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Design and implementation of a fluid flow instrumentation system based on supervisory control and data acquisition (SCADA) and programmable logic controllers (PLCs)

Raden Roro Hasna Humaira[1], Eki Ahmad Zaki Hamidi[2], Azwar Mudzakkir Ridwan [3]
[1,2,3]Department of Electrical Engineering, UIN Sunan Gunung Djati Bandung, Indonesia

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ABSTRACT

that may lead to operational failures. This study aims to design and develop an instrumentation system capable of performing monitoring, control, and early warning functions through the integration of a pressure transmitter, Haiwell AC12M0R PLC, HMI, and SCADA using TCP/IP and Wi-Fi communication protocols. The system design includes hardware development, ladder diagram programming, and configuration of a cloud-connected HMI–SCADA interface. System testing was conducted by varying pressure setpoints to simulate different operating conditions. The test results indicate that the system operates as designed, as evidenced by alarm activation at a pressure of 6 bar, proportional opening of the Pressure Control Valve (PCV) when the pressure exceeds the 5 bar setpoint, and activation of safety functions under high-high pressure conditions at 9 bar, where the system triggers an alarm, closes the Shut Down Valve (SDV), and automatically stops the pump. The PCV response time was recorded at 0.1–0.2 seconds, while the SDV fully closed within 5–6 seconds. All process data can be monitored in real time through the HMI and cloud-integrated SCADA system, enabling remote monitoring via smartphone. Overall, the developed instrumentation system prototype functions in accordance with the control logic and performs reliably under the simulated operational scenarios.

Corresponding Author:

Eki Ahmad Zaki Hamidi,
Electrical Engineering Department, Faculty of Science & Technology, UIN Sunan Gunung Djati Bandung Jl. A. H. Nasution No. 105, Cibiru, Bandung, Indonesia. 40614
Email: ekiahmadzaki@uinsgd.ac.id

1. INTRODUCTION

The oil and gas industry is a sector that faces high risks related to leaks and fires in piping systems. These systems serve as the main fluid distribution channels and are critical elements in operational safety [1]. The failure to detect pressure fluctuations or indications of leaks can result in serious incidents, including explosions and fires. These incidents can lead to material losses and fatal consequences for workers and the surrounding community.

The conflagration that transpired at the Jakarta Integrated Terminal (ITJ) on 3 March 2023 serves to underscore the pivotal function of early detection and protection systems. The incident resulted in 19 fatalities, 49 injuries, and the evacuation of hundreds of residents [2]. Incidents of this nature have also occurred at several PT Pertamina oil refineries in recent years [3]. The majority of theseincidents were attributed to the failure of early leak detection in piping systems or the inability of control systems to anticipate overpressure, thereby posing a significant risk to worker safety, the environment, and company assets [4]. Current systems have yet to demonstrate full capacity for expeditious response to pressure fluctuations, thereby amplifying the risk of overpressure, which can ultimately result in system failure [5].

The objective of this study is to design and implement an instrumentation system based on the principles of Programmable Logic Controller (PLC), Human Machine Interface (HMI), and Supervisory Control and Data Acquisition (SCADA). The implementation of this system is intended to enhance the existing instrumentation system in fluid flow. The PLC functions as a deterministic logic controller, capable of executing protection actions expeditiously based on pressure sensor readings. The function of the PCV (Pressure Control Valve) is to regulate valve opening in order to maintain stable pressure. The SDV (Shut Down Valve) is designed to shut off the flow in critical conditions, while the alarm provides an early warning to the operator. The system has been designed to prevent overpressure by automatically regulating the operation of pumps, valves, and alarms based on pressure transmitter readings. Integration with HMI and SCADA facilitates real-time monitoring of system conditions, thereby providing early warnings.

2. METHOD

The research method was conducted through structured stages to achieve the system objectives. The sequence of research phases is illustrated in Figure 1.

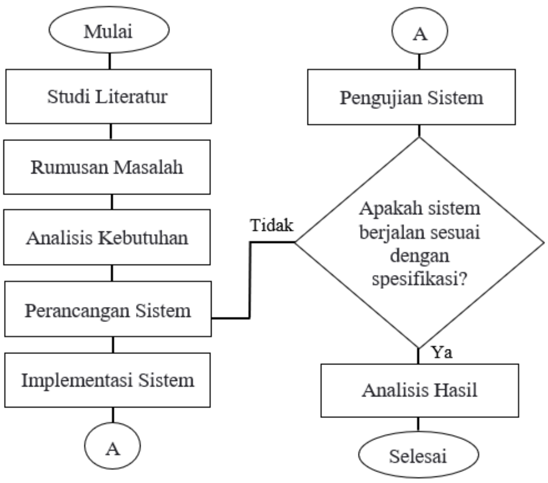


Figure 1. The following diagram illustrates the flowchart of the research process.

As illustrated in Figure 1, the system development process commences with a literature study, followed by problem formulation and needs analysis, culminating in system design. Subsequent to this, the system is implemented and evaluated in order to ascertain its conformity with the specified requirements. Should the process fail to meet the specified requirements, it will revert to the design stage. Should the system meet the specified requirements, it is then subjected to rigorous testing. The results of these tests are subsequently analysed. The process is terminated once the system has achieved the specified objectives.

2.1. System design

The instrumentation system that has been designed is a prototype for real-time monitoring and control of fluid pressure in pipelines. In this system design, a Piping and Instrumentation Diagram (P&ID) was created using AutoCAD 2021 software, as illustrated in Figure 2.

