Prototype and monitoring system of phasor measurement unit based on the internet of things

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ABSTRACT

This research resulting the method to reduce phasor measurement unit (PMU) amount and optimization of PMU replacement using a combination of Integer linear k-means. The first step of modeling is using a lot of PMUs that are optimized at Bendul Merisi network using integer linear k-means clustering for achieving an optimum solution of amount and replacement of PMU to be installed. The second step is estimating the uninstalled bus's power and voltage. PMU is using modified adaptive neuro-fuzzy inference system (ANFIS) of hybrid particle swarm optimization (PSO)-genetic algorithm (GA). The third step is to test and simulate the hardware design of the research for offline and online data. Research also tested network transmission of Java–Bali 500 kV. Designed simulation can calculate the active and reactive power of each bus in clusters so the total active and reactive power of each cluster can be known. Device tests to transmit data using internet of things (IoT) from a laboratory scale during 7 days have an average of 2.8 seconds while the field test required an average of 10.416 seconds during 24 hours.

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1. INTRODUCTION

Smart grid requires the use of fast and accurate two-way communication even with a large number of sensors using computing technology. Smart grids can carry out integrated communication for a wide area, including response to power requests, distribution automation, monitoring control, and data acquisition (SCADA) [1]. Integrated system communication is capable of controlling the power grid system in real-time, exchanging information and data to optimize system reliability, asset utilization, and security systems [2]. The analytical method used in this study is the heuristic method. Simulation using the software requires data parameters obtained from the results of manual measurements in the field and the analysis is carried out offline so that the analysis results only provide static information based on when the measurements were made. For a smart grid, an accurate and continuous analysis result is needed that provides continuous information on changes that occur in the system dynamically.

The phasor measurement unit (PMU) is a control device that can be used to carry out measurements continuously and provide real-time data. This PMU is installed on every bus in the network system. PMU installation on each bus in the network system is needed to measure and control the network system so that all values and conditions can be monitored at any time. Therefore, internet of things (IoT) Technology is needed so that users can monitor at any time and wherever they are. The developed research is about the prototype and monitoring system of a PMU based on the internet of things (IoT).

The Internet of Things is evolving in incredible ways over the last decade and is still the increasing trend in academic and industrial research [3], [4]. Almost everything, every area, device, sensor, and software is connected. The internet of things (IoT) idea is developed parallelly with wireless sensor network (WSN) resulting in requirement inclination files from industry and perspective research. It is due to cheap availability, and low-powered miniature components such as processors, radios, and sensors that are often integrated into a single chip (system of a chip) [5]–[12].

WSNs are having many applications in weather monitoring, disaster management, inventory tracking, smart room, habitat observation, target tracker, supervision, and many more [13]. Wireless technology such Wi-Fi, Bluetooth, Zigbee, RFID, and IPv6 low power wireless personal area network (6LoWPAN) allow the device to be connected to the internet and other feeders. Cloud services collect, save, and analyze data collected by the sensor and allow people to take compatible decisions [14]–[24]. Based on the cited literature and this paper, we have tried to build a program to validate optimal PMU replacement in South Surabaya Distribution System in Bendul Merisi feeder [25]. The results will be monitored using the internet of things by smartphone in real-time. Integer linear k-means clustering method received from data of PLN which then processed using the described method to find optimal PMU placement. Estimation of power and voltage with modified adaptive neuro-fuzzy inference system (ANFIS) of hybrid particle swarm optimization (PSO)-genetic algorithm (GA) will be discussed [26].

2. RESEARCH METHODS

2.1. Load flow simulation analysis

According to Bendul Merisi feeder data, simulation analysis begins with software to analyze the load flow of the Bendul Merisi feeder distribution network. Single line from load flow result of early data received with a condition where voltage assumed to be balanced without load, used voltage is 20 kV and Cos phi 0.8. Peak load data along with line impedance from the first analysis is electric load data and impedance load which will be analyzed and simulated to find active power (P) and reactive power (Q) in each bus and the result will be described in Table 1.

