PLC Based Monitoring of Induction Motor

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Abstract —**The efforts will be taken to monitor and control, system for the induction motor, based on programmable logic controller (PLC) technology is described in this project topic. Also, the implementation of the hardware and software for speed control and protection with the results obtained from tests on induction motor performance will be provided. The PLC develops connection between the operational parameters to the speed requested by the user and monitors the system during normal operation and under trip conditions. Tests of the induction motor system driven by inverter and controlled by PLC prove a higher accuracy in speed regulation as compared to a conventional V/ f control system. The efficiency of PLC control is increased at high speeds up to 95% of the synchronous speed. Thus, PLC proves themselves as a very versatile and effective tool in industrial control of electric drives.**

Key Words — **Computer-controlled systems, computerized monitoring, electric drives, induction Motors, programmable logic controllers (PLC)**

I. INTRODUCTION

With the rapidly changes on industries and information technologies in recent years, some traditional bulk electronic appliances have to be controlled for a long time. The monitoring of all equipment has been performed through the use of computers. Most equipment uses PLC to connect with Computers to control each load and electricity consuming devices. Programmable Logic Controllers (PLC) are widely used in industrial control because they are inexpensive, easy to install and very flexible in applications. A PLC connects with the external world through its inputs and outputs. Since technology for motion control of electric drives became available, the use of programmable logic controllers (PLC) with power electronics in electric machines applications has been introduced in the manufacturing automation , This use offers advantages such as lower voltage drop when turned on and the ability to control motors and other equipment with a virtually unity power factor . Many factories use PLC in automation processes to decrease production cost and to increase quality and reliability. Other applications include machine tools with improved precision computerized numerical control (CNC) due to the use of PLC. To obtain accurate industrial electric drive systems, it is essential to use PLC interfaced with power converters, personal computers, and other electric equipment. Nevertheless, this makes the equipment more sophisticated, complex, and expensive. A power factor controller for a three phase induction motor utilizes PLC to improve the power factor and to keep its voltage to frequency ratio constant under the whole control conditions. The vector control integrated

circuit uses a complex programmable logic device (CPLD) and integer arithmetic for the voltage or current regulation of three-phase pulse-width modulation (PWM) inverters. Many applications of induction motors require besides the motor control functionality, the handling of several specific analog and digital I/O signals, home signals, trip signals, on/off/reverse commands. In such cases, a control unit involving a PLC must be added to the system structure. The following paper presents a PLC-based monitoring and control system for a three-phase induction motor. It describes the design and implementation of the configured hardware and software. The test results obtained on induction motor performance show improved efficiency and increased accuracy in variable-load constant-speed controlled operation. Thus, the PLC correlates and controls the operational parameters to the speed set point requested by the user and monitors the induction motor system during normal operation and under trip conditions.

1. PLC as a System Controller

Programmable logic controllers are modular, industrially hardened computers which perform control functions through modular input and output (I/O) modules. The operation of a controller by envisioning that it repeatedly performs three steps:
a) Reads inputs from input modules
b) Solves pre-programmed control logic
c) Generates outputs to output modules based on the control logic solutions. Input devices and output devices of the process are connected to the PLC and the control program is entered into the PLC memory. The PLC continuously control the inputs and activates the outputs according to the control program. This PLC system is of modular type composed of specific hardware building blocks (modules), which plug directly into a proprietary bus: a central processor unit (CPU), a power supply unit, input-output modules I/O and a program terminal. Such a modular approach has the advantage that the initial configuration can be expanded for other future applications such as multi machine systems or computer linking.

2. Control System of Induction Motor

This phase involves making implementation decisions such as the interfacing between different software modules, the breakdown of software across multiple processors, assigning inputs and outputs to I/O cards, etc. PLC software, once written must be easy and intuitive to follow. PLCs are an combine part of the domain system; advances in the

technology of the system will effect the requirements of the PLC software. PLC software must therefore be maintainable and expandable. The block diagram of the experimental system is illustrated. The following configurations can be obtained from this setup.

a) A closed-loop control system for constant speed operation, configured with speed feedback. The Induction motor drives a variable load, is fed by an inverter and the PLC monitors the inverter output.

