JURNAL INFOTEL
Informatics - Telecommunication - Electronics
Website: http://ejournal.st3telkom.ac.id/index.php/infotel
ISSN: 2085-3688; e-ISSN: 2460-0997

Monitoring of three-phase distribution power transformer based on the Internet of Things (IoT) and SCADA

Yusnan Badruzzaman[1], Revi Alvin Razaqi[2,*]
[1]Semarang State Polytechnic
[2]PT. PLN (Persero) ULP Rambipuji
[1]Prof. H. Soedarto S.H. Street, Tembalang, Semarang 50275, Indonesia
[2]Jl. Mangunsarkoro, No. 11, Jember 68152, Indonesia
[*]Corresponding email: revialvinrazaqi@pln.co.id

Received 27 March 2023, Revised 27 April 2023, Accepted 30 April 2023

Abstract — Monitoring the performance of a three-phase distribution transformer is an effort to improve the performance of the transformer under the standards specified in the SPLN. The indicators used are the efficiency and regulation of the three-phase transformer voltage, current, power, and transformer loading, as well as the transformer loading, which is sought to be a maximum of 80 % for maintaining the transformer lifetime. The three-phase distribution transformer is one of the assets of PT. PLN (Persero) deals with the smooth distribution of electricity to customers where this transformer reduces medium voltage (20/11,5 kV) to low voltage (400/231 V) with the same power. Therefore, the continuity of electricity distribution to the customer is highly dependent on the condition and performance of the transformer. This reason underlies the importance of monitoring the performance of three-phase distribution transformers. Some elements that need to be monitored include voltage (sensor ZMPT101B), current (sensor ACS712 30 A), power, and transformer loading for electrical and temperature indicators (sensor DS18B20) and oil level (sensor HC SR04) for mechanical indicators. The sensors are then processed and programmed using the Arduino Mega 2560, which has been given an additional module in the form of an Ethernet shield and a router. The results of monitoring the performance of distribution transformers are the results of calculations by sensors that have a small difference so that the information sent from the sensor to the Arduino Mega 2560 and then to SCADA can be used as a benchmark for transformer performance. The monitoring results are then transmitted by the WiFi network and displayed by SCADA. The monitoring results displayed by SCADA will later be used as the basis for transformer maintenance.

Keywords – monitoring equipment, monitoring process, SCADA, the three-phase distribution transformers

I. Introduction

The reliability and the continuity of an electric power distribution system are closely related to the transformer because this equipment is directly connected to the customer. The general problem that may occur in a transformer is the condition of the voltage cannot be detected early whether the transformer is faulty or not. The damage to the transformer causes the continuity of service to consumers to be disrupted [1], [2]. This condition certainly affected system average interruption duration index (SAIDI) and system average interruption frequency index (SAIFI). One of the elements that must be monitored is the overloading of the transformer, which causes the temperature of the transformer to increase and will reduce the life of the transformer. The temperature rise in the transformer is based on the outside air temperature or the temperature of the intake coolant. At the transformer's working point, the air's temperature should not exceed 40 °C or with a daily and annual average temperature of 30 °C.

Transformers in Indonesia for distribution networks usually have specifications (20 kV - 400 V) for three phases and (11.5 kV – 231V) for one phase [3], [4]. Based on data from the temperature rise test of transformers conducted at the Electricity Laboratory of PT. PLN (Indonesia's State Owned Enterprise), at the Center for Electricity Research and Development, it can be estimated that the life of transformers operated in Indonesia at 100 % load conditions of rated load assuming continuous loading and a normal life expectancy of 20 years, *i.e.* distribution transformer

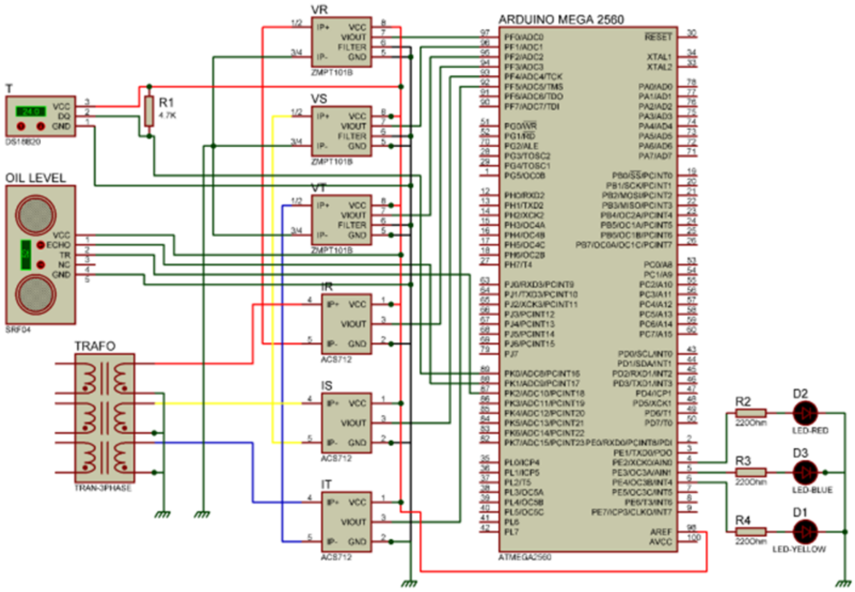

Fig. 1. Wiring diagram.

