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Real-Time Data Acquisition and Monitoring of Three Phase Load Balance in Electricity Distribution

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Abstract

A real-time monitoring mechanism for three-phase electrical power distribution panels is essentially needed to ensure that the power is evenly distributed across all phases, so that the efficiency of energy usage could be maintained. This paper presents monitoring and data acquisition system for three-phase balance distribution. The system ensures balanced distribution of electrical power in order to enhance the efficiency and reliability of power systems. It leverages advanced technologies to collect, analyze, and report data, providing valuable insights into the performance of the power distribution network. Data acquisition is established by using sensor PZEM004T to measure the electricity parameters which is integrated with Arduino microcontroller. In addition, real-time monitoring system is visualized through dashboard data management for more informative data acquisition and analytic purposes. The performance is evaluated by testing the instrument and application at a distribution panel within a span of five days to monitor electrical parameters.. The results show that real-time monitoring system for three phase balance works perfectly to provide actual data and phase balance condition. The phase imbalance values are higher during the peak working hours where the loads are dynamics and extensively used.The highest value of imbalance obtained from monitoring results was 105.68% at 07.00 AM – 10.00 AM.56 while the lowest imbalance value obtained from monitoring results was 57.18% at 14.10 PM – 04.00 PM.

Keywords: 3-Phase Power Balance; IoT System; load balance dashboards;PZEM-004T

1. Introduction

Power distribution system is directly related to users of electrical energy, especially users of medium voltage and low voltage electricity. Usually there is often an unbalanced load on the phases or an overload occurs due to the use of electrical equipment from electrical energy consumers. Load balance between phases is required for equal distribution of loads so as to minimize changes caused by full load. This is also important because it is useful in optimization techniques to produce a reliable and efficient system [1], [2]. In low voltage electricity distribution networks, one of the main equipment used is the 3 phase distribution transformer. This transformer functions to lower the voltage so that the voltage can be used safely by consumers on low voltage networks such as households, street lights, schools, and so on.

In electric power distribution, a load imbalance occurs due to the asynchronous timing of the load ignition. Load imbalance between each phase (R phase, S phase, and T phase) causes current to flow in the transformer neutral. So that the unbalanced factor leads to the occurrence of neutral current could increase the power losses and reduce the efficiency of the transformer [3]. Therefore, in the distribution of electric power, load imbalances must be minimized in order to achieve optimal distribution efficiency. The distribution system needs to be properly planned to guarantee that it operates within the set parameters [4]. In every building construction, there must be an electrical installation plan according to the needs required by the building itself. However, it is often found that field conditions change after the building is put into operation and the load is added. This condition will cause load contention [5].

The 3-phase balance data monitoring and acquisition system are an early detection of imbalances and faults in the system, allowing for preventive maintenance, optimization of energy consumption and load distribution across phases, and enhanced system reliability and reduced downtime. As well as to gain better understanding

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of the power usage patterns, helping with energy management strategies. An earlier study designed a smart monitoring system for Three Phase inverters using an Android Application which saves time and simplifies the process of monitoring the condition of a 3-phase electrical system [6]. Another study has developed an electrical energy controller by employing IoT technology, utilizing Arduino, PZEM-004T Module, Wemos, and a real-time clock as a microcontroller. The tool offers several advantages, including the ability to remotely switch on/off household electrical systems, automatic overload or short circuit protection, and the ability to monitor current, voltage, power, and energy/cost consumption [7]. An electrical current balancing monitoring device using current sensor and an Arduino microcontroller has been designed [8], [9]. Microcontroller and relay switching has been used in lowering three phase line unbalance as well as lowering current in the system's neutral wire to keep the three phase voltage stable and regulated [10]. Today, real-time monitoring using microcontrollers has been expanded for robotic controllers and tracking system [11].

Voltage unbalance factors (VUF) [12], [13], and the percent voltage unbalance (PVU) [14] are the key performance measurements for the three-phase imbalance detection. To improve distribution system performance and reduce losses, it is crucial to reorganize the network by rescheduling the loads [15]. This can only be conducted if the load imbalance is predicted using historical data or implementing machine learning algorithm [16].