b) An open-loop control system for variable speed and variable frequency operation. The induction motor Drives a variable load and is fed by control mode.

c) The standard variable speed operation. The induction motor drives a variable load and is fed by a constant voltage-constant frequency standard three-phase supply. The open-loop configuration b) can be obtained from the closed-loop configuration a) by removing the speed feedback. On the other hand, operation c) results if the entire control system is bypassed. PLC's programming is based on the logic demands of input devices and the programs implemented are predominantly logical rather than numerical computational algorithms. Most of the programmed operations work on a straight forward two-state "on or off" basis and these alternate possibilities correspond to "true or false" (logical form) and "1 or 0" (binary form), respectively. Thus, PLCs offer a flexible programmable alternative to electrical circuit relay-based control systems built using analog devices. The programming method used is the ladder diagram method. The PLC system provides a design environment in the form of software tools running on a host computer terminal which allows ladder diagrams to be developed, verified, tested, and diagnosed. First, the high-level program is written in ladder diagrams. Then, the ladder diagram is converted into binary instruction codes so that they can be stored in random-access memory (RAM) or erasable programmable read-only memory (EPROM). Each successive instruction is decoded and performed by the CPU. The function of the CPU is to monitor the operation of memory and I/O devices and to process data according to the program. Each input and output connection point on a PLC has an address used to identify the I/O bit. The method for the direct representation of data associated with the inputs, outputs, and memory is based on the fact that the PLC memory is organized into three regions: input image memory (I), output image memory (Q), and internal memory (M). Any memory location is referenced directly using %I, %Q, and %M .The PLC program uses a cyclic scan in the main program loop such that periodic checks are made to the input variables. The program loop starts by scanning the inputs to the system and storing their states in fixed memory locations (input image memory I). The updated output states are stored in fixed memory locations (output image memory Q).The output values held in memory are then used to set and reset the physical outputs of the PLC simultaneously at the end of the program scan. For the given PLC, the time taken to complete one cycle or the scan time is 0, 18 ms/K (for 1000

steps) and with a maximum program capacity of 1000 steps. The development system comprises a host computer (PC) connected via an RS232 a port to the target PLC. The host computer provides the software environment to perform file editing, storage, printing, and program operation monitoring.
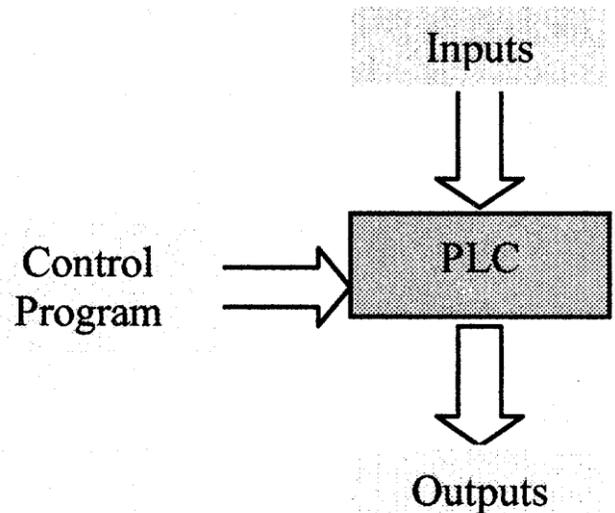

Fig.1: Block Diagram of PLC

The process of developing the program to run on the PLC consists of: using an editor to draw the source ladder program, converting the source program to binary object code which will run on the PLC' s microprocessor and downloading the object code from the PC to the PLC system via the serial communication port. The PLC system is online when it is in active control of the machine and monitors any data to check for correct operation.

3. Hardware Description

The control system is implemented and tested for a wound rotor induction motor, having the technical specifications given in Table 1. The induction motor drives a dc generator, which supplies a variable R load. The three-phase power supply is connected to a three-phase main switch and then to a three-phase thermal overload relay, which provides protection against current overloads. The relay output is interfaced to the rectifier, which rectifies the three-phase voltage and gives a dc input to the insulated gate bipolar transistor (IGBT) inverter. Its technical specifications are summarized in Table. The IGBT inverter converts the dc voltage input to three-phase voltage output, which is supplied to the stator of the induction motor. On the other the inverter is connected to the PLC-based controller. This controller is based on a PLC modular system. The PLC architecture refers to its internal hardware and software. As a microprocessor-based system, the PLC system hardware is designed and built up with the following modules:

• Central processor unit (CPU)
• Discrete output module (DOM)
• Discrete input module (DIM)
• Analog outputs module (AOM)
• Analog inputs module (AIM)
• Power supply.

