The external controller solutions (ECS) based on programmable logic controller with human-machine interface: A case study for the water level simulator plant

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Received: 26 October 2024 Revised: 21 December 2024 Accepted: 23 December 2024

Abstract— The External Controller Solutions (ECS) is designed with flexibility and able to be integrated with various plants. The ECS has been built using PLC and HMI. Several tests have been carried out in developing this ECS, including testing Digital Input/Output (DI/DO) and Analog Input/Output (AI/AO) voltages. This ECS be able to control up-to 8 devices simultaneously with the data refresh time interval of 100 ms and be able to handle up-to 10,000 operating cycles within 24 hours without significant performance degradation. ECS performance is very good, proven by the results showing that the system runs well within 20-35 °C of the temperature range and 20%-80% of humidity. To show the advantage of ECS, it has already been integrated on the Water Level Simulator (WLS) plant and successfully controlled the flow through the VSD at 54 RPM/Hz in range of 15-30 Hz.

Keywords—External Controller, PLC controller, integrated controller.

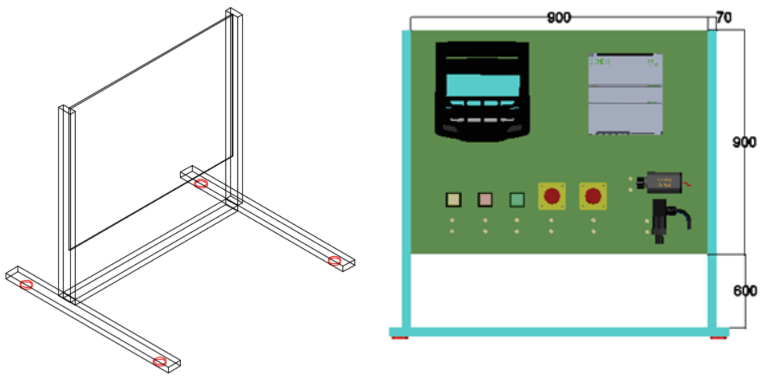
1. INTRODUCTION

Industrial instrumentation engineering plays a vital role in optimizing automation processes. A solid understanding of industrial Programmable Logic Controller (PLC) basics is essential [1], [2]. Engineers must be adept in planning, organizing, overseeing, and controlling industrial automation efficiently. In today's digital era, integrating information technology into production and management processes, such as industrial automation, data analysis, and simulation modeling, is crucial [3]. PLCs gather data from various sensors and devices in a plant, transmitting it to cloud platforms for rapid processing and secure storage [4]. This enables real-time monitoring and remote control of plant operations, facilitating faster decision-making and process optimization. However, cloud storage poses data security risks and relies on a stable internet connection, which can impact system operations if disrupted [5]. PLC features include flexible programming, real-time process control, robust communication capabilities, data-driven monitoring and decision-making, and increasing cybersecurity. These features support Industry 4.0[6] and IoT in industrial settings [7], [8].

The External Controller Solution (ECS) kit is a device kit which is flexible and easy to integrate with various plants, enhances practical application. This ECS includes buildable display as human machine interface (HMI), push buttons and indicator lights for input and control, allowing seamless integration with existing plant systems. In this research, a Water Level Control (WLC) plant is used for the study case [9]. In the previous case Programming of the PLC system is in the form of a Ladder diagram-based program syntax structure assisted by GX Works-2 32-bit [10]. The operating system's performance during synchronization is in the form of input from the operating panel, and several sensors on the input path are processed in the PLC program so that appropriate and precise output can be produced [11]. Performance when observing the output signals from several sensors installed in the operating system has functioned so that the operation of several devices on the output path is by the programming results embedded in the PLC [3] and in other cases This trainer and practicum module was developed to teach lecturers to explain PLC-based electric motor control material [12]. The PLC trainer in this study uses the Zelio PLC module type SR2 B201FU . This study used the research & development method in the trainer design and preparing the PLC practicum module. The research instruments used by the researcher were media experts and validation sheet material experts to test the trainer's suitability for the Electrical Machine Control Practicum application [13]. PLC manufacturing The results of the study showed that the size of the PLC developed based on the Electrical Machine trainer kit for the bottom and rear sides is 44.1 cm x 100 cm and 92.7 cm x 100 cm, respectively. It has a front tilt angle of 80°, the panel board is made of acrylic, the body is made of aluminium plate, and the PLC is installed with the Zelio SR2. 201FU brand. The PLC-based Electrical Machine trainer kit shows satisfactory performance, as indicated by the entire description, and the work can function appropriately according to plan [14].

2. METHOD

In this research, the model system of ECS was designed on the board and attached to the framework for its flexibility. It includes a sensor, a PLC, a HMI, motors, some buttons and pilot lamps to control and monitor a process. Through the ECS, users can develop PLC programming, connect and control various plants based on algorithm they have created. The ECS has been designed on 900 cm x 900 cm board with 1,5 m height of framework, shown by Figure 1.



(a) (b)

Figure 1. The ECS System Design: (a) framework and (b) user-view board

The selection of components in this research takes various factors into consideration such as number of inputs and outputs (I/O), processing speed, communication capabilities, manufacturer availability and support, and supported programming languages. The system's flexibility in being easily expanded and recons is essential, along with the ability of the PLC to communicate with other devices in the system. In addition, the input/output (I/O) module selection must consider the type of signal to be connected, such as digital, analogue, or special connections such as high-speed encoders or sensors. Furthermore, in selecting a communication module, it is necessary to consider compatibility with the protocols used in the system, whether it is Ethernet/IP, Profibus, or Modbus, and the ability to connect to external devices.

The ECS not only has adaptive features with various plants, but also equipped with basic automation features so that without being connected to the plant, ECS can show its own automatic performance by adopting the "Simple Automation" scheme using PLC. In this process, a ladder diagram program (Figure 2) has built to test the PLC's operation and function of the PLC's input and output. The test involved 2 push buttons, 3 pilot lamps and the HMI display. By pressing the ON button, controller will send signal to turn on three lamps simultaneously. The same thing happens if the off button is pressed.