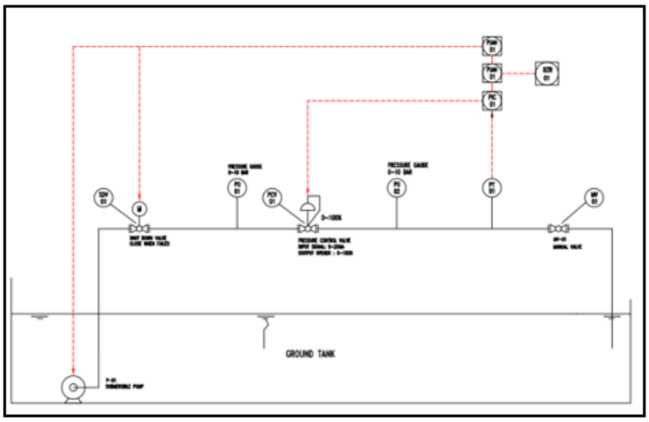
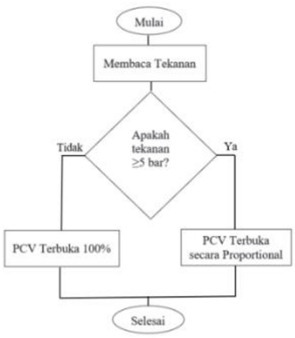


Figure 2. The following essay will provide a comprehensive overview of the Piping and Instrumentation Diagram (P&ID) of fluid flow.

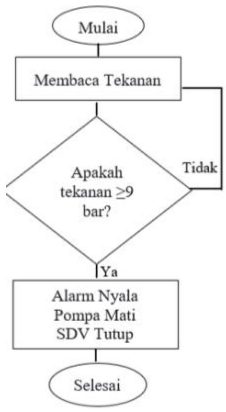
The system design consists of the following components: hardware, which includes a pressure transmitter, Haiwell PLC, PCV, SDV and a pump; interface devices, which consist of HMI and TCP/IP and Wi-Fi-based SCADA; and software, which is comprised of ladder diagrams and SCADA configurations.

The control process is facilitated by the Haiwell AC12M0R PLC, which functions as follows: it reads the pressure, processes the signal, and executes control commands from the pressure transmitter. In addition, it runs control logic to regulate the PCV, SDV, pump, and alarm. The display of process data is facilitated through HMI and SCADA for the purpose of real-time remote monitoring. The system functions automatically in accordance with pressure values; consequently, the control response is contingent on the precision of the sensors and the ladder diagram program employed.

The development of the system involved the conceptualisation of two primary systems: the pressure control system and the safety system. Figure 3 presents a schematic representation of the control system, illustrating the regulation of fluid pressure through the utilisation of a pressure transmitter and a pressure control valve (PCV). As illustrated in Figure 4, the safety system flowchart outlines a strategy for averting overpressure conditions through the coordinated activation of the SDV, buzzer, and pump.



