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Design and Implementation of Industrial Crane Automation System Using Programmable Logic Controller (PLC)

EI EI CHO[1], ZAW MIN MIN HTUN[2]

[1]Dept of ECE, Mandalay Technological University, Mandalay, Myanmar, Email: eieicho3@gmail.com.

[2]Dept of ECE, Technological University, Maubin , Myanmar, Email: zawminminhtun@gmail.com.

Abstract: This paper describes the automatic control of overhead travelling crane. An overhead travelling crane, also known as a bridge crane, is a type of crane where the hook-and-line mechanism runs along a horizontal beam that it runs along two widely separated rails. The advantage of the box girder type configuration results in a system that has a lower deadweight yet a stronger overall system integrity. Also included would be a hoist to lift the items, the bridge, which spans the area covered by the crane, and a trolley to move along the bridge. The operation of overhead travelling crane is completely controlled by using Programmable Logic Controller (PLC) which is used for automation of real-world processes, such as control of machinery on factory assembly lines. The system sequence of operation is designed by ladder diagram and PLC programming software. In this project, we are using sensors that are used to sense the overhead travelling crane motion. By implementing this project, man power can be decreased and the production of the industry can be increased. The PLC provides several other major advantages over logic chips in that they would be reprogrammed easily, trouble shooted with a video screen that showed which contacts are open or close, and their program could be stored and downloaded into the machine control at a later date.

Keywords: Overhead Travelling Crane Automation, Programmable Logic Controller (PLC), Sensors.

I. INTRODUCTION

Overhead travelling crane is an important device, widely used in industries, steelworks, dockyards, railways are etc. The work that can be accomplished by many workers can also be accomplished by a skilful worker with only a crane. Many kinds of cranes effect benefit various fields with their efficiencies. Using overhead travelling crane will be also effective in industrial development. Electric overhead travelling cranes are normally used for handling loads over a rectangular area and their capacity may vary from 1 ton to upwards of 350 tons. They have been supplied with capacities up to 200 tons and span up to 150(46m); serving power stations, factories, steelworks and covered stores, and for outdoor duties at timber yards, storage areas, gasworks, etc.

The standard crane comprises a welded steel frame, liberally rated crane-type motors, high-carbon steel gears, precision ball bearings, oil-sealed gear-boxes, robust electro-mechanism brake, automatic over winding prevention and centralized lubrication. In this paper, Programmable Logic Controller (PLC) is used to control the overhead travelling crane movements. This paper mainly presents the programming and operation of an Overhead Travelling Crane in Automobile Production Factory. It can pick up the container which included an automobile to a desired place. PLC can control operation sequence of a large system surveying special module such as link, analog and position control. The controlled program is developed by using ladder diagram and necessary mnemonics codes are also provided [1-5][9].

II. WHAT IS PLC?

A Programmable Logic Controller is a solid state control system that continuously monitors the status of devices connected as inputs. Based upon a user written program, stored in memory, it controls the status of devices connected as outputs.

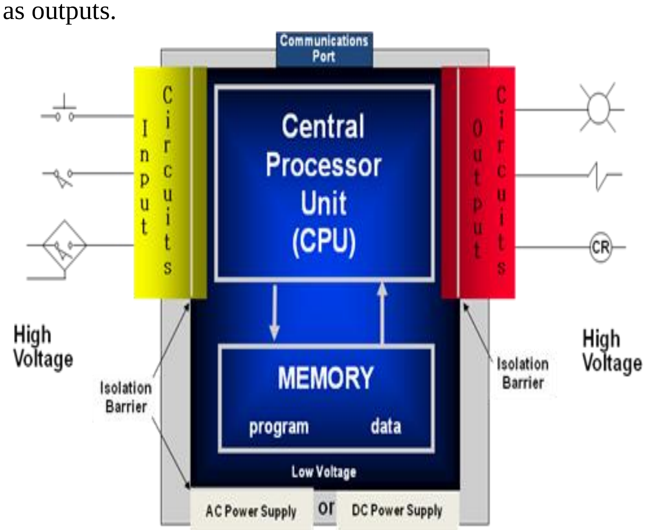

Figure 1. Inside a PLC.

A. Operating cycle of PLC

There are four steps in PLC operations. They are (1) Input scan, (2) Program scan, (3) Output scan, and (4) Housekeeping.

1. Input scan- scan the state of the inputs
2. Program scan- processes the program logic
3. Output scan- energize/de-energize the outputs
4. Housekeeping- this step includes communication, internal diagnostics, etc.

These steps are continuously repeated and processed in a loop.

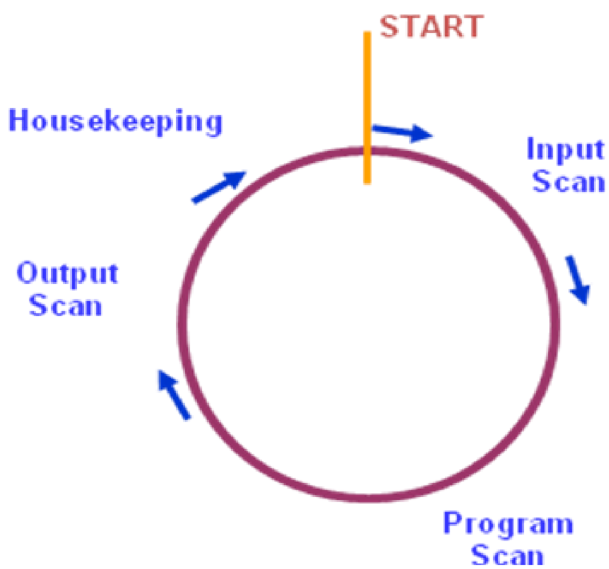

Figure 2. Operating cycle of PLC.