Other details of the PLC configuration are shown in Tables 3 and 4. A speed sensor is used for the speed feedback, a current sensor is used for the load current feedback, and a second current sensor is connected to the stator circuits. Thus, the two feedback loops of the closed-loop system are setup by using the load current sensor, the speed sensor, and the AIM. A tachogenerator is used for speed sensing. The induction machine drives its shaft mechanically and an output voltage is produced, the magnitude of which is proportional to the speed of rotation. Polarity depends on the direction of rotation. The voltage signal from the tachogenerator must match the specified voltage range of the AIM (0–5 V dc and 200-k internal resistance). Other PLC external control circuits are designed using a low-voltage supply of 24 V dc. For the manual control, the scheme is equipped with start, stop, and trip push buttons, as well as with a forward and backward direction selector switch.
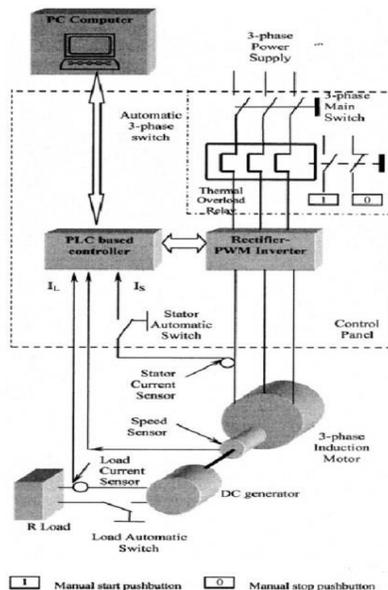

Fig.2: Control System

As shown in Fig. 2, all of the described components: a main switch, an automatic three-phase switch, an automatic single phase switch, a three-phase thermal overload relay, a load automatic switch, signal lamps (forward, backward, start, stop, trip), push buttons (start, stop, trip), a selector switch (for the forward/backward direction of rotation), a speed selector, a gain selector, as well as the PLC modules and the rectifier-inverter are installed in a control panel. The program is downloaded into the PLC from a personal computer PC and an RS232 serial interface.

4. Software Description

Most of the programmed operations work on a straight forward two-state "on or off" basis and these alternate possibilities correspond to "true or false" (logical form) and "1 or 0" (binary form), respectively. Thus, PLCs offer a flexible programmable alternative to electrical circuit relay-based control systems built using analog devices. The programming method used is the ladder diagram method. First, the high-level program is written in ladder diagrams. Then, the ladder diagram is converted into binary instruction codes so that they can be stored in random-access memory (RAM) or erasable programmable read-only memory (EPROM). Each successive instruction is decoded and executed by the CPU. The function of the CPU is to monitor the operation of memory and I/O devices and to process data according to the program. Each input and output connection point on a PLC has an address used to recognize the I/O bit. The method for the direct representation of data associated with the inputs, outputs, and memory is based on the fact that the PLC memory is organized into three regions: input image memory (I), output image memory (Q), and internal memory (M). Any memory location is referenced directly using %I, %Q, and %M (Table 3). The PLC program uses a cyclic scan in the main program loop such that periodic checks are made to the input variables (Fig. 3). The program loop starts by scanning the inputs to the system and storing their states in fixed memory locations (input image memory I). The ladder program is then executed step-by-step. Scanning the program and solving the logic of the various ladder rungs determine the output states. The updated output states are stored in fixed memory locations (output image memory Q). The output values held in memory are then used to set and reset the physical outputs of the PLC simultaneously at the end of the program scan. For the given PLC, the time taken to complete one cycle or the scan time is 0, 18 ms/K (for 1000 steps) and with a maximum program capacity of 1000 steps. The development system comprises a host computer (PC) connected via an RS232 port to the target PLC. The host computer provides the software environment to perform file editing, storage, printing, and program operation monitoring. The process of developing the program to run on the PLC consists of: using an editor to draw the source ladder program, converting the source program to binary object code which will run on the PLC's microprocessor and downloading the object code from the PC to the PLC system via the serial communication port. The PLC system is online when it is in active control of the machine and monitors any data to check for correct operation.
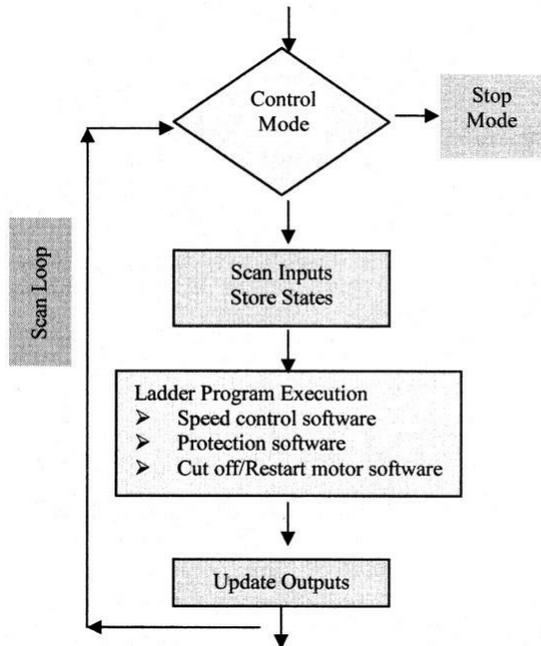
Fig. 3: Flowchart of the main program