Previous studies that have been conducted to monitor the balance of electricity provide real time information of voltage, current, and frequency variables. However, the monitoring system do not have data acquisition system which offers reporting feature of all the measurement results. Therefore, a more comprehensive monitoring system is developed by expanding the monitoring range so that the system can carry out real-time monitoring and the system becomes more effective and efficient in terms of accessing the monitoring system, as well as adding data acquisition to obtain data to determine the imbalance presentation.

The structure of the paper is outlined as follows, the material and method used in this work is described in Section 2. Section 3 covers results and discussion and the conclusion is provided in Section 4.

2. Materials and Methods

The 3-phase balance monitoring system is established using the Arduino Pro Mini microcontroller, Wemos and the PZEM-004T sensor as the main component and other components such as the Nextion LCD to display measurement values of voltage, current, power factor, average current, and percentage of imbalance.

2.1. Hardware system

The block diagram created is intended as a reference for making hardware in order to simplify the assembly process.

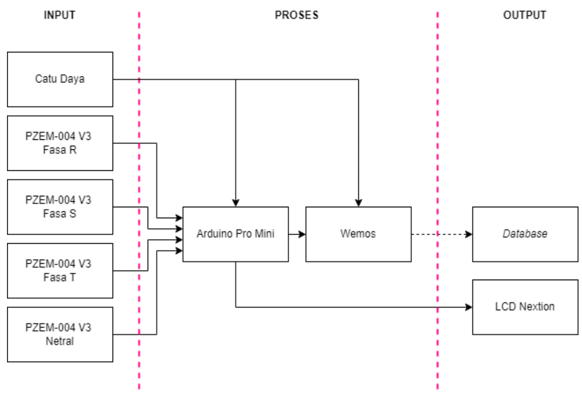

Figure 1. Hardware block diagram

Figure 1 shows the diagram of the hardware design frm input to output part. The power supply from the HLK 10M02 which will be connected to all components including the sensor. The PZEM-004T sensor will send data in the form of serial software to the Arduino pro mini so that the value of the voltage and current on each phase that has been installed will be processed by Arduino. Arduino will calculate these values and display the data on the Nextion LCD and will also send the data to Wemos for further processing as database. Furthermore, the dashboard monitoring application will automatically update the values on the graph about the condition of the distribution panel being measured. Figure 2 shows the wiring diagram of the instrument.

The schematic diagram of electronics design is presented in Fig. 3. This figure shows the connection and configuration of electronic elements.