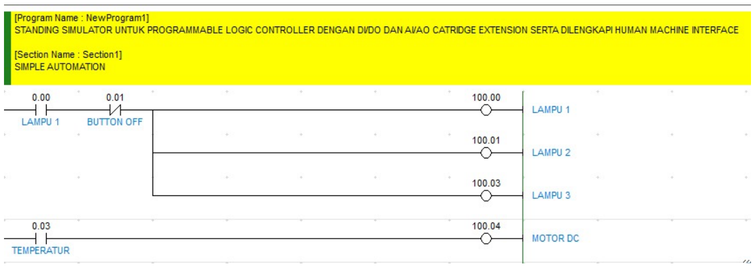
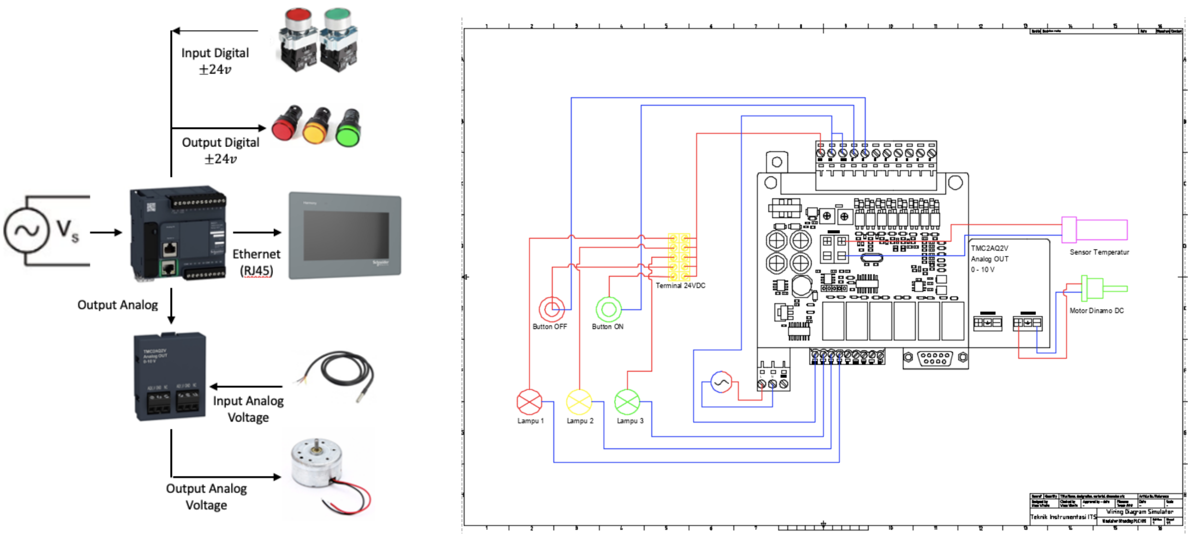


Figure 2. Simple Automation Test Function Simulator

After ladder diagram of a "simple automation" has been done, then we have designed a wiring diagram as shown in Figure 3, which provides a clear and detailed picture of all electrical connections between various components in the system. This wiring circuit includes connections between PLC inputs and outputs, control signals, electrical power, and various additional devices such as sensors, actuators, relays, and switches. The wiring diagram serves as a practical guide during system installation or repair, allowing technicians to quickly identify and resolve any wiring or connection problems that may occur.



(a) (b)

Figure 3. (a) The ECS scheme and (b) the wiring diagram of 'simple automation' feature

This data is then processed by the ECS's central processing unit (CPU) according to a pre-programmed control program. The program contains control logic that dictates how the PLC should respond to various input conditions by executing the appropriate outputs. Once processed, the control logic results are directed to the ECS's output modules that control devices or actuators. The ECS workflow also includes monitoring and maintenance steps during system operation. The ECS's can be equipped with a user interface or human-machine interface (HMI) that allows the user to monitor the operational conditions of the system in real-time, check the status of inputs and outputs, and access data.

To ensure the controller can operate the system accurately, we have done some scenario tests. First, input-output (I/O)test of controller. Second, simple automation test which involves HMI function, such as changing setpoints, starting or stopping processes, and monitoring equipment status. Third, monitoring system performance tests to ensure the controller and HMI be able to show the real-time and accurate measurement to the user.

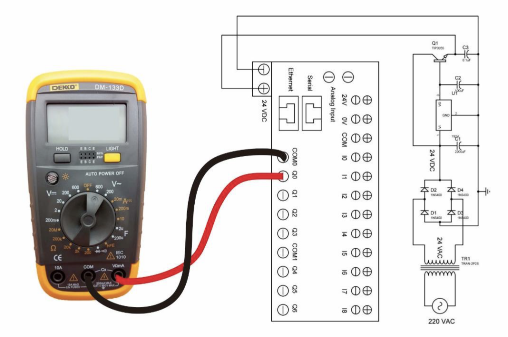


Figure 4. Controller I/O Test Scheme

Digital input test (Table 1) is a documentation tool used in control system testing to record the results of testing various digital inputs. The table includes columns that record the number or label of each input tested, a description of each input's function, and the status of the input condition during the test, whether it was active (ON) or inactive (OFF). Additional columns may also include test results that record whether the inputs functioned as expected or had problems that required correction. The Digital Output test table is a documentation tool used in control system testing to record the results of testing digital outputs. The table is typically structured in rows and columns, each representing one digital output tested and each containing relevant information related to the test results. The process should produce an output of 24VDC, which can help identify potential errors or failures in processing IO signals and allow for corrections before implementation in a production environment. In addition, IO testing also includes compatibility checks between the PLC and the IO hardware used, ensuring that the two interact effectively. Thus, the IO testing function on PLC mitigates the risk of errors and improves the reliability of the overall automation system, as shown in Table 1.

Table 1. Controller I/O Validation

Input	Lamp Q0.0	Lamp Q0.1	Lamp Q0.2	Notes
Button ON	ON	ON	ON	Check/Fail
Button OFF	OFF	OFF	OFF	Check/Fail

According to the table, we need to ensure that the lamp light is up as it should when the push-button is ON. Then, when the push-button is OFF, the lamp turns off as it should. If the system fail to respond, the user has to re-check the wiring system and do re-commissioning.

