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Portable Real-Time Monitoring System for PT PLN ULP Cikarang Kota Distribution Substation Based on IoT and PZM 004T Sensor

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ABSTRACT: *One of PT PLN ULP Cikarang Kota's commitments is to maintain the quality level of electricity services to maintain reliability and ensure the sustainability of electrical energy distribution. Maintenance of distribution transformers is an important key in making this happen. The effectiveness of using distribution transformers is 80% of the total capacity to prevent interference. Currently there is no tool available that can detect overload and record peak load times. This research realizes real-time monitoring of distribution substations in the PT PLN ULP Cikarang Kota area using the PZEM 004T sensor and IoT-based. The PZEM 004T sensor sends the reading results to the ESP32 microcontroller to be processed and sent to the ThingSpeak page. The reading results become material for analyzing usage patterns and the basis for making decisions on measures to prevent distribution transformer disturbances. The research was conducted at three distribution substations with residential, industrial, and a combination of residential and industrial customer types. The research results showed that the voltage at the home customer substation was normal and the purely industrial customer substation as well as the industrial and home customer substation experienced over voltage of 0.6% and 1.5%. The loading of distribution substations for industrial and home customers experienced an overload of 147% and the loading of all types of substations experienced unbalance with the highest imbalance of 77% at purely industrial customer substations.*

KEYWORDS: *PT PLN, electricity, transformer, overload, PZEM 004T.*

I. INTRODUCTION

Considering the importance of electricity needs in Indonesia, PT PLN (Persero) must make every effort to ensure that electricity can continue to be distributed and can be enjoyed by the community according to the provisions of the quality of service that has been set. Distribution transformers are an important component in the electricity distribution system and the part closest to consumers that must be considered and maintained regularly.

Distribution transformers with loads exceeding 80% or overload will experience an increase in temperature and cause heat [1]. Continuous increases in temperature in the Transformer will damage the insulation and materials and reduce the effective life of the distribution transformer. Effective substation loading (below 80%) will have an impact on increasing reliability and maintaining service quality [2]. This background is the basis for designing a portable real-time monitoring system for substations based on IoT and PZEM 004T sensor. This study functions to determine the large capacity of use and peak load time of distribution transformers in the PT PLN ULP Cikarang Kota, Bekasi Regency, West Java work environment.

II. THEORY

Distribution transformers are tools used to transfer electrical energy between two circuits through electromagnetically induced circuits. Distribution transformers found in the PT PLN ULP Cikarang Kota environment are step down transformers of 20,000 V with a low voltage network system phase of 380 V.

The 20,000 V alternating voltage connected to the primary coil will be flowed and create magnetic lines of force around the ferromagnetic core of the transformer. The magnetic force created will be strengthened by the presence of an iron core. Furthermore, the primary side will induce a secondary side voltage where the value will depend on the number of secondary turns or 380 V [2]. Distribution transformers have main components including: iron core, transformer coil, transformer oil, bushing, tap changer.

In general, the materials used as insulation include mineral oil where transformer oil will protect the infrastructure on high voltage electricity with good insulation quality and high temperature stability [3]. Distribution transformers are designed to have fins as a cooling system by enlarging their cross-sectional area and as an area that is directly connected to the outside air so as to accelerate the release of heat circulation caused by the iron core and coils due to copper losses.

According to IEC 354, the territory of Indonesia has ambient annual temperature at 30° C and temperature rise from distribution transformers (oil/winding/hot spot) is 50 / 55 / 68 K [4].

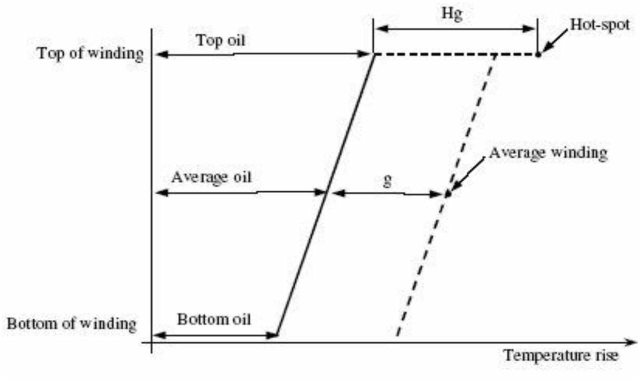


Fig 1. Temperature curve based on IEC 60354

In SPLN 50/1982 and D3.002-21:2007 which discuss the maximum continuous load on distribution transformers is not more than 80% and SPLN 50/1997 which discusses this matter states that distribution transformers with loads above 80% can be handled using the insertion substation transformer method, load breaking, or transformer mutation [1].

