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Design of Control Panel for Assembling of X-Actuator Using Automation

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***Abstract*—Smart automation systems have revolutionized how industries operate by using connected technology to improve precision, efficiency, and environmental responsibility. The combination of IoT (Internet of Things), AI (Artificial Intelligence) and superior control systems allow manufacturers to produce more accurately and efficiently than they ever thought possible. This paper will present a design for an automation control panel used to automate and integrate all aspects of actuator assembly via PLC and HMI systems. The design will contain both electrical and electronic components, all of which will connect to a PLC and HMI as part of an integrated automation system that reduces the need for human interaction while improving accuracy and productivity. This paper will also detail how the automation control panel design will create measurable benefits benefiting factory assembly accuracy, product delivery accuracy, operational efficiency, and providing scalable automation solutions for larger factory applications**

***Index Terms*—Industry 4.0, Automation, PLC (Programmable Logic Controllers), HMI (Human-Machine Interface), Actuators, Control Panels, Control Panel Fabrication, Automation Control Panel Design & Scalability of Automation Applications within the Industrial Sector.**

I. INTRODUCTION

The design of industrial control panels is crucial in industrial automation since the design can influence user operation and the efficiency of the entire process or system being controlled by the control panel through the motion of the actuator assembly. In the actuator assembly process of the X-actuator using a PLC system, precision in assembling the X-actuator is critical because all electrical, electronic and automation components are connected to a single, central automation control panel. Therefore, the design of the control panel must ensure all electric, electronic and automation components work together through proper installation methods, establish a safe, functioning automation system, and provide the user with easy access for maintenance and repair. The study will focus on establishing a systematic approach to the design of an industrial control panel for the X-actuator automated assembly station. The X-actuator is a linear actuator that produces linear motion for industrial applications by changing electrical energy into mechanical energy and is frequently used in assembly lines, robotics, and CNC interfaces to provide the linear motion to achieve precise repetitive positions for parts.

When designing an operation, there are many components to consider in order to ensure a well-functioning machine, such as Programmable Logic Controllers (PLC's), Sensors, Relays & HMIs. As with any other part of the design process, the layout and documentation should be carefully thought out and structured. The entire design should ensure the proper models, locations, and Industries Standard interfaces are used to help improve both the functional and operational aspects of the machine. By preparing designs instead of executing them, this research can illustrate how a well-Engineer designed project can help reduce assembly defects, improve productivity and support the goals of Industry 4.0. Overall, the project showed that control panel design creates a foundational element for advanced automation in today's manufacturing environment.

II. TERMINOLOGY AND CONCEPT FOR THE CONTROL PANEL

Control Panels are usually built as a complete assembly made up of both electrical & electronic assemblies/devices; however, Control Panels may also utilize some type of computer-based control logic to automate & monitor the processes that are being performed in industries. The Control Panel will basically be used to provide power (via a single distribution point) to the entire control panel, as well as provide the control logic to each of the devices (therefore) connectively related to the Control Panel, and finally, provide the operator with means to interact with/manage the automated devices. In additions to the above listed

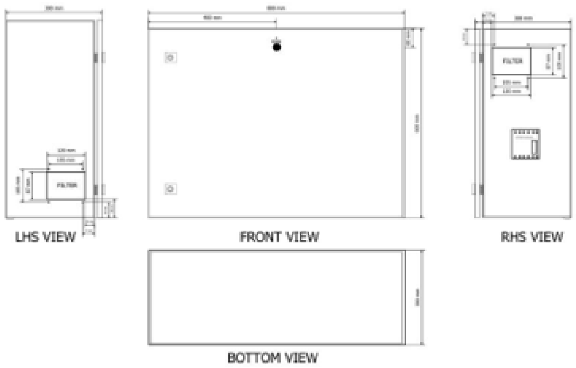

Figure1: Layout of Control Panel

Considerations it is therefore vital that Control Panels be constructed safely effectively, thus being able to support Quality and Longevity of equipment that is used industrially for processing within the economies; with respect to control panels, there are two major categories/considerations that must be adhered to and are stated within the international standard being;

I. Selecting Material

The type of enclosure material will greatly affect the durability and safety of your control panel. Most control panels are made with mild steel because they offer the highest combination of mechanical strength and effective grounding capabilities. Mild-steel control panels will typically be powder-coated or painted on the outside in order to protect them from corrosion. Chemical plants and outdoor environments generally prefer polycarbonate or fiberglass for enclosures because of their lightweight nature, as well as their non-conductive and corrosion-resistant properties. The material dimensions should be selected based on the following characteristics: environmental conditions, mechanical loads, and safety requirements.