The system starts with a power supply (Vs) that provides the voltage required for the entire system to operate. On the digital input section, there are red and green pushbuttons that each produce a +24V signal when pressed. The signals from these buttons are fed into the programmable logic controller (PLC) through the digital input port. Furthermore, the digital output from the PLC is used to control the red, yellow, and green indicator lights, which indicate the operational status of the system. The PLC is also connected to a human-machine interface (HMI) display via an Ethernet interface, allowing users to monitor and control the process in real time. In addition, there is an analog output module connected to the actuator in the mechanical system, which functions to adjust the water level in the water level control plant based on the signal received from the PLC. This entire system is used to control and monitor the process in the simulator standing trainer kit, with integrated data communication between the PLC, HMI, and actuator.

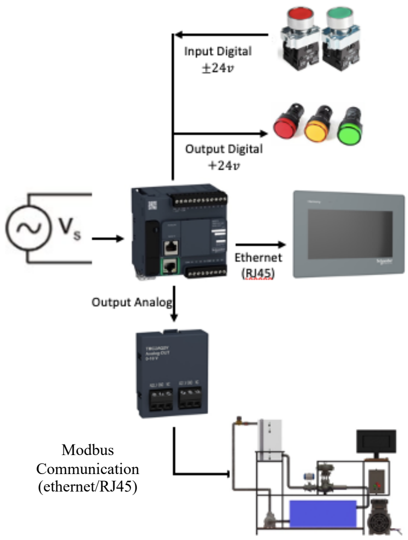


Figure 5. Plant water level control modification workflow

The ECS testing on a plant is an important stage to ensure the successful implementation of an industrial automation system. Testing is carried out to verify that the ECS can control and monitor the operation of the water level control plant efficiently per the design and specifications set. At this step, testing involves all elements connected to the ECS, including Pushbuttons, lights, actuators, and other hardware, to ensure proper integration and accurate response. By involving comprehensive testing on the plant, developers can identify potential problems, respond effectively to changing conditions, and ensure that the ECS automation system operates optimally to support operational efficiency. The following in Table 2 is the steps for testing the Plant Water Level Control.

Table 2. Plant Water Level Control Testing Steps

	Preparation
Preparation of Tools and Materials	• Th ECS and its program. • Schematic wiring diagram. Water level sensor. Actuators (pumps, valves, etc.). • The ECS and its program. • Schematic wiring diagram. Water level sensor. Actuator
Initial Check	• Make sure all components are in good condition. • Check the cable connections according to the wiring diagram.
	ECS Program Verification
Load Program to PLC	• Upload the designed water level control program to the ECS. • Run the program simulation in the ECS software to ensure the control logic is working correctly.
	Hardware Testing
Pushbutton and Light Testing	• Press each pushbutton and check that the indicator lights are functioning as expected.
Actuator Testing	• Activate actuators (such as pumps) via the ECS and ensure they respond according to program instructions.
	System Integration Testing
Overall Testing	• Run the overall control system. • Observe the system response to changes in water level. • Record the test results for each scenario.

The ECS testing on a plant is an essential stage in ensuring the successful implementation of an industrial automation system. Tests are carried out to verify that the ECS can control and monitor the operation of the water level control plant efficiently according to the design and specifications that have been determined. At this stage, testing involves all elements connected to the ECS, including pushbuttons, lights, actuators, and other hardware, to ensure proper integration and accurate response. By engaging in comprehensive plant testing, developers can identify potential problems, respond effectively to changing conditions, and ensure that the ECS automation system operates optimally.

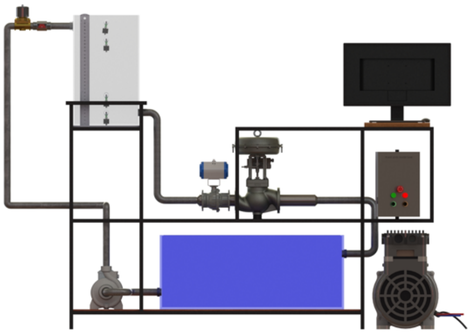


Figure 6. The Water Level Control Plant

Controlling the water level in the plant uses the ECS controller that regulates the frequency of a single-phase motor involving several components. This system usually consists of a water tank, level sensor, single-phase motor, Variable Speed Drive (VSD), and ECS. Data from the VSD is sent to the ECS, which then processes the information and gives commands to the ECS to regulate the frequency of the single-phase motor. This frequency change controls the rotation speed of the motor for three stages, which regulates the flow of water entering or leaving the tank. This system allows the motor speed to be maintained automatically at a predetermined level. Additionally, advanced diagnostics are often incorporated into the ECS system to continuously monitor the health and performance of the control system components. These diagnostics help in detecting faults or inefficiencies early, allowing for preventive maintenance and minimizing downtime. The integration of Human-Machine Interface (HMI) with the ECS further enhances the monitoring and control capabilities, providing operators with real-time data visualization, control options, and alerts. This ensures that any deviations from the desired water levels can be promptly addressed, maintaining the overall efficiency and reliability of the water level control system.

3. RESULT AND DISCUSSION

The ECS systems are designed using acrylic as the material. The results of this processing are then translated into outputs that control actuators, such as motors and existing lights. A touchscreen HMI provides an easy-to-understand graphical display of production process status, control parameters, and other important information.

Table 1 ***Trainer Kit Item***

Device	*Input*		*Output*	
	Physical Quantities	Signal	Physical Quantities	Signal
Temperature Transmitter	Temperature	Analog	Voltage	Analog
DC Motor	Voltage	Analog	Rotational Speed	Analog
Potentiometer	Voltage	Analog	Resistance/OHM	Analog
DC Pilot Lamp	Voltage	Digital	Lumen	Digital
Push Button	Voltage	Digital	Voltage	Digital

In the ECS, items in Table 3 are included as input and output from a PLC. The temperature transmitter output is analogue and will be used as input from an analogue PLC to affect the rotation of the DC Motor. The temperature transmitter will control the DC motor according to the heat by the transmitter's temperature. The lights themselves will be influenced by the push button that is pressed according to the ladder diagram provided. Several simulation variations exist for ladder diagrams from a digital input and output, where these inputs and outputs are based on training questions from BNSP, a PLC certification institution.