B. Advantages of Programmable Logic Controller(PLC)

Flexibility; In the past, each different electronically controlled production machine required its own controller. Now just one model of a PLC can easily run many machines. Each of the 15 machines under PLC control would have its own distinct program. Implementing Changes and Correcting Errors; A PLC program circuit or sequence can be changed in a matter of minutes. Also, if a programmable error has to be corrected in a PLC control ladder diagram, a change can be done in quickly. Large Quantities of Contacts; The PLC has a large number of contacts for each coil available in its programming.

Lower Cost; Improved technology makes it possible to pact more functions into smaller and less expensive packages.
Pilot Running; A PLC programmed circuit can be pre-run and evaluated in the office or lab. The program can be typed in, tested, observed, and modified if needed, saving valuable factory floor, which can be very time-consuming.
Visual Observation; A PLC circuit's operation can be seen during operation directly on a CRT screen.
Speed of Operation; The speed for the PLC logic operation is determined by time, which is a matter of milliseconds.
Ladder or Boolean Programming Method; The PLC programming can be accomplished in the ladder mode by an electrian or technician.
Reliability; The PLC is made up of solid state electronic components with high reliability rates.
Documentation; An immediate printout of the true PLC circuit is available in minutes, if required.
Simplicity of Ordering Control System Components; A PLC is one device with one delivery date. When the PLC arrives, all the counters, relays, and other components also arrive.
Security; A PLC program change cannot be made unless the PLC is properly unlocked and programmed.
Ease of Change by Reprogramming; Since the PLC can be reprogrammed quickly, mixed production processing can be accomplished.

C. Disadvantages of Programmable Logic Controller (PLC)

Fixed Program Applications; some applications are single-function applications in the use of drum controller/sequencers for an overall cost advantage.
Environmental Considerations; certain process environments, such as high heat and vibration, interfere with the electronic devices in PLCs, which limits their use.
Fail-save Operation; Auto restart, of course, can be programmed in the PLC; however, in some PLC programs, may have to apply an input voltage to cause a device to stop. These systems are not "fail-save". These disadvantages can be overcome by adding safety relays to a PLC system.
Fixed-circuit Operation; If the circuit in operation is never altered, a fixed control system might be less costly than PLC. The PLC is most effective when periodic changes in operation are made [7][10].

D. Structure of PLC

A PLC consists, like any computer, of a control and an arithmetic unit as well as a program and a data memory (memory marker). In addition a PLC has timers, an interface to the so-called programming device and input/output units, which cover one or more groups of input/outputs depending on the size and level of expansion of the controller.

Input Unit: The input unit conduce the acquisition of analog and digital input signals. Additionally it offers a decoder to allow the control a targeted access to the relevant module via a gate circuit.

Output Unit: Even with the output unit there can be differences between analog and digital modules. The storage of the binary output values on the respective output card is necessary to generate a continuous output signal from the pulse-shaped output values from the controller. The output modules can still possibly include means for monitoring the outputs for short circuit and to switch off the outputs in case of failure.

Timers: The timers make it possible the formation of the necessary times for control engineering tasks in the range from 0.01 s to 1000 min.

Memory Markers: Memory Markers are memory parts of the PLC in which the controller saves (marks) the signal states.

Program Memory: The program memory contains the instructions of the user program in machine code (e.g. 16-bit words at consecutive address). For this purpose buffered write-read memory is normally used.

Control Unit: The control unit reads the instructions of the automation program in the order of the addresses from the program memory and runs the specified operations.

Bus System: A backplane bus called bus connects program memory, control unit, and I/O units (inputs and outputs) in the PLC [11].

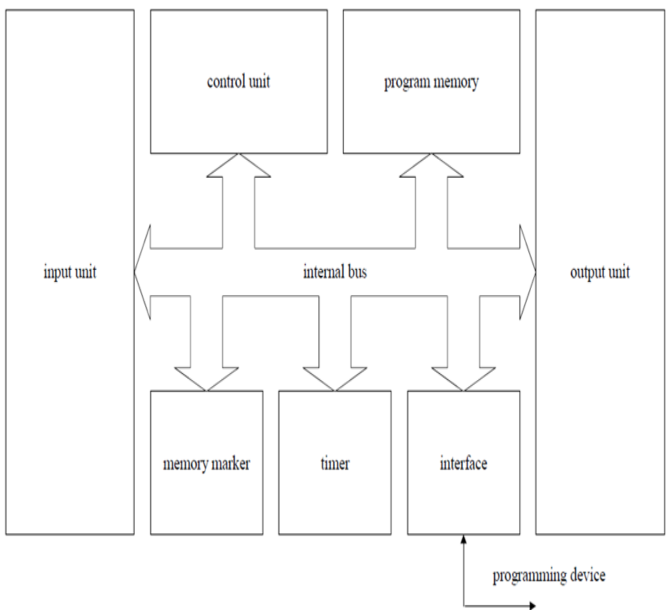

Figure 3. Structure of a PLC.

E. Programming of a PLC

Control tasks are recorded by the user in a program. By the use of a set of language elements, the program for specific tasks is created. Since tasks for the processing of binary signals are handled, the language elements for these functions are interrupted. From such limited requirements, five programming languages were developed for practical use:

- Ladder diagram (LD)
- Function block diagram (FBD)
- Instruction list (IL)
- Flow languages (AS)
- Structured Text (ST)

Among them, the programming language of PLC that is used in this paper is Ladder diagram (LD).

III. THE HISTORY OF CRANE AUTOMATION

PLCs have been in use in container cranes for about 25 years. Neither the PLCs nor the digital DC drives introduced in the mid-eighties did result in any significant improvement of functionality of the container cranes. The PLCs and drives could not solve any of the three key crane processes:

1. Measurement and control of load sway.
2. Communication between crane and terminal control.
3. Obstacle and target identification.