II. Mechanical Load (Stress):

$$\sigma = \frac{F}{A}$$

Applied Force (F) = Cross Sectional Area (A)

The standard thickness of a panel with a base material of mild steel (MS) is between 1.6mm and 2mm; for panels with a base material made from 304 stainless steel the range is between 1.5mm and 3mm; for panels made from polycarbonate the standard thickness is 3mm to 5mm.

III. Layout Design:

The layout of each section of the panel must adhere to both ergonomic and functional standards. It is essential to keep all high voltage apparatus separated from all low voltage control circuits in order to limit interference and improve device safety.

Components that will require frequent operator access, including HMIs, switches, and PLCs, should be positioned either at the height of the operator's eyes or otherwise easily accessible. All components should have an appropriate amount of space between them to allow for heat dissipation and maintenance.

There should be an obvious, logical flow of power through the panel from the incoming power supply, through the distribution section, through to the control section. This makes troubleshooting the panel much easier.

IV. Wire Standards:

Structured wiring practices will provide both safety and simplify maintenance. All wiring utilized in this project complies with the International Electrotechnical Commission (IEC) standards (IEC 60204) and other Institute of Electrical and Electronics Engineers (IEEE) guidelines.

Phases, neutrals, earth wires and control wires are color coded. Control and power wiring are separated to further reduce any potential for electromagnetic interference.

V. Safety Compliance

Control Panel Designs must prioritize safety. The Low Voltage Switchgear and Control Gear (IEC 61439) standard specifies most of the requirements for safe operation of Control Panel and Control Gear Assemblies. Control Panel and Control Gear Assemblies must be grounded and shielded to prevent Electric Shock, as well as Electromagnetic Interference (EMI) and Electrostatic Discharge (ESD). Emergency Stop buttons should be located in accessible areas, such as in the front of the Control

Panel to allow quick disconnection of Power in case of failure. Every Control Panel Assembly should contain Protective Devices (Fuses, Miniature Circuit Breakers or MCBs, and Earth Leakage Circuit Breakers - ELCBs), which protect Equipment from Excessive Current and/or Excessive Leakage.

To further improve safety for persons using or operating Control Panels or Equipment, all Equipment should have Clear Warning Labels, Insulated Barriers, and Lockable Cabinets.

VI. Cooling and Ventilation

It is necessary to perform thermal management of electronics in order to achieve optimal equipment performance and to extend the equipment's useful life. When equipment operating at a low heat load, passive cooling methods (e.g., ventilation slots and conducting heat away from components through natural convection) can be implemented. However, active cooling methods (e.g., fans, blowers or air conditioning units) should be utilized for high heat loads. The maximum allowable rise in temperature according to the IEC 61439 standard for control panels is usually in the range of 30–35 °C above the ambient temperature. Sensitive components (e.g., programmable logic controllers and human–machine interfaces) should not have a case temperature exceeding 40–50 °C; the maximum case temperature for power components depends on the manufacturer's specification, but will typically range from 60–70 °C. Establishing proper clearance and spacing, and performing a thermal analysis, is critical to validating the effectiveness of cooling methods selected and for ensuring reliable operation of the equipment.

III. CALCULATION FOR THE MATERIAL SELECTION

The method of calculating the control panel design is an important early step in the electrical system design process. This design procedure ensures that all components of an assembled control, the wire itself, the fuse, circuit breakers, busbars, and protective devices, are accurately sized for the expected load with regards to safety.

The first step is to determine the total connected load and calculate the current demand. This will dictate the main breaker size and incoming conductor size selection. Then, each branch circuit will be reviewed to determine the appropriate wire size based on the current rating, voltage drop, and temperature rise of each circuit, and the appropriate protective devices that will be installed. After the above parameters are completed, the short-circuit current will be calculated to verify the breaking capacity of MCBs and the thermal withstand of the conductors that will be utilized.

These calculations of each circuit are completed in sequence, resulting in a design that meets the IEC standards for control panel design, minimizes the amount of energy wasted, and provides reliable operation under both normal and fault conditions.

Earthing and/or leakage protection devices are also included in the System so that both the operator and the apparatus are protected.