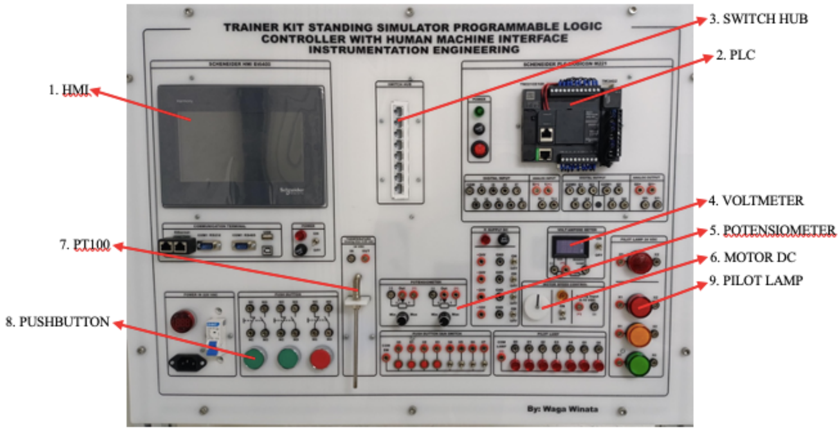


Figure 1. The ECS

The local test results of the PLC and HMI standing systems showed satisfactory achievements. The entire ladder diagram was implemented successfully, resulting in consistent and efficient operations that were in line with the established specifications. No significant anomalies were recorded during the test period, and the system performance showed consistent and reliable stability. In response to these findings, corrective measures will be implemented immediately to address the detected issues and ensure that the system performance reaches the expected perfection. Verification of the Ladder program found that the implementation was carried out using the established methodology. A thorough analysis of the algorithms and data structures used found that the program had been able to carry out its tasks with high efficiency. In addition, this verification also confirmed that the code had met security standards and was reliable in its use. Thus, the results of this verification of the Ladder program are ready to be implemented in a production environment with guaranteed quality. In addition, in this verification process, several recommendations for improvement were also revealed that could improve the quality and performance of the program.

3 Alternating Lights, the complete working principle of the three alternating lamp program is to utilize the concept of sequential control to regulate the switching of the lights alternately according to the order specified by the TON command with preset 3. Initially, one lamp will be turned on while the other two are turned off. Furthermore, gradually, the lamp turned on will be turned off, and the other lamps will be turned on in the same order. This process will continue to repeat itself, creating a continuous lamp-switching effect using NO as on and NC as off the interlock of the circuit. With %Q0.0 as LAMP #1, %Q0.1 as LAMP #2, and the last %Q0.2 as LAMP #3 and the initial NC as the lock of the interlock circuit. With a 3-second timer alternately with the timer code %TM0 for the first TIMER #1 with type TON and Q output to the side of the production and the lock for the RUNG #0 circuit uses LAMP #1 with Ladder code %Q0.0 and the second lock uses TIMER #3Q with Ladder code %TM2.Q. For RUNG #1, the lock circuit is LAMP #2 with Ladder code %Q0.1, then enters TIMER #2 with Ladder code %TM1, and Q enters the output of RUNG #1 with a TON type timer and 3 seconds present. Then, RUNG#2 is the same as RUNG#1 with the LAMP#3 lock with the Ladder code %Q0.2 with a TON type timer with the same present 3s. Then, the Q output from RUNG#2enters the production from the RUNG itself, as in Figure 8 and 9.

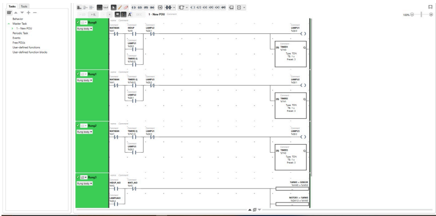


Figure 2. Ladder diagram 3 Alternating Lights

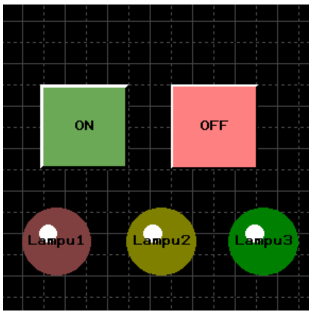


Figure 3. HMI 3 Lights Automatic Display

Automatic Bell In its working principle, the automatic bell system utilizes a Ladder diagram to represent its control logic. The working principle of this system is based on continuous monitoring of input from sensors or other environmental conditions. When the input meets the specified requirements, the logic circuit in the Ladder diagram will regulate the activation of the output, which in this context is the sound of the bell. Ladder diagrams provide clarity and ease in visually understanding system operations, thus facilitating the verification process. %M4 as auxiliary 2 to interlock RUNG#1 and %M5 as auxiliary 3 to interlock RUNG#2 to assist programming as a lock for the Ladder so that it is not disconnected from the Input and Timer using the TON command with the presence of 3sec. At RUNG#0 enter %M0 as NO to turn on the next NC with Addressing %M4 with code BANTU#2 then enter again to BANTU#3 with Addressing %M5 with Ladder NC to break the locking circuit from RUNG#0 by entering the next NC with Addressing %TM0.Q and the output of RUNG#0 is BANTU#1 with Addressing M3 and added letting at RUNG#0 with Addressing the same as the output at Addressing production of the circuit, namely %M3. RUNG#1 and RUNG#2 are the same as RUNG#0, with NC as the circuit breaker as in Figure 10, Figure 11, and HMI displayed in Figure 12.