The safe limit of transformer loading can be written in Equation (1)

$$S_{Max} = 80\%\ x\ S_{Transformator} \quad (1)$$

Information:

S_{Max} = Safe Load Limit (kVA)

$S_{Transformator}$ = Transformator capacity power (kVA)

The loading of distribution transformers has long been regulated in SPLN No. 1 of 1995, which states that the requirements for system reliability are that the loading of distribution transformers must not exceed 80% of the capacity rating and the percentage of voltage drop distributed to customers must not exceed +5% or -10% of the ideal voltage, namely 220 V for 1-phase customers and 380 V for 3-phase customers [2].

In determining the size of the distribution transformer usage, it can be calculated in Equation (2)

$$S_{usage} = \frac{V\ x\ I}{1000} \quad (2)$$

Information:

S_{usage} = Apparent Power Usage (kVA)

V = Average Voltage (Volts)

I = Total Current (Ampere)

The percentage of distribution transformer loading can be calculated in Equation (3)

$$\%\ Load = \frac{S_{usage}}{S_{Transformator}}\ x\ 100\% \quad (3)$$

Information:

$\%Load$ = Precentage of loading (Percent)

S_{usage} = Apparent Power Usage (kVA)

$S_{Transformator}$ Transformator capacity power (kVA)

In SPLN 17/1979, distribution transformers can be loaded more than 80% with the provision of the permitted K2 value and the K2 value is not more than 1.5. For this, the following aspects are needed to calculate the distribution transformer loading, including:

1) *Conduct measurements to determine the average load of distribution transformers in 24 hours.*
2) *Grouping the average loading of Off-Peak Load Time (LWBP) and Peak Load Time (WBP). Peak load is the highest amount of energy used from the electricity network in a certain period of time.*
3) *After knowing the average LWBP and WBP loading, the duration of the loading (t) will be known.*
4) *Determine the values of K1 and K2 with Equation (4)*

$$K1 = \frac{S_{LWBP}}{S_{Ttransformator}} \qquad K2 = \frac{S_{WBP}}{S_{Ttransformator}} \quad (4)$$

Information:

$K1$ = condition 1
$K2$ = condition 2
S_{LWBP} Peak Load Time External Power (kVA)
S_{WBP} Peak Load Time Power (kVA)

After the calculation is carried out, it can be seen whether the K2 value is in accordance with existing provisions by looking at Fig 2.

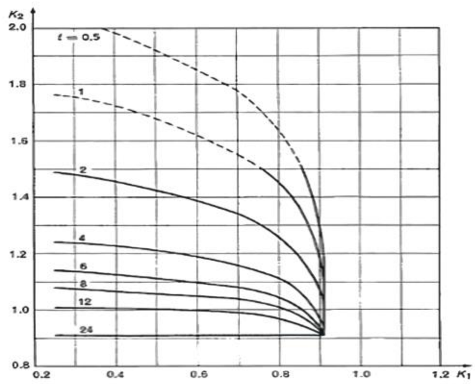


Fig 2. Loading graph of ONAN/ONAF cooling transformer with ambient temperature of 30°C

In distribution substations with a capacity of 160KVA or less, the direction will be divided into 1 or a maximum of 2 directions. The load imbalance in distribution substations is regulated in IEEE std 446-1995, which is 5% - 20% [1]. To determine the load imbalance in each direction, it can be determined by Equation (5).

$$\mathrm{I}_{Unbalance} = \frac{(\left|\frac{I_R}{I_{AV}} - 1\right|) + (\left|\frac{I_s}{I_{AV}} - 1\right|) + (\left|\frac{I_T}{I_{AV}} - 1\right|)}{3} \times 100\% \quad (5)$$

Information:

$\mathrm{I}_{Unbalance}$ = Unabalanced Load (%)

I_{AV} = Average Instantaneous Load (A)

I_R = Phase Load R (A)

I_S = Average Load of Phase S (A)

I_T = Average Load Phase T (A)

In order to improve the performance and uniqueness of this research, we take references that have the same concept as comparison material.

