Hybrid Method for Customized Control of Induction Motor

S. Takiyar and B. K. Chauhan

***Abstract*—A hybrid method utilizing ladder logic diagram modeled Programmable Logic Controller and Pulse Width Modulation based variable frequency drive has been proposed for controlling the prime mover; induction motor. The paper epitomizes the basic requirements of the proposed panel based on ergonomics. The proposed design covers the implementation parameters aiming to ameliorate the human machine interaction. This computer controlled systems has the ability to continuously evolve its control strategy conditions for flexible operations. The tasks complied through the control panel include customized starting, direction controlling, inching and speed controlling.**

***Index Terms*—Ladder logic diagram, programmable logic controller, pulse width modulation, voltage frequency speed drive.**

I. Introduction

Due to the robustness, reliability, low price and negligible maintenance induction motors (IM) are most used for variable speed industrial applications, mentioned in [1]. Hence, IM though being inherently incapable of providing speed variation is still capable to accomplish the task by utilizing various inverter based techniques as discussed in [2]. In this paper the open loop Pulse Width Modulation (PWM) [3] based Voltage by Frequency (V/Hz) technique has been utilized.

As is already known for an IM:

$$N = 120f / P \text{ and } V = 4.44\ \varnothing N f$$

V= EMF induced per turn

N= Synchronous Revolutions per minute

f=supply frequency (in cycles/sec)

P = number of motor winding poles

Therefore, by keeping V/f constant the flux can be maintained at maximum rated value which ensures the maximum torque to remain constant and keeps the speed torque characteristics from de-shaping [4]. It is required because an IM is a high efficiency machine when working close to rated torque [1] unlike at the part loads when a major rift emerges between the values of copper and iron losses; drastically affecting the efficiency of the motor.

With the rapid evolution of industry in both spheres of mass production and application variability continuous monitoring of the prime movers has become a compulsion. The main parameters catered in the paper involve starting customization which aids starting the same optionally either via star-delta or by direct on line. Speed control and direction control have also been accomplished utilizing a potentiometer and a Variable Frequency Drive (VFD). Inching [5] operation has also been done with in this paper.

The evolution of industry has not been single handed it has also been assisted with a comparable and complimentary growth in information technology which has resulted in development and adoption of various control devices which also act as communication interface. One of such devices is Programmable Logic Controller (PLC) utilized in this scheme.

Since, the technology for motion control of electric drives has evolved; the use of programmable logic controller assisted by power electronics in electric machine applications has been introduced in manufacturing automation [6].It has many reasons comprising the high efficiency of Programmable Logic Controller (PLC), control at high speeds, which may go upto 95% [7] and the ease of use, involving continuous evolutions [8] in control strategy. Though being a complex optocoupler based device, it can simply be comprehended as an electronic equipment consisting of a processor which executes a control program to alter the state of an output image table [9]. Now a day, PLC is a dominant technology utilized in control automation system modeled on Ladder Logic Diagram (LLD) [10] which has been employed in this paper.

II. Problem Description

With the indiscriminately adapted trend in discrete part manufacturing towards faster and higher precision part production –more parts per minute; with better quality time based controls are an omni demanded facility at the factory floor. The forces of deregulation and competition have also shown effect on the organizational utilities – forcing the evolution of automation and information strategies competitive industries. Tests have proved that an inverter driven induction motor system, controlled by PLC facilitates higher accuracy in speed regulation when compared to a conventional *V/f* control system [11] used over the years.

The net result was a general trend towards "Open Protocols" [12]. Open protocols have re-casted process control and data acquisition. As the lines between operations blur, end users reap benefits of sharing data among many

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functional areas within their facility. The ability to circulate information easily throughout the enterprise via different open computing solutions and platforms, both horizontally and vertically, cuts costs, speeds development, and promotes improved operating efficiency [13].

In this study PLC is the open system which provides a cost effective solution to real time control for autonomous applications in various sized process plants. To obtain an accurate and fleshed out controlling of an induction motor a PLC interfaced with Drive, personal computer, and other electric equipment is used. The widely acknowledged "Affinity Laws" [14] have corroborated the high energy savings reaped from the adoption of VFDs' in various applications. This paper proposes a panel design which shall further the cost effectiveness of the automated plants by eliminating the requirement of a qualified personnel to operate the drive [15] or PLC.

