction motor and workstation (personal computer) has been delivered, configured and integrated together for the monitoring and control of a motor driving a conveyor load.

Various control schemes have been used to operate the induction motor in speed and position control modes of operation using PLC programming developed on the workstation.

Figure 1 shows the real time control set up which was configured and tested for the experiment.

Figure 1 The real time control set up

II. RELATED WORKS

A few selected research papers related to PLC and Variable Frequency Drive has been done to study the various methodologies used by the researchers.

J Ahir et al. [2] in their research have worked on the design and development of PLC and SCADA based control panel of monitoring of three-phase induction motor. They have continuously monitored measurements of voltage, current, temperature and speed for protection purposes. It was found that PLC was able to achieve optimum accuracy with a virtually power factor along with easy error detection and correction, along with being more reliable than traditional methods. The monitoring of three-phase induction motor driven by VFD, with PLC as a controller provided high accuracy in the regulation of its speed. **Maria G. Ioannides et al. [3]** has developed a PLC based continuously monitoring and control of a three-phase induction motor. Various types of sensors were used for monitoring the parameters such as speed and current. With the help of PLC ladder logic programming, it was proven that speed control of motor was achieved with high accuracy as well as efficiency. It was found that at high speeds and loads, the efficiency of the system was increased up to 10 to 12%. In brief this paper proved that PLC was a versatile and efficient control tool in industrial electric drives applications. **N D Ramesh [5]** presented a study on PLC which uses a programmable memory for implementing specific functions such as logic sequencing, timing, counting, and arithmetic control through digital or analog input/output modules. The functions of PLC include on-off control, sequential control, feedback control and motion control, to name a few. Industrial PLCs normally operate at an input-output voltage supply of 24V DC. Physical connections from the real world to the PLC are designated inputs such as limit switches, push button switches, sensors or basically anything that works on the principle of "switching" a signal on or off. Outputs of a PLC are usually solenoids, lamps, contactors, relays, etc. The number of digital input/outputs can be increased by adding additional digital input/output modules. One of the most common methods of PLC programming is also known as Ladder Logic programming which is a language using relay symbols as a base in an image similar to a hard-wired relay sequence. It looks like a ladder, whose sides are the power rail on the left and ground rail on the right. The rungs of the ladder consist of virtual relay components which perform certain tasks based on the instructions given in the program. **S. Da'na [4]** has discussed the design and implementation of a platform to remotely monitor and control PLC-based processes over TCP/IP or by using the GSM network. The platform is built using industry-standard off-the-shelf PLCs. Integrated with each PLC are communication processors that can be used for connectivity to the network and to a GSM modem. The communication processor module (Ethernet module) used in this work, provides an industrial compatible protocol over TCP/IP that achieves the same functionality as Profinet but at a much higher bandwidth (10/100 Mbps). Additionally, a mobile-based communication protocol that facilitates remote monitoring and control of PLCs using SMS messages has also been developed. The intent here is to provide system users with a back-up communication mechanism in case of a network failure. **M Zajmovic et al. [6]** presented a paper on the management of induction motors using PLC which executes instructions according to the programmed logic and sends signals to the Variable Speed Drives, from which it receives feedback of the motor speed so as to control its speed by modulation of voltage and frequency. A Zelio PLC was used with the help of a frequency transformer which controlled a 5.5 kW asynchronous induction motor at a speed of 1500 rpm. A windows XP operating system with SCADA software from DAQFactory was used for interfacing to the induction motor through an Ethernet connection. **W J Weber et al. [9]** discussed about the advent of the VFD system and its benefits, such as greater reliability, smaller size, lower production costs, better performance and increased automation potential as compared to conventional methods of control by which it allows continuous control of motor speed and torque, thereby increasing efficiency and flexibility. Various processes are sensed and fed back to the central plant controller, which after receiving inputs from an operator via the Human Machine Interface (HMI). The controller then instructs the VFD to maintain optimum performance according to the desired inputs. The basic function of VFD is to synthesize the voltages and frequency applied to a motor so as to control and achieve desired speed and/or torque. **A R Al-Ali et al. [14]** proposed a power factor controller for a three-phase induction motor using PLC to improve the power factor of a three-phase induction motor. For the purpose of attaining maximum torque, its voltage to frequency ratio is kept constant. A three-phase squirrel cage induction motor is coupled with a dc shunt generator and an electronic conditioning circuit. Features like interlocking, i.e., disabling the controller until it detects currents, voltage, frequency and power factor angles, switch failure detection, monitoring voltage to frequency ratio constant during correcting the power factor, independent control of reactive currents in each phase and maximum compensation even when switch failure occurs, have been incorporated. **Cristina Anita Bejan et al. [16]** presented a method of practical laboratories for teaching purpose in SCADA system which is focused to develop applications using an integrated automation system from Siemens - Totally Integrated Automation Democase with distributed peripheral employing Profibus and Ethernet communications. The final application is targeted to control an induction motor with associated frequency touch-screen human machine interface to program the motor speed and to show variables, trends and alarms. **Mihai Iacob et al. [17]** presented the design and implementation of a SCADA system for a central heating and power plant meant to supervise and control field distributed electric devices using Siemens software and equipment. The old equipments were replaced by using PLCs, servers, modern approaches regarding network equipments and topologies and flexible monitoring stations. Remote actions and uninterrupted monitoring were made possible due to redundant servers and web-based applications via web server. The system was shown to have various advantages like remote and safe operation and monitoring from anywhere in the world, evolution charts for one week, archives, easy to interpret alarm system and most importantly-flexibility, scalability and powerful modular structure. **Mini J. Thomas et al. [18]** presented a report about the design, commissioning and functioning of a state-of-the-art SCADA laboratory facility at Jamia Milia Islamia, New Delhi, India which has been designed with a purpose to function as a research and training center for utilities, faculty members and students. This lab provides hands on learning experience on SCADA system, and its applications to the management, supervision and control of an electric power System. One of the unique features of the SCADA laboratory, that makes it the only one of its kind, is the use of a distributed processing system, which supports a global database. Various research activities like adaptive and intelligent control of integrated power systems, preprocessing of data at the RTU level using Fuzzy Logic and Fuzzy-Genetic algorithm, substation automation etc. are already being supported by this laboratory.