Table 1. Load peak value based on Bendul Merisi feeder measurement

Bus m to n	Impedance	S (kW)	V (Volt)	I (Ampere)	Cos Phi	Sin Phi
Z1 to Z2	0.07861+0.02931 i	745	19,913	21.4	0.8	0.6
Z2 to Z3	0.05553+0.02071 i	208	19,910	6	0.8	0.6
Z2 to Z4	0.19424+0.07244 i	496	19,869	14.2	0.8	0.6
Z4 to Z5	0.09788+0.03650 i	483	19,832	13.8	0.8	0.6
Z5 to Z6	0.23836+0.08889 i	319	19,801	9.1	0.8	0.6
Z6 to Z7	0.39681+0.14724 i	689	19,793	19.7	0.8	0.6
Z6 to Z8	0.27760+0.10355 i	290	19,783	8.3	0.8	0.6
Z8 to Z9	0.04869+0.01816 i	455	19,768	13	0.8	0.6
Z9 to Z10	0.13845+0.05163 i	350	19,760	10	0.8	0.6
Z10 to Z11	0.27005+0.10071 i	363	19,755	10.4	0.8	0.6

2.2. Online and offline hybrid system

The first step is to collect data from feeder distribution network. Load flow is analyzed using simulation to calculate voltage, current, active power, reactive power, and power factor. The next step is to cluster locations by using a data group from the simulation to receive the optimum PMU replacement location and minimum amount of sensors using the integer linear k-means clustering method.

The second step is to design Bendul Merisi feeder distribution using simulink. The design was applied to distribution network online simulator. In simulink, a sensor placed on determining the location and input network is available. The distribution data is simulated by adjusting the values of trigger points. Triggered values are from the load, which is simulated using a resistor to transmit voltage to the microcontroller to convert into digital data and will be transmitted through a USB line to the computer. Digital data is the load input value of the simulator and consists of 10 points. The microcontroller is applied as a multiplexer to transmit load input data separately to the simulator. The next step is to apply the training to all from each bus with integer linear k-means offline. Then also apply testing by sampling only a few buses online from external data. The third step is the simulation, monitoring the voltage magnitude value, current, and power of each sensor’s output.

Figure 1 is describing the analysis process of the offline and online monitoring by simulink. The first step is to assemble the single line diagram in software with complete impedance lines and loads. The second step is to record the voltage, current, active power, and reactive power data received from the software running result. The third step is to calculate active power and reactive power using the electric power formula with data generated from the first and second steps. The fourth step is to calculate the total electric power received from the third step with the total power of each cluster. The fifth step is to calculate the voltage drop that occurred in Bendul Merisi Feeder with the load data and impedance value according to the second step. The sixth step is to simulate and estimate simulink simulation utilization designed to know the power in each hour of each bus from the newest data received in 6 hours.

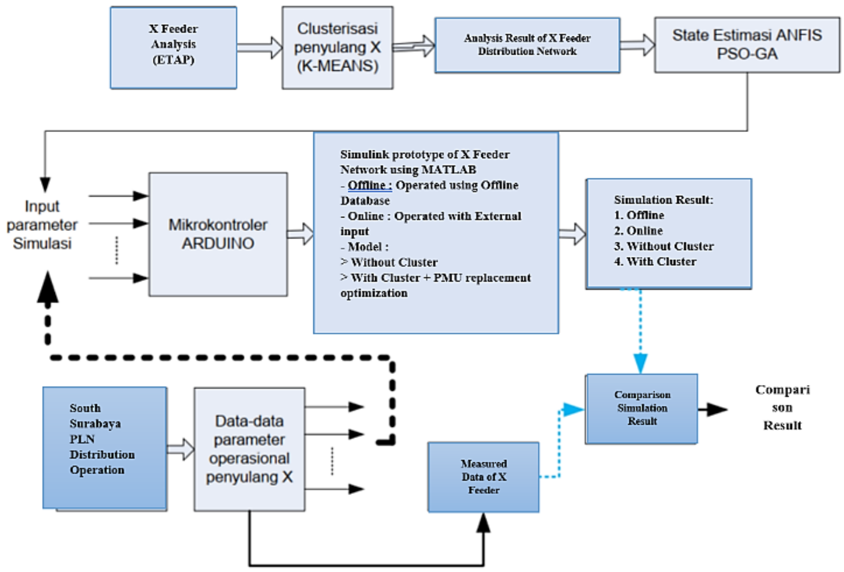


Figure 1. Online and offline monitoring by Simulink

2.3. System design and testing

The received data design and experiment of simulation describe the active power, reactive power, current, and voltage value that flowing in each determined bus according to the single line diagram of the Bendul Merisi network shown in previous Figure 1. Figure 2 is the flowchart of the system design and testing procedure. The flowchart will describe how the system process works and how the testing will be done.

