Arduino based mini scada for power distribution system relay control

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ABSTRACT
This study aims to develop a mini SCADA system as a simpler and more affordable alternative solution for educational and research purposes, especially in the control of relays in distribution system modules. Design and implement of a mini SCADA prototype are able to control the relay in real-time while evaluating the performance of the system in terms of response speed, control accuracy, and operational reliability. The research adopts both quantitative and qualitative approach with laboratory experiment methods at Malikussaleh University, utilizing Arduino Uno, PZEM-004T sensors, relay modules, and LabVIEW software integration for monitoring and controlling. The test results showed that the system successfully monitored electrical parameters (voltage, current, power, and frequency) with a good level of sensor accuracy (error ≤0.03%), and was able to activate automatic protection against under/over voltage and over current conditions with a fast response according to the set limit. These findings confirm that mini SCADA is not only feasible as a means of practical learning, but also has the potential to be an early model for the implementation of small-scale distribution control such as microgrids. In addition, this study provides empirical evidence that simple hardware integration with open-source software can result in efficient and applicable control systems. In conclusion, this study makes a significant contribution to expanding the understanding of SCADA integration with distribution relays, while opening up further research opportunities related to system communication optimization to reduce response delays and improve operational resilience in the future.

Keywords: ***Mini SCADA, Relay, LabVIEW, Distribution, Controlling***

ABSTRAK
Penelitian ini bertujuan untuk mengembangkan sistem SCADA mini sebagai solusi alternatif yang lebih sederhana dan terjangkau untuk tujuan pendidikan dan penelitian, terutama dalam pengendalian relay pada modul sistem distribusi. Perancangan dan implementasi dari SCADA mini mampu mengendalikan relay secara *real-time*, sekaligus mengevaluasi kinerja sistem dari segi kecepatan respons, akurasi kontrol, dan keandalan operasional. Penelitian ini menggunakan pendekatan kuantitatif dan kualitatif dengan metode eksperimen laboratorium di Universitas Malikussaleh, memanfaatkan Arduino Uno, sensor PZEM-004T, modul relay, dan integrasi perangkat lunak LabVIEW untuk pemantauan dan pengendalian. Hasil pengujian menunjukkan bahwa sistem berhasil memantau parameter listrik (tegangan, arus, daya, dan frekuensi) dengan tingkat akurasi sensor yang baik (kesalahan ≤0,03%), dan mampu mengaktifkan proteksi otomatis terhadap kondisi tegangan lebih/kurang dan arus berlebih dengan respons cepat sesuai batas yang ditetapkan. Temuan ini menegaskan bahwa mini SCADA tidak hanya layak sebagai sarana pembelajaran praktis, tetapi juga memiliki potensi menjadi model awal untuk penerapan pengendalian distribusi skala kecil seperti mikrogrid. Selain itu, penelitian ini memberikan bukti empiris bahwa integrasi perangkat keras sederhana dengan perangkat lunak sumber terbuka dapat menghasilkan sistem kontrol yang efisien dan dapat diterapkan. Sebagai kesimpulan, penelitian ini memberikan kontribusi yang signifikan dalam memperluas pemahaman tentang integrasi SCADA dengan relay distribusi, sekaligus membuka peluang penelitian lebih lanjut terkait optimisasi komunikasi sistem untuk mengurangi keterlambatan respons dan meningkatkan ketahanan operasional di masa depan.

Kata kunci: Mini SCADA,Rele, LabVIEW, Distribusi, Pengaturan

1. INTRODUCTION

The rapid development of the electric power system requires a reliable, efficient, and able to work in real-time, especially in the electricity distribution system. Distribution systems have an important role in the distribution of electrical energy to consumers, where disturbances such as overvoltage, undervoltage, and overcurrent can degrade system reliability and potentially damage electrical equipment [1]. Therefore, a monitoring and protection system is needed that is able to detect operating conditions quickly and accurately.

Supervisory Control and Data Acquisition (SCADA) is a system that is widely applied to industrial-scale power networks to carry out centralized monitoring, control, and protection [2]. Through the SCADA system, operators can monitor network conditions, control equipment, and make quick decisions based on data obtained from the field [3]. However, the implementation of conventional SCADA systems requires high investment costs, complex infrastructure, and competent human resources, making it less suitable for application in educational laboratories or small-scale distribution systems.

As an alternative to these limitations, the Mini SCADA concept began to be widely developed as a simpler and more economical solution [4]. Mini SCADA generally utilizes microcontrollers and graphical interface software to perform monitoring of electrical parameters [5][6]. Several previous studies have shown that Mini SCADA is capable of monitoring voltage, current, and power in real-time [7]. However, most Mini SCADA implementations still focus on monitoring functions, while control and protection functions, specifically real-time operation of relays, have not been discussed in depth.