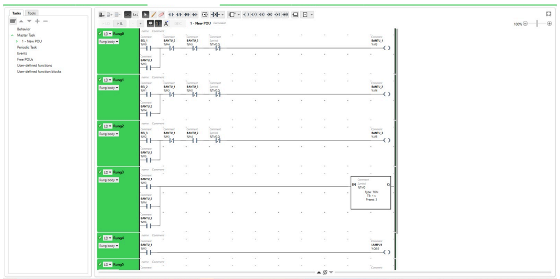


Figure 4. Ladder diagram Automatic Bell 1

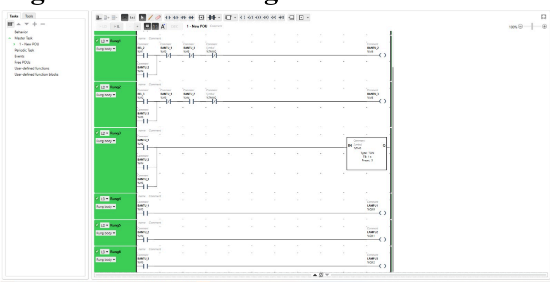


Figure 5. Ladder diagram Automatic Bell 2

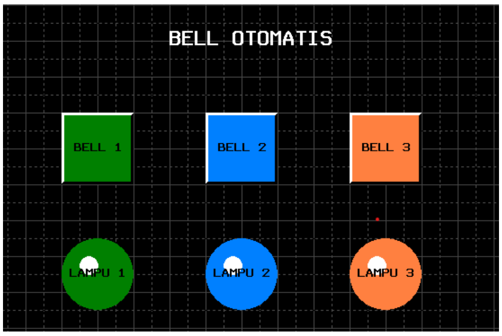


Figure 6. HMI Display Automatic Bell

Conveyors are generally set to automatically transport goods or materials from one point to another. This process begins with detecting objects to be transported by sensors that are given command %I0.4. After detection, the conveyor motor is activated to move conveyor 3 in the desired direction and speed sequentially and continuously with the command %Q0.3 and the interlock command the same as %Q0.3. For conveyor 2 with the command %Q0.1, the interlock command with the code %Q0.1, and the timer command %TM0.Q. Sensor2 with the command %I0.3 with NO, with sensor1 %I0.2 as the interlock circuit breaker as %Q0.0 with the interlock circuit. In Figure 13 and Figure 14, the Timer with the command %TM0 with present 5sec by activating from NC %TM0.Q.

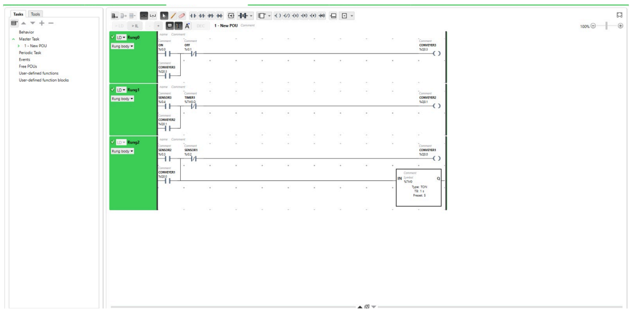


Figure 7. Ladder diagram Conveyor

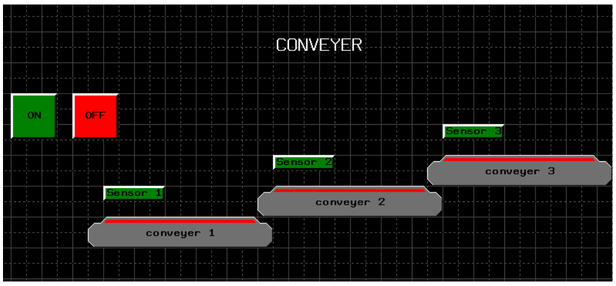


Figure 8. Conveyor HMI Display

Exhaust fan control in the Ladder diagram is based on ladder programming logic that regulates the flow of execution of control functions. The diagram visualizes the sequence of logical steps that control the exhaust fan and the Stove when turned on with the commands %Q0.0 and %Q0.1. NC %I0.1 is the interlock circuit breaker from the Stove, and the emergency command is the breaker %I0.2, which has the same NC command. Then, the Stove gives a signal to the timer with the TOF command %TM0 with a present of 10sec to turn off the circuit. And %TM0.Q as turning on the exhaust fan with the command %Q0.1 and its interlock circuit with the command %M0 as an interlock. To turn on the exhaust fan, the control enters with NO from the Stove with the input %Q0.0 on RUNG # 1. It enters the TOF timer as a circuit breaker with TIMER # 1 and a present of 10s with the Addressing of the timer being %TM0, and the output Q of the timer enters the output of RUNG # 1 as in Figure 15 and Figure 16.

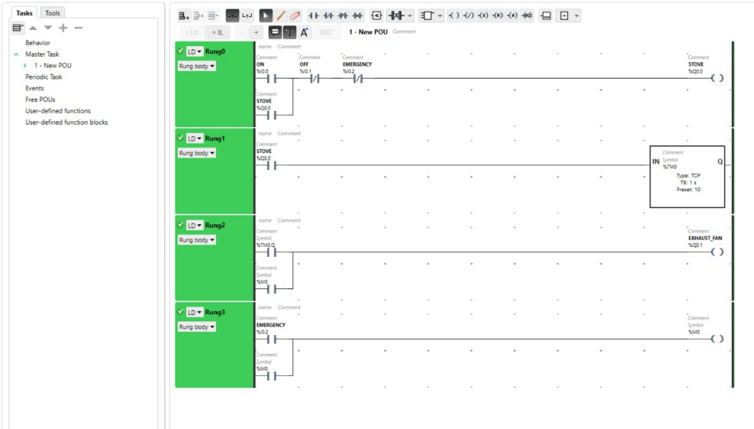


Figure 9. Ladder diagram Exhaust Fan Control

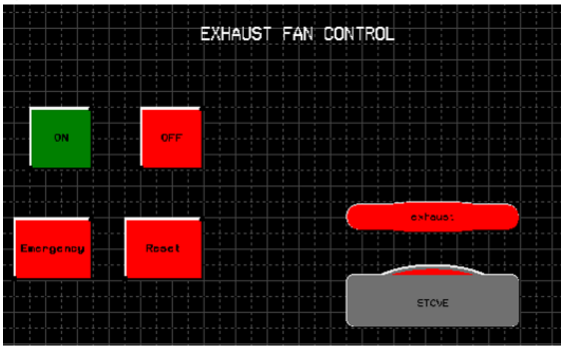


Figure 10. Exhaust Fan Control HMI Display

The fish feeding system can also be equipped with additional fish motion sensors to detect the presence of fish around the feeding area. If there are fish, the ON button %I0.0 button is OFF %I0.2 with NC switch conditions and auxiliary contacts using memory %M2. This working principle ensures that feed is provided automatically and efficiently, improving fish welfare and facilitating the overall management of fish farming. With input %M0 as timer input %TM0 and output VALVE # 1 with contact %Q0.0 as the opening of the valve and which entered timer 2 %TM1 and input from VALVE # 1 with Addressing %Q0.0 and assisted by %M0. Then, for RUNG # 4 with input %M0, enter NC VALVE # 1 with Address %Q0.0 and VALVE # 2 with NC %Q0.1 input to timer %TM2 and output VALVE3 %Q0.2. Then, from the input %M0 to %TM3 with a 60-second timer, the output %M1 is shown in Figure 17 and Figure 18.