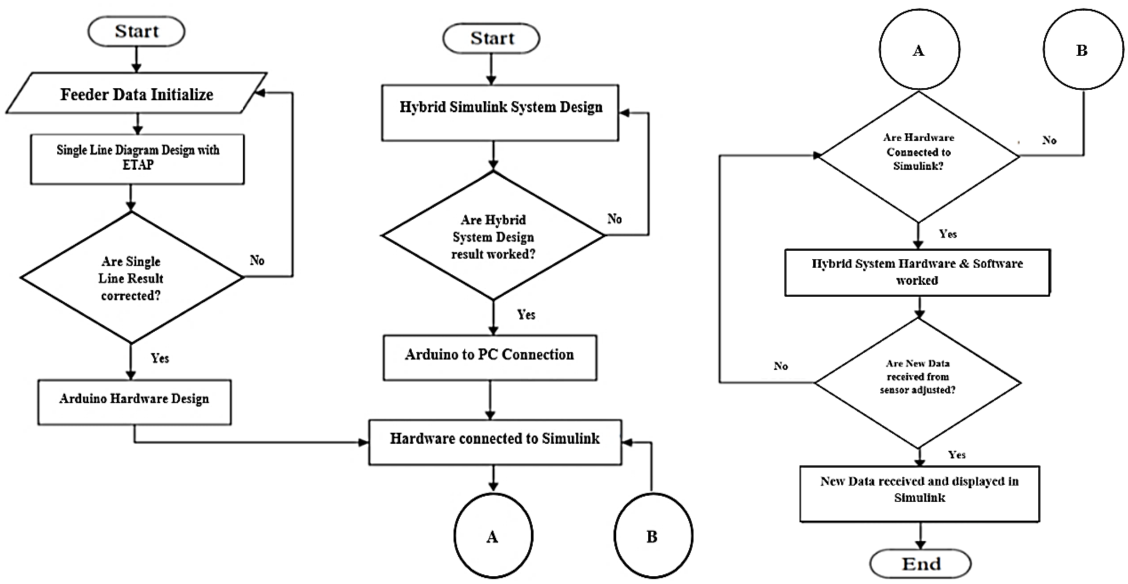


Figure 2. System design and testing flowchart

2.4. Simulink software design

The design and assembly of the online and online hybrid systems of the Bendul Merisi feeder network are shown in Figure 3. It is also describing the flow process of the system through blocks. The process starts with data gathering from ETAP to the recipient which is the smartphone.