In electricity distribution systems, relays have a very important role as a protective device to cut off the network in the event of a disturbance [8][9]. The reliability of the protection system is highly dependent on the speed and accuracy of the relay's work in responding to abnormal conditions. Therefore, SCADA systems that only function as monitoring tools without adequate control and protection capabilities do not fully represent the true operating conditions of the distribution system. This shows the need for a Mini SCADA that is not only capable of monitoring, but also can control the relay and evaluate its performance [10].

Several related studies have developed microcontroller-based monitoring systems and human-machine interfaces (HMIs) for electrical applications [11]. However, studies that specifically evaluated the relay control response based on protective limitations such as overvoltage, undervoltage, and overcurrent are still relatively limited. In addition, system testing under various load conditions, including unbalanced loads, has also not been comprehensively reported.

Based on this background, this study proposes the development of a Mini SCADA system based on Arduino Uno and LabVIEW for monitoring and controlling relays in power distribution system modules. The system is equipped with a PZEM-004T sensor for electrical parameter measurement and supports manual and automatic relay control modes. The main contribution of this study lies in the evaluation of the performance of the Mini SCADA system in terms of monitoring accuracy, relay control response, and the reliability of the protection system under normal and abnormal operating conditions. The developed system is expected to be used as a learning medium in the laboratory and become the basis for further development of electricity distribution automation systems.

2. RESEARCH METHOD

This research uses an experimental method by designing, implementing, and testing the Mini SCADA system on a laboratory-scale electrical distribution system module. This method was chosen to evaluate the system's performance in monitoring electrical parameters and real-time relay control under various operating conditions.

2.1. Mini SCADA System Architecture

The architecture of the Mini SCADA system developed consists of three main parts, namely data acquisition devices, processing and control units, and user interfaces. The PZEM-004T sensor functions as a data acquisition device to measure electrical parameters in the form of voltage, current, and power on the load side. The measurement data is then sent to the Arduino Uno microcontroller as a data processing unit and relay controller. The data is then communicated to a computer running the LabVIEW software as a Human Machine Interface (HMI) to display system information and send control commands. The architecture of the developed Mini SCADA system is shown in Figure 1 [12][13]. The system consists of a data acquisition layer, a processing and control layer, and a supervisory layer. The PZEM-004T sensor is used to measure electrical parameters and transmit data to Arduino Uno as the main controller [14][15]. The measurement data is then displayed on the LabVIEW interface, while control commands are sent back to the Arduino Uno to control the relay module.

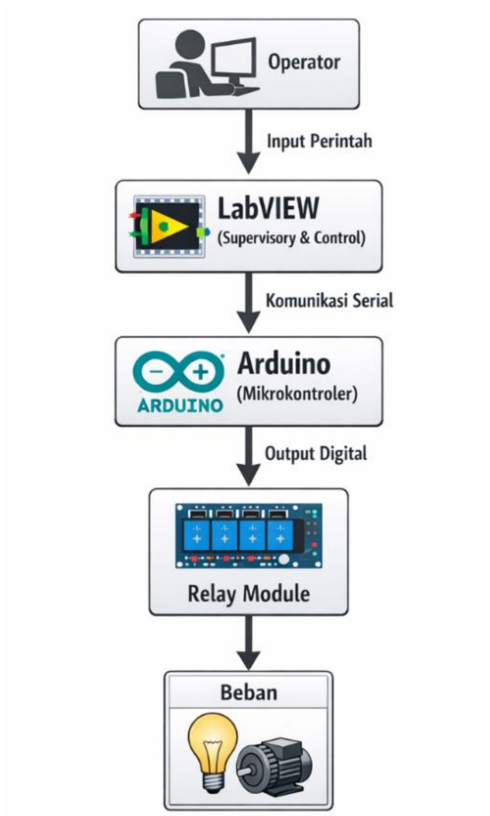

Figure 1. Architecture of the proposed Mini SCADA system

2.2. Hardware Design

The main hardware used in this study includes Arduino Uno, PZEM-004T sensor, relay module, and power distribution system module as test objects. Arduino Uno is used as the main controller of the system that receives data from sensors and executes the relay control logic. The PZEM-004T sensor is used to measure voltage, current, and power parameters in real-time. The relay module serves as an actuator to disconnect and connect loads based on commands from the Mini SCADA system. All hardware is integrated into a distribution system module designed to simulate both normal and faulty operating conditions.