Having reviewed some of the work being done in the field of VFD, PLC and SCADA, the next chapter explains about the objectives of this present work and the research methodology being used.

III. OBJECTIVES AND OVERVIEW OF THE PROPOSED MECHANISM

A. Objectives

A PLC-SCADA based monitoring and control system for a Variable Frequency Drive system was developed which controls a three-phase induction motor attached to a conveyor belt, having three proximity sensors serving as inputs to the PLC's ladder logic programming. . PLC was introduced in the 1970's for the automotive manufacturing industry to provide a replacement for large relay based control panels. With the advent of the microprocessor, PLCs have been enhanced to accomplish more complex industrial applications over the years. SCADA is a type of industrial control system which are computer-controlled systems for monitoring and control of industrial processes. A distinct advantage of SCADA lies in the control ability of large scale processes which includes multiple sites and large distances.

The integration of PLC and SCADA for industrial automation comprises of: a human-machine interface which is the device presenting processed data to a human operator, who monitors and controls the process; a Remote Terminal Unit collects the information by connecting to sensors in the process, converting sensor signals to digital data and sending digital data to the supervisory system after which that information is displayed on a number of operator screens; PLC used as field devices for their economical, versatile, flexible and configurable attributes.

This integrated system provides a platform for developing the concepts for thorough understanding of how an industrial automated system works comprising of all the above components.

B. V/f method of speed control

The motor speed can be controlled by varying supply frequency. Voltage induced in stator is directly proportional to product of supply frequency and air-gap flux. If stator drop is neglected, terminal voltage can be considered proportional to product of frequency and flux. V_1 α f.Φ Effect of supply frequency change without terminal voltage change:

1. Reduction of supply frequency without change in terminal voltage will cause an increase in the air gap flux thereby saturating the motor. This will cause the increase in magnetizing current, core loss and stator copper loss and cause distortion in line current and voltage and produce high-pitch noise.
2. Increase of supply frequency without change in terminal voltage will cause decrease in flux therefore leading to reduction of torque capability of the motor.

Figure 2 shows the Torque-Speed characteristics of an induction motor supplied directly from the main supply.