These technological obstacles did delay the introduction of automation and centralized control by decades compared with other industry applications. The last step in the process towards fully automated container cranes can now be taken using laser transducers as the eyes of the crane and using high speed communication networks for transmissions of video signals. The development of automation for cranes is now faster than in other industry areas and the ports industry is quickly catching up with the paper, chemical and metals industries [12].

IV. INTEGRATED CRANE CONTROL CONCEPT

The first integrated crane control concept is designed for handling of the complete control and automation of an industrial crane. The total functions are built up of a number of distinct building blocks which can be installed from the beginning or added on after the delivery of the crane. Many of the building blocks are tightly connected to each other and requires as system designed and built with the total functionality to achieve the right performance. Already the basic drive and control package has to be designed to handle the real time and communication requirements of the automation functions.

V. DRIVE AND CONTROL

A number of features are needed in the basic drive and control package of the crane to enable the addition of automation and information system functions.

1. Powerful process controller with advanced multitasking, capable of handling several time critical control loops simultaneously.
2. High speed communication links between drives, transducers and controls.
3. Accurate measurement and fast transmission of drive positions and speeds.
4. Communication interfaces for all necessary drive, transducer, remote control and information system equipment. Centralized interface for diagnostics of the complete system.

VI. AUTOMATED CRANE COTROL

A crane with electronic load control is well prepared for automatic, unmanned operation. To realize the unmanned operation the crane must be equipped with “eyes” to be able to identify obstacles and the position of targets like vehicles and stacks of containers. The automated control sequence is the brain of the unmanned crane. The sequence control is built up to handle various types of motions with and without load and with different combinations of hoist, trolley and gantry motions.

VII. OPERATION OF OVERHEAD TRAVELLING CRANE USING PROGRAMMABLE LOGIC CONTROLLE (PLC)

The girder of a crane moves in the travelling axis, the trolley moves in the traversing axis and the object transferred by the crane goes up and down. Their movements are described with positions and velocities in the X-Y-Z coordinates, as shown in figure. The travelling axis is described with X axis, the traversing axis with Y axis and movement of the object in up and down direction with Z axis. Firstly, the hook is in the up-condition. When switch or input is ON, the hook moves down by running motor No.3. Sensor No.1 is the down-condition sensor (+20'). When it signals, motor No.3 stops and then Timer No.1 operates. At that time, Timer No.1 counts for 1 minute. During that time, operator 1 hangs the load on the hook. After 1 minute, motor No.3 is in the up-condition (+ Z direction) to haul up the load at a height 3' from the ground. Sensor No.2 is the same as that height. When the load reaches 3' height from the ground, motor No.3 rests. Then, motor No.1 operates and moves along the X- direction (+180'). When sensor No.3 signals that movement on X-direction is over, motor No.2 starts. Motor No.2 moves along the Y-direction as soon as motor No.1 stops. Sensor No.4 signals that the movement on Y-direction (+ 10') is finished. Next, motor No.3 starts again.

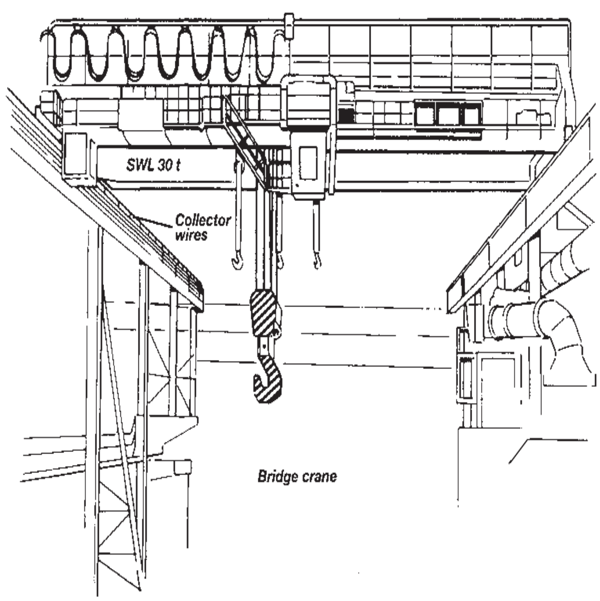

Figure 4. Overhead travelling Crane structure[6].

Motor No.3 hangs the load down in the down condition (-Z direction) while motor No.2 stops. By the time sensor No.5 notifies that the load reaches on the floor, motor No.3 stops and Timer No.2 starts to count for 1 minute. Operator 2 hangs the load down from the hook during 1 minute. Later, the hook rises up in the up-condition (+ Z direction) after making this process. If sensor No.6 signals, motor No.3 stops. Next, motor No.2 starts running along the reverse direction (- Y direction). Sensor No.7 also detects that motor No.2 moves along the –Y direction. If sensor No.7 signals to stop motor No.2, motor No.1 operates. That operation will stop if sensor No.8 informs. This process operates continuously until the operator switches off.

VIII. FLOWCHART OF OVERHEAD TRAVELLING CRANE OPERATION

The following figures 5 to 11 shows Overall flowchart of overhead travelling crane using Programmable Logic Controller (PLC), operates in forward and reverse direction for different motors

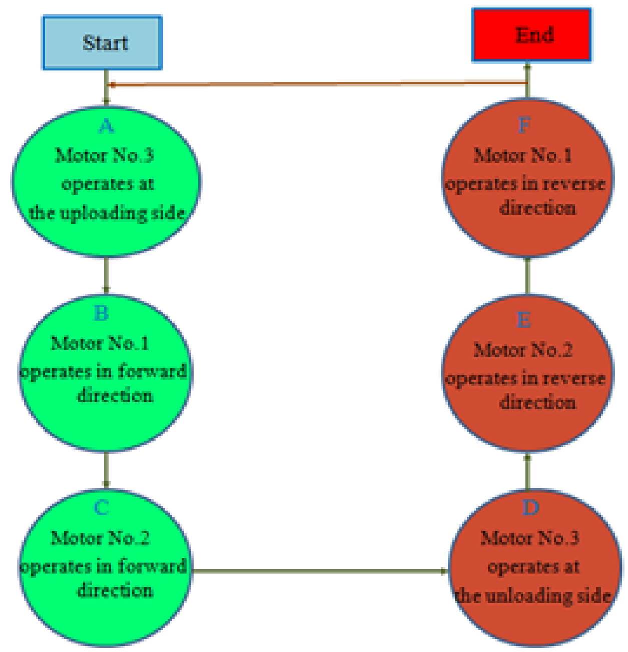

Figure 5. Overall flowchart of overhead travelling crane using Programmable Logic Controller (PLC).