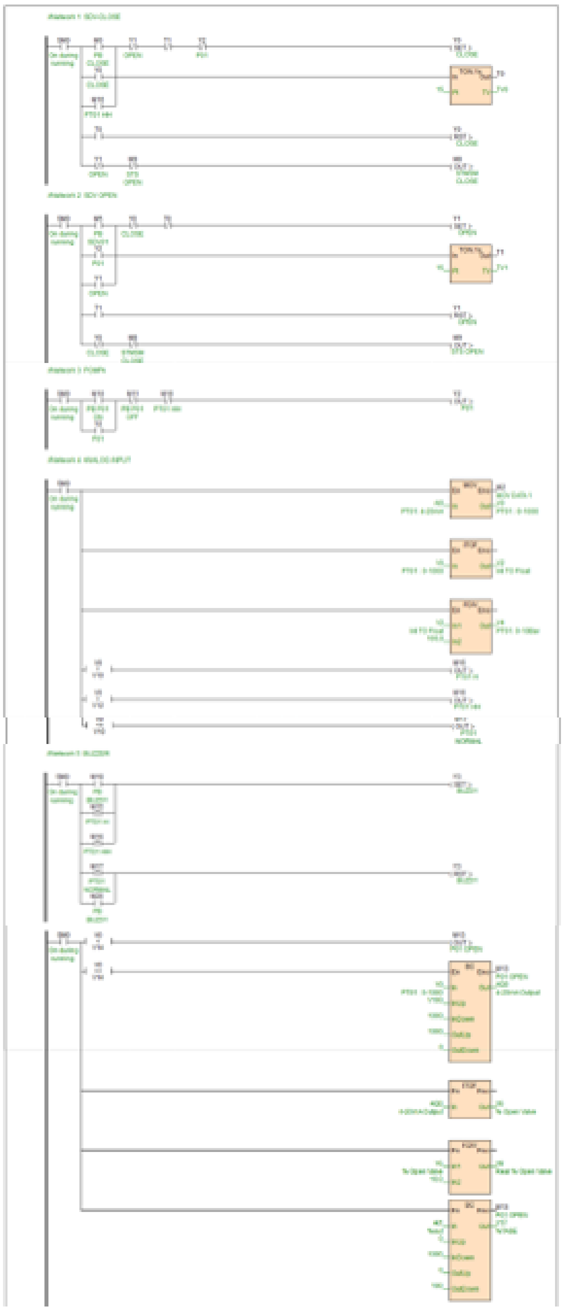
Gambar 3. *Flowchart Pressure Control*



Gambar 4. *Flowchart Pressure Safety*

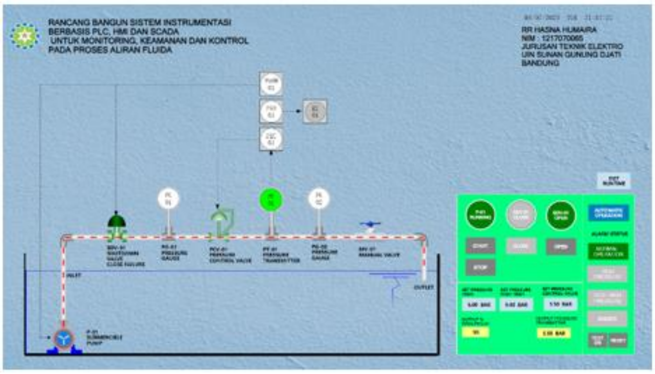
2.2. Software Design

The software design for this system utilises a programming platform, namely HaiwellHappy software version 2.2.13 for PLC (Programmable Logic Controller) and Haiwell Cloud SCADA version 3.40.1 for SCADA (Supervisory Control and Data Acquisition). The software design for the Programmable Logic Controller (PLC) comprises various input and output components, including three digital inputs designated as 'start', 'stop' and 'emergency', two analog inputs labelled 'PCV' and 'Pressure Transmitter', three digital outputs categorised as 'Relay contact', 'Pump', 'SDV' and 'Buzzer', and a single analog output labelled 'PCV control signal'. As illustrated in Figure 5, the designed and converted flowchart has been implemented as a ladder diagram.



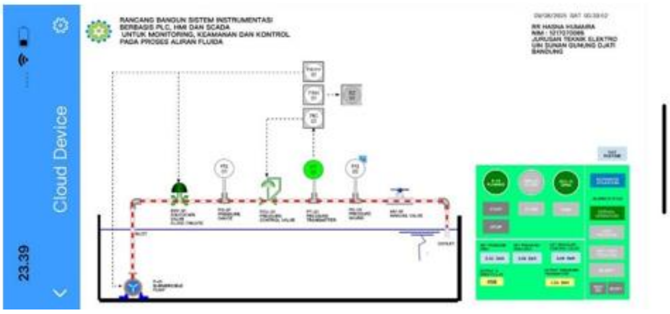
Gambar 5. *Ladder Diagram*

The software design for this system utilises a programming platform, namely HaiwellHappy software version 2.2.13 for PLC (Programmable Logic Controller) and Haiwell Cloud SCADA version 3.40.1 for SCADA (Supervisory Control and Data Acquisition). The software design for the Programmable Logic Controller (PLC) comprises various input and output components, including three digital inputs designated as 'start', 'stop' and 'emergency', two analog inputs labelled 'PCV' and 'Pressure Transmitter', three digital outputs categorised as 'Relay contact', 'Pump', 'SDV' and 'Buzzer', and a single analog output labelled 'PCV control signal'. As illustrated in Figure 5, the designed and converted flowchart has been implemented as a ladder diagram.



Gambar 6. Tampilan SCADA

As illustrated in Figure 7, the implementation of the SCADA interface on the Haiwell Cloud SCADA application involves the conversion of the designed SCADA into a process display, accessible via mobile devices. The display in question presents real-time information on pressure, actuator conditions, and alarm status.



Gambar 7. Tampilan *Cloud*

2.3. Electronic and Mechanical System Design

The system design employed in this study adheres to the close-loop control principle in the pressure control section. In this section, the actual pressure value, as measured by the 4–20 mA pressure transmitter, is transmitted back (i.e. feedback) to the programmable logic controller (PLC) for comparison with the setpoint. As illustrated in Figure 8, the instrumentation system in the fluid flow process is depicted schematically.

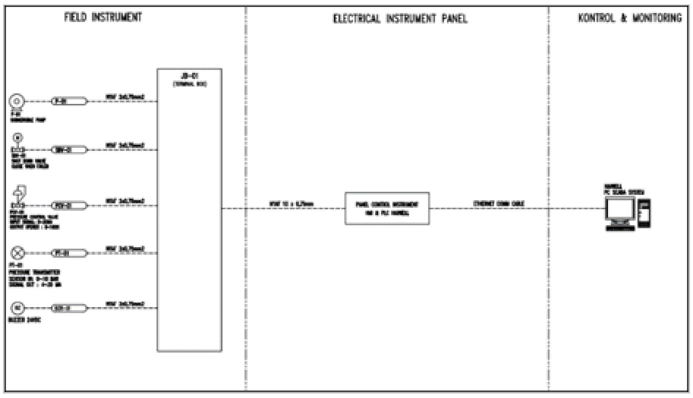


Figure 8. System Block Diagram

The system design employed in this study utilises a Haiwell AC12M0R PLC as the primary controller. The Programmable Logic Controller (PLC) is connected to three digital inputs, designated as 'start', 'stop' and 'emergency'; two analog inputs, designated as 'PCV' and '4–20 mA pressure transmitter'; three digital outputs, designated as 'relay contact', 'pump' and 'SDV', and 'buzzer'; and one analog output, designated as '4–20 mA PCV control signal'. The system's power source is derived from a 220V alternating current (AC) voltage, which is then reduced to 24V direct current (DC) by a power supply unit. The distribution of this current is then conducted in accordance with the voltage requirements of the pertinent components, namely the PLC, relay, transmitter, and actuator. Power distribution is also directed to the HMI module and communication devices for TCP/IP-based SCADA and Cloud connections. The control panel wiring diagram is illustrated in Figure 9.