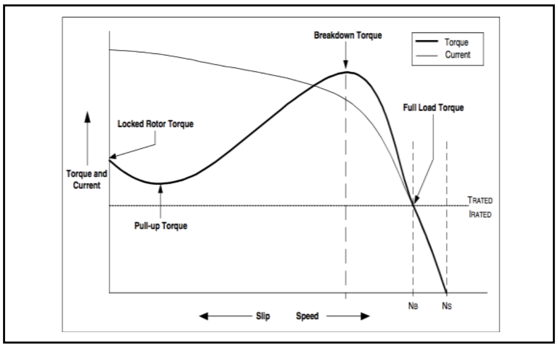

Figure 2 Torque speed characteristics of induction motor

The base speed of the induction motor is directly proportional to the supply frequency and the number of poles of the motor. Since it is not possible to change the number of poles, the only option to change the speed of the induction motor is by changing the supply frequency.

The torque developed by the induction motor is directly proportional to the ratio of the applied voltage and the frequency of supply. By changing the voltage and the frequency, but by keeping their ratio constant, the torque developed can be kept constant throughout the speed range. This is the main focus of V/f method of speed control. Figure 3 shows the torque-speed characteristics of the induction motor with VF control.

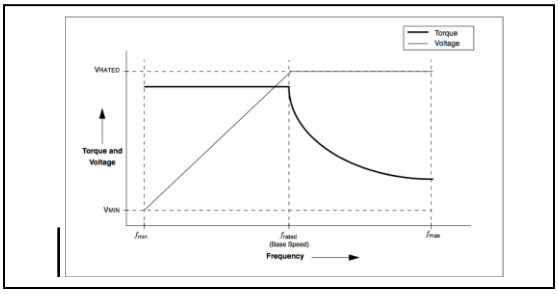

Figure 3 Torque speed characteristics of induction motor

A constant V/f ratio produces a constant maximum torque, except at low speeds or frequencies. The maximum torque will have lower value in motoring operation and larger value in braking operation due to reduction in flux during motoring operation and increase in flux during braking operation.

The advantages of this method are:

1. Speed control of motor
2. Starting current required is lower.
3. Stable operating region of the motor is increased.
4. At base speed, the voltage and frequency achieve their rated values.
5. Acceleration and deceleration of the motor can be controlled by controlling the change of supply frequency to the motor with respect to time.

C. Overview of the proposed mechanism

A Variable Frequency Drive is a device used in a drive system consisting of the following three main sub-systems:

AC motor, main drive controller assembly, and drive operator interface. The AC electric motor used in a VFD system is a three-phase induction motor which is generally the most economical motor choice. The VFD controller is a solid state power electronics conversion system consisting of three distinct sub-systems: a rectifier bridge converter, a direct current link, and an inverter. In a VSI drive, the DC link consists of a capacitor which smoothens out the converter's DC output ripple and provides a stiff input to the inverter. This filtered DC voltage is converted to quasi-sinusoidal AC voltage output using the inverter's active switching elements. VSI drives provide higher power factor and lower harmonic distortion than phase-controlled Current Source Inverter.

VFD control has been chosen specifically because they provide the advantages of energy savings, low motor starting current, reduction of thermal and mechanical stresses on motors and belts during starts, simple installation, high power factor and lower KVA.

A PLC-SCADA based control system has been set up comprising of an Allen-Bradley PLC, an Allen-Bradley PowerFlex 4M Variable Frequency Drive, a three-phase induction motor and the workstation has been developed, configured and integrated together for the monitoring and control of the motor driving a conveyor belt load.

Various control schemes have been used to operate the induction motor in Speed and Position control modes of operation using PLC programming and through animated SCADA screens developed on the workstation.

Variable Frequency Drives are generally required because many applications are not run at the same speed all of the time due to surrounding circumstances. The revolutions per minute of the driven shaft need to be increased or decreased depending on load changes, application requirement or other circumstances.

The PLC has been connected to control and monitor a VFD which is the acts as a go-between the three-phase induction motor and the PLC. A conveyor load is connected to the induction motor and three proximity sensor inputs are connected uniformly across the conveyor. The forward direction of the motor is controlled by the first sensor, the second sensor directs the motor to pause for a given period of time and the reverse direction of the motor is controlled by the third sensor.

The sensor inputs are fed to the PLC which processes the inputs according to the ladder logic programming and initiates corresponding output to the VFD. The VFD in turn once again processes the PLC input to it and accordingly controls the speed and position of the three-phase induction motor. Ladder logic programming is carried out in RS-Logix in the personal computer.

SCADA elements are written into the ladder logic program itself by assigning a tag or point which represents a single input or output value monitored or controlled by the system. With the help of SCADA system, labour costs are reduced by minimizing site visits for inspection, data collection and making rectifications. User defined controls such as start, stop are developed on the software window in order to control the system remotely.