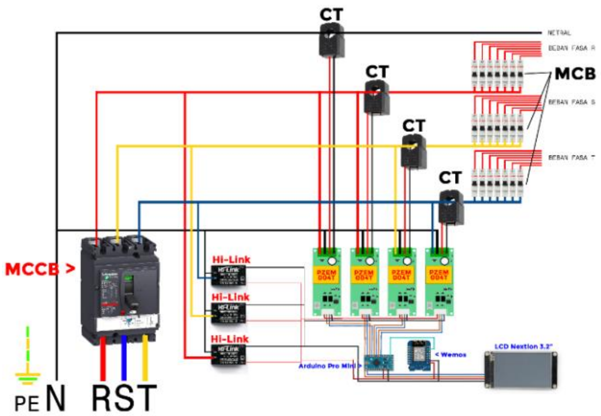

Figure 2. Design wiring diagram

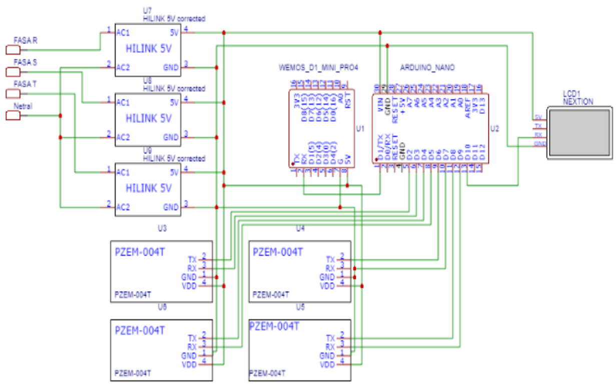

Figure 3. Schematic diagram

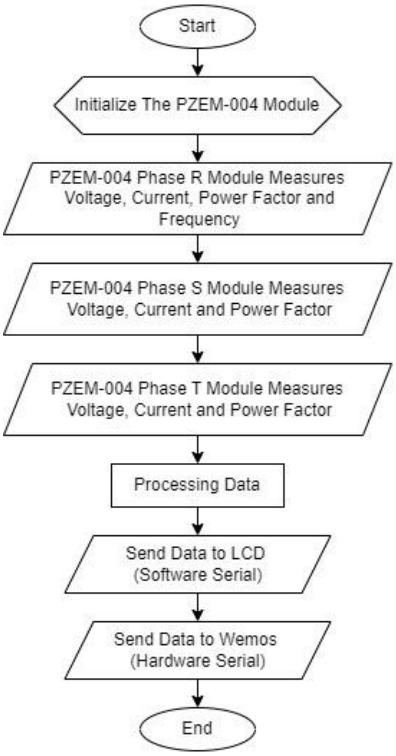

Figure 4. Arduino flow chart

2.2. *Software system*

The monitoring application and data acquisition are built through several stages. Firstly, data reading system on the Arduino which functions to manage measured data and send the data to the LCD and also Wemos. Secondly, designing the system displays on the Nextion LCD received from Arduino, and the latter is data acquisition and dashboard monitoring system.

2.2.1. *System design on Arduino*

This system includes data retrieval from the PZEM-004T sensor which will manage data in the form of voltage, current, power factor, frequency and also unbalance values. This is programmed in the Arduino IDE software. Figure 4 shows the flow chart of system where PZEM-004 sensor measures the electrical variables in each phase than send it to LCD for real time display and also to Wemos for data acquisition and monitoring system.

2.2.2. *Monitoring design on LCD*

For direct media monitoring, the Nextion LCD is used, which must be programmed and designed in the Nextion Editor software before it can be used to get a Human Machine Interface (HMI). Figure 5 shows the results of HMI design to visualize the electricity parameters which are measured. It displays variables are voltage, current, power factor, frequency, and the imbalance value.

2.2.3. *Data acquisiton and dashboard monitoring*

Electricity power parameters will be sent to the database via a wi-fi network connected to Wemos. This system is programmed on the Arduino IDE software. The following is a flow chart of this system.

Figure 5. Human Machine Interface (HMI) design on the Nextion LCD

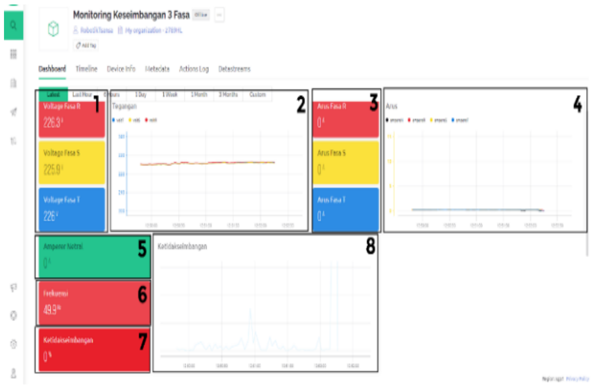

Figure 6. Dashboard design result

A dashboard monitoring designed on the *blynk* website using label components and also a chart where each value is sourced from the blynk database. The values on the labels and charts will change according to the updated data sent from Wemos. The dashboard preview can be seen in Fig. 6.