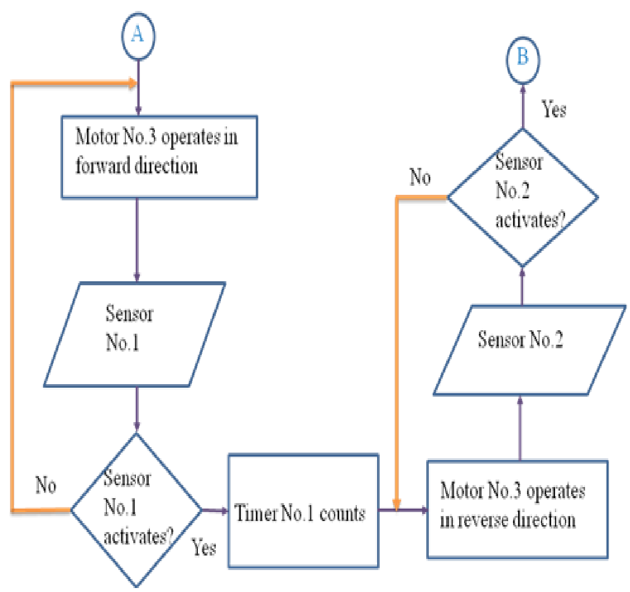

Figure 6. Motor No.3 operates at the uploading side

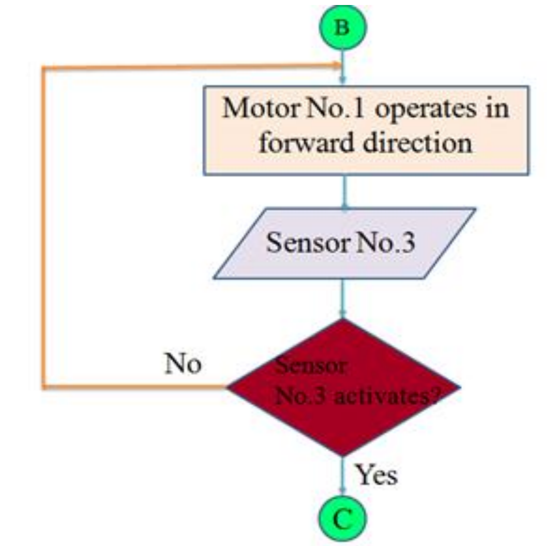

Figure 7. Motor No.1 operates in forward direction

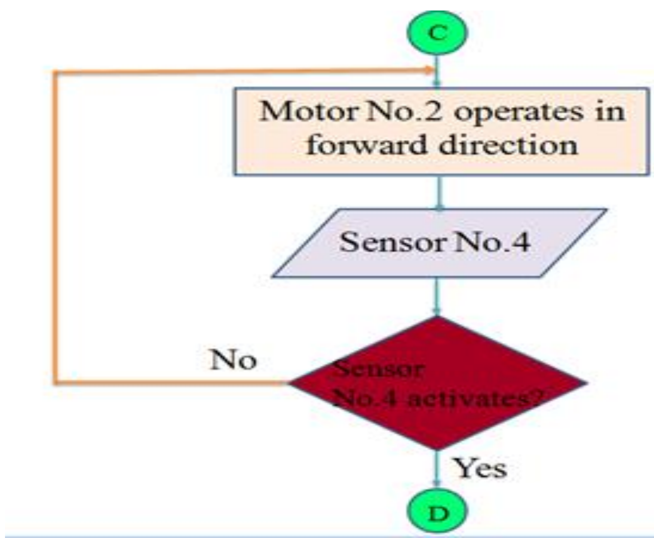

Figure 8. Motor No.2 operates in forward direction

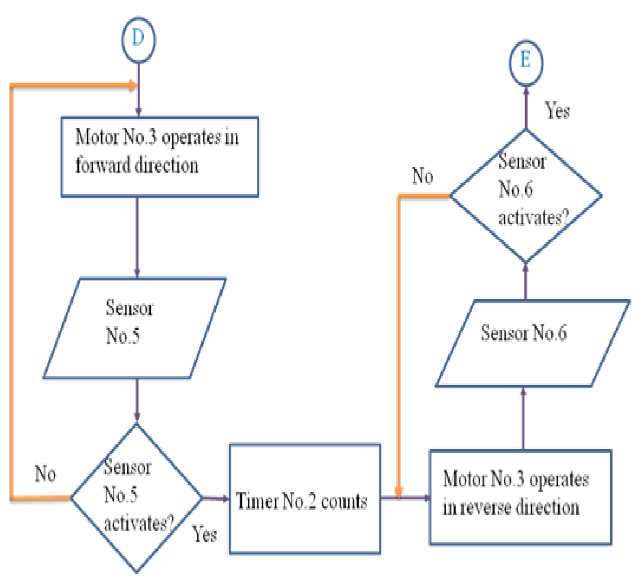

Figure 9. Motor No.3 operates at the unloading side

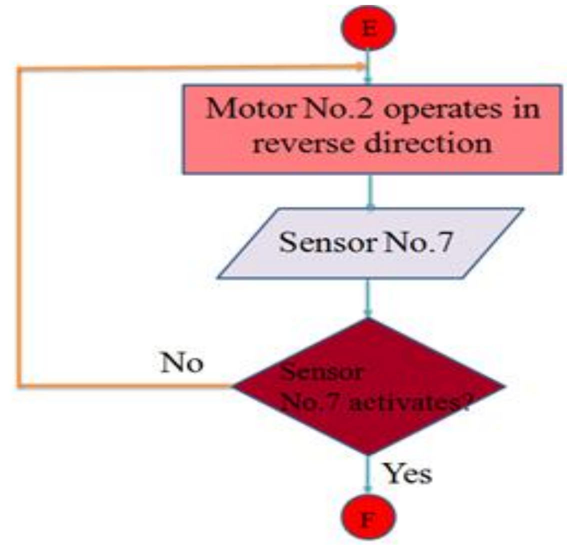

Figure 10. Motor No.2 operates in reverse direction

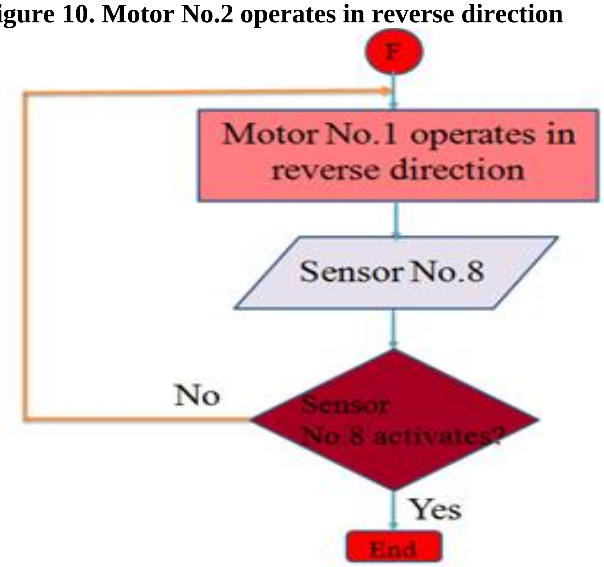

Figure 11. Motor No.1 operates in reverse direction