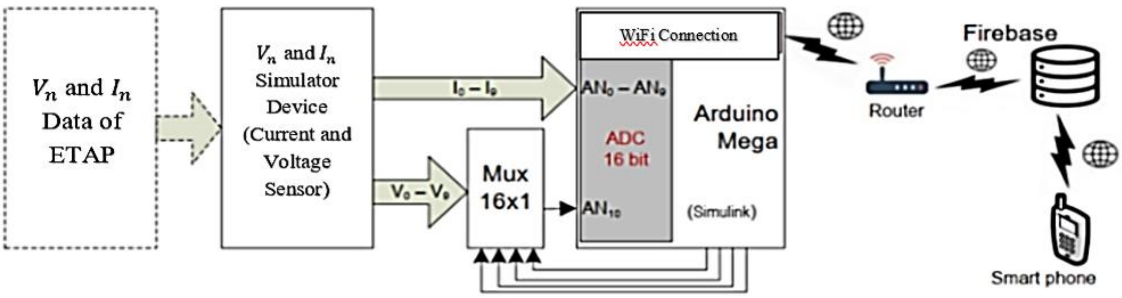


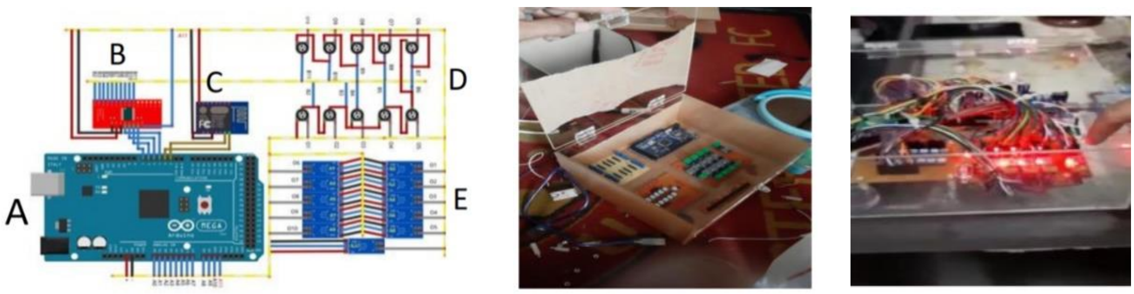
Figure 3. Simulink simulation process

Figure 3 describes the Simulink simulation process. Voltage (Vn) and current (In) data were received from the simulation of the Bendul Merisi distribution network with 10 buses. The data was simulated using a 10 voltage sensor (Vn) of variable resistor and 10 current sensor (In). The value of voltage and current can be adjusted by adjusting the resistance value of a variable resistor. Current port I_0 to I_9 connected to pin AN_0–AN_9 of ADC block 16 bit of Arduino mega and voltage port V_0 to V_9 connected to pin AN_{10} of ADC block 16 bit after multiplexer 16×1 bit.

Voltage and current data (V_0-V_9, I_0-I_9) received by Arduino were processed using a program similar to simulink to calculate active power and reactive power value. Voltage, current, and power data are transmitted to the internet using wifi and platform IoT firebase. By using this platform, the data can be accessed using a smartphone from any location. From the simulation, voltage and current values can be adjusted using variable resistor values, so real-time can be adjusted via smartphone.

2.5. Internet of things monitoring and hardware design

The hardware design is displayed in Figure 4. The hardware consists of five components: i) microcontroller Arduino mega 2560, ii) 16 channel analog multiplexers, iii) ESP8266 WiFi module, iv) ACS712 current sensor, and v) variable resistor. Figures 4(a) to 4(c) describes the block diagram of the hardware design.



(a) (b) (c)

Figure 4. Internet of things hardware design with (a) hardware connection, (b) hardware assembly, and (c) hardware running output

Microcontroller works as current and voltage data sensor reading, controlling multiplexer selector, and also transmitting data via wire through WiFi. Microcontroller Arduino mega 2560 will convert the analog signal of 10 ACS712 sensors and 10 variable resistors into digital form through the ADC of the microcontroller. ADC data from ACS712 sensing result will be converted into current form while variable resistor result will convert into voltage. Since the ADC pin amount of Arduino mega 2560 is insufficient for the total sensor amount, applied a 16-channel analog multiplexer as a selector so the analog signal from variable resistor was detected by microcontroller. Pin configuration of the selector from 0 to 3 will be into pins 4 to 7 consecutively from the microcontroller as channel position adjustment. The process requires binary number calculation in channel location determination in which the decimal value of the channel will be converted to binary form (1 or 0). The multiplexer is supplied by a 5 V of Arduino VCC pin.

ESP8266 Wifi module is a tool to mediate data communication via a wire between client and server. In the research, ESP8266 worked as a current and voltage data transmitter of buses 2–11 monitored by smartphone. The principle of the module is a serial communication form so at the configuration, the available receiver (Rx) and transmitter (Tx) pin in which Rx is connected to the Tx pin of Arduino mega and Tx pin will be connected to the Rx pin of Arduino.

ACS712 principle is to read the current received by the sensor. In this research, the ACS712 sensor consists of 10 units with reading accuracy of current capabilities to a maximum of 30 A. The sensor input configuration will be series assembled into a load that is to be detected and supplied by 5 V. of 10 ACS712 sensors, output pin from the sensor will be connected to ADC pin A_0–A_{10} consecutively on microcontroller Arduino mega. The variable resistor principle is to regulate voltage passing through the resistor. In this research, 10 units of variable resistor were applied as initialization of supplied voltage of 5 V. Output from variable resistor will be into analog pin 0 to 10 of 16 channel multiplexer consecutively.