From the image of the results of the dashboard design, there is a description of each component as follows:

1. Voltage Label (Red for R phase, yellow for S phase, and blue for T phase).
2. Voltage graph (red line for R phase, yellow for S phase, and blue for T phase).
3. Current Label (Red for R phase, yellow for S phase, blue for T phase)
4. Current Graph (red line for R phase, yellow for S phase, blue for T phase, and black for neutral current).
5. Neutral Flow Labels
6. Frequency Labels
7. Imbalance label
8. Imbalance Chart

3. **Results and Discussion**

The real time measurements start from a 3-phase sources, each phase and grounded neutral will have an Open CT from the PZEM-004T sensor as a reading for each phase. Then the measurement value will be displayed on the LCD screen and parsed to Wemos to be recorded in the database. Furthermore, remote monitoring can be accessed from the dashboard and presented in the form of numbers and graphs.

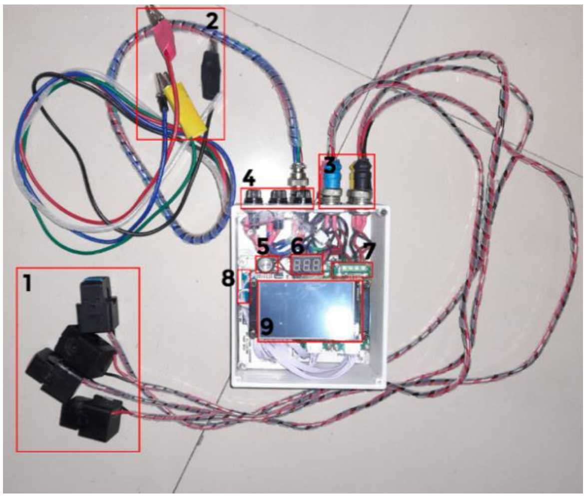

Figure 7. The instrument

3.1. Hardware

The results of the mechanical and electrical design are shown in Fig. 7. The instrument consists of :

1. Current transformer (red for R phase, yellow for S phase, blue for T phase, and black for neutral wire)
2. Crocodile Clips (Red for R phase, yellow for S phase, blue for T phase, and black for neutral wire)
3. CB Connectors for Current Transformers and Alligator Clips
4. Fuse Holders
5. Switches
6. DC Voltage Indicator
7. PZEM-004T
8. Wemos & Arduino
9. LCD Nextion

Furthermore, the results of the Human Machine Interface of monitoring system which consists of display on LCD Nextion and web-based dashboard monitoring are shown in Figure 8. The LCD provides data presentation on decimal values while web dashboard uses combination of decimal values and graphical visualization of each variable.

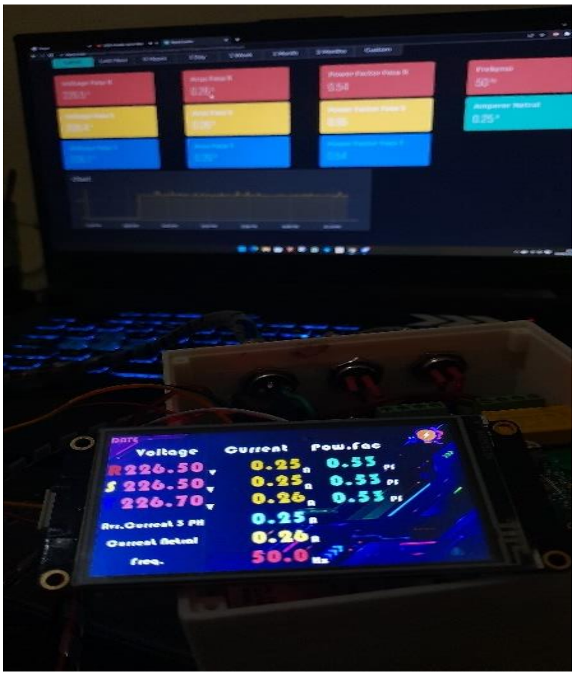

Figure 8. Human Machine Interface of monitoring system

3.2. Testing results

Testing is conducted to evaluate the system's performance of measurement instrument and the real-time monitoring application. The instruments is placed at the Electrical Mechanical Workshop, Department of Electrical Engineering, PNUP.