In the research of M. L Pattiapon, Muhammad Faisal Darmawan and A Soleman in the title Design of Real Time Distribution Substation Load Monitoring Tool Using Product Design Method at PT PLN (Persero) Rayon Baguala in 2019. The research conducted utilizes the ACS712 sensor as a current meter and the ZMPT101B sensor as a voltage meter. The results of the sensor readings will then be processed using the Arduino Mega 2560 microcontroller. The MATLAB Graphical User Interface (GUI) program was chosen as a medium for displaying several variables that measure the state of the distribution substation that was extracted [5].

In the research of Ignatius I Wayan Rexci Indra Permana, Cok Gede Indra Partha and Ngakan Putu Satriya Utama with the title Design of Load Current Monitoring System at Distribution Substation Using Short Message Service written in 2017, research was conducted to create a tool that can control and monitor directly the distribution substation based on short message service or SMS (Short Message Service) in real-time. The tools used are Arduino Mega 2560 microcontroller, IComSat v1.1-SIM900 GSM GPRS Module, Micro SD Card Module, RTC (Real-Time Clock) Module, and YHDC SCT 013-000 1V current sensor [6].

In the research of Wendhi Yuniarto, Irman I, Suparno s and Rus Man entitled Designing a Monitoring and Control System for Electrical Energy in 3 Phase Loads Using ESP32 Based on the Internet of Thing (IoT) in 2023, research was conducted to improve efficiency and load sharing arrangements in the Laboratory and Electronics Workshop of Politeknik Negeri Pontianak (POLNEP). This research applies Internet of Thing (IoT) technology with the tools used, namely ESP32 and PZEM 004T sensors to measure voltage, current, power factor and frequency of the electricity network [7].

In the research of Syaiful Bahri, Muhammad Jumnahdi and Wahri Sunanda entitled Designing a Blynk-Based Current, Voltage and Power Monitoring Tool (Study at the Dharma Research Building, University of Bangka Belitung) integrates the PZEM 004T sensor with the Blynk application on the device to determine the real-time measurement efficiency. This study aims to show the difference in value between the measurement results of the PZEM 004T sensor and conventional measuring instruments. The difference in total power from the monitoring tool compared to conventional measuring instruments is 1.77% [8].

In Ridho Ariandi and Kartika's research entitled Detection of Voltage Imbalance in Distribution Transformers Based on PZEM 004T Sensor Notified by Buzzer in 2022. This research aims to mitigate Distribution Transformer damage caused by load imbalance and transformer oil temperature rise. Combining PZEM 004T sensors as current and voltage sensors and DS18B20 sensors as temperature sensors and Arduino Uno as the brain that processes the readings of the two sensors. The percentage error set from this research is 5% of the ideal voltage imbalance capacity [9].

In this prototype design using ESP32 as a microcontroller that will execute readings from the PZEM 004T sensor and equipped with a 150/5A current transformer clamp. The utilization of current transformer clamp in this research makes this research more flexible in determining the amount of load capacity on the object to be researched. The results of the sensor readings are then sent to the ThingSpeak cloud to be visualized in the form of graphs that can be accessed in real-time.

III. METHODOLOGY

The methodology of this research is carried out by designing a portable real-time monitoring tool for PT PLN ULP Cikarang Kota distribution substation using an IoT-based PZEM 004T sensor [10] with ESP32 microcontroller [11, 12]. The monitoring results will be sent to the ThingSpeak page [13] as a basis for analysis and decision making for distribution transformer loading.

A. DESIGN OF PORTABLE REAL-TIME MONITORING EQUIPMENT FOR DISTRIBUTION SUBSTATION

In the process of completing this research, it is necessary stages to design a distribution substation loading monitoring tool. In general, the system that will be used is as follows Fig 3.

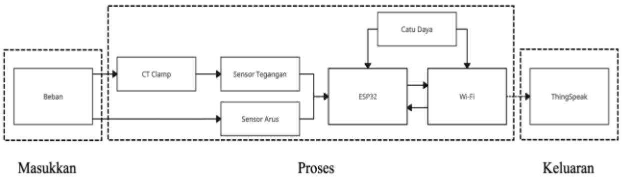


Fig 3. Real-Time Distribution Substation Monitoring System Design

The PZEM 004T sensor will read the voltage, read the current with the help of the Current Transformer Clamp, and other important aspects needed to be further processed on the ESP32 microcontroller. The ESP32 microcontroller will be connected to Thing Speak via Wi-Fi Hotspot. Thing Speak page Data is sent to be further analyzed.