Figure 4 shows the system layout diagram.

Figure 4 System layout diagram

IV. EXPERIMENTAL WORK

A. *Experimental setup*

1. The Allen-Bradley PowerFlex 4M AC drive is the smallest and most cost effective drive which provides powerful motor speed control in a compact, space saving design.

   Table 1 shows the VFD specifications used in the experiment.

Table 1 VFD specifications

Rated Output	0.75 kW (1 Hp)
Rated Voltage	240 V AC, single phase
Rated Current	4.2 A
Rated Torque	3.5 kg

2. The PLC used in this project was **Allen Bradley MicroLogix 1400 series**. The basic parts of a 1400 series PLC are Power Supply, CPU, Discrete Input Module and Discrete Output Module.

   Table 2 shows the PLC specifications used in the experiment.

Table 2 PLC specifications

Sl	Description	Details
1	Dimensions HxWxD	90 x 180 x 87 mm
2	Weight	0.9 kg
3	Number of I/O	24 inputs (20 digital 4 analog) and 14 outputs (12 digital 2 analog)
4	Power supply voltage	24V DC
5	Power supply inrush Current	24V DC: 15 A for 20 ms
6	Power consumption	50W

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3. Input Variables taken:
   - Three proximity sensors to detect motion of object on conveyor belt
   - Frequency parameter of VFD to control output

4. Output response – speed and position of three-phase induction motor driving a conveyor belt load.

B. Conduction of Experiments

Allen-Bradley PLC, Allen-Bradley PowerFlex 4M Variable Frequency Drive, a three-phase induction motor driving a conveyor belt load controlled by ladder logic software and Intouch 9.5 software was connected for the conduction of the experiment in which for various values of input supply frequencies, the corresponding values of motor speed in rpm were obtained as shown in Table 3.

Table 3 Frequency input vs. speed output

Input supply frequency in Hz	Motor speed in rpm
0	0
5	250
10	620
15	940
20	1240
25	1495
30	1809
35	2100
40	2350
45	2590
50	2800
55	3200
60	3450

V. RESULT AND DISCUSSION

A. Ladder Logic Programming

The experiments were conducted based on ladder logic programming which is a software installed on a personal computer according to which the PLC takes the sensor inputs, processes them according to the program and gives the output to the VFD which again processes this input within the drive and finally controls the speed and position of the motor. The ladder logic programming is shown in Figure 5

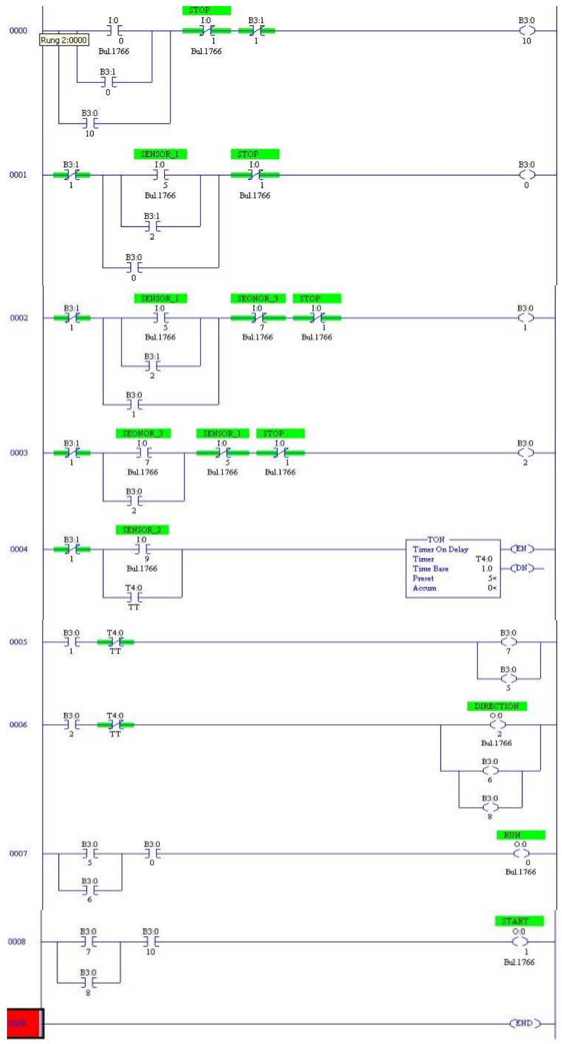

Figure 5 Ladder logic programming for VFD control of induction motor

B. Frequency vs. speed graph

By varying the frequency of the VFD from 0 to rated frequency, the speed control of the motor was increased accordingly. In this way, speed control of the motor was achieved by varying the frequency. With the help of ladder logic programming, motor position was controlled in the forward and reverse direction as per the object passing through the first and third sensor accordingly.