Data collection for system testing was carried out by installing a 3-phase Balance Monitoring System tool on the electrical panel of the electrical workshop, Campus Electrical Engineering building 1. Data collection is taken five days in a row. Table 4, Table 5, and Table 6 presented the measurement results by PZEM-004T sensor and multimeter of voltage, phase current, and frequency variables respectively. Error percentage is calculated from the difference of measured value using Multimeter over the measured value using sensor PZEM-004T.

3.2.1. Voltage

Table 7 shows that the highest voltage conditions occurred on Day 5 at 10.05.39 AM with a voltage of 259.9 V. The lowest voltage occurred on Day 1 at 2.38.37 PM with a voltage of 217.3 V. The voltage value has exceeded the tolerance limit for the voltage value set by PT.PLN (Persero) where the reasonable voltage limit is 231V (220V + 5%). The cause of this is the occurrence of sudden changes in load resulting in over voltage.

3.2.2. Frequency

Table 8 presents the lowest and highest frequency measurement. It can be seen that the highest frequency conditions occurred on Day 5 at 09.29.42 PM with frequency 50.4Hz. The lowest frequency is on Day 1 at 08.20.37 AM at 49.6 Hz.

Tabel 4. Comparison of voltage measurement results of PZEM, dashboard, and multimeter

Voltage	PZEM-004T (V)	*Dashboard*	Multimeter (V)	Error (%)
VR	232.1	232.1	231.5	0.259
VS	224.9	224.9	225.2	0.133
VT	228.1	228.1	227.2	0.395
Average				0.262

Tabel 5. Comparison of current measurement results of PZEM, Dashboard, and Multimeter

Phase Current	PZEM-004T (A)	*Dashboard*	Multimeter (A)	Error (%)
IR	4.48	4.48	4.58	2.183
IS	0.58	0.58	0.593	2.192
IT	0.56	0.56	0.573	2.269
IN	0.21	0.21	0.214	1.869
Average				2.128

Tabel 6. Comparison of frequency measurement results of PZEM, Dashboard, and Multimeter

Measurement	PZEM-004T (Hz)	*Dashboard* (Hz)	Multimeter (Hz)	Error (%)
1	49.9	49.9	49.5	0.81
2	50.2	50.2	50.0	0.40
3	49.9	49.9	49.4	1.01
Average				0.74

Table 7. Lowest and highest voltage measurement data

Day	line	Lowest Voltage		Highest Voltage	
		Value (V)	Hour	Value (V)	Hour
Day 1	RN	217.3	2:38:37PM	236.2	3:29:50PM
	SN	217.1	10:04:42AM	232.1	6:54:22 AM
	TN	217.4	2:42:09PM	230.5	7:48:14 AM
Day 2	RN	219.1	7:44:59AM	235.3	7:06:39AM
	SN	218.7	2:35:52PM	232.1	7:04:32AM
	TN	218.4	1:30:57PM	230.4	7:00:09AM
Day 3	RN	218.4	9:58:07AM	234.9	7:03:15AM
	SN	218.2	10:01:29 AM	231.2	9:58:07AM
	TN	219.6	1:42:09PM	229.9	10:01:29 AM
Day 4	RN	220	10:39:52 AM	234.3	9:21:11AM
	SN	222	6:55:46 AM	232.2	5:23:12PM
	TN	223.1	6:55:47 AM	232.5	11:09:34 AM
Day 5	RN	220.8	6:58:57AM	234	10:04:09 AM
	SN	219.3	6:58:57AM	232.8	7:16:49 AM
	TN	219.6	9:46:25AM	259.9	10:05:39 AM

Based on the standards set by PT.PLN (Persero), the nominal frequency on the network is 50.00 (fifty point zero zero) Hz, the system frequency can go up to 52.00 (fifty two point zero zero) Hz and down to with 47.00 (forty seven point zero zero) Hz in extraordinary circumstances. From these standards the frequency that occurred during the testing is still classified as the standard set by PT. PLN (Persero).