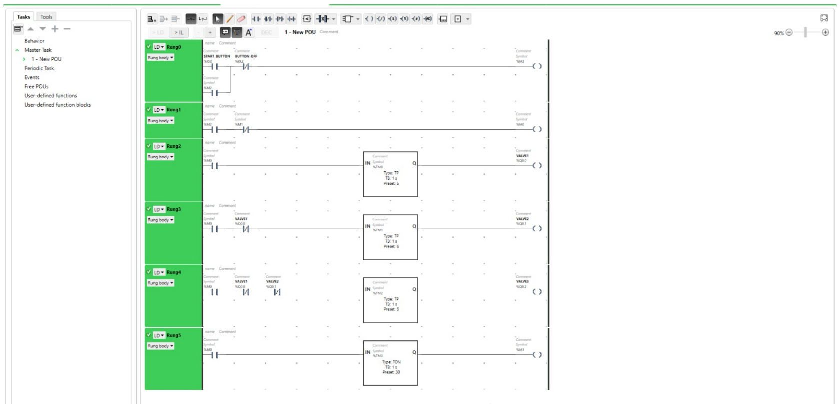


Figure 11. Ladder diagram Fish Feeding System

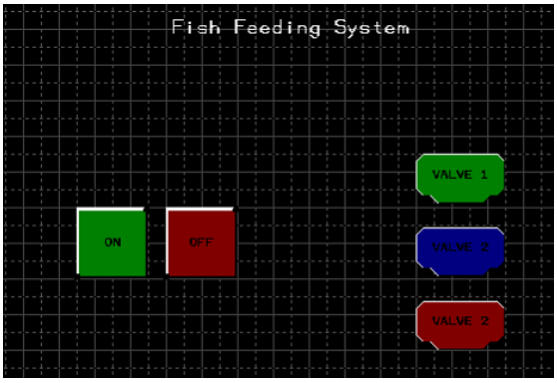


Figure 12. HMI Fish Feeding System display

Analog Program Verification Results is nn entering analog programs there are some scaling done in Min and Max. For Min it is set to 0 and Max 1000 because to get 10vdc to become the max voltage. From the temperature measurement range of 0-100 degrees Celsius as in Figure 19.

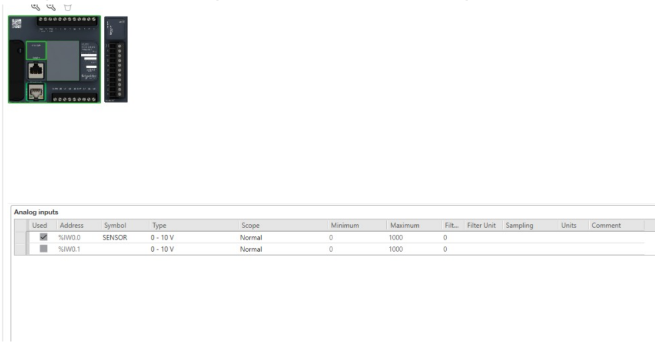


Figure 13. PLC Scalling

In the Ladder diagram, life uses NO %M2 as its life from Analog, NC as a circuit breaker with Address %M3 and enters the Analog Input as a sensor with Address %MW0:=%IW0.0 as a PT 100 sensor. %QW1.0 : = %QW1.0 =%MW0 for analog sensors using the rule >300 when the voltage has reached 3v or the motor rotation is 3v, it will turn on LAMP #4 with Address %Q0.3 as a lamp. For additional memory from the Ladder, it uses %MW0, which is paired with the sensor code using analogue Input with Addressing %IW0.0. At the bottom of the Ladder, the motor enters with memory %QW1.0, then enters memory %MW0, then is given an indicator lamp LAMPU#AIO with the Ladder code or Addressing %Q0.4 and the IF command on RUNG#1 with the Addressing command %IW0.0 >300 as the on command, the indicator lamp will turn on if it is more than 300 or 3v and enters the indicator LAMPU#4 with Addressing %Q0.3 as the indicator as in Figure 20 and Figure 21.

Figure 14. Analog Program Ladder Diagram

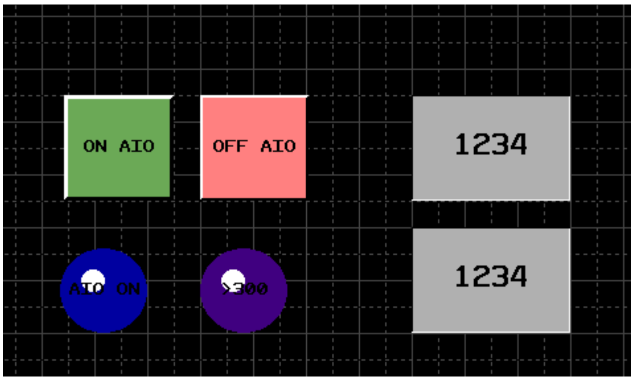


Figure 15. Analog test HMI display

Digital Input Output in The TM221CE16R PLC with 24V input voltage and validation at 23.9V can be used in a 16-channel I/O (Input/Output) configuration. In this context, "16 channels" refers to the total inputs and outputs on the PLC device. With a 24V input voltage, each input channel can accept digital signals from external input devices operating at the same voltage, such as switches, sensors, or push buttons. With a 16-channel I/O configuration, the TM221CE16R PLC can handle various control tasks in more complex systems, as shown in Tables 4 and 5.