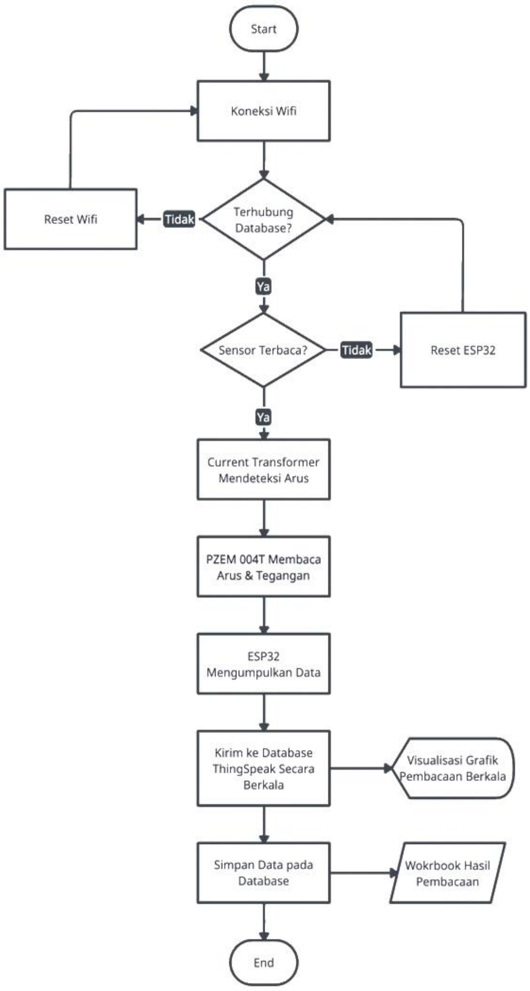


Fig 4. Flowchart of Real-Time Distribution Substation Monitoring System

B. PORTABLE REAL-TIME MONITORING SESIGN FOR DISTRIBUTION SUBSTATION

In the distribution substation that will be analyzed in this study is a distribution substation with two directions so that it requires 6 PZEM 004T sensors. In current reading, the PZEM 004T will be equipped with a current transformer clamp 150/5 to be able to read a higher current range with a factor of 30.

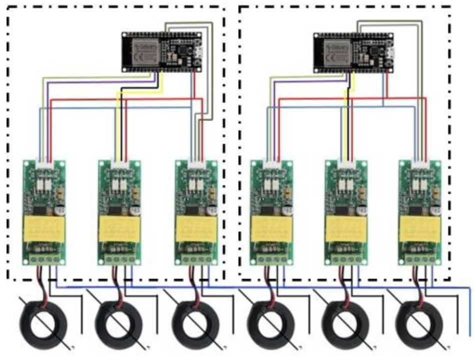


Fig 5. Schematic Diagram

IV. RESULTS AND DISCUSSION

The following are the results and discussions of several measurement tests that have been carried out on 3 distribution substations with the loading types of residential substations, industrial substations and combined substations for industrial and residential customers.

A. RESIDENTIAL CUSTOMER LOAD TEST RESULTS

Test data was conducted for 24 hours at the Pilar Imanan - G (PLRG) Distribution Substation located in a housing complex in Serang Village, South Cikarang District, Bekasi Regency. This distribution substation has a transformer capacity of 100 kVA. To determine the safe limit of the load on the PLRG Substation, we can refer to Equation (1).

$$S_{Max}\,\text{G. PLRG} = 80\% \times 100\ \text{kVA} = 80\ \text{kVA}$$

Measurements at the distribution substation were carried out on May 28, 2024 at 15:50 WIB and ended on May 29, 2024 at 18:17 WIB.