with continuous loading with an ambient temperature of 20 °C and a winding temperature of 98 °C [5], [6].

So far, PT. PLN (Persero) only performs routine maintenance according to schedule at certain times, and in the event of a failure abroad, it is very difficult to know the status of the problematic transformer maintenance schedule [7] Based on these conditions, a real-time transformer condition monitoring system is needed. With this concept, PT. PLN (Persero) can find out early on which transformers are faulty. This monitoring is very necessary for connection with the need for a sustainable and guaranteed distribution of electrical energy [8]. The main challenge in the Internet of Things (IoT) is bridging the gap between the physical world and the information world. Such as how to process data obtained from electronic equipment through an interface between the user and the equipment. Sensors collect raw physical data from real-time scenarios and convert it into a machine-understandable format so that it will be easily exchanged between different data formats [9]. Therefore, the author aims to develop tools and devices that can monitor the performance of the IoT and SCADA-based three-phase distribution transformers [10]–[12].

In 2016, Odhekar *et al.* [13], propose viable solutions for SCADA systems, including applications such as water level monitoring, transformer temperature monitoring, capacity control, and oil level monitoring. This system is capable of running these industrial applications. It provides an excellent web-based solution for accessing all collected data and devices. It uses web-based applications to allow users to access data or devices across organizations within the industry via the Internet. It also overcomes the problem of weak cryptography used in SCADA [14], [15].

Our research proposed the three-phase distribution transformers, equipment for stepping down the voltage from medium to low voltage network with constant power, is a type of PT. PLN (Persero) assets that have a direct relationship with customers. The condition and the performance of the transformer affect how the continuity of the electricity is distributed. Hence, the monitoring process of the three-phase distribution transformer's condition and performance should be done. Some elements which have to be monitored, such as voltage (ZMPT101B sensor), current (ACS712 30 A sensor), power, and transformer load.

II. Research Method

This three-phase distribution transformer device uses Arduino Mega 2560 as the main component. It uses an Ethernet shield and router to control sensors, receive data from sensors, and send data to SCADA. Arduino Mega is a microcontroller board based on the ATmega2560. There are 54 digital I/O pins, 16 analog inputs, 4 UARTs (hardware serial ports), a 16MHz crystal oscillator, a USB connector, a power jack, an ICSP header, and a reset button. Contains everything needed to support the microcontroller. First, connect it to your computer with a USB cable, or power it on with an AC-DC adapter or battery [16], [17]. These boards are inexpensive, reliable, and versatile advanced electronic platforms, wired or wireless at the hardware level, for manipulating analog and digital data and controlling and monitoring electrical devices. This board has an interface function. The Arduino IDE programming environment offers flexibility, simplicity, and library customization capabilities. It features a serial monitor to display data transmitted or collected by system sensors on a connected computer terminal [18]. The converter reading being monitored is the voltage from the voltage converter voltage sensor, the ZMPT101B sensor. ZMPT101B has excellent performance with high voltage accuracy and consistency. This sensor can measure voltages up to 250 V AC. The ZMPT101B sensor is easy to use and features a multi-turn trimming potentiometer to adjust (calibrate) the ADC output. The ADC output is set the same as the reference input [19]. The ACS712 30A sensor is a Hall sensor developed by Allegro MicroSystems, an American electronics company specializing in integrated circuits for monitoring and control in various fields.

The ACS712 is a relatively inexpensive, compact, and accurate AC and DC sensor suitable for industrial and commercial use. It has 2100 VAC insulation and low-resistance power conductors. Operates up to 8 V DC and has an output voltage comparable to 66mV/A during operation Temperature using the DS18B20 sensor, a temperature sensor that can measure temperature from -55 °C to +125 °C with +-5 % accuracy. Based on the 1-wire protocol that revolutionized the digital world. Its 1-wire protocol allows it to control multiple sensors from a single pin on the microcontroller [20], and the transmitter and receiver are HC SR04 ultrasonic rangefinders labeled T and R, respectively. You can control the levels. The rangefinder produces sound waves with a frequency of 40 kHz. Objects reflect sound waves and return them to the receiver. The sensor provides information about how long sound waves can propagate from the sensor to the object and back [21].