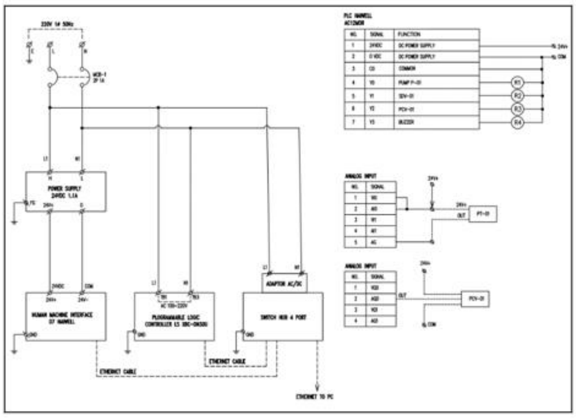


Figure 9. *Wiring Diagram Panel Control*

The implementation of the control panel was then executed in accordance with the stipulated design. The control panel functions as a power distribution centre and control centre for all instrumentation devices shown in Figure 10.

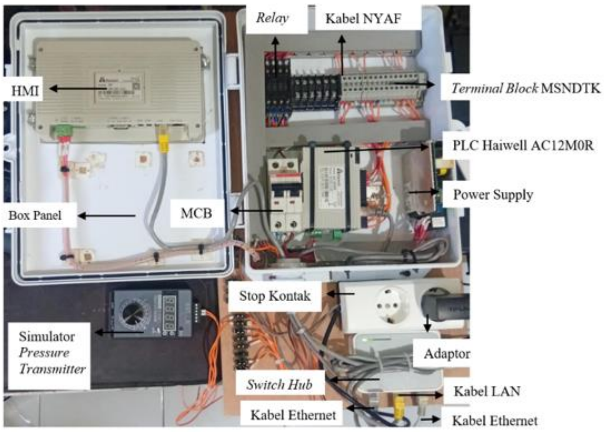


Figure 10. Control Panel Design Results

The mechanical structure of the prototype has been designed as a physical frame that provides support for all components of the fluid flow process. The structure comprises a wooden main frame, with ½ inch PVC pipes serving as fluid flow channels, and various connections such as 90° elbows, female tees, female adapters, and male adapters, forming a piping configuration in accordance with the P&ID. At the system's upstream, a submersible pump is placed within an aquarium that functions as a ground tank. From there, the flow is directed towards a series of instruments. The results of the prototype design of the instrumentation system in the fluid flow process, along with additional information on the components used to facilitate the identification of their functions and positions, can be seen in Figure 11.

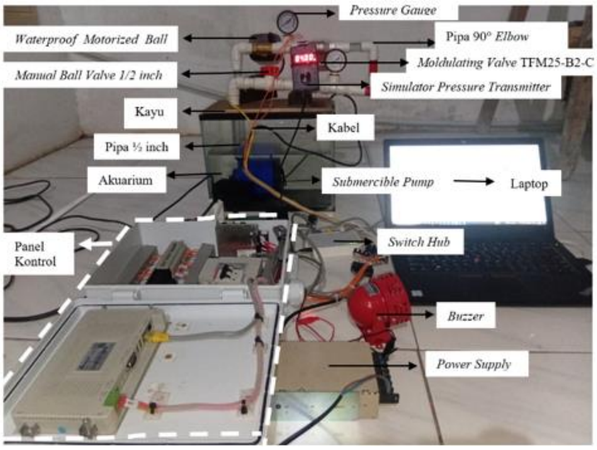


Figure 11. The following section presents the results of the prototype design.

3. RESULT AND DISCUSSION

3.1. system Testing and Evaluation

A series of experiments was conducted in order to evaluate the performance of the instrumentation system in accurately controlling pressure in the fluid flow process. This evaluation was based on the control logic programmed in the PLC.

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3.2. Equipment Testing

The testing of the equipment centred on the performance of the pressure transmitter, the primary sensor, in conjunction with the buzzer, PCV, SDV, and pump actuators, which execute commands based on actual pressure values. The setpoint and protection limit values that have been established are utilised to evaluate the system's capacity to execute suitable actions, encompassing flow control and shutdown procedures, thereby ensuring the process operates stably and in accordance with the designated operating conditions.

1) The initial procedure is that of the buzzer test

The process of testing the pressure alarm function on the Buzzer, as illustrated in Figure 6, is as follows:

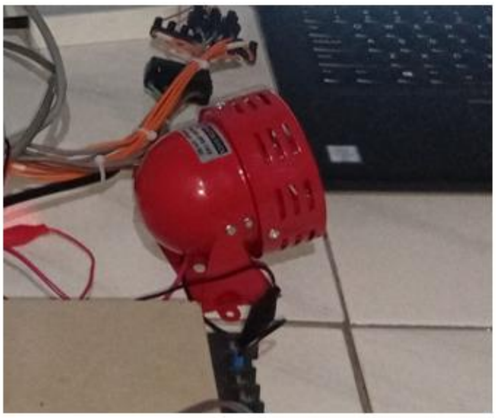

Figure 12. The following report details the process of conducting a buzzer test.

The test results for the Buzzer are displayed in Table 1, which provides a comparison between the pressure setpoint conditions that were established and the response of the Buzzer that was observed within the system. The objective of the test was to ascertain that the buzzer is activated exclusively when the pressure reaches the pre-determined limit of 6 bar. The experiment involved the utilisation of seven distinct pressure condition combinations, each meticulously designed to elicit a specific buzzer response in accordance with the predefined alarm logic.