A. Proposed Methodology

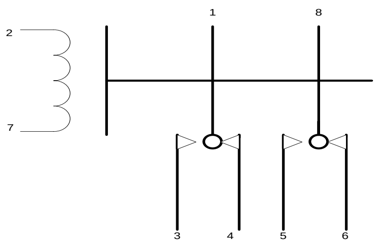

Fig. 1. Relay

Programmable logic controller is an industrially hardened modular computer which executes control functions through modular input and output (I/O) modules. It is a 24V D.C. operational [16] device. Generally the commercial kits are provided with a 230V A.C /24V D.C SMPS inbuilt. The output and input voltage levels also range close to 24V. Thus, when the output of PLC is used to actuate a particular operation in the setup there are no voltage level issues to be catered to. In this panel model a switching relay [17] 24V D.C. /230V A.C would be connected to the output terminals of the PLC (Fig. 1) and it provides for switching as per the LLD voltage levels. This relay is electromechanical in nature whose coil terminals (2, 7) responds to 24V D.C. and the contact 3 (NO type) is used to pass the AC line voltage through it.

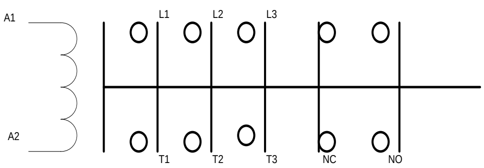

Fig. 2. Contactor

The requirement of the model is to operate a three phase Induction Motor hence, contactors (Fig. 2) are used to transfer a three phase at output terminals T1, T2 and T3 from the drive provided phase shift supply from UT1, VT2 and WT2 to L1, L2 and L3 [18].

The A1 of the contactor coil is energized by the voltage at terminal 3 of the relay which corresponds to LLD output levels in turn actuating the switching of the hard wired set up.

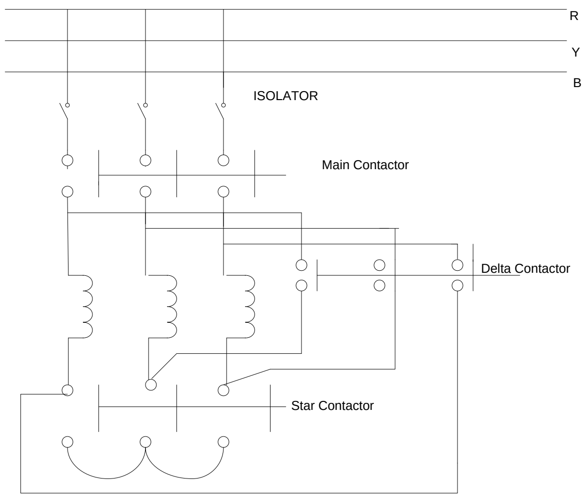

Fig. 3. Power Circuit Connection

In this study, the objective is to customize staring operations into Direct on Line (DOL) and Star Delta, which could be made available for use at the push of a button allocated at the panel top, depending on requirement based on the size of the motor connected at the output terminals of the panel. For this purpose, a configuration of connections has been developed between the three contactors (Fig. 3) which furthers the elimination of any hard wired change requirement. Apart from basic block diagrams terminal wise connections have been discussed in the next section.