Table.1: Induction Motor Technical Specification

Connection Type	Delta/ Star
Input voltage	400v
Input current	1.5A
Rated power	1HP
Input frequency	50Hz
No. of pole	4
Rated speed	1500 RPM

II. MATHEMATICAL MODELING OF 3-PHASE INDUCTION MOTOR EXISTING IN MACHINE LAB:

An induction motor can be considered as a rotating transformer whose magnetic circuit is separated by an air gap. The stator is considered as primary and rotor is taken as secondary winding. Air gap between the two is considered as the core of the transformer. When the secondary is short-circuited through external impedance the AC power supplied to primary induces an opposing current in the short circuited secondary. Thus mutual emf is produced due to relative motion between stator and rotor. As rotor of induction motor is in rotating position as compared to secondary of a transformer so it is known as rotating transformer. Induction machine is different from other type of electric motors in the sense that secondary currents are produced by induction, as in a transformer. And they are not being supplied by a dc exciter or other external power sources, as in other machines. The equivalent circuit for induction motor is shown in fig.
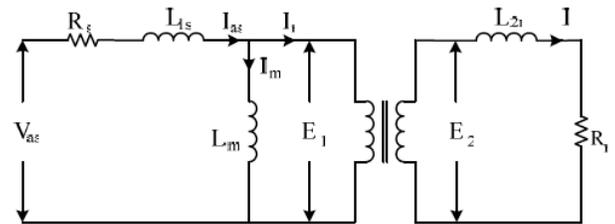

Fig.4: Elementary equivalent circuit for induction motor

Where
Rs = Stator Resistance
Rr = Rotor resistance
L1s = stator inductance
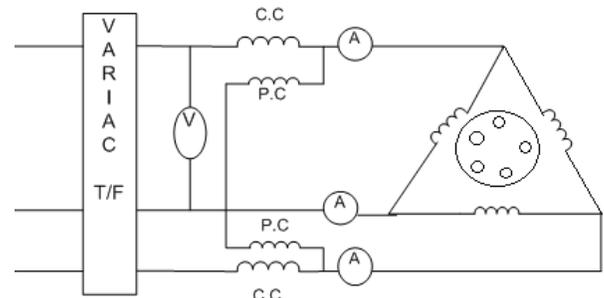L2r = Rotor inductance
Lm =Magnetizing Inductance

Fig.5: circuit diagram of No load test

Im = magnetizing Current
Vas = voltage applied to stator
E1 = self induced e.m.f in stator side
E2 = mutually induced e.m.f in rotor side.
These all parameters of induction motor are measured and given in Table. Now first of all for calculation of constant losses (core, friction and windage) we run the induction motor without load as described below. The values of different parameters of 3-O squirrel cage induction motor existing in Machine lab are tabulated below.