IX. MODEL DESIGNATION OF IVC1-1006 MAT

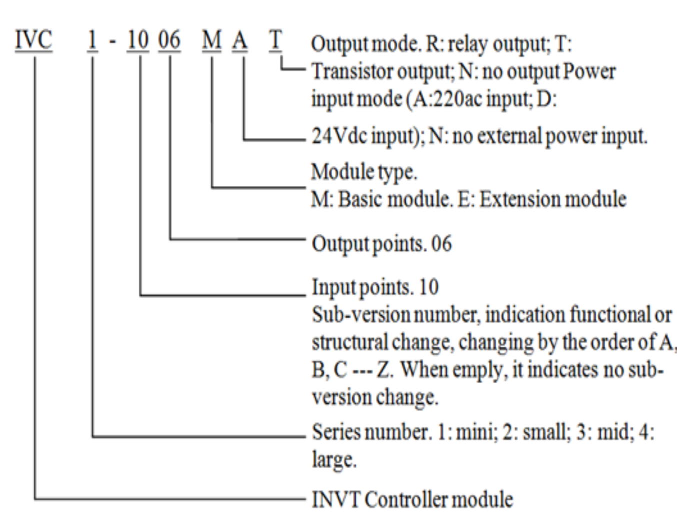

Figure 12. Designation of Ivc1-1006 Mat

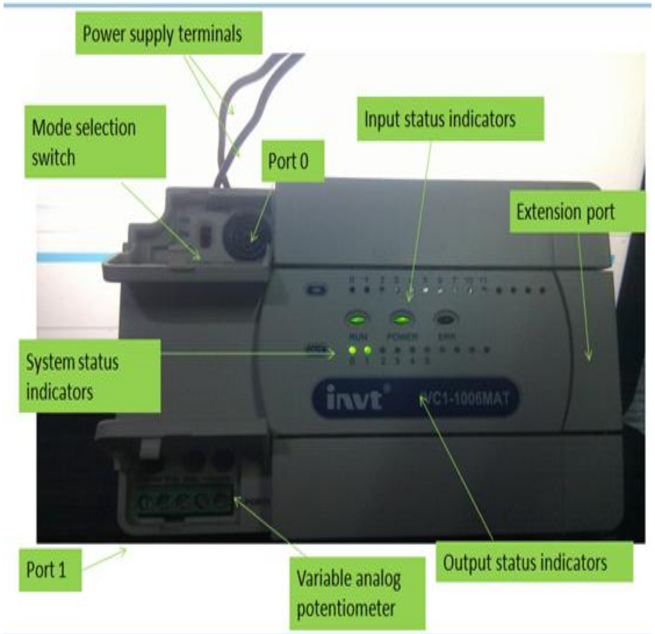

Figure13: Outline of Basic Module.

Figures 12, 13 and 14 shows the design of the proposed model with Terminal layouts of different I/O.

- Port 0 and Port 1 are communication terminals.
- Port 0 uses RS232 mode with Mini DIN8 socket.
- Port 1 uses RS485 or RS232 mode.
- The busbar socket is for connecting the extension module.
- The mode selection switch has three positions: ON, TM and OFF [8].