B. Inter-Contactor and Inter-Relay Connections

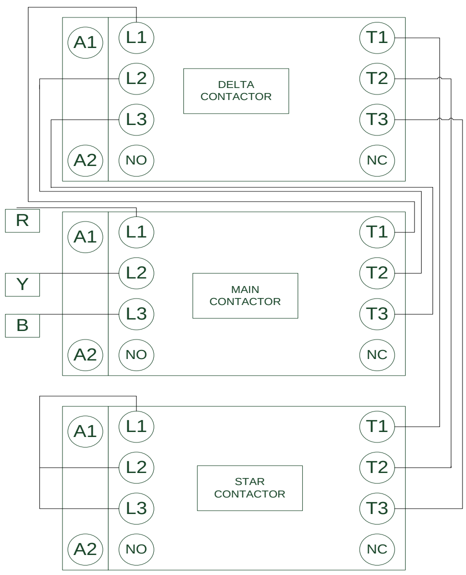

Fig. 4. Inter contactor connections

The contactor connections have been demonstrated in Fig. 4. It is by virtue of this arrangement that the starting of the motor is customized. Apart from the connections shown A2 of all the contactors are shorted with any one of them fed through the line terminal of SMPS. A1 terminals of each contactor are connected to the terminal 3 of the corresponding Relays.

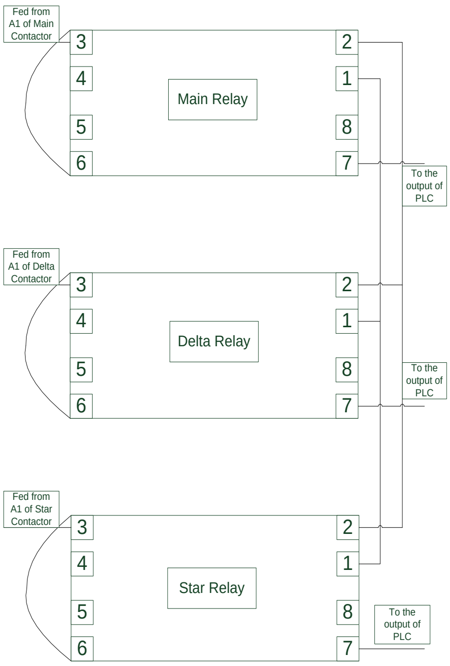

Fig. 5. Inter relay connections

Fig. 5 aptly represents terminal based inter relay connections.

Terminals 1 are shorted and fed with the neutral supply from SMPS. Terminals 2 are also shorted and connected to negative 24V D.C supply at PLC output for proper energization of the relay coil.

All the 7 terminals are connected to Output of PLC as per the addressing. As mentioned later in Table I:

O: 0/1 Main Contactor/Relay
O: 0/2 Star Contactor/Relay
O: 0/3 Delta Contactor/Relay

Terminals 3 as connected to the corresponding A1 of the contactors.

C. Drive Connections

The phase shifted three phase supply is generated at the drive terminals UT1, VT2 and WT3 (Fig. 6) from a single phase AC supply provided at SL1 and RL1 ports. But the control circuitry of the drive needs only a 24 V DC supply to actuate it provided at control terminal 11 (Figure 7) which is further shorted with terminal 1 to enable the drive to operate [19].

Speed control is provided through a potentiometer possibly of size 10KΩ or above (for better and more controlled variation). This is done with help of the control point 13 which is electrically isolated from the providing a variable input of 0-10V. The three terminals of the potentiometer are precisely connected to ports 12, 13 and 14. While operational characteristic of 13th port is mentioned; port 14 provides for ground and port 2 provides a constant 10V output which is varied and fed as an input to port 13 by the potentiometer.

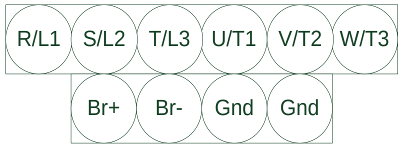

Fig. 6. Power terminal block

The power connections work on A.C voltage levels. While S/L2 is supplied from line R/L1 is connected with the neutral.

U/T1, V/T2 and W/T3 assist to provide a phase shift to A.C supply and hence, create a three phase supply.

Br+ and Br- are used in the braking mode.

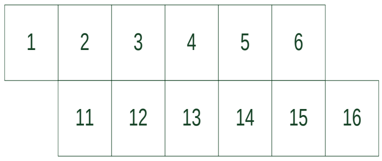

Fig. 7. Control terminal block

1 and 11 terminals of the control block remain shorted to enable operation on the drive.

11, 12 provide a 24v output and a 10v output respectively.

13, 15 provide a 0 to 10v variable input and a 4 to 24ma output respectively.

14, 4 act as ground.

2, 3 provide direction control of operation.