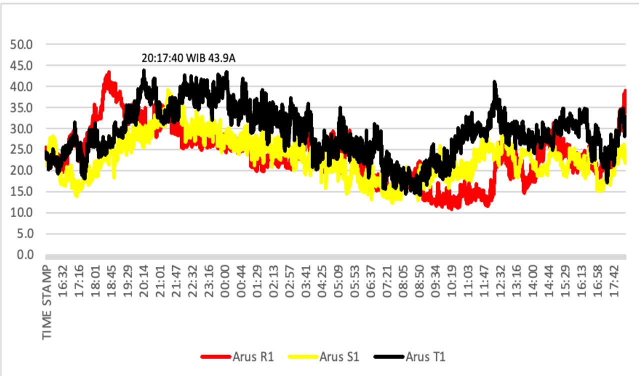


Fig 6. PLRG Substation Load Curve

Based on the curve above, the maximum load of the PLRG substation on route 1 is 109.2 A with an average load for each route being in phase R1=23.6 A, S1=23.2 A, T1=28.8 A. Research data on the PLRG distribution substation will be displayed in Tbl 1.

Tbl 1. PLRG Distribution Substation Research Data

No	Research Variables	Major Load	Unit
1	Maximum Voltage	229.3	Volt
2	Minimum Voltage	221.0	Volt
3	Average Voltage	225.3	Volt
4	Maximum Load	43.9	Ampere
5	Average Load R	23.6	Ampere
6	Average Load S	23.2	Ampere
7	Average Load T	28.8	Ampere
8	Average Usage Percentage	17.0	%
9	Maximum Usage Percentage	29.7	%
10	Maximum Load Time	20:17:40	WIB

At the PLRG distribution substation, the maximum voltage is at 239.3 Volts on route 1. The minimum voltage of the PLRG distribution substation is at 221.0 Volts on route 1. The magnitude of the phase voltage of the PLRG distribution substation is 390 V. With a percentage scale of voltage drop in +5% and -10%, the PLRG distribution substation is at normal voltage.

The peak load on route 1 occurred at 20:17:40 WIB with a maximum current on route 1 of 43.9 A. The average load of the PLRG distribution substation is 25.2 A. The peak load usage of the PLRG distribution substation can be calculated in Equation (2).

$$S_{Pemakaian\ LWBP} = \frac{\sqrt{3} \times 390 \times 25.2}{1000} = 17.0\ kVA$$

$$S_{Pemakaian\ WBP} = \frac{\sqrt{3} \times 390 \times 43.9}{1000} = 29.7\ kVA$$

To determine the percentage of peak load usage at the PLRG distribution substation, Equation 3 is used

$$\%Beban\ Puncak = \frac{29.7\ \text{kVA}}{100\ \text{kVA}} \times 100\% = 30\ \%$$

In the measurements that have been carried out, the total maximum unbalanced load was obtained at phase R=14.3 A, S=17.5 A, and T=33.1 A. To determine the load imbalance at the PLRG distribution substation, it can be determined using Equation (5).

$$I_{Unbalance} = \frac{\left(\left|\frac{14.3}{21.6} - 1\right|\right) + \left(\left|\frac{17.5}{21.6} - 1\right|\right) + \left(\left|\frac{33.1}{21.6} - 1\right|\right)}{3} \times 100\% = 35\%$$

The highest load imbalance at the PLRG distribution substation occurred at 11:14:47 WIB with a percentage of 35%. The graph of the load imbalance at the PLRG distribution substation can be seen in Fig 7.

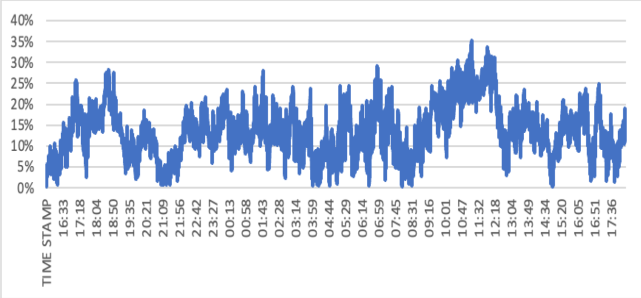


Fig 7. Unbalance graph of PLRG distribution substation

B. INDUSTRIAL CUSTOMER LOAD TEST RESULT

In this type, a distribution substation is determined which is a supplier of electricity for industrial customers. Test data was conducted for 24 hours at the Farika Beton Distribution Substation (FARI) located on Jl. Raya Cibarusah Ds Sukasari, Kec. South Cikarang, Bekasi Regency. This distribution substation has a transformer capacity of 100 kVA. To determine the safe limit of the large load on the FARI Substation, Equation (1) can be used.

$$S_{Max}\,\text{G. FARI} = 80\% \times 100\ \text{kVA} = 80\ \text{kVA}$$

Measurements at the distribution substation were conducted on June 5, 2024 at 15:40 WIB and ended on June 6, 2024 at 15:31 WIB. The measurement result curve is shown in Fig 8.