Table 1. *Buzzer Test Result*

Test No.	**Actual Pressure (Bar)**	**Actual Result**	**Test Result**
1.	5 Bar	*Buzzer Off*	according to
2.	5,5 Bar	*Buzzer Off*	according to
3.	5,9 Bar	*Buzzer Off*	according to
4.	6 Bar	*Buzzer On*	according to
5.	7 Bar	*Buzzer On*	according to
6.	8 Bar	*Buzzer On*	according to
7.	9 Bar	*Buzzer On*	according to

As demonstrated in Table 1, the results of the experiment indicate that the buzzer response is in full compliance with the pressure conditions that were tested. In circumstances where the pressure falls below the setpoint, the buzzer remains inactive. Conversely, when the pressure attains the high pressure value, the preset alarm function is initiated, resulting in the sounding of the buzzer. As demonstrated in Table 1, the experimental findings indicate the efficacy of the pressure alarm function, which operates in accordance with the prescribed control logic, thereby issuing alerts as intended.

2) Pressure Control Valve (PCV) Testing

The experiment was conducted to ensure that the PCV opens proportionally when the pressure exceeds the specified setpoint of 5 Bar. The process of testing the pressure control function on the PCV is demonstrated in Figure 13 below.

Figure 13. *Pressure Control Valve* (PCV) Testing Process

Following the execution of the testing process, as illustrated in Figure 13, the PCV opening value was documented and subsequently analysed in relation to the reference value, with the analysis being based on the pressure setpoint. A total of 12 pressure setpoint combinations were utilised in the experimental investigation, with each combination yielding a distinct valve opening response and alarm status from the PCV with an open valve setpoint at a pressure of 5 Bar. The results of the test are set out in Table 2 below.

As demonstrated in Table 2, the PCV response demonstrates full compliance with the pressure setpoint that was tested. When the pressure falls below 8 Bar, the valve opens at a high percentage (100% to 50%) and the system status remains "Normal". Upon attaining a pressure of 8 bar, the status transitions to "High Pressure", prompting the valve to close further, with a range of 40% to 10%. It is evident that, at a pressure of 9 bar, there is a transition in status to "High High Pressure", thus signifying the activation of the high-level alarm function. As demonstrated in Table 2, the PCV has been shown to possess the capacity to function effectively. It has been demonstrated to be capable of regulating valve opening and providing pressure status signals in accordance with the established control logic.

Table 2. *Pressure Control Valve* (PCV) Test Results

Test No.	**Actual Pressure (Bar)**	***Open Valve* Aktual *(%)***	**Response Time (s)**
1	3.5	100 Open	-
2	4.5	100 Open	-
3	5	100 Open	-
4	5.5	90 Open	2
5	6	80 Open	1
6	6.5	70 Open	2
7	7	60 Open	1
8	7.5	50 Open	1
9	8	40 Open	1
10	8.5	30 Open	1
11	9	20 Open	1
12	9.5	10 Open	1

3) Shut Down Valve (SDV) Testing

The process of testing the pressure control function on the PCV is demonstrated in Figure 14. The objective of the test was to ensure that the PCV opens proportionally when the pressure exceeds the specified setpoint of 5 Bar.

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Gambar 14 Proses Pengujian *Shut Downl Valve* (SDV)

After carrying out the SDV testing process shown in Figure 8, the open-close status of the SDV was recorded and compared with the reference value based on the system pressure conditions. A total of eight pressure setpoint combinations were used in the test, with each combination producing an open response at the corresponding pressure. The test results can be seen in Table 3 below.

Tabel 3. Hasil Pengujian *Shut Down Valve* (SDV)

Test No.	**Actual Pressure (Bar)**	***Setpoint* SDV**	**Actual Results**	**Response Time (s)**
1	2,6 Bar	5 Bar	Open	
2	4,8 Bar	5 Bar	Open	-
3	5,5 Bar	5 Bar	Closed	7 second
4	6,3 Bar	6 Bar	Closed	6 second
5	7,6 Bar	7 Bar	Closed	6 second
6	8,4 Bar	8 Bar	Closed	6 second
7	9,1 Bar	9 Bar	Closed	7 second

It is evident from an analysis of the data presented in Table 3 that the SDV is operating in accordance with its designated function. The SDV remains open when the actual pressure is below the setpoint, as evidenced by tests 1 and 2, and closes consistently when the actual pressure exceeds the setpoint, as demonstrated by tests 3 to 7. The system response time also demonstrates consistent performance, with a range of 6 to 7 seconds observed across all pressure variations.

4) Pomp Testing

The objective of the pump testing process is to verify the performance of the pump in accordance with the specified control logic. The control logic necessitates the continuous operation of the pump and the automatic cessation of its function once the pressure reaches the preset protection limit of 9 Bar. The process of pump testing is illustrated in Figure 15 below.

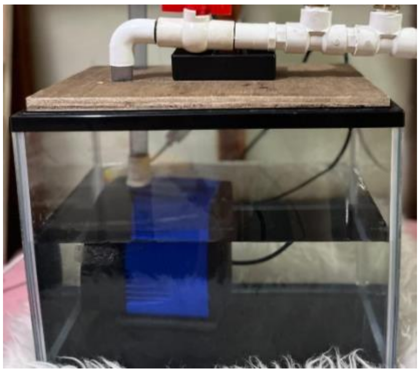

Figure 1. pump Testsing Process

Following the execution of the pump function test, the pump's operational status was documented and evaluated in relation to the system pressure conditions. The test was conducted using six combinations of pressure conditions, with an automatic shutdown setpoint at 6 bar. Each combination produced a different operating status (on/off) based on the specified control logic.