A. Terminal layouts of different I/O

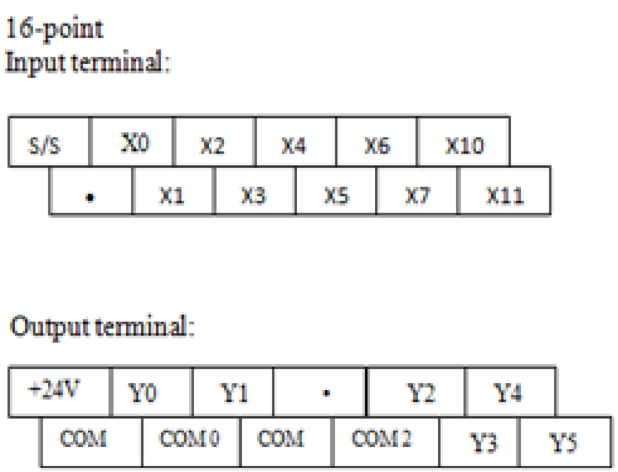

Figure 14. Terminal layouts of different I/O

B. Input characteristic and specification

TABLE 1: INPUT CHARACTERISTIC

Item		High-speed input terminals X0~X7	General input terminal
Input mode		Source mode or sink mode, set through s/s terminal	
Electric parameters	Input voltage	24Vdc	
	Input impedance	3.3kΩ	4.3 kΩ
	Input ON	External circuit resistance < 400Ω	
	Input OFF	External circuit resistance >24kΩ	

C. Output characteristic and specification

TABLE II: OUTPUT CHARACTERISTIC

Item	Relay output	Transistor output
Output mode	When output state is ON, the circuit is closed; OFF, open	
Common terminal	Divided into multiple groups, each with a common terminal COMn, suitable for control circuits with different potentials. All common terminals are isolated from each other	
Voltage	220Vac; 24Vdc, no polarity requirement	24Vdc, correct polarity required
Current	Accord with output electric specs (see following Table)	
Difference	High driving voltage, large current	Small driving current, high frequency, long lifespan
Application	Loads with low action frequency such as intermediate relay, contactor coil, and LEDs	Loads with high frequency and long life, such as control servo amplifier and electromagnet that action frequently

Item	Relay output terminal	Transistor output terminal
Switched voltage	Below 250Vac, 30Vdc	5~24Vdc
Circuit isolation	By Relay	PhotoCoupler

Operation indication		Relay output contacts closed. LED on	LED is on when optical coupler is driven
Leakage current of open circuit		/	Less than 0.1 mA/30Vdc
Minimum load		2mA/5Vdc	5mA (5~24Vdc)
Max. output current	Resistive load	2A/1 point; 8A/4 points, using a COM 8A/8 points, using a COM	Y0, Y1: 0.3A/1 point Others: 0.3A/1 point 0.8/4 point: 1.2A/6 point 1.6A/8 point. Above 8 points, total current increases 0.1A at each point increse
	Inductive load	220Vac, 80VA	Y0, Y1: 7.2W/24Vdc Others: 12W/24Vdc
	Illumination load	220Vac, 100W	Y0, Y1: 0.9W/24Vdc Others: 1.5W/24Vdc
Response time	OFF→ON	20ms Max	Y0, Y1: 10us Others: 0.5ms
	ON→OFF	20ms Max	
Y0, Y1 max, output frequency			Each channel: 100kHz
Output common terminal		Y0-COM0: Y1-COM1. After Y2 every 8 terminals use one isolated common terminal	
Fuse protection		No	