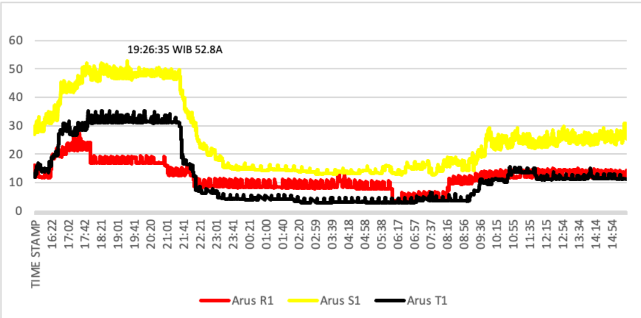


Fig 8. FARI substation load curve

Based on the curve above, the maximum load of the FARI substation on route 1 is 108.8 A with the average load of each route being in phase R1=12.0 A, S1=25.5 A, T1=12.4 A. Research data on the FARI distribution substation is shown in Tbl 2.

Tbl 2. FARI Distribution Substation Research Data

No	Research Variables	Major Load	Unit
1	Maximum Voltage	234.5	Volt
2	Minimum Voltage	216.6	Volt
3	Average Voltage	226.6	Volt
4	Maximum Load	52.8	Ampere

No	Research Variables	Major Load	Unit
5	Average Load R	12.0	Ampere
6	Average Load S	25.5	Ampere
7	Average Load T	12.4	Ampere
8	Average Usage Percentage	11.3	%
9	Maximum Usage Percentage	35.9	%
10	Maximum Load Time	19:26:35	WIB

At the FARI distribution substation, the maximum voltage is at 234.5 Volts on route 1. The minimum voltage at the FARI distribution substation is at 216.0 Volts on route 1. With a voltage drop percentage scale of +5% and -10%, the FARI distribution substation experiences an overvoltage of 1.5%.

The peak load on route 1 occurred at 19:26:35 WIB with a maximum current on route 1 of 52.8 A. The average load of the FARI distribution substation is 16.6 A. The voltage of the phases of the FARI distribution substation is 392.5 V. The peak load usage of the FARI distribution substation can be calculated in Equation (2).

$$S_{Pemakaian\ LWBP} = \frac{\sqrt{3} \times 392.5 \times 16.6}{1000} = 11.3\ kVA$$

$$S_{Pemakaian\ WBP} = \frac{\sqrt{3} \times 392.5 \times 52.8}{1000} = 35.9\ kVA$$

To determine the percentage of peak load usage at the FARI distribution substation, Equation 3 is used:

$$\%Beban\ Puncak = \frac{35.9\ \text{kVA}}{100\ \text{kVA}} \times 100\% = 36\%$$

In the measurements that have been carried out, the total maximum unbalanced load was obtained at phase R=3.7 A, S=17 A, and T=3 A. To determine the load imbalance at the FARI distribution substation, it can be determined using Equation (5).

$$\mathrm{I}_{Unbalance} = \frac{\left(\left|\frac{3.7}{7.9}-1\right|\right)+\left(\left|\frac{17}{7.9}-1\right|\right)+\left(\left|\frac{3}{7.9}-1\right|\right)}{3} \times 100\% = 77\%$$

The highest load imbalance at the FARI distribution substation occurred at 06:41:26 WIB with a percentage of 77%. The FARI distribution substation load imbalance graph can be seen in Fig 9.

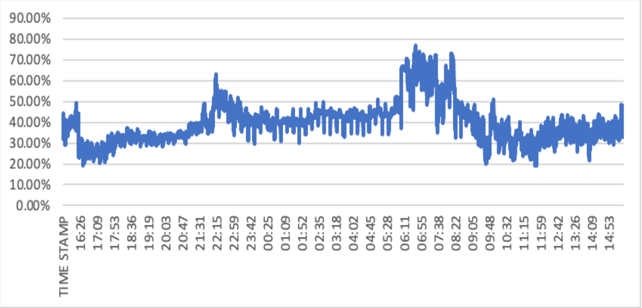


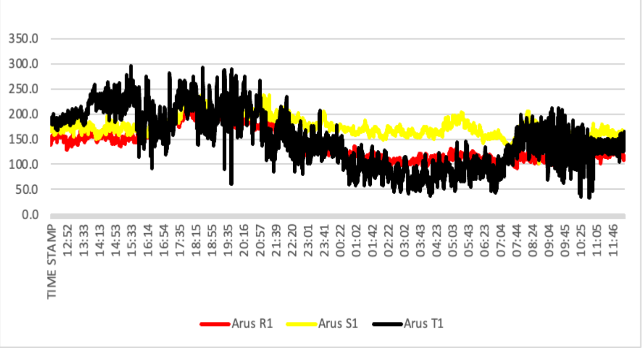
Fig 9. FARI distribution substation imbalance graph