Table 4. Pump Testing Results

Test No.	Actual Pressure (Bar)	Result Actual	Test Result
1	3.2 Bar	Open	According to
2	4.8 Bar	Open	According to
3	6 Bar	Closed	According to
4	7 Bar	Closed	According to
5	8 Bar	Closed	According to
6	9 Bar	Closed	According to

Based on the test results listed in the table, it can be concluded that the pump operates in accordance with the specified control logic. The pump opens at pressures below 5 bar and closes at pressures above 6 bar. The results of the entire test series demonstrate the consistency of the pump's performance in response to changes in system pressure. After carrying out the SDV testing process as shown in Figure 8, the SDV open/close status was recorded and compared with the reference value based on system pressure conditions. A total of eight pressure setpoint combinations were used in the test, each producing an open response at each entered pressure. The test result data can be seen in Table 3 below.

3.3. Pengujian Notifikasi Sistem

Pengujian notifikasi sistem dilakukan untuk memverifikasi fungsi pengiriman pesan peringatan secara *real-time* ke perangkat pengguna. Pengujian menggunakan variasi kondisi tekanan yang melampaui *setpoint high pressure* dan *highhigh pressure*. Data hasil pengujian respons sistem notifikasi terhadap berbagai kondisi tekanan dapat dilihat pada Tabel 5.

Test No.	**Pressure Conditions (High/High Pressure)**	**Response Time (s)**	**Test Results**
1	Pressure 6,5 bar (*High Pressure*)	0,1 second	According to
2	Pressure 7 bar (*High Pressure*)	0,1 second	According to

3	Pressure 7,87 bar (*High Pressure*)	0,1 second	According to
4	Pressue 8 bar (*High Pressure*)	0,1 second	According to
5	Pressure 8,5 bar (*High Pressure*)	0,1 second	According to
6	Pressure 9.85 bar (*HighHigh Pressure*)	0,2 second	According to
7	Pressure 9.90 bar (*HighHigh Pressure*)	0,1second	According to
8	Pressure 9.91 bar (*HighHigh Pressure*)	0,1 second	According to

Table 5. System Notification Testing

As demonstrated in Table 5, seven tests were conducted for each notification entered, thereby demonstrating that the system issued warning notifications for both high pressure and very high pressure conditions. In the presence of high pressure conditions measuring 6.5 bar, 7 bar, 7.5 bar and 8 bar, the system reliably displays warning notifications within 0.1 seconds. In the presence of high pressure conditions measuring 9.85 bar, 9.90 bar and 9.91 bar, the system exhibited a response time ranging from 0.1 seconds to 0.2 seconds. The findings of the study demonstrate that the smartphone-based alarm notification system functions in real time as intended..

3.4. PLC-HMI-SCADA Communication Testing

A series of tests were carried out with the objective of verifying the integration and data exchange between the components of the control system. The testing encompassed a range of communication scenarios, encompassing data monitoring, device control, and status synchronisation. The outcomes of the communication system testing between PLC, HMI, and SCADA are presented in Table 6 below.

Type of Communication	**Action**	**Test Results**
Laptop ↔ HMI (online test)	Press the ON button on the HMI	According to
PLC → HMI (status *monitoring*)	Analog value changes in the PLC	According to
PLC → SCADA (*monitoring*)	Simulate pressure of 7 Bar	According to
SCADA → PLC (control)	Control the pump from SCADA	According to
SCADA ↔ HMI (synchronization)	Actuator ON via HMI	According to
SCADA ↔ PLC (saat offline)	Disconnect the internet connection	According to

Table 6. PLC-HMI-SCADA Communication Test Results

The results of the test indicate that all communication functions are operating in accordance with the specified parameters. In real-time performance, analogue/digital data such as pressure and actuator status can be displayed and controlled on the HMI, and SCADA can execute remote control functions.

3.5. Overall System Testing

Testing is conducted to ensure that all devices in the system operate according to specifications under various operating conditions, and to ensure that control, alarm, and shutdown functions operate in accordance with industry safety standards. The regulation of pressure during testing is achieved through the establishment of setpoints, which are determined based on the safe limits of components and pipes, with the objective of maintaining the Maximum Allowable Working Pressure (MAWP) below the permissible limits. The MAWP value is determined in accordance with the ASME B31.3 standard, taking into account the material, wall thickness, diameter, and weld joint factor.

The setpoint value is also adjusted to the maximum pressure specifications of the Pressure Control Valve (PCV), Shut Down Valve (SDV), and 1/2 inch pipe components, so that the maximum pressure is within the 1–10 Bar pressure range. The selection of this set point is consistent with the Layer of Protection philosophy (IEC 61511), in which the alarm and automatic shutdown systems function as layered protection to maintain operational safety.

The system is subjected to testing in two distinct conditions: in a state of unloading, and under conditions of high pressure and elevated pressure levels. The no-load test is used to verify the basic function of the system, while the load test uses pressure setpoint variations based on ISA-51.1 and IEC 61298-2 standards, with the following stages:

The high-pressure alarm is initiated and the positive pressure valve (PCV) opens proportionally when the pressure exceeds the set point.