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Figure 6 shows the graph for the experiment conducted

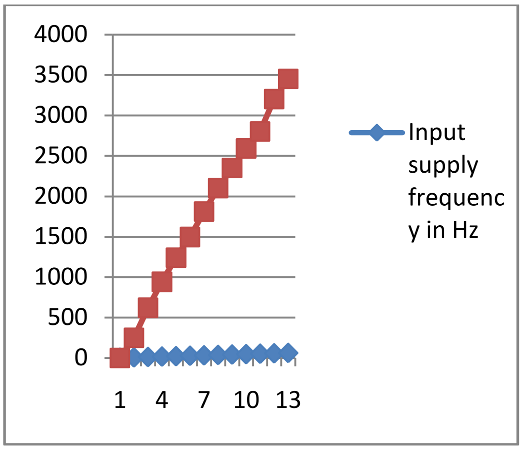

Figure 6 Frequency input vs. speed output

C. SCADA program output

The SCADA program was also written using ladder logic and then run simultaneously from the SCADA screen developed by Intouch Software Edition 9.5 The SCADA software enables human operator to control the entire operation away from the plant and just by using the virtual inputs designated on his computer screen. Table 4 shows the input-output address of the SCADA program. Figure 7 shows the SCADA screen shot of animation of the plant which was previously controlled by the ladder logic program. This type of motor control is helpful when the operator has to control the motor from a remote location directly through the screen of the workstation.

Table 4 Input-output address of SCADA program

TAG NAME	TAG TYPE	ACCESS NAME	TAG LINK
BOTT	MEMORY REAL	MEMORY	MEMORY
L1	I/O DISCRETE	DRIVE	B3:0/10
L2	I/O DISCRETE	DRIVE	B3:0/6
L3	I/O DISCRETE	DRIVE	B3:0/5
L4	I/O DISCRETE	DRIVE	T4:0/TT
SEN1	I/O DISCRETE	DRIVE	B3:0/5
SEN2	I/O DISCRETE	DRIVE	T4:0/TT
SEN3	I/O DISCRETE	DRIVE	B3:0/6
SW1	I/O INTEGER	DRIVE	B3:1/0
SW2	I/O INTEGER	DRIVE	B3:1/1
SW3	I/O INTEGER	DRIVE	B3:1/2
TIMER	I/O INTEGER	DRIVE	T4:0.ACC
WH	MEMORY REAL	MEMORY	MEMORY

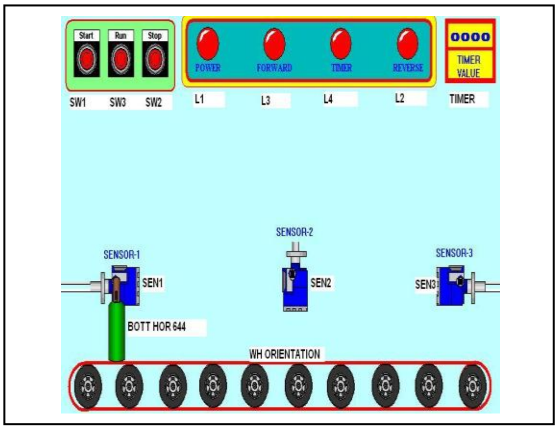

Figure 7 SCADA screen shot of animation of real-time control setup

VI. CONCLUSION

The present work was motivated to develop a scheme to monitor and control a Variable Frequency Drive using PLC. A thorough study of all the hardware components was done including their specifications, functioning and overall performance. Software platform namely AllenBradley ladder logic programming RS Linx was comprehended, analysed and implemented.

A 0.75 KW three-phase induction motor was fully automated using a Variable Frequency Drive and PLC. The drive used in this set-up offered various control modes of motor operation. The configuration and settings to run the motor in two control modes viz., speed and position were done systematically A ladder logic program was developed and verified in RS Linx software which enabled the motor to obtain two different positions in succession with a specified time interval between the positions. A complete study and practical hands on the PLC and the drive operation have imparted a fairly good idea about the industrial automation systems.

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