D. Overall Circuit Connections

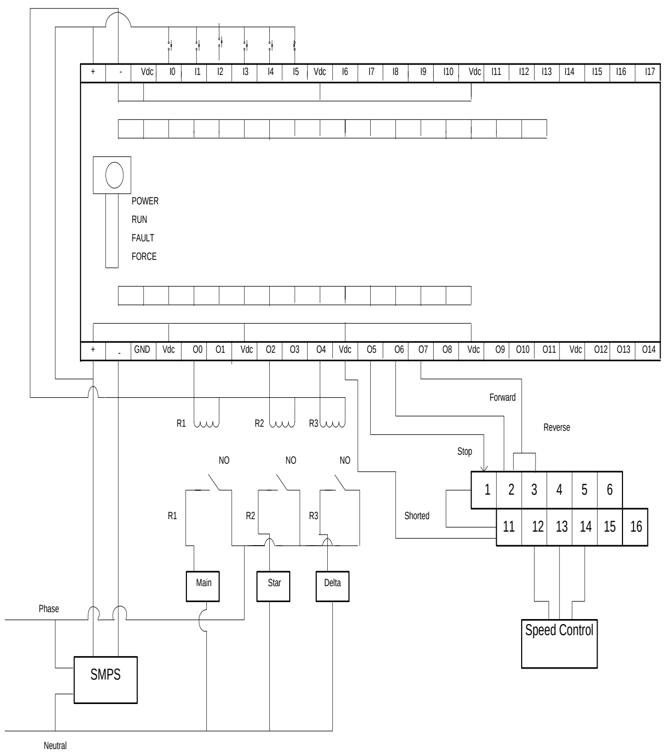

Fig. 8. Overall circuit diagram

The complete setup can be understood and summarized by studying the Overall Circuit Diagram (Fig. 8) and the LLD (Fig. 9) used to implement the required operation on this experimental kit.

The operation of a PLC can be understood by contemplating the fact that it repeatedly and cyclically performs three steps:

a) Reads inputs from input modules

b) Determines preprogrammed control logic

c) Generates outputs to output modules based on the control logic solutions.

For physical replication of the above process when in demand of a particular operation we push a button; it sends a high signal to the address which updates the same level in the LLD. The program implementing the required logic dictates which terminal should go high; scans the program and updates the voltage levels at its output terminals, which in turn switch the relays connected to the corresponding output terminals; thereby implementing the logic in real time system. Contactors in turn correspond to these relay outputs and provide the supply to the induction motor terminals corresponding to the required operation actuated by the push button at the panel top.

The Vdc at the input of PLC are shorted to provide Sourcing [20] while those at output to attain sinking [20] vital for accuracy and avoiding false actuation levels.

E. The Pursuit Cycle for LLD

The PLC system provides software tools running on a host computer which furnishes a design environment permitting ladder diagrams to be developed, verified, tested, and diagnosed. Advancing serially first, the high-level program is formatted as ladder diagrams which are then modeled as binary instruction codes which can be stored in random-access memory (RAM) or erasable programmable read-only memory (EPROM), finally decoded and executed by the CPU. The programs implemented are predominantly logical rather than computational algorithms. The CPU processes data according to the program and controls the input/output and memory devises.

Most of the programmed operations work on two-state, “on or off” basis. These alternate possibilities correspond to “true or false” (logical form) and “1 or 0” (binary form), respectively. The PLC program uses a cyclically scans the main program loop such that the input variables are updated regularly. The program loop initiates with an input scan to the system furthered by storing their states in fixed memory locations. The ladder program is then executed rung-by-rung [21]. Scanning and solving the logic of the various ladder rungs determines the output states which are stored in fixed memory locations. The output values hence held then set and reset the physical outputs of the PLC simultaneously at the end of the program scan.

The following diagram (Fig. 9) when correlated with the hardware setup effectuates implementation of the proposed panel. Though we may assign any address to any input or output but for the LLD represented above for this particular panel the addressing have been replicated to assist in deciphering the logic used while developing the LLD. While Table I defines output addresses Table II does that for the inputs.