Table 2. Digital Input Channel

Digital Input TM221CE16R		
Digital Input	**Input Voltage (V)**	**Digital Input Voltage Validation (V)**
Channel 1	24	23,9
Channel 2	24	23,9
Channel 3	24	23,9
Channel 4	24	23,9
Channel 5	24	23,9
Channel 6	24	23,9
Channel 7	24	23,9
Channel 8	24	23,9
Channel 9	24	23,9

Table 3. Digital Output Channel

Digital Output TM221CE16R		
Digital Input	**Volt Input (V)**	**Digital Input Voltage Validation (V)**
Channel 1	24	23,9
Channel 2	24	23,9
Channel 3	24	23,9
Channel 4	24	23,9
Channel 5	24	23,9
Channel 6	24	23,9
Channel 7	24	23,9

Validation at 23.9V indicates the voltage threshold that must be met for the input signal to be considered valid. For example, if the input voltage on one of the channels reaches or exceeds 23.9V, the PLC will interpret the signal as "active" or "true", and if the voltage drops below 23.9V, the signal will be considered "inactive" or "false". Similarly, on the output channel, the PLC can send a digital signal with a

voltage of 24V to an external output device such as a relay or solenoid, to control other devices in the system. This allows the PLC to perform the control functions required in industrial automation applications with high precision and reliability.
The accuracy of a PLC output channel is:

$$1-\left(\frac{24-23{,}9}{n-24}\right)\times 100 = 99{,}583\%$$

The accuracy of the voltage measurement in the table is approximately 99.583%.

Analogue temperature sensors may be connected directly to the controller module, which then transmits data to the monitoring system using analogue signals. This process allows for accurate and real-time temperature measurement, as well as precise control of the production environment. The experiment was carried out 15 times. Then, the maximum voltage in the sensor results was 9.9v, while from the validation, the difference is 0.1v, so for the error of the measured voltage is around 0.1v, the minimum voltage from the measurement is 0.66v at a temperature of 20 degrees, the maximum temperature is 90 degrees because the temperature cannot reach 100 degrees in a maximum voltage of 9.9v and in the validation it is read 9.91v.

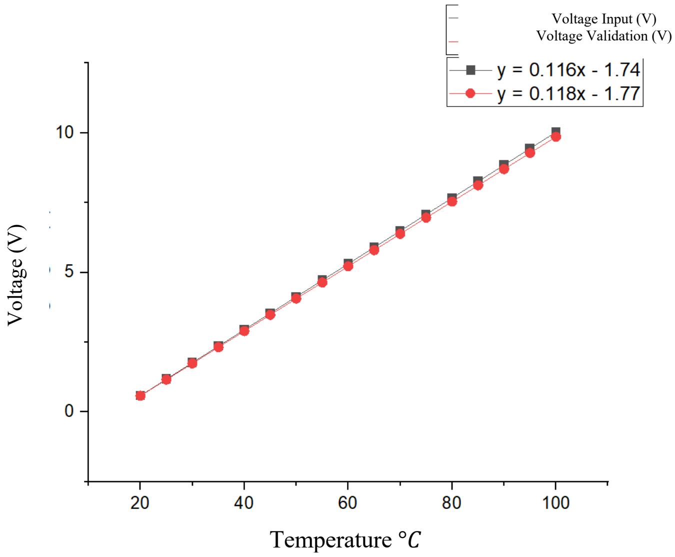


Figure 16. The Static Characteristic Graph of Temperature Sensor

Particularly in this case, where the test is conducted from 20 to 100 degrees Celsius in 5-degree increments, a validator is needed. The validator will compare the voltage generated by the temperature sensor at each test point with the expected value based on a linear increase. If the sensor response matches the expectation, then the sensor is considered to have good linearity. In the context of the 17-point test from 20 to 100 degrees in 5-degree increments in Figure 22, the validator will check whether each voltage generated by the sensor matches the expected value based on a linear increase. If there is a significant difference between the measured value and the expected value, then the sensor may not be showing adequate linearity. Therefore, such testing allows for a comprehensive evaluation of the performance of the temperature sensor under various temperature conditions.

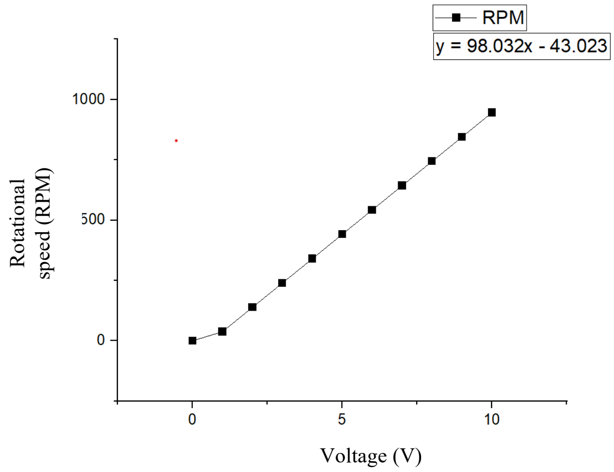


Figure 17. DC Motor Graphics

A DC motor graph showing the relationship between input voltage and rotational speed of motor is an important tool to analyze the motor's performance characteristics. On the X-axis of the graph, we will show the input voltage applied to the DC motor, ranging from 0 volts to 10 volts, in Figure 23. On the Y-axis, we will plot the motor RPM, which is the revolutions per minute produced by the DC motor in response to that voltage. As the input voltage increases, the motor RPM is expected to increase. This is because increased voltage provides more energy to the motor, which in turn produces faster rotational motion. Note, however, that the relationship between voltage and RPM is not always linear. There are limits to the increase in RPM that a particular DC motor can achieve, which may be due to factors such as the torque supplied by the motor, the load imposed on it, or the physical limitations of the motor itself.

The graph used in a DC motor speed control system is usually a linear graph that shows the relationship between temperature input and DC motor rotation speed output. This graph helps in understanding how changes in temperature affect the rotational speed of a DC motor and how the control system can adjust the rotational speed of a DC motor based on the ambient temperature. In the example of a DC motor speed control system using a PLC above in Figure 25 with an M221 controller and PT100 temperature sensor, a linearity graph can be used to display the relationship between environmental temperature and DC motor rotation speed. This graph can help in understanding how the control system can adjust the rotation speed of a DC motor based on environmental temperature, such as when the temperature increases.