C. RESIDENTIAL AND INDUSTRIAL CUSTOMER LOAD TEST RESULT

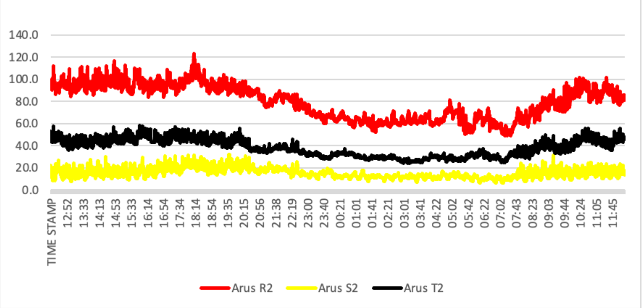
The test was conducted on May 27, 2024 at the Pasir Sari - C (PSRC) distribution substation located in Sukadami Village, South Cikarang District, Bekasi Regency. The PSRC distribution substation has customers with industrial customer types such as welding workshops, customers for office needs and private homes. The PSRC distribution substation has a transformer capacity of 160 kVA. At a capacity of 160 kVA, the safe limit for the PSRC distribution substation can be calculated from Equation (1).

$$S_{Max}\ \text{G. PSRC} = 80\% \times 160\ \text{kVA} = 128\ \text{kVA}$$

After the test equipment was installed at the PSRC distribution substation, the measurement result curve was obtained as shown in Fig 10.



(a)



(b)

Fig 10. PSRC Substation Load Curve (a) Route 1 and (b) Route 2

Based on the curve above, the maximum load of the PSRC substation on route 1 is 295.3 A with an average load for each route being in phase R1 = 138.4

A, S1 = 174.9 A, T1 = 149.5 A. The maximum load on route 2 is 123.0 A with an average load on R2 = 79.3 A, S2 = 14.8 A, T2 = 37.6 A. Research data on the PSRC distribution substation is shown in Tbl 3.

Tbl 3. FARI Distribution Substation Research Data

No	Research Variable	Major Load 1	Major Load 2	Length
1	Maximum Voltage	232.3	232.3	Volt
2	Minimum Voltage	220.8	220.8	Volt
3	Average Voltage	227.9	227.8	Volt
4	Maximum Load	295.3	123.0	Ampere
5	Average Load R	128.4	79.3	Ampere
6	Average Load S	174.9	14.8	Ampere
7	Average Load T	149.5	37.6	Ampere
8	Average Usage Percentage	74.7	18.5	%
9	Maximum Usage Percentage	126.2	52.6	%
10	Maximum Load Time	15:34:48	18:12:12	WIB

At the PSRC distribution substation, the maximum voltage is at 232.3 Volts on route 1 and route 2. The minimum voltage of the PSRC distribution substation is at 220.8 Volts on route 1 and 220.7 Volts on route 2. The magnitude of the phase-phase voltage is 394.7 V. With a voltage drop percentage scale of +5% and -10% (209 V – 231 V) the PSRC distribution substation experiences an overvoltage of 0.6%.

The peak load on routes 1 and 2 has a different time, the first peak load at 15:34:48 WIB which occurred on route 1 of the PSRC substation showed a current of 295.3 A. For the peak load on route 2, it occurred at 18:12:12 WIB with a load of 123 A. The total peak load on the PSRC substation is 343.4 A and the average load on the route is 198.2 A. The use of peak load on the PSRC distribution substation can be calculated in Equation (2).

$$S_{Pemakaian\ LWBP} = \frac{\sqrt{3} \times 394.7 \times 198.2}{1000} = 135\ kVA$$

$$S_{Pemakaian\ WBP} = \frac{\sqrt{3} \times 394.7 \times 343.4}{1000} = 235\ kVA$$