2.3. Software Design

The software on the Mini SCADA system was developed using LabVIEW as the user interface and the Arduino IDE as the microcontroller programming. LabVIEW functions to display measurement data in numerical form and visual indicators, as well as provide control buttons for relay operation. Data communication between Arduino Uno and LabVIEW is done through serial communication. The system supports two operating modes, namely manual mode, where the relay is controlled directly by the user via HMI, and automatic mode, where the relay works based on predefined protection limits.

2.4. System Protection Scheme

The protection scheme on the Mini SCADA system is designed to detect abnormal conditions in the power distribution system, including over-voltage, under-voltage, and over-current. Protection limit values are determined based on system specifications and testing needs. If the measured electrical parameters exceed or are below the preset limit, Arduino Uno will command the relay module to automatically cut off the load. Fault condition and relay status information is displayed in real-time on the LabVIEW interface.

2.5. Testing Scenarios

System testing is carried out to evaluate the performance of Mini SCADA under various operating conditions. Test scenarios include normal load conditions, unbalanced loads, and fault conditions with voltage and current variations. Each test is performed to observe the accuracy of monitoring electrical parameters, relay control response, and the reliability of the protection system. The test result data is recorded and analyzed to determine the overall performance of the system.

3. RESULTS AND DISCUSSION

3.1. Electrical Parameter Monitoring Results

The Mini SCADA system test was carried out to determine the system's ability to monitor electrical parameters in the power distribution system module. The observed parameters include voltage, current, and electrical power. The measurement data is obtained from the PZEM-004T sensor and displayed in real-time on the LabVIEW interface. . The results of monitoring electrical parameters in the distribution system module are shown in Table 1.

Table 1. Parameter Monitoring Result

Experiment	**Sensor Voltage (V) No-load Condition**			**Clamp Meter Voltage (V) No-Load Condition**			***Error %***		
	R	**S**	**T**	**R**	**S**	**T**	**z**	**S**	**T**
1	203,7	204,2	203,5	203,65	204,15	203,45	0,02	0,02	0,02
2	201,9	201,2	200	201,85	201,15	199,95	0,02	0,02	0,03
3	200	199,5	199,8	199,95	199,45	199,75	0,03	0,03	0,03
4	200	199,5	199,8	199,95	199,45	199,75	0,03	0,03	0,03
5	200,5	199,6	199,7	200,45	199,55	199,65	0,02	0,03	0,03
6	200,5	199,6	199,7	200,45	199,55	199,65	0,02	0,03	0,03

The test results show that the system is capable of displaying voltage, current, and power values continuously and stably. The display on the LabVIEW HMI shows the change in the value of the electrical parameters according to the given load conditions. This shows that the data communication between the sensor, Arduino Uno, and LabVIEW is running well Graph of the distribution system voltage monitoring results shown in Figure 2.

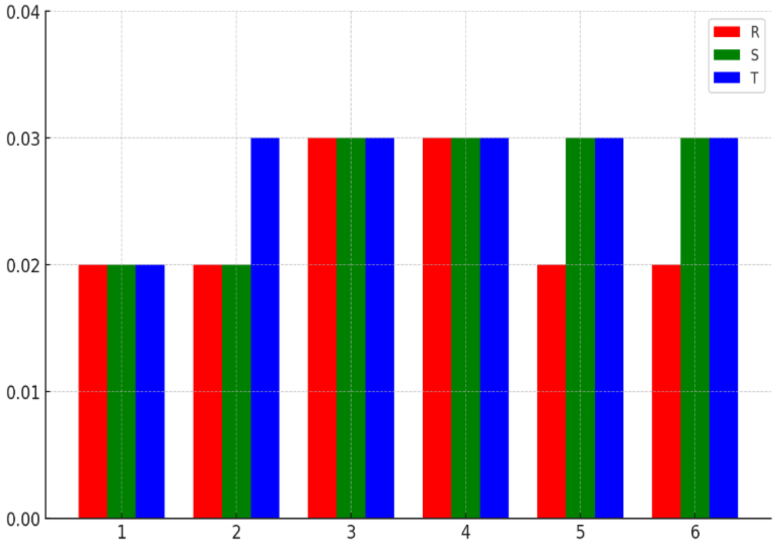

Figure 2. Voltage monitoring result under normal operating conditions

3.2. Relay Control Results

Relay control testing is carried out in two modes, namely manual mode and automatic mode. In manual mode, the relay is controlled directly by the user via the ON/OFF button on the LabVIEW interface. The test results showed that the relay could respond well to every command given through HMI, where the relay's state changes were displayed in real-time. The results of the relay control test in manual and automatic mode are shown in Table 2.