Table.2:

Symbol	Input Quantities	Values
hp	HORSE POWER	1
R.P.M.	SPEED (REV/MIN)	1500
φ	PHASE	3
F	FREQUENCY	50
P	NO. OF POᵩLE	4
V(L/L)	LINE TO LINE VOLTAGE	400
Rs	Stator Resistance	0.45

NO LOAD TEST:

The no load test for an induction motor measures the rotational losses of the motor and provides information about its magnetization current. The circuit diagram for the no load test is given below.
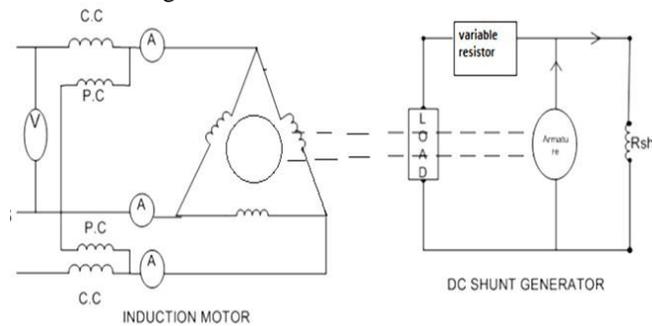

Fig. 6: circuit diagram for load test

We connected squirrel cage induction motor with variable transformer because of the reason that input voltages in all three phases have their particular and same value. No fluctuation of voltages will occur. Now first of all calculate the line to line voltage and line current with the help of clamp on meter. We will take average of currents and voltages in 3-phases as follows
Table.3:

Vo	Io	W1	W2	Speed	Stator cu. loss	Constant loss
400	1.5	110W	50W	1500	I^2R	?

1) Stator Cu. Loss = Io^2Rs = $(1.5)^2$ * 0.45 = 1.0125 Watt
2) Pin (Input Power) = Wattmeter Reading* multiplying factor = 160 Watt * 2 = 320 Watt
3) Constant Loss = Pin – Stator Cu. Loss = 320 – 1.0125 = 318.9875 Watt.

LOAD TEST:
Now the change of load take place by changing the value of spring balance. We have to take observations at each change of load. First of all make connections according to circuit diagram shown above then using clamp on meter measure line to line voltage and line current respectively at each load by taking average of three currents and voltages on three phases. Note down the input power taken by induction motor at each load by using the equation. Measure stator copper losses at each load by using equation. Now value of stator copper loss changes at each load because value of line current is changing with every load. Calculate the synchronous speed of 3-phase squirrel cage induction motor by using formula
Ns= 120f / P
After this we measure the speed of rotor at each load by using stroboscope explained earlier in section 3.2.3. Now we start calculations from the observations discussed above. Slip is the difference between synchronous speed and actual speed of rotor.

Slip (S) = (Ns - N) / Ns
If we want to find the input power of rotor we should subtract the stator Cu losses from the total input power of motor as follows
Table.4:

Sr. No	V	I_L	W1	W2	Speed	Bal(S1)	Bal(S2)
01	400	1.08	200	360	1460	1	1
02	400	1.4	40	680	1436	6	1.5
03	400	1.68	100	800	1400	10	1.5
04	400	2.04	240	960	1360	12	2

CALCULATIONS:
1) INPUT POWER = (W1 + W2)
☐ P in (1) = 200+360 =560 Watts
☐ P in (2) = 40+680=720 Watts
☐ P in (3) = 100+800 = 900 Watt
☐ P in (4) = 240+96=1200 Watt

2) STATOR CU. LOSS = IL^2 * Rs
1..Stator Cu. Loss (1) =1.08^2 * 0.45 = 0.52488 Watts
2..Stator Cu. Loss (2) =1.4^2 * 0.45 = 0.882 Watts
3..Stator Cu. Loss (3) =1.68^2 * 0.45= 1.2700 Watts
4..Stator Cu. Loss (4) =2.04^2 * 0.45= 1.8727Watts

3) Constant Losses = 318.9875 Watt .... (N.L. Test)