To determine the percentage of peak load usage at the PSRC distribution substation, Equation 3 is used:

$$\%Beban\ Puncak = \frac{235\ \text{kVA}}{160\ \text{kVA}} \times 100\% = 147\%$$

Due to the percentage of peak load at the PSRC distribution substation >80%, the K1 and K2 values are needed to determine the feasibility of use according to SPLN 17/1979. To determine the K1 and K2 values, they can be found using Equation (4).

$$K1 = \frac{135\ kVA}{160\ \text{kVA}} = 0.8$$

$$K2 = \frac{235\ kVA}{160\ \text{kVA}} = 1.47$$

If the values of K1 and K2 are entered into the distribution transformer loading graph, it is known that with a value of K1 = 0.8 and a maximum value of K2 of 1.47 (147% of the nominal power of the transformer), the safe limit for peak load operation time is 1 hour. The loading graph on K1 and K2 of the PSRC distribution substation is shown in Fig 11.

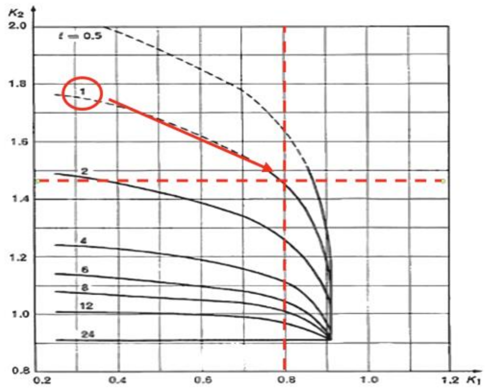


Fig 11. Loading graph of K1 and K2 PSRC Distribution Substation

In the measurements that have been carried out, the total maximum unbalanced load was obtained at phase R=281.6 A, S=243.8 A, and T=99.6 A. To determine the load imbalance at the PSRC distribution substation, it can be determined using Equation (5).

$$I_{Unbalance} = \frac{\left(\left|\frac{281.6}{208.4} - 1\right|\right) + \left(\left|\frac{243.8}{208.4} - 1\right|\right) + \left(\left|\frac{99.6}{208.4} - 1\right|\right)}{3} \times 100\% = 35\%$$

The highest load imbalance at the PSRC distribution substation occurred at 19:46:08 WIB with a percentage of 35%. The PSRC distribution substation load imbalance graph can be seen in Fig 12.

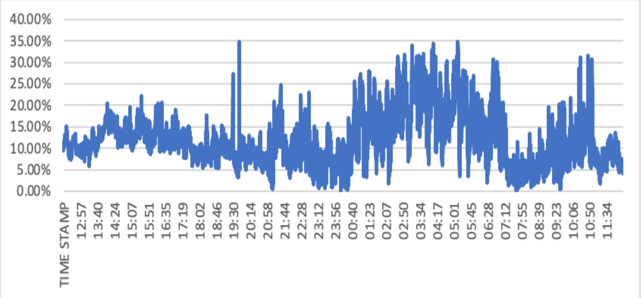


Fig 12. Unbalance graph of PSRC distribution Substation

V. CONCLUSION

Based on the test results, the voltage and peak load measurements were obtained which were carried out at 3 distribution substations in the PT PLN ULP Cikarang Kota area with the measurement results

The PLRG substation was at normal voltage and experienced a peak load on route 1 at 20:17:40 WIB with a peak load of 43.9 A and experienced the highest load imbalance of 35% at 11:14:47 WIB.

The FARI substation experienced an overvoltage on route 1 of 1.5% and experienced a peak load on route 1 at 19:26:35 WIB with a peak load of 52.8 A and experienced the highest load imbalance of 77% at 06:41:26 WIB.

The PSRC substation experienced overvoltage on route 1 and route 2 of 0.6% and experienced a peak load on route 1 at 15:34:48 WIB with a peak load of 295.3 A and a peak load on route 2 at 18:12:12 WIB with a peak load of 123 A. The highest load imbalance at the PSRC substation was 35% at 19:46:08 WIB.

From the measurements at the PSRC, PLRG, and FARI substations, it was found that the PSRC substation experienced an overload of 147% and all three substations experienced an unbalance condition of >20%. Based on testing and analysis, it is necessary to cut the load or add capacity to the PSRC substation and improve the load imbalance at the PSRC, PLRG and FARI substations.

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