Table 8. Lowest and highest frequency measurement data

Day	Hour	Frequency (Hz)	Information
Day 1	08:20:52 AM	49.6	Lowest
	10:59:18AM	50.3	Highest
Day 2	07:36:33 AM	49.7	Lowest
	10:27:10AM	50.3	Highest
Day 3	04:32:20 PM	49.6	Lowest
	03:14:50PM	50.2	Highest
Day 4	02:30:48PM	49.5	Lowest
	08:54:10 AM	50.3	Highest
Day 5	04:32:20 PM	49.6	Lowest
	09:29:42 AM	50.4	Highest

Figure 9 shows the frequency value on Day 5 from 06.58.57 AM to 16:45:45 PM. The highest frequency shown is 50.4 Hz and the lowest is 49.6 Hz.

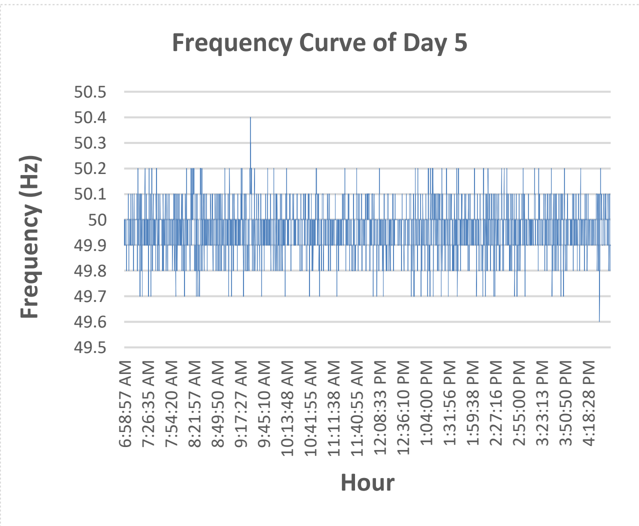

Figure 9. Frequency chart on Day 5

3.2.3. Current/Load

As a natural law, the current measurement current is inversely proportional to voltage. It can be evaluated that the lowest current conditions occurred on Day 5 at 10.04.54 PM with a current of 0.12 A (Phase T). Meanwhile, the highest current is on Day 1 at 12.42.45 PM was 10.51 A (Phase R).

Table 9. Lowest and highest current measurement data

Day	line	Lowest Current		Highest Flow	
		Value (A)	Hour	Value (A)	Hour
Day 1	R	0.29	6:54:14 AM	10.51	12:42:45PM
	S	0.49	7:32:46AM	6,46	1:28:57PM
	T	0.2	10:49:38AM	1.52	2:07:50PM
	N	0.03	7:03:55 AM	0.96	1:58:40PM
Day 2	R	0.28	5:08:40 PM	9.93	8:25:42 AM
	S	0.48	4:15:05PM	2.05	11:19:53 AM
	T	0.31	1:38:12PM	3.69	9:17:10AM
	N	0.03	5:49:52PM	0.6	11:08:36AM
Day 3	R	0.27	4:09:27PM	9.88	12:45:25PM
	S	0.49	7:45:42AM	2.81	8:06:50AM
	T	0.31	10:29:12 AM	1.74	12:45:25PM
	N	0.03	7:05:15 AM	0.91	10:29:43 AM
Day 4	R	0.26	4:12:17PM	9,41	10:55:32AM
	S	0.48	4:06:02PM	2,23	3:05:28PM
	T	0.31	4:12:00PM	1.81	12:37:17 PM
	N	0.03	7:20:46AM	0.8	9:42:21AM
Day 5	R	0.27	6:59:02AM	9.88	12:45:25PM
	S	0.49	7:27:37AM	2.62	8:10:49AM
	T	0.12	10:04:54 AM	1.74	12:45:25PM
	N	0.03	7:14:19AM	2.63	9:50:52 AM

3.2.4. Phase imbalance

The 3-phase imbalance is analyzed by calculating the imbalance coefficient which consists of the coefficients a, b and c which are calculated from the load imbalance percentage equation. For example, on the reading of Day 1 at 07.00 AM – 10.00 AM the values for the coefficients a, b and c are calculated as follows, so that an imbalance of 76.31% is obtained.