3. RESULTS AND DISCUSSION

3.1. Hardware testing

System configuration is using voltage and current sources. The output of the simulation result was displayed using an internet application as monitoring media by smartphone. On circuit can be monitored in real-time using the internet so the displayed result is compatible with the environment condition in a relatively very quick time. Electrical energy resulting voltage and current. The sensor in the input configuration is in series with the load that will be detected and supplied by 5 V. From 10 ACS712 sensors, pin output will be connected to ADC pin of A_0–A_9 consecutively on Microcontroller. The output of the variable resistor is connected to pin 0–9 of 16 channel analog multiplexer consecutively, displayed in Figure 5. Microcontroller Arduino mega 2560 pin configuration of selector 0-3 connected to pin 4–7 consecutively as channel position adjustment that will be read. Multiplexer controlling selector and sending data via wire through Wifi media. Data received through smartphone android. ESP8266 Wifi module applied as data communication media via a wire between client and server. A smartphone displaying calculation results that receive current and voltage data through Wifi module media.

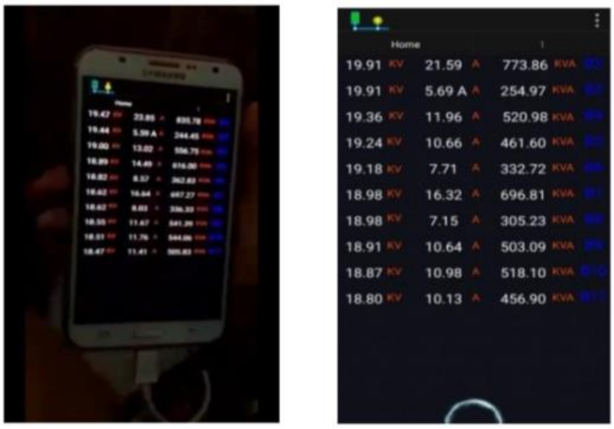


Figure 5. Display data from smartphone

3.2. Internet of things testing

Figure 6 describes the monitoring process as follows: from current and voltage sensor to Arduino Mega, voltage and current data are processed to receive information required by the user. The information is transmitted to Firebase as data storage media using Wifi module ESP8266 which connects the microcontroller to the router. Firebase worked as data storage media that can be accessed by smartphone anytime and anywhere using the internet. The monitoring test is done in two steps, the laboratory test, and the field test. The tests are done for seven (7) days from Monday to Saturday (27th July to 1st August).

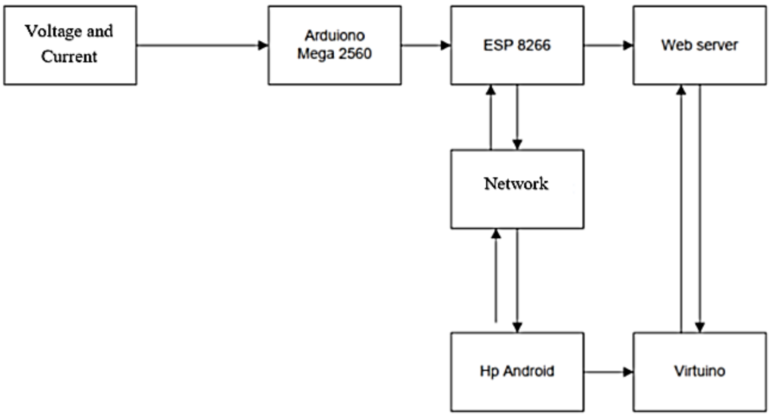


Figure 6. Smartphone system monitoring block diagram

From laboratorium test result, a distance of 2 to 4 meters using Wi-Fi require 2 seconds for data to be received by the smartphone. The Hardware was tested each hour for every 24 hours on Monday and Tuesday. While a distance of 6 to 8 meters requires 3 seconds, tested on Wednesday and Thursday. The distance of 10 to 12 meters requires 4 seconds and was tested on Friday and Saturday. On Sunday, the hardware was tested for a distance of 14 meters and 5 seconds duration. Table 2 shows the laboratory test result during 24 hours on Monday, while Table 3 shows the laboratory test result during 24 hours on Sunday.