All below calculations provide a systematic control panel design process that transforms the schematic diagrams into an actual electrical system that is functional and safe. The calculations that were performed above are for the Single Line Diagram for a single branch circuit.

Given supply is 230 Ac, 50Hz.

Total connected load is 5.5 Kw. (from lamp, fan, SMPS, Socket, relays)

Total Current flowing in the panel:

$$I = \frac{P}{V}$$

$$= \frac{5500}{230}$$

$$= 23.9 \text{ A}$$

Wire size must be 4 sq.mm

Cooling Fan Circuit:

Load from fan was 1.32 W, for 230V AC.:

$$I = \frac{1.32}{230} = 0.05 \text{ A}$$

Wire size must be 1.5 sq.mm.

Panel Lamp:

Load from lamp was 15W, for 230V, AC:

$$I = \frac{15}{230} = 0.06 \text{ A}$$

Wire size must be 1.5sq.mm.

MCBs are required to protect the Electronic Component or EC panels from being damaged by a fault. This will allow for the proper branch load to be run. With

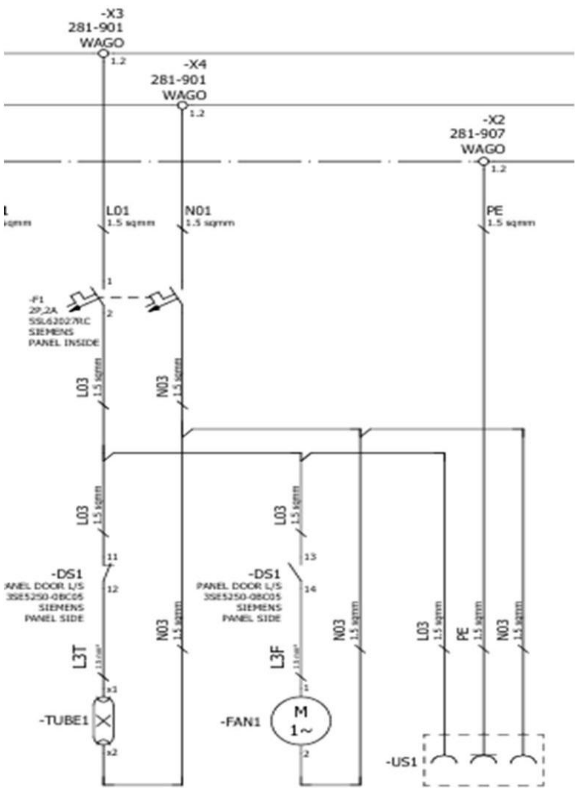

Figure2: Single Line Layout of on branch in Panel

an MCB in place, all components in the entire electrical system have been chosen using the Electrical Engineering Calculation Process.

Measures have been taken to maintain the temperature of Conduit Rise in accordance with IEC 61439 temperature rise of 30 - 35 °C above the ambient temperature. An ambient temperature of 40 °C will result in Insulation ratings of copper conductors used in the PVC insulated copper conductor selected will be ≥75 °C to be within the requirements. Also, emergency stop switches and other safety devices will be integrated into the electrical installation.

As a result of the Electrical Engineering Calculation process, electrical equipment will be wired and protected in accordance with electrical engineering industry standards. All branch circuits on the panel will be wired and protected from the electrical load based on the Electrical Engineering Calculation process.

Circuit	Current (A)	Wire Size	MCBRating	Remarks
Main Incoming	23.9	4 sq.mm	32 A, C	Full panel protection
Cooling Fan	0.11	1.5 sq.mm	2 A, B	Small resistive load
Panel Lamps/Indicators	0.11	1.5 sq.mm	2 A, B	Low power circuits
SMP5L Input	4.5	1.5 sq.mm	4 A, C	Allows inrush current
Universal Socket	5	1.5 sq.mm	2 A, C	General purpose
Relay Coil	0.2	1.5 sq.mm	–	DC control circuit

Table1: Electrical Design Calculations for Panel Circuits

IV. COMPONENT FINALIZATION & JUSTIFICATION

The components for the actuator assembly panel were designed not as independent pieces, but as part of an integrated and systematic design process, considering the relationship of the various layers of electrical protection, automation control, quality assurance, and operator interface with one another. Each of the components was chosen based on what quantities could be calculated, what the Industry Standards were for that specific part, and how easily the part would connect with the other components of the complete design.