4) Slip (S) = (Ns - N) / Ns
☐ S(1) = 0.0266
☐ S(2) = 0.0426
☐ S(3) = 0.0666
☐ S(4) = 0.0933

5) ROTOR INPUT = P in - IL^2 * Rs .... St. Cu. Loss
☐ Rotor Input (1) = 560 – 0.52488 = 559.4751
☐ Rotor Input (2) = 720 – 0.882 = 719.118
☐ Rotor Input (3) = 900 – 1.2700 = 898.73
☐ Rotor Input (4) = 1200 – 1.8727 = 1198.12

6) Rotor Cu. Loss = Rotor Input * Slip (S)
☐ Rotor Cu. Loss (1) = 559.4751 * 0.0266= 14.88
☐ Rotor Cu. Loss (2) = 719.118 * 0.0426= 30.36
☐ Rotor Cu. Loss (3) = 898.73 * 0.0666 = 59.855
☐ Rotor Cu. Loss (4) = 1198.12 * 0.0933 = 111.784
7) Total Loss = (Constant Loss) + (St. Cu. Loss) + (Rotor Cu. Loss)
☐ Total Loss (3) = 318.9875 + 1.2700 + 59.85 = 380.10
☐ Total Loss (4) = 318.9875 + 1.8727 + 111.78 = 432.64

8) P out = P in – Total Loss
☐ P Out (3) = 900 – 380.10 = 519.9
☐ P Out (4) = 1200 – 432.64 = 767.36

9) % Efficiency = (Output / Input) * 100
☐ % Efficiency (3) = (519.9 / 900) * 100 = 57.76
☐ % Efficiency (4) = (767.36 / 1200) * 100 = 63.94

10)T out (TORQUE)= 9.55 * (P out / N)
- T out (3) = 9.55 * (519.9 / 1400) = 3.5464
- T out (4) = 9.55 * (767.36 / 1360) = 5.3884

Result: 5

Sr. No.	Pin	Stator cu. Loss	Slip	Constant loss	Rotor Input
1	560	0.52	0.02	318.98	557.47
2	720	0.88	0.04	318.98	719.11
3	900	1.27	0.06	318.98	898.73
4	1200	1.87	0.09	318.98	1198.12

Rotor cu. Loss	Total loss	P_{out}	% efficiency	T_{out}
14.88	334.39	225.61	40.28	o.1547
30.63	350.40	369.51	51.32	2.4570
59.85	380.10	519.9	57.76	3.5464
117.78	432.66	767.36	63.94	5.3884

RESULTS

The system was tested during operation with varying loads including tests on induction motor speed control performance and tests for trip situations. The efficiency of PLC control is increased at high speeds up to 95% of the synchronous speed. Also showing all of above results in SCADA screen.
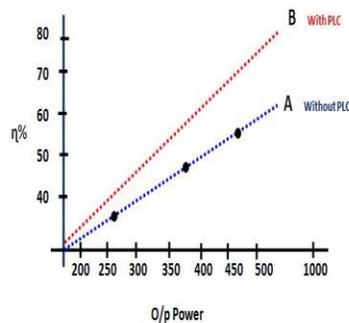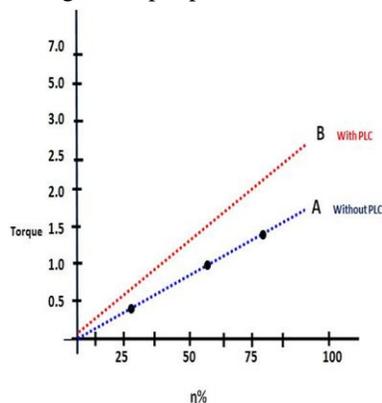

Fig.7: Output power v/s Efficiency

Fig.8: Efficiency v/s Torque

CONCLUSION

Using PLC system, successful experimental results were obtained will be used in automated systems with an induction motor. The monitoring control system of the induction motor driven by inverter and controlled by plc proves its high despite the simplicity of the speed control method used, this system presents:
• Constant speed for changes in load torque;
• Full torque available over a wider speed range;
• Very good accuracy in closed-loop speed control scheme;
• Higher efficiency;
Thus, the plc proved to be a versatile and efficient control tool in industrial electric drives applications.

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