X. LADDER DIAGRAM FOR OVERHEAD TRAVELLING CRANE

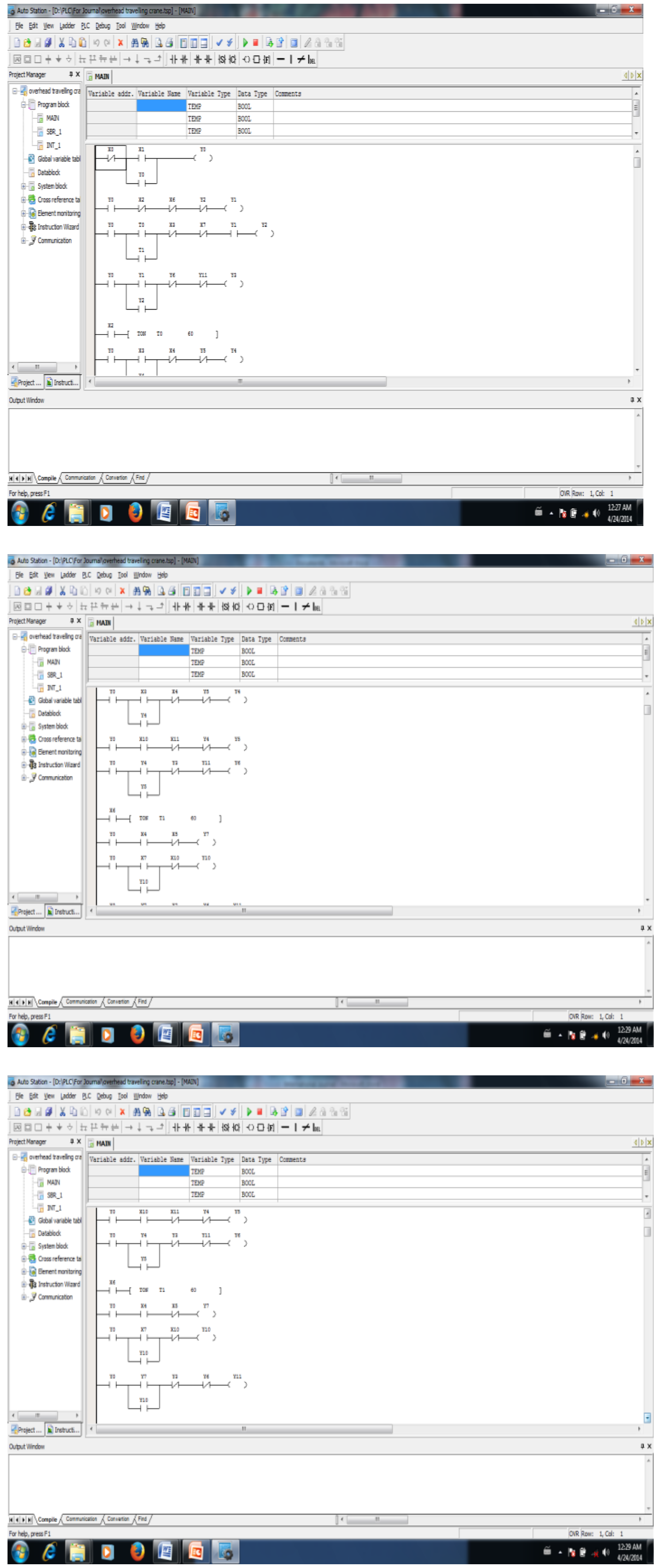

Figure 15. Ladder Diagrams for Overhead Travelling Crane

XI. LIST OF SYMBOL MEANING FROM LADDER DIAGRAM

X0 – System stop
X1 – System start
X2 – Sensor No.1 (20')
X3 – Sensor No.2 (3' above the ground & Motor No.1 operates in forward direction)
X4 – Sensor No.3 (end of X direction & start of Y direction)
X5 – Sensor No.4 (end of Y direction & start of –Z direction)
X6 – Sensor No.5 (Load reaches at the ground)
X7 – Sensor No.6 (The hook reaches to the original position & Motor No.2 operates in reverse direction)
X10 – Sensor No.7 (end of Y direction & Motor No.1 operates in reverse direction)
X11- Sensor No.8 (Motor No.1 stops & the hook reaches to the original position)
Y0 – Master Control Relay
Y1 - Motor No.3 (forward direction)
Y2 – Motor No.3 (reverse direction)
Y3 – Motor No.3 for Z direction
T0 – Timing Solenoid No.1
Y4 – Motor No.1 (forward direction)
Y5 – Motor No.1 (reverse direction)
Y6 – Motor No.1 for X direction
Y7 – Motor No.2 (forward direction)
Y10 – Motor No.2 (reverse direction)
Y11 – Motor No.2 for Y direction
T1 – Timing Solenoid No.2