• High-High Pressure: The activation of the alarm is followed by the closure of the SDV and the cessation of the pump, both of which occur automatically when pressure reaches the highest set point. In this study, the Shut Down Valve (SDV) functions as the final layer of protection, designed to halt fluid flow once the pressure reaches the high-high pressure limit. The selection of SDV setpoints is varied in order to simulate a range of operating conditions, from initial protection to the point at which the allowable overpressure limit is approached, in accordance with the stipulations of the API RP 521 standard.

The determination of the safe distance between setpoints complies with the IEC 61511 standard, with a minimum difference of 5–10% of the full scale reading required for the high-pressure alarm in order to avoid simultaneous activation of the two protection systems. Setpoint variations include low, medium and high zones, in accordance with ISA 51.1 and IEC 61298-2, in order to test the response across the entire measurement range. The setpoint variations to be tested are shown in Table 7 below.

Variasi	***Setpoint Pressure High***	***Setpoint Pressure High-High***	***Setpoint Pressure Control Valve***
1–3	3 Bar	6 Bar	2 Bar
4–6	4 Bar	7 Bar	3 Bar
7–9	5 Bar	8 Bar	4 Bar
10–12	6 Bar	9 Bar	5 Bar

Table 7 Variations in Tested Setpoints

The system was tested 12 times in reference to the specified pressure setpoint. Water was used as the test fluid. As no flow meter sensor was used and the pressure value was not measured using a pressure sensor but simulated using a pressure transmitter simulator, the fluid flow rate in this test was assumed to be 20 L/minute. The results of the overall system testing can be seen in Table 8 below.

Table 8. Overall System Testing Results

No	**Tekanan (Bar)**	***Setpoint* (H/HH)**	**PCV (Set/ Open%)**	**SDV**	**Pompa**	**Status Alarm**
1	1.93 Bar	3 Bar/ 6 Bar	2 Bar/ 100%	opened	On	-
2	5.55 Bar	3 Bar/ 6 Bar	2 Bar/ 54%	opened	On	*High*
3	6.43 Bar	3 Bar/	2 Bar/	closed	Stop	*High High*

No	Tekanan (Bar)	*Setpoint* (H/HH)	PCV (Set/ Open%)	SDV	Pompa	Status Alarm
		6 Bar	32%			
4	3.25 Bar	4 Bar/ 7 Bar	3 Bar/ 96%	opened	On	-
5	5.30 Bar	4 Bar / 7 Bar	3 Bar/ 66%	opened	On	*High*
6	8.68 Bar	4 Bar/ 7 Bar	3 Bar/ 18%	closed	Stop	*High High*
7	4.61 Bar	5 Bar/ 8 Bar	4 Bar/ 89%	opened	On	-
8	5.05 Bar	5 Bar/ 8 Bar	4 Bar/ 81%	opened	On	*High*
9	8.56 Bar	5/8 Bar	4 Bar/ 23%	closed	Stop	*High High*
10	5.05 Bar	6/9 Bar	5 Bar/ 98%	opened	On	-
11	6.37 Bar	6/9 Bar	5 Bar/ 71%	opened	On	*High*
12	9.85 Bar	6/9 Bar	5 Bar/ 2%	closed	*Stop*	*High High*

Table 8 shows that setpoint H is the high pressure limit and setpoint HH is the high high pressure limit. PCV (Set/Opening (%)) indicates the pressure control valve setpoint with the valve opening expressed as a percentage, while the shut down valve (SDV), pump and alarm status indicate the actuator status during testing.

Based on Table 8, the pressure control system exhibits a consistent, tiered response to pressure increases. When the pressure is below the high (H) setpoint, the PCV remains fully open without activating the alarm. When the pressure reaches or exceeds the H setpoint, the high alarm is activated and the PCV begins to close proportionally to stabilise the pressure. When the pressure reaches the high high (HH) setpoint, the system activates the HH alarm, accompanied by the closure of the shut down valve (SDV) and automatic pump shutdown as a final protective measure.

3.6. Analysis of Result

All tests conducted on this PLC and SCADA-based instrumentation system confirm that it operates successfully according to the planned design. The test results demonstrate that the system can perform monitoring, control and protection functions in an integrated manner, in line with its intended use.

The pressure control system achieved an accuracy of 97.7%, with a maximum deviation of only 2.3% between the setpoint and the actual value. This was due to the PCV functioning with precision and being capable of proportionally adjusting the valve opening from 100% to 2% as the pressure increased from 5 bar to 9.85 bar. The system response time was recorded at 0.1–0.2 seconds based on test data. Of the 12 tests conducted in total, 11 responded within 0.1 seconds and only one took 0.2 seconds.

The protection system was successfully tested with a 100% success rate based on the test data. Data from Table 8 proves that the high-pressure alarm is consistently active, while final protection through the SDV and pump shutdown is activated at high pressure. The SDV closing time of 5–6 seconds meets the 100% safety standard for preventing overpressure.

Table 6 shows that system integration achieved 100% performance, with all data communication between the PLC, HMI and SCADA running as intended. The system successfully displayed real-time data and provided consistent, uninterrupted remote monitoring access throughout the testing period.

Of the 12 test variations with setpoints of 3–9 bar, the system demonstrated 98% stability and consistent performance under all operating conditions. Only two of the 12 tests showed a deviation of 2.3%, while the other 10 tests had deviations below 2%.

All components functioned as intended without failure, proving the system's 100% reliability. This instrumentation system prototype was successful overall, with a 99.2% implementation success rate — the weighted average of all performance parameters — and it can be used to control and protect fluid flow systems in industrial environments.