TABLE I: ADDRESSING FOR OUTPUT

Addressing	Mode/Element Actuated
O:0/0	Stop
O:0/1	Main Contactor/Relay
O:0/2	Star Contactor/Relay
O:0/3	Delta Contactor/Relay
O:0/4	Reverse
O:0/5	Forward

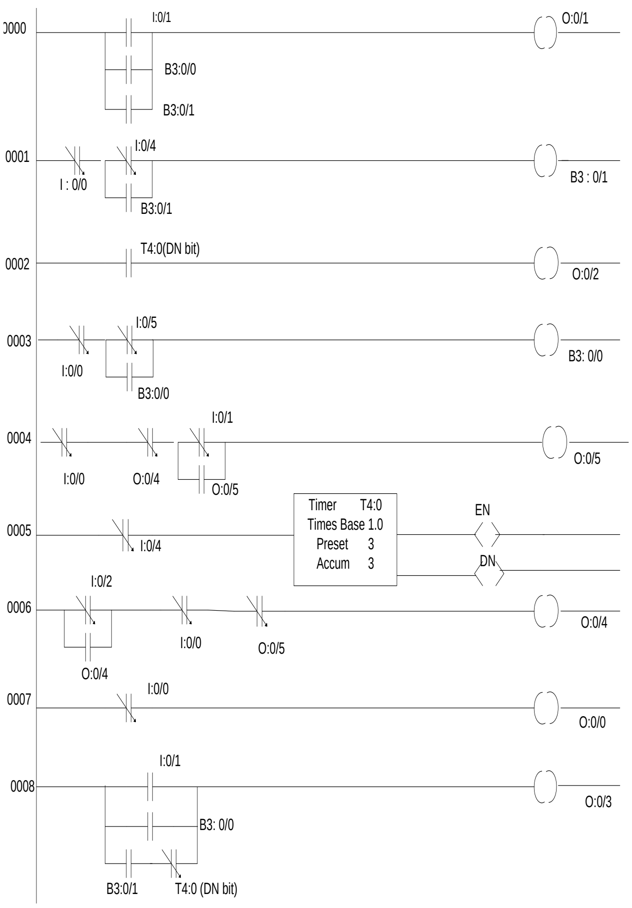

Fig. 9. LLD

TABLE II: ADDRESSING FOR INPUT

Addressing	Push Button Allocated
I:0/0	Stop
I:0/1	Inching
I:0/2	Reverse
I:0/3	Forward
I:0/4	Star Delta Starting
I:0/5	Direct Online Starting

While the inputs to the PLC are the commands from the push buttons which act as a human machine interface to the operator, the outputs actuate the allocated elements required for the accomplishment of the required task. Thus, customizing the various operations on the IM with operational efforts reduced to the push of a button allocated at the panel for the particular operation.

III. Component Specifications

Table III specifies the details of the induction motor used in the setup. Table IV and V demarcate the specifications of VFD and contactors. The value of contactors used depends on the specification of motor and the loading factor (here for demonstration we have used small valued contactor as the motor is run at no load in the setup). Similarly Table VI demonstrates the values for relays used.

TABLE III: Induction Motor Specification

Parameter	Value
Input Voltage	415V AC
Input Current	2.1 Ampere
Rated Power	0.75 KW
Input Frequency	50Hz
Number Of Pole	4
Rated Speed	1440R.P.M

TABLE IV: VFD Specification

Parameter	Value
Model	Power Flux 4
Make	Allen Bradely
Power	0.75 KW
Input	4.1 Amp,3 phase Ac,380-480V,50Hz
Output	2.1 Amp,3 phase AC, 380-480V, 0.2-400Hz

TABLE V (a, b, c): Contactor Specifications

TABLE V(a):

Parameter	Value
Make	ICON (IndoAsian)
Coil Energization	9 Ampere
Short Circuit Values	5kA RMS 600V Max Max Fuse 25 Ampere CB 25 Ampere Torque 0.8 Nm

TABLE V(b):

U_e		220/ 230	380/ 415	660/ 690	V AC
AC-3	I_e	9	9	6.6	A
AC-3	P_e	2.2	4	5.5	KW

TABLE V(c):