XII. TIMING DIAGRAM OF OVERHEAD TRAVELLING CRANE

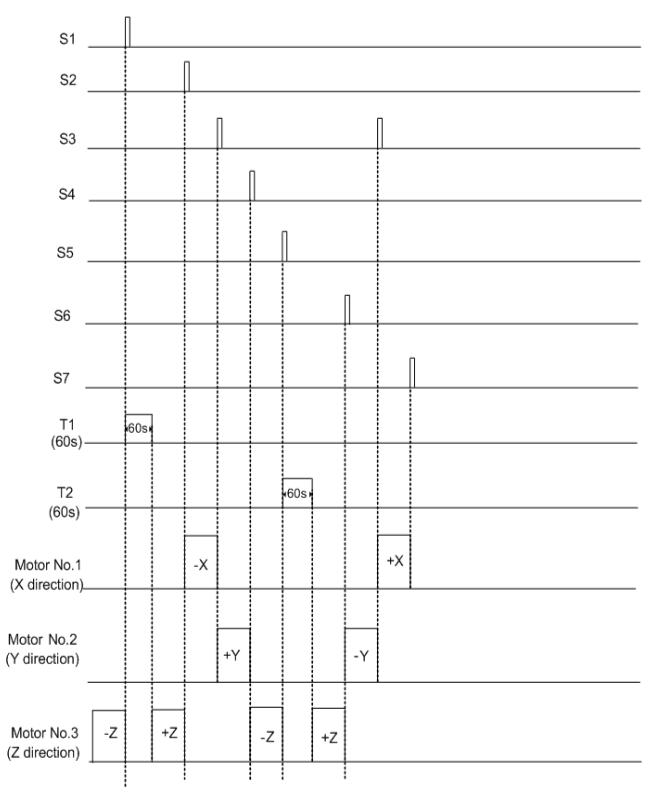

Figure 16. Timing Diagram of Overhead Travelling Crane

XIII. RESULTS FROM TESTING WITH INVT

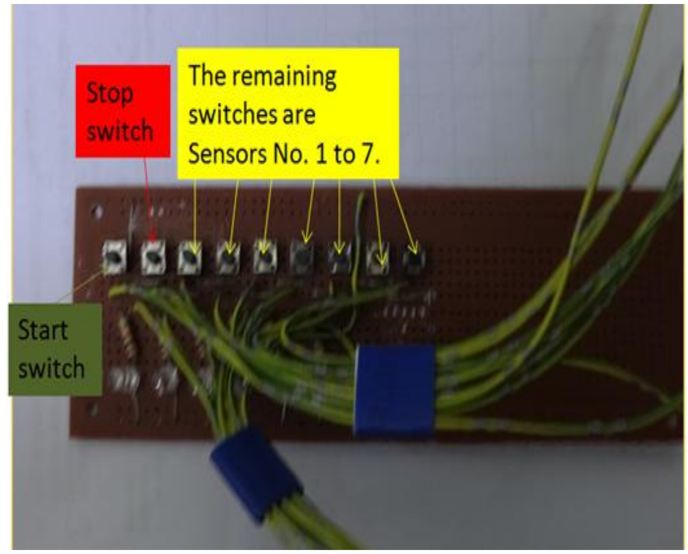

Figure 17. Input switches

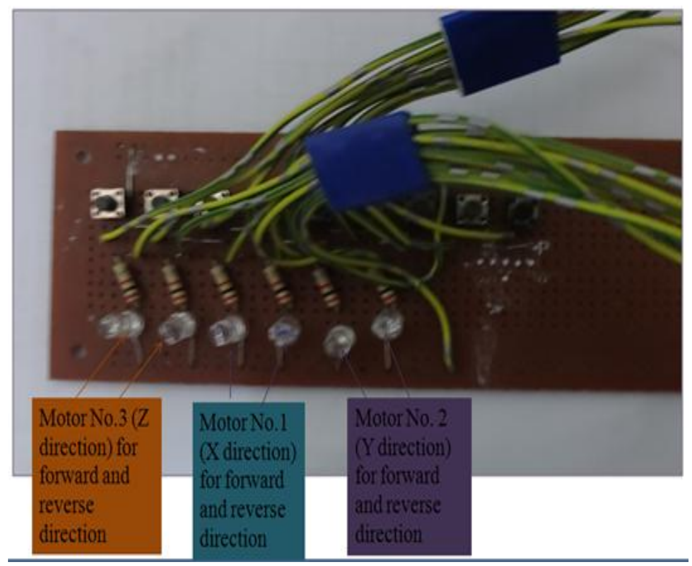

Figure 18. Output monitoring light

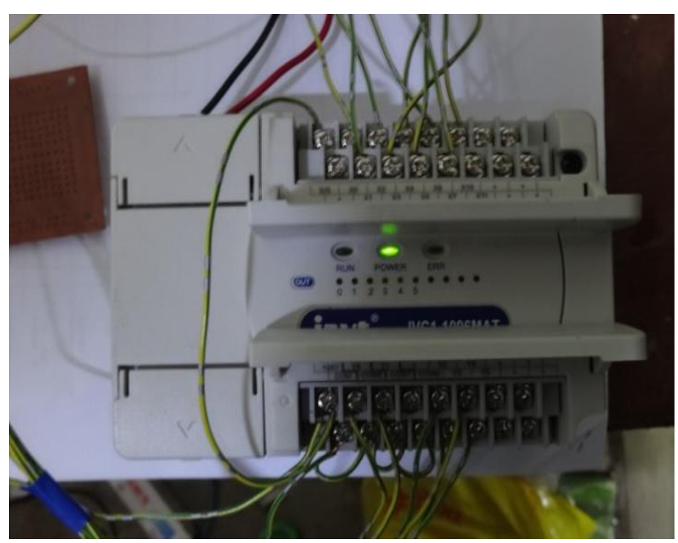

Figure 19. Wiring connection

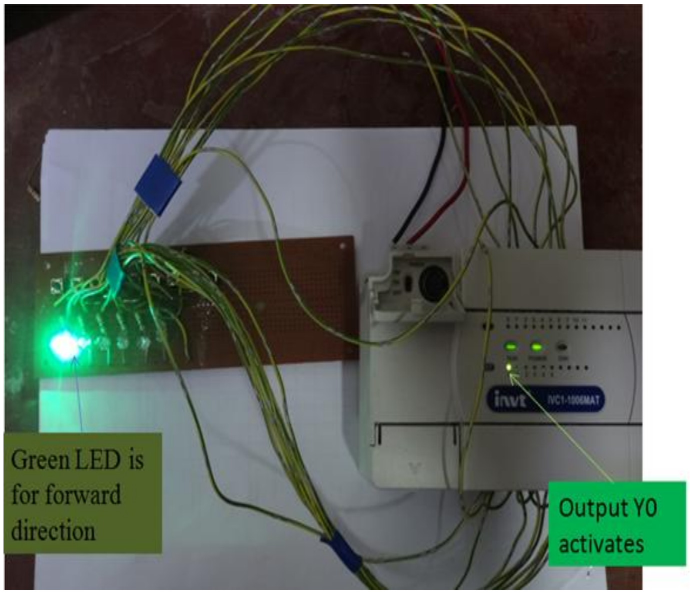

Figure 20. Motor No.3 runs in forward direction.

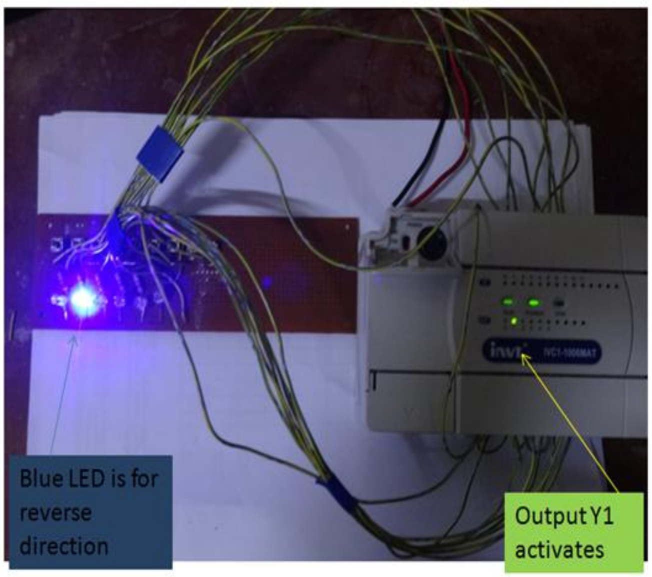

Figure 21. Motor No.3 runs in reverse direction.

From figure 17 to 21 shows the result of the INVT testing.

XIV. CONCLUSION

In this paper, Programmable Logic Controller (PLC) applying in industrial work shop is one of the most important features of PLCs. Besides, it makes changes in the control system easy and cheap. In future definitely PLC is dominated on all other controlling methods. The operation of overhead travelling crane is successfully done with the use of PLC. Nowadays, the factory automation and control processes are more and more complicated. Again, control field is expanding to include the complete factory and total control systems combined with feedback control, data processing and centralized monitoring systems. The advantages of PLC are reduced overall manufacturing costs, environmental safety for operating personnel, prompt emergency recognition and reaction and general convenience. The objective of controlling Overhead travelling crane is for lifting the industrial field. This crane is mainly used to lift and transport goods and assembling plant, metal working shop, mechanical maintenance shop and warehouses, also for equipment erection and maintenance such as gate for power station, etc. The program (PLC) controlled motor is got more benefit the operation of crane. Motors are controlled by PLC which in overhead travelling cranes is applied in factory.

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