4. CONCLUSION

Based on the research results, the prototype of the fluid flow instrumentation system was successfully implemented using a pressure transmitter, a Haiwell AC12M0R PLC, an HMI and a TCP/IP-based SCADA system with Wi-Fi connectivity. The performance of the instrumentation system in the fluid flow process was in accordance with the program logic, as demonstrated by simulation and quantitative testing results. The entire test series, which involved 12 tests with different setpoint variations, showed a 100% success rate for the tested scenarios. At pressures of ≥6 bar, the buzzer activated as an early warning with 100% success in all experiments. The PCV began to respond proportionally when the pressure exceeded the 5 bar setpoint. The response time was 0.1–0.2 seconds with 100% accuracy and consistent valve opening reduction following the control command. In an emergency condition (i.e. pressure ≥9 bar), the system automatically executes the safety shutdown function with 100% success. This is marked by a continuously active buzzer (100% alarm success), the SDV closing fully within 5–6 seconds (100% closure success) and the pump stopping in time to secure the system. All data, alarms and actuator status can be monitored in real time through the HMI and SCADA interfaces with a delay of less than one second and 100% reading accuracy. This ensures that communication, monitoring and control processes run stably and according to their intended use.

REFERENCES

[1] M. Z. Mahfud, D. Satrijo, and T. Prahasto, "Desain Dan Analisis Tegangan Sistem Perpipaan Main Steam (*High Pressure*) Pada Combined Cycle Power Plant," Jurnal Teknik Mesin, vol. 4, no. 1, pp. 79-88, Jan. 2016. https://ejournal3.undip.ac.id/index.php/jtm/article/view/12839.

[2] BNPB. (n.d.). Kebakaran Depo Pertamina Plumpang Sitrep I Sabtu, 4 Maret 2023 Sitrep #1 Kebakaran Depo Pertamina Plumpang. https://megapolitan.kompas.com/read/2023/03/04/19194131/kebakaran-depo-pertamina-plumpang-bnpb-18-orang-masih-dicari?page=1.

[3] Z. Hasanah Siregar and A. Hasibuan, "Tanggap Darurat K3 Terhadap Kebakaran Di Industri Migas : Literature Review," Gudang J. Multidisiplin Ilmu, vol. 2, pp. 134–142, 2024, doi: https://doi.org/10.59435/gjmi.v2i6.505.

[4] J. Jalaluddin, S. Akmal, N. ZA, and I. Ishak, "Analisa Profil Aliran Fluida Cair Dan Pressure Drop Pada Pipa L Menggunakan Metode Simulasi Computational Fluid Dynamic (Cfd)," J. Teknol. Kim. Unimal, vol. 8, no. 1, p. 97, 2019, doi: 10.29103/jtku.v8i1.3396.

[5] A. Afrizal, U. A. Ahmad, and J. S. Wicaksana, "Desain Dan Implementasi Alat Deteksi Kebocoran Pipa Air Menggunakan Sensor Pressure Transmitter Studi Kasus Pdam Kabupaten Madiun," eProceedings Eng., vol. 9, no. 3, pp. 966–973, 2022, [Online]https://openlibrarypublications.telkomuniversity.ac.id/index.php/engineering/article/view/17931/17565%0.

[6] D. R. Sirait and V. F. R. B. Tarigan, "Rancang bangun sistem aliran fluida menggunakan water pump dan float switch tangki berbasis PLC," Konsep Konf. Nas. Soc. dan Eng. Polmed, vol. 5, no. 1, pp. 947–954, 2025, [Online].https://ojs.polmed.ac.id/index.php/Konsep2021/article/view/1850.

[7] V. Ray, Sonhaji, and K. Elly, "Prototype Steam Plant sebagai Penyedia Sumber Daya Listrik pada Sistem Vessel To Grid (V2G)", Jurritek, vol. 4, no. 3, pp. 440–461, Sep. 2025. https://doi.org/10.55606/jurritek.v4i3.6721.

[8] X. Zhang et al., "Numerical and Experimental Study on the Shutdown Transition Process of a Large Axial Flow Pump System Focusing on the Influence of Gate Control," J. Mar. Sci. Eng., vol. 11, no. 2, 2023, doi: https://doi.org/10.3390/jmse11020280.

[9] B. Mulyati, "Rancang Bangun Alat Pengukur Kecepatan Aliran Air Menggunakan Water Flow Sensor Berbasis Arduino Uno," J. Inform. Teknol. dan Sains, vol. 2, no. 1, pp. 1–11, 2023, doi: 10.56244/formateks.v2i1.721.

[10] I. M. Madeira, M. A. R. Lucumi, and H. R. B. Orlande, "State estimation problem for the detection of valve closure in gas pipelines," Inverse Probl. Sci. Eng., vol. 29, no. 12, pp. 2186–2206, 2021, doi: 10.1080/17415977.2021.1910682.

[11] R. P. H. Wibowo and A. Adriansyah, "Operation Analysis of Automation System Terminal Implementation in LPG Terminal," 2020 2nd Int. Conf. Broadband Commun. Wirel. Sensors Powering, BCWSP 2020, pp. 42–46, 2020, doi: 10.1109/BCWSP50066.2020.9249451.

[12] E. A. Z. Hamidi, T. Gustiana, M. R. Effendi, and P. A. M. Hambali, "Design and Implementation Supervisory Control and Data Acquisition (SCADA) of Flocculation Process of Water Treatment Plant (WTP) Using Raspberry Pi," Proceeding 2019 5th Int. Conf. Wirel. Telemat. ICWT 2019, pp. 1–7, 2019, doi: 10.1109/ICWT47785.2019.8978240.