Electrical Protection and Distribution The design is based on the premise that electrical power has to be distributed to the various systems that they will use reliably. A 32A Type C MCB is used as the main incoming device, based on the amount of power consumed and the possibility that there will be inrush loads when activating automation equipment. The Branch MCBs are rated 2A, 4A, and 6A and will provide electrical service to lamps, relays, and power sockets and have been selected to ensure selective tripping. The correct wire sizes for all of the different circuits were calculated using a combination of different methods for voltage drop analysis and current rating. The copper busbar sizes were also calculated for short-circuit loading capacity. All of the above components do not work in isolation, and therefore they are all part of the complete electrical supply to provide power and safe, reliable operation to the PLC, camera, HMI (Human Machine Interface), and Nut Runner Controller.

Siemens S7 1215 PLC (Automation Control) The PLC is positioned at the heart of the system due to its modularity, built-in Ethernet capability, and support for Industry 4.0 within the automation network. The PLC was selected on the basis that it could take inputs from all sensor/switch devices, execute logic designed into the program, and provide control for everything coming out of the PLC such as relays, motors, and tower lights. In addition, it provides integration ports (digital I/O and Ethernet) that allow for connecting electrical/mechanical (protection) layer of the system to other higher levels of automation (in this instance, the Keyence camera, nut runner controller, and Pro Face HMI cannot communicate in a feedback loop without the PLC).

Keyence IV3 500CA Smart
Camera (Quality Assurance) The Keyence smart camera was chosen to improve the quality assurance inspection capability of the system. Its ability to auto-focus and provide vision tools for real time inspection of the O rings, circlips, and assemblies made this a necessary component. The Keyence camera is not only capable of performing the necessary inspection, but it integrates directly with the PLC via Ethernet for real time inspection results (PASS/FAIL) back to the PLC logic, HMI screens, and control of next operations. Therefore, the Keyence camera serves as an active feedback node within the automation network, rather than a stand-alone quality tool.

Nut Runner Controller (Fastening Integrity) The completed Nut Runner Controller has been validated for torque and fastening accuracy. The Nut Runner Controller has three justifications: First, it provides assurance of safety and reliability; Second, it provides assurance of reliability when integrated into a system (i.e., torque and angle data are sent via Ethernet/RS 232 to the PLC, recorded for traceability); and Third, it allows for a closed loop of fastening integrity through continuous monitoring and relation to inspection and operator feedback.

Operator Interface (Pro Face HMI) The Pro Face HMI was selected for its user-friendly, easy to use interface for monitoring and controlling; however, the Pro Face HMI is also the interface where all the subsystems come together. The Pro Face HMI displays inspection results from a camera, torque data from a nut runner, and status data from a PLC, and all of these measurements can be immediately detected by the operator due to the visibility from tower lamps and alarms wired to the PLC outputs.

V. SYSTEM INTEGRATION AND APPLICATION

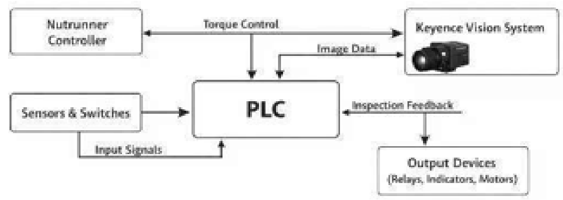

Figure3: Integration Layout for the PLC, Camera & Nut Runner System.

The automation system assembly line for actuators consists of an integration of various technologies, including a networked environment, structured cabling, a programmable logic controller (PLC), a vision system made by Keyence, a nut runner controller, and a human-machine interface (HMI). Each part is interconnected using structured cabling and communication ports. The PLC is the integration hub of the entire system; its input/output (I/O) modules, as well as its communications ports, make up the backbone of the integration. Sensors and push buttons will transmit their digital input signals to the input terminals of the PLC. The PLC will control the outputs to the actuators, relays and tower lights. In addition, it will use Ethernet ports (via a LAN network) connected to an industrial hub/switch to transfer information to/from the Keyence vision system, the nut runner controller and the HMI.

The integration of the Keyence vision system is done through an Ethernet communication connection to the PLC.