V AC		110/ 120	20 8	220/ 240	46 0	60 0
Max HP	1 PH	0.5	-	1	-	-
Max HP	3 PH	3	3	3	5	5

TABLE VI: Relay Specifications

Parameter	Value
Switching Details	250V AC/28V DC , 10 Ampere resistance
Contact Details	250V, 50/60 Hz, 10 Ampere(NO), 5Ampere (NC), Cos ϕ=1
Make	Omron

IV. Software Requirements

The host computers' software environment enables file editing, storage, printing, and program operation monitoring. The process of developing the program to binary object code which will run on the PLC's microprocessor has already been discussed beforehand. This object code is then downloaded from the PC to the PLC system via the serial communication port. The PLC system when online actively controls the machine and monitors data.

The RSLogix™ is a compiled software package apt for batch, motion, safety, discrete and drive based applications. It offers an easy-to- use IEC61131-3 compliant interface, symbolic programming with structures and arrays and a comprehensive instruction set that serves many types of applications compatible with PLC Micrologix 1000 (digital)[22]. It provides ladder logic, structured text, function block diagram and sequential function chart editors for program development.

RSLinx Classic™ is acts as the communication server for the above implementation. It provides plant-floor device connectivity for a wide variety of Rockwell Software applications such as RSLogix™ [23]. It serves for open interfacing of third-party HMI, data collection and analysis packaging. RSLinx Classic is supportive towards multiple software applications simultaneously, communicating to a variety of devices on many different automation industrial networks.

V. Results and Discussion

Successful results were obtained on the setup from the scheme designed, indicating the efficacy of a programmable logic controller for the control and design of a VFD driven induction motor.

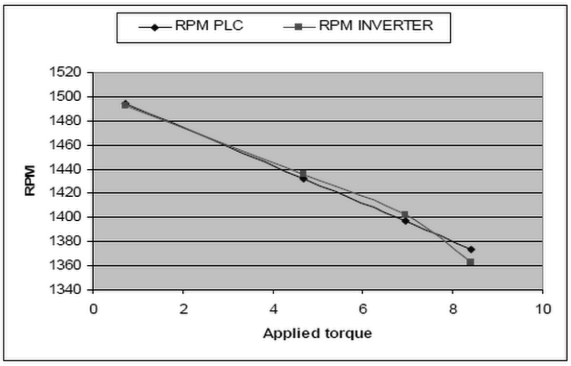

Fig. 10. Speed torque performance comparison of PLC and Inverter (Source [13])

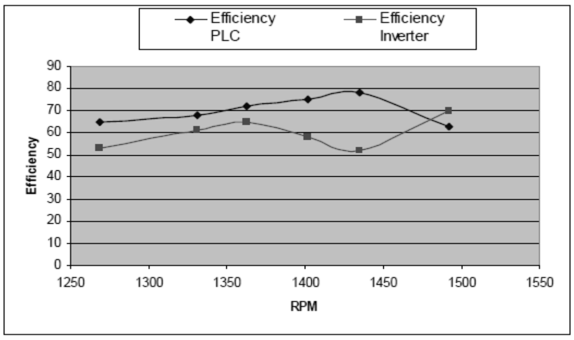

Fig. 11. Efficiency comparison (Source [13])

The effectiveness of the PLC based control software is satisfactory up to 96% of the synchronous speed; specifically, at high speeds and loads, the efficiency of PLC-controlled system is increased up to 10–12% as compared to the configuration of the induction motor supplied from a standard network [13] which is also demarcated by the graphs shown above.

The study embodies simple principles with slightly complex logics for the panel. Despite the simplicity of the implementation a time bound speed variation and starting customization was obtained with immaculate switching accuracy for the various intended operations. Hence, the relevance of a PLC for automated applications is fostered and established.

VI. Conclusion

The hybrid customized panel was successfully implemented in its entirety; experimentally verifying the design proposed for the objectives targeted. The suitability of a PLC for task specific automated systems is hence, established. The improved performance of PLC based systems over conventional systems further justifies the practical utility of the setup.

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