Table 2. Experiment Result from Relay Control

No	**Condition**	**Set *Point***	**Measurement Value**	**Relay Response**	**Load State**	**Explanation**
1.	Normal	V=220 Volt	215 Volt	Closed	Connected	The system works normally
2.	*Under Voltage*	V<100 Volt	95 Volt	Open	Disconnected	Automatically Relay trip
3.	*Over Voltage*	V>230 Volt	232 Volt	Open	Disconnected	Automatically Relay trip
4.	*Over Current*	I> 1,2 Amphere	1,4 Amphere	Open	Disconnected	Automatically Relay trip
5.	Normal voltage over trip	V=220 Volt	215 Volt	Closed	Connected	Load becomes normal

In automatic mode, the relay works based on the protection limits that have been defined on the system. When the voltage or current value exceeds the set limit, the system automatically gives a command to the relay to break the load. The relay status and the interference condition are displayed on the HMI, so that the user can know the system condition directly. A LabVIEW-based HMI Mini SCADA interface is shown in Figure 3.

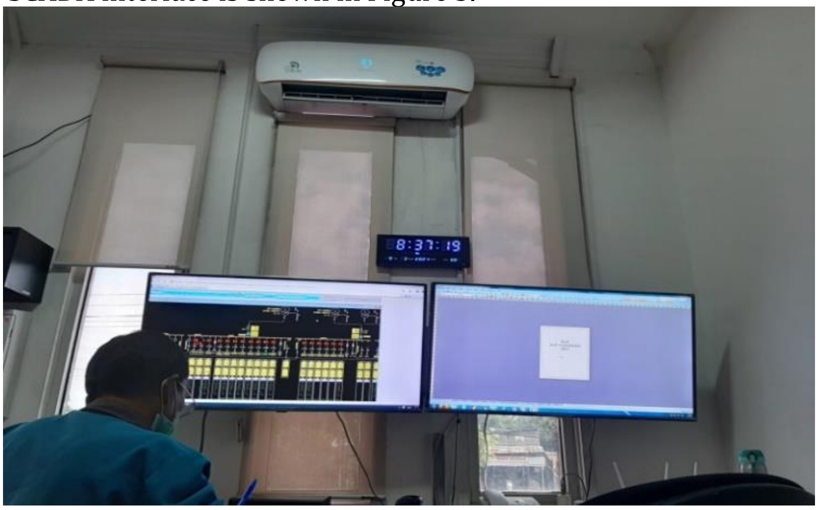

Figure 3. LabVIEW-based HMI for monitoring and relay control

3.3. Protection System Response Results

Testing of the protection system is carried out by providing a variety of operating conditions, such as overvoltage, undervoltage, and overcurrent. The test results showed that the system was able to detect abnormal conditions and activate the protection relay automatically. The relay breaks the load when the electrical parameters are outside the predetermined safe limits. The response of the protection system to the interference conditions is shown in Table 3.

Table 3. Protection System Response

No	Condition	Set *Point*	Measurement Value	Relay Response	Load State	Keterangan
1.	Normal	V=220 Volt	215 V	closed	connected	The system works normally
2.	*Under Voltage*	V<100 Volt	95 V	open	Disconnected	Automatically Relay Trip
3.	*Over Voltage*	V>230 Volt	232 V	Open	Disconnected	Automatically Relay Trip
4.	*Over Current*	I>1,2 Amphere	1,4 A	Open	Disconnected	Automatically Relay Trip
5.	Normal Voltage over trip	V=220 Volt	215 V	Closed	Connected	Load Becomes Normal

In addition, the system is also tested under unbalanced load conditions to determine the reliability of the system under more complex operating conditions. The test results show that the Mini SCADA system is still able to monitor and control the relay well under these conditions.

4. CONCLUSION

This research has successfully developed and implemented a Mini SCADA system based on Arduino Uno and LabVIEW for monitoring and controlling relays in power distribution system modules. The test results show that the Mini SCADA system is capable to control the relay in both manual and automatic modes. In manual mode, the relay can respond well to commands from the user through HMI, while in automatic mode the relay can work based on the predetermined protection limit. The system is also able to detect abnormal conditions such as overvoltage, undervoltage, and overcurrent, as well as execute automatic load termination as a form of distribution system protection.Based on the test results on normal, unbalanced, and disruptive load conditions, it can be concluded that the Mini SCADA system developed has reliable performance in carrying out the monitoring and control functions of the relay. This integration of monitoring and control functions shows that Mini SCADA can not only be used as a monitoring tool, but can also represent the basic functions of conventional SCADA systems on a laboratory scale.

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