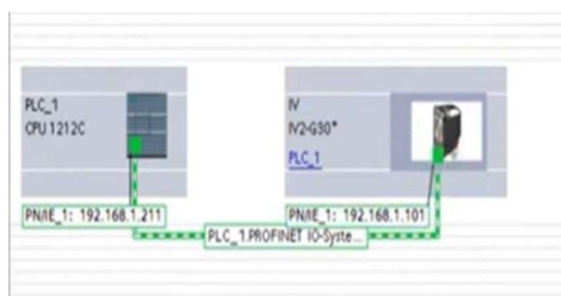

Figure4: Intergration of PLC & Camera

Each inspection trigger from the PLC is sent to the Keyence vision system through the hub. The Keyence vision system will send the PLC the results of the inspection (pass/fail) through the Ethernet connection established by the PLC and hub. The results of the vision inspection will be recorded by the PLC and displayed on the HMI at the same time. The use of Ethernet cabling provides a fast and reliable data transmission method between the Keyence vision system and the PLC, allowing for real-time inspections.

The connection between the nutrunner controller and the PLC depend on how the two were configured for instance: (1) Using Ethernet for communication; (2) Using serial communications via RS232 or RS485, depending upon configuration. (3) If connections are made via the HUB, a request from the PLC to begin fastening triggers an execution request being sent from the HUB to the nut runner controller and the fastener is tightened to torque and angle specifications. Feedback on the torque and angle is communicated back into the PLC, which logs the feedback value and continues to provide feedback items to the HMI display. The result of this integration to fastener operations, along with all other operational activities, like inspections and operator observations, become part of an overall communication loop.

The HMI display will be connected directly to the PLC using Ethernet and will allow the operator to execute cycles, view the results of inspections performed by the camera, view the torque data currently being generated by the nut runner controller, receive visual and audible feedback immediately (from tower lights and alarms) when connecting the RILO's output port into the PLC's output port, and therefore, establish a reliable means for operators to utilize . Each of these components ensures that when any of these components communicate simultaneously with the PLC, they function as a closed-loop automated communication facility, allowing for iterative cycles.

Logic, sequencing and communication across the entire machine is done through the use of a PLC based control system.

The Ethernet Hub/Switch acts as the primary means of communication between all devices/instruments on the machine via a single communication backbone.

- Keyence Camera utilizes Ethernet communication for vision inspection.
- Nut Runner Controller utilizes Ethernet/Serial port for torque control.
- HMI utilizes Ethernet for the operator interface and monitoring of the machine. These integrated communication methods are used to provide simultaneous inspection, fastening and operator interaction amongst all subsystems in a single port-based-network environment. completed matches the correct sequence of operations.

The push of the start button by an operator sends a start signal to the PLC, which then triggers PLC logic to perform the operation of the previous step. Operations can include cameras capturing images, greasing components, or activating cylinders.

The PLC has built-in interlocks designed to keep operators safe and to ensure proper use of equipment (e.g., a verified vision system will only allow greasing of the part if it has been confirmed that the O-ring was placed correctly.)

The PLC also helps synchronize parts across the three different assembly cells OP10, OP20 & the third).

The Keyence camera/vision systems are located at several different locations along the assembly line to confirm the assembly is being done correctly. At all inspection points, the PLC sends a trigger signal to the camera, which then captures an image of the component being inspected and verifies that the O-rings, circlips, etc., are correctly placed.

The inspection result, whether the components are OK or NG (not good), is sent back to the PLC, which either allows the process to continue or stops the process until the operator resolves the issue.