Table 2. Laboratorium test result on Monday

Time	Distance (m)	Received data		Duration (second)
		Available	None	
01:03	2	V	-	2
03:05	2	V	-	2
05:07	2	V	-	2
07:09	2	V	-	2
09:12	2	V	-	2
11:21	2	V	-	2
13:43	2	V	-	2
15:14	2	V	-	2
17:20	2	V	-	2
19:01	2	V	-	2
21:14	2	V	-	2
23:10	2	V	-	2

Table 3. Laboratorium test result on Sunday

Time	Distance (m)	Received Data		Duration (Second)
		Available	None	
01:15	14	V	-	5
03:12	14	V	-	5
05:15	14	V	-	5
07:16	14	V	-	5
09:01	14	V	-	5
11:12	14	V	-	5
13:19	14	V	-	5
15:12	14	V	-	5
17:12	14	V	-	5
19:01	14	V	-	5
21:14	14	V	-	5
23:10	14	V	-	5

Tables 2 and 3 described the laboratory test result on different days. Within each day, the test is observed for 24 hours, and the data is recorded every two hours. Figures 7 and 8 display the monitoring result in a graph. Next is to field test the hardware with the location in Madiun starting from South Wiguna Street (Gunung Anyar) and then received at Petung Rejo Village at Magetan with a distance of 185 km.

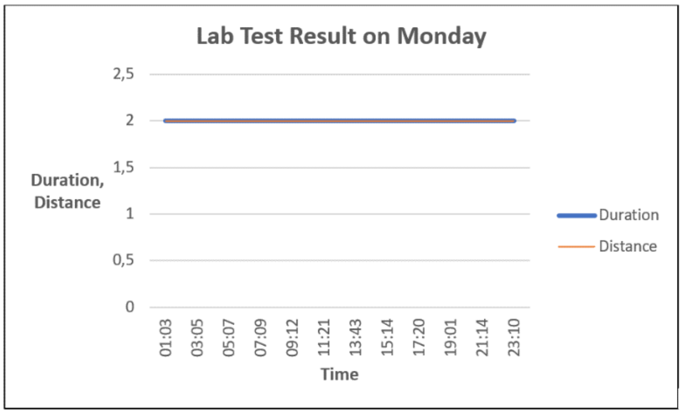


Figure 7. Monitoring result graph with IoT on Monday

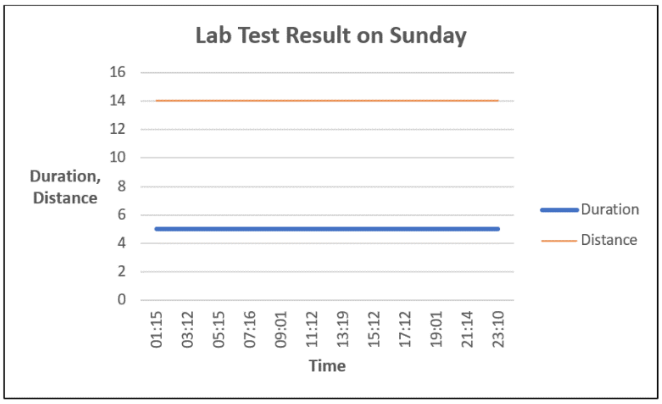


Figure 8. Monitoring result graph using IoT on Sunday

Table 4 shows the field test result of 7 days. Figures 9 and 10 show a comparison graph between the distance and time of received data by smartphone. The duration of transmission of 24 hours is 10,416 seconds. Based on the result of the simulation of the experiment and calculation of Arduino, can be concluded that the usage of the potentiometer as a component for adjusting the voltage and current input value from Feeder data is not giving 100% accuracy with the desired input value so sometimes input value can be above the original value and sometimes below the original input value. Hardware test of laboratory scale in 7 days has an average time of 2.8 seconds, while the field test requires an average time of 10,416 seconds in 24 hours.