$$a = \frac{IR}{\frac{IR+IS+IT}{3}} = \frac{7,42}{3,4583} = 2,1447 \quad (1)$$

$$b = \frac{IS}{\frac{IR+IS+IT}{3}} = \frac{2,52}{3,483} = 0,7298 \quad (2)$$

$$c = \frac{IT}{\frac{IR+IS+IT}{3}} = \frac{0,43}{3,483} = 0,1255 \quad (3)$$

$$\%\ \text{Load Imbalance} = \frac{\{|a-1| + |b-1| + |c-1|\}}{3} \times 100\% \quad (4)$$

$$= \frac{\{|2,1447-1| + |0,7298-1| + |0,1255-1|\}}{3} \times 100\%$$

$$= \frac{1,1447 + 0,2702 + 0,8745}{3} \times 100\%$$

$$= \frac{2,2894}{3} \times 100\% = 0,764 \times 100\% = 76,31\%$$

Table 10 provides the results of imbalance coefficients during the testing in five days.

Data from load current measurements can be seen the percent imbalance from the lowest of 57.18% to the highest of 105.68%. From this value it is far from the standard load imbalance regulated in IEEE std 446 – 1980, which is 5% - 20%. This happens bec ause the current in phase R serves a very large load than phases S and T. One of the consequences of an imbalance is that there is a current in the Neutral wire. The tendency for the highest imbalance to occur occurs at 10.01 AM to 14.00 PM because at that time the peak load occurs.

Table 10. Calculation of imbalance

Day	Hour	Average Line Flow				Imbalance (%)
		R	S	T	N	
Day 1	07.00 AM - 10.00 AM	7.42	2.52	0.43	0.26	76.31
	10.01AM - 14.00 PM	7.13	3.98	0.54	0.25	57.35
	14.10 PM - 04.00 PM	7.75	5.47	0.66	0.23	57.18
Day 2	07.00 AM - 10.00 AM	8.03	0.89	0.40	0.32	105.68
	10.01 AM - 14.00 PM	6.34	0.86	0.77	0.24	92.38
	14.10 PM - 04.30 PM	6.40	0.93	0.33	0.25	100.41
Day 3	07.00 AM - 10.00 AM	5.09	0.86	0.33	0.25	95.65
	10.01 AM - 14.00 PM	5.92	0.89	0.33	0.27	99.26
	14.10 PM - 04.00 PM	4.08	0.86	0.33	0.18	88.25
Day 4	07.00 AM - 10.00 AM	3.98	0.83	0.66	0.19	78.92
	10.01 AM - 14.00 PM	5.38	0.74	0.72	0.25	90.61
	14.10 PM - 04.00 PM	4.89	0.77	0.81	0.23	84.50
Day 5	07.00 AM - 10.00 AM	5.55	0.76	0.33	0.27	100.67
	10.01AM - 14.00 PM	5.88	0.89	0.33	0.26	99.13
	14.10 PM - 04.00 PM	4.08	0.86	0.33	0.18	88.25

3. Conclusion

The 3-phase balance monitoring system has been successfully designed using Arduino as a microcontroller, PZEM-004T sensor as a measure of electrical parameters, Nextion LCD as a direct interface and Wemos as communication to the dashboard application. Therefore, the 3-phase balance condition can also be remotely monitored in real-time and recorded data can be accessed anytime. The voltage, frequency and current monitoring system are functioning properly and can monitor dynamic conditions during five days of testing. On the period of testing, it is revealed that the lowest measured voltage is 217.3 V and the highest is 259.9 V from the measured value there is an over voltage due to the tolerance set by PT. PLN (Persero) with a maximum over voltage of 231V. This over voltage incident occurred due to a sudden change in load, it can be seen in the load curve at that time which jumped from 4.84 A to 7.88 A. The phase imbalance value obtained higher during the peak working hours which is relevant with the load characters on the workshop testing location.

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