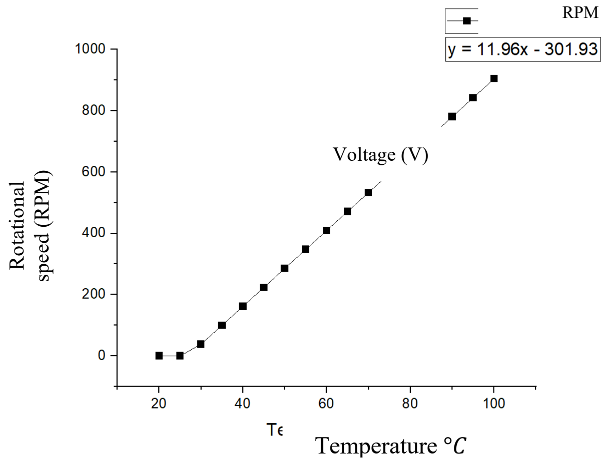


Figure 24. Temperature on Motor Rotation

The 10k potentiometer is used as a sensor to measure environmental temperature. The ambient temperature measured by the 10k potentiometer is then sent to the PLC as an analog input. The PLC, as a programmable device, uses environmental temperature information to control the rotation speed of the DC motor, as in Figure 25. The rotation speed of a DC motor can be adjusted variably using environmental temperature information measured by a 10k potentiometer. The graph of the linearity of the 10k potentiometer against a DC motor shows that the rotational speed of the DC motor changes linearly with variations in the measured environmental temperature. This means that the PLC can accurately control the rotation speed of the DC motor based on ecological temperature information received from the 10k potentiometer. This graph also shows that a PLC can be used to control a DC motor effectively by using input from a 10k potentiometer as an environmental temperature sensor.

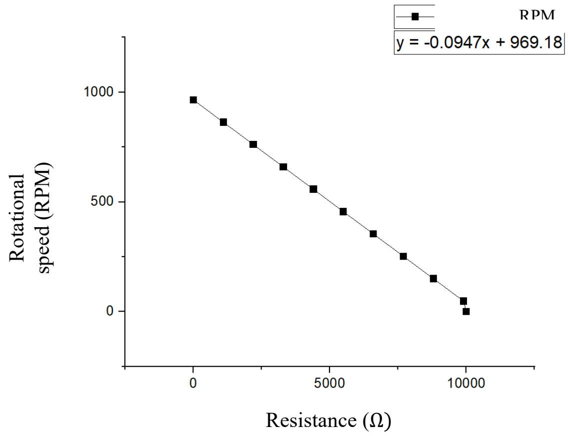


Figure 25. Resistance to DC Motor Rotation

This test uses three different speeds in plant water level control, namely 20Hz, 25Hz, and 30Hz, where this external controller, the Trainer kit standing simulator, Programmable Logic Controller with Human Machine Interface, can run according to the instructions from the Ladder diagram commands read on the HMI and functions using the buttons available on the Trainer. Kit. It also uses Modbus communication with an RJ45 cable for commands into the VSD.

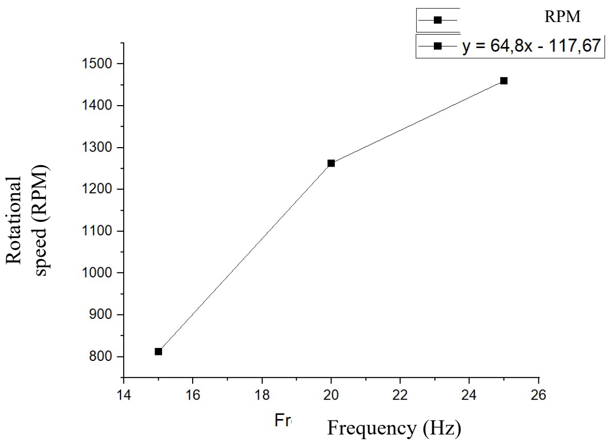


Figure 26. Standing Frequency of 1-Phase Motor Rotation

Analysis of the Plant Water Level Control Test in Figure 26 shows three-speed controls for rotating a pump. Where the pump is entered into the VSD as a frequency controller that enters the pump starting from 15Hz, 20 Hz, and 25 Hz, all of which have their own RPM speed. For Speed 1, which is 15Hz, the pump speed is plodding. This is the minimum pump speed of the Plant Water Level Control setting limit. The pump rotates at around 800 RPM and has a frequency of 20 Hz at 1200 RPM and a frequency of 25 Hz at 1400 RPM. Where 3 This speed control will affect the flow rate of the flow flowing into the water storage tank; the higher the frequency given, the faster the flow rate will be and the quicker the tank will be filled.

This study presents a highly accurate External Controller Solution (ECS) capable of maintaining a voltage output deviation of only 0.01V, ensuring precise control and monitoring. The ECS also demonstrated superior scalability, with analog input/output scaling that achieves a maximum voltage of 10V for a temperature range of 0–100°C, such as 0.59V at 20°C and 3.54V at 45°C. Additionally, its integration with a water level control plant highlighted exceptional performance, successfully regulating motor speed through a Variable Speed Drive (VSD) at 54 RPM/Hz within a frequency range of 15–30 Hz. Compared to similar studies, which often focus on specific plant integrations or trainer kits with limited adaptability, this ECS provides broader functionality by supporting multiple device operations, high-frequency responsiveness, and sustained performance over extended cycles. These attributes establish the ECS as a robust and versatile automation solution that surpasses traditional PLC-based implementations in flexibility and environmental resilience.

4. CONCLUSION

Display Design on HMI can be communicated with IP Address 192.168.1.52 for the ladder in the ECS program, which can be communicated with IP Address 192.168.1.53 as the ECS protocol. Testing shows that the ECS output voltage has a difference of only about 0.01V compared to the validator, indicating high accuracy. Analog Input/Output Scaling: Scaling is carried out to ensure the maximum voltage output reaches 10V from a temperature measurement range of 0-100°C. Min = 0 and Max = 1000. A temperature of 20°C produces a voltage of 0.59V, corresponding to a low RPM. A temperature of 45°C produces a voltage of 3.54V, corresponding to a high RPM. The ECS output voltage has a difference of only about 0.01V compared to the validator, indicating high accuracy in this system. The test results show that ECS can control rotational speed of motor through VSD on Water Level Plant at 54 RPM/Hz in range of 15-30 Hz.

Acknowledgment

The authors would like to thank Institut Teknologi Sepuluh Nopember for the financial support. This work was funded through Research Funding Program no 1763/PKS/ITS/2022.

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