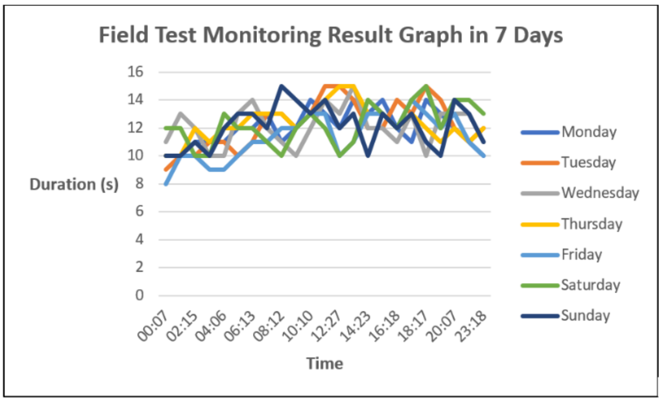


Figure 9. Field test monitoring result graph in 7 days

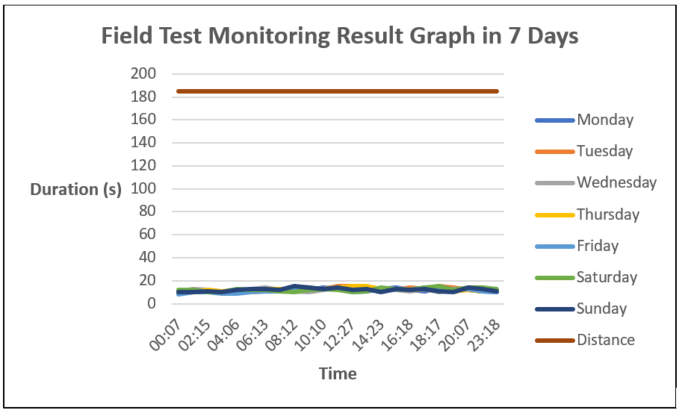


Figure 10. Field test monitoring result from received data by smartphone in 7 days

Table 4. Field test result in 7 days

Time	Distance (km)	Monday (second)	Tuesday (second)	Wednesday (second)	Thursday (second)	Friday (second)	Saturday (second)	Sunday (second)
01:13	185	10	10	13	10	10	12	10
03:11	185	11	11	10	11	9	10	10
05:01	185	12	10	13	12	10	12	13
07:20	185	13	13	12	13	11	11	12
09:21	185	12	12	10	12	12	12	14
11:14	185	13	15	14	14	13	12	14
13:15	185	14	14	15	15	11	11	13
15:06	185	14	12	12	13	13	13	13
17:27	185	11	13	13	13	14	14	13
19:19	185	13	14	13	11	12	12	10
21:10	185	11	11	13	11	11	14	13
23:18	185	10	12	11	12	10	13	11

4. CONCLUSION

The research is giving contributions in the form of a method for reducing PMU amount and optimization of PMU replacement using a combination called integer linear k-means. Bendul Merisi feeder with radial distribution network has 11 buses, so it required optimization of PMU replacement. Application of integer linear k-means clustering method for PMU replacement optimation showing good results. With 11 bus networks, requiring only 3 PMUs so happened decline of PMUs amounted to 73%. Data parameters of voltage, current, and impedance are measurement result data from the field and have decimal values. PMU replacement results of buses 3, 6, and 10 are optimal PMU replacement locations. For data tested in the transmission network with phase angle and voltage parameters, with 19 bus Jawali 500 kV can get 3 clusters using the method placed in bus 6, 9, or 10, and bus 13 with a declination of 84% of PMU replacement. Results from hardware validation and simulation can be applied to another feeder if we are looking for active power and reactive power from each bus since error result comparison between simulation result and mathematical calculation results in <1% error. The designed simulation is also able to calculate active power and reactive power value in each bus of each cluster so we can also receive a total of active power and reactive power of each cluster. Hardware testing uses the internet of things to transmit data on a laboratory scale within 7 days, having an average duration of 2,8 seconds. While field tests required an average duration of 10,416 seconds within 24 hours.

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BIOGRAPHIES OF AUTHORS

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