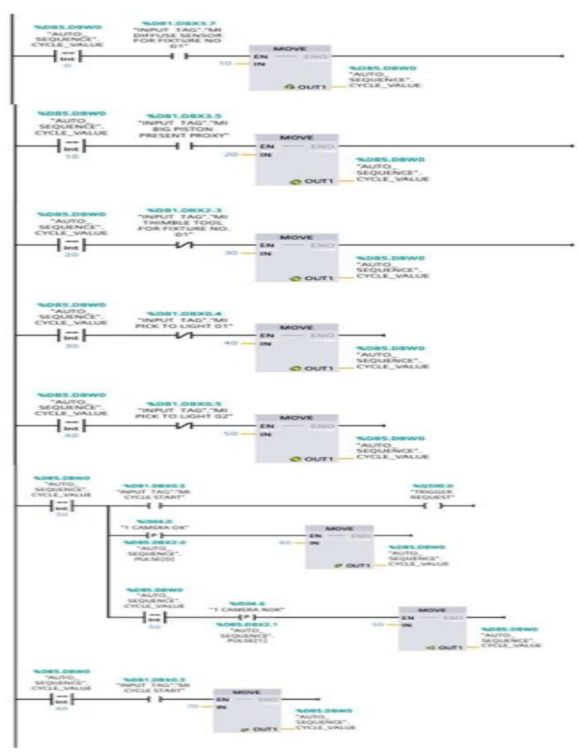

Figure5: PLC Programming of the one fixture operation

VI. SMART AUTOMATION OUTCOME

The Programmable Logic Controller (PLC) is the central access point for all operations being performed along the entire assembly line. It gets information from the tools/fixtures, controls operator input, and provides a means of ensuring that every step

These closed-loop inspections will guarantee a zero-defect assembly process and will eliminate the need for manual inspections by increasing accuracy and consistency throughout the assembly process.

At the time of OP20 fastening, the nut runner controller is utilized for the tightening of bolts, plugs, and adapters. After receiving confirmation from the PLC that the components are properly positioned, the nut runner controller begins to tighten fasteners according to the necessary torque and angle specifications. During this process, the controller continuously measures the value of each fastener being tightened and relays this information back to the PLC. If the torque meets the specified limits, the PLC will log the data into memory and progress the assembly process; conversely, if the torque is outside of the limits specified, an alarm will sound. The integration of the nut runner controller with the PLC provides a method to ensure mechanical integrity, traceability, and that all assembly processes are completed to all assembly standards.

The PLC, Keyence camera and nut runner controllers together form a smart automation loop. The PLC is used to orchestrate the sequence of events throughout the loop, while the camera provides vision inspection to ensure quality and reliability, and the nut runner controller secures the mechanical reliability of all fasteners being tightened. The PLC also receives and processes feedback from both the camera and the nut runner controllers, enabling it to perform automatic decision-making, error handling, and data logging functions. Together, these controllers create a fully integrated, digitally controlled, Industry 4.0 compliant actuator assembly line that provides electrical safety, operational efficiency, and advanced automation abilities.

VII. DESIGN OUTCOME

The completed actuator assembly system incorporates electrical safety, automatic control, and mechanical dependability into a compact, standards compliant panel/enclosure. The panel contains breakers, fuses, conductors and busbars that were each sized by way of detailed calculations to assure the safe transfer of power; auxiliary devices (relays, SMPS, terminal blocks) were arranged neatly within PVC cable ducts to enable both access and compliance. Ergonomically operated and providing clear operator feedback via both the human machine interface (HMI) cut-out, tower lamps and cable glands, the enclosure was designed to facilitate ease of operation. In terms of function, the programmable logic controller (PLC) is the central controller that coordinates the sensors, fixtures, and actuators. The Keyence vision system is capable of conducting real-time inspection at several points throughout the assembly process (e.g., O ring placement, circlip positioning and assembly orientation), verifying the correct performance of each operation. The nut runner controller is used to apply precise torque, while feedback loops provide necessary information back to the PLC for traceability. The integration of these devices into a closed-loop automation system greatly reduces the risk of human error while assuring zero defect manufacturing.

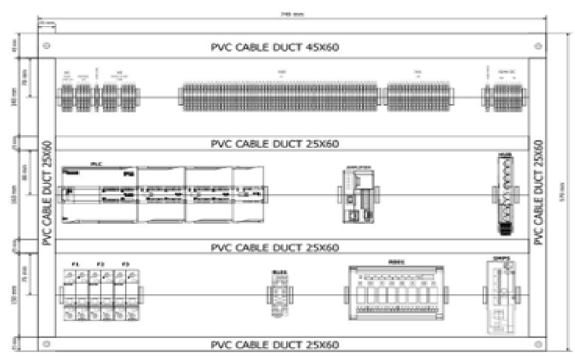

Figure6: Design of Control Panel of X-Actuator

By comparing the productivity for manual assembly to that of automated assembly, the analysis quantifies how significant the benefits of automation can be for a manufacturing enterprise. For instance, while it took an average of 18.31 minutes (1098.3 seconds) per assembly operation, the production potential was only 26 actuators for a 480-minute (8 hour) shift. On the other hand, the actual automated assembly method allows for 36 actuators to be manufactured per shift at the cycle time established by the consumer of 7.41 minutes (445 seconds) per assembly operation.

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