A. Wiring Diagram

Fig. 1 shows how to connect each part of the sensors to Arduino Mega 2560. Temperature sensor (DS18B20) connected to A8 pinout, voltage sensor ZMPT101B (R phase) connected to A0 pinout, voltage sensor ZMPT101B (S phase) connected to A1 pinout, voltage sensor ZMPT101B (T phase) connected to A2 pinout. Then the current sensor ACS712 (R phase) is connected to the A3 pinout, the current sensor ACS712 (S phase) is connected to the A4 pinout, current sensor ACS712 (T phase) is connected to the A5 pinout.

The IP+ of each current sensor input is connected in series into the secondary side of the transformer with the maximum range (without current transformer) is 30 A. Then the IP- of each current sensor input is connected to the IP+ of each voltage sensor input with the maximum range is 250 V, and each IP- side is connected into the ground (connected Y). Last, the oil level sensor HC SR04 is connected to the A9 pinout. VCC and ground of each part parallelized. But all those pinouts are connected to the Ethernet Shield module plugged into Arduino Mega 2560. The input power to activate Arduino Mega 2560 and each sensor uses an adaptor 220 V AC to 9 V DC with a maximum current of 4 A. Then the RJ45 cable connected from Ethernet Shield to the router.

Fig. 2 is the architecture of the monitoring system of a three-phase distribution transformer. Inputs that are processed are voltage, current, oil temperature, and transformer oil level. This data will be sent to VTSCADA via the ethernet shield network by the router to be displayed by the SCADA system.

B. Arduino Mega 2560 Communication with SCADA

SCADA is the basis of distribution automation systems. A typical SCADA system consists of I/O signaling hardware, controls, software, networking, and communications [24]. The SCADA system also provides a host control function for supervisors to control predefined settings. A SCADA system typically implements a distributed database, commonly called a tag database, containing data items called tags or points. A dot represents a single input or output value that is monitored or controlled by the system [25]. The ability to monitor and control electrical equipment remotely was first used in the generation and transmission sector of the electric power industry [26].

The Modbus TCP/IP protocol is used for communication between SCADA and Arduino Mega 2560. The Modbus/TCP protocol is generally used in SCADA systems for communication between Human Machine Interfaces (HMI) and Programmable Logic Controllers (PLCs) [27], [28]. Communication is done by equating the name/TCP/IP address of the VTSCADA IP address with the Modbus IP encoding of the Arduino IDE application. An Arduino Mega 2560 connected to an Ethernet shield is connected to a router configured as an access point using an RJ45 cable. The PC-SCADA server is connected to the radio signal sent by the router. The IP address between the router and the PC server is set differently from the IP address used for Modbus encoding in the Arduino IDE application [17], [29]. The Ethernet shield is based on the Wiznet W5100 ethernet chip. The Ethernet library is used in writing programs so that the Arduino board can connect to the network using an Ethernet shield. On the ethernet shield, there is a micro-SD slot, which can be used to store files that can be accessed via the network. The onboard micro-SD card reader is accessed using the SD library.

C. Data Logger

A data logger (data recorder) is an electronic device that records data from time to time both integrated with sensors and instruments in it as well as external sensors and instruments. Or briefly, a data logger is a tool for logging data [30].

III. Testing Monitoring Equipment and Result

The monitoring equipment was tested and carried out at the generator house of Semarang State Polytechnic on October 1 until October 5, 2020. The test cannot

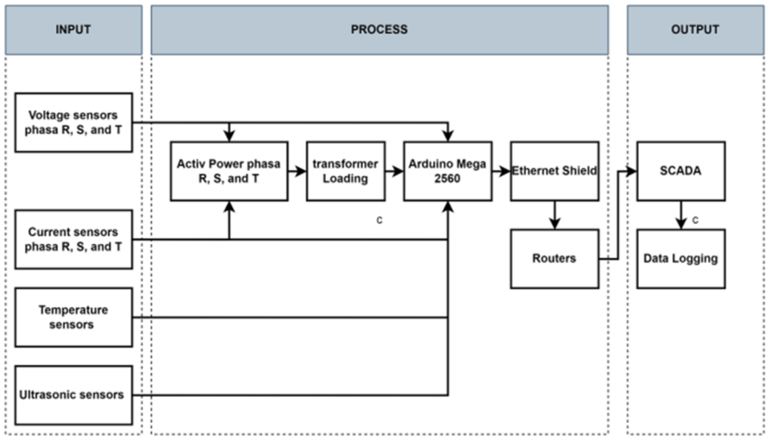

Fig. 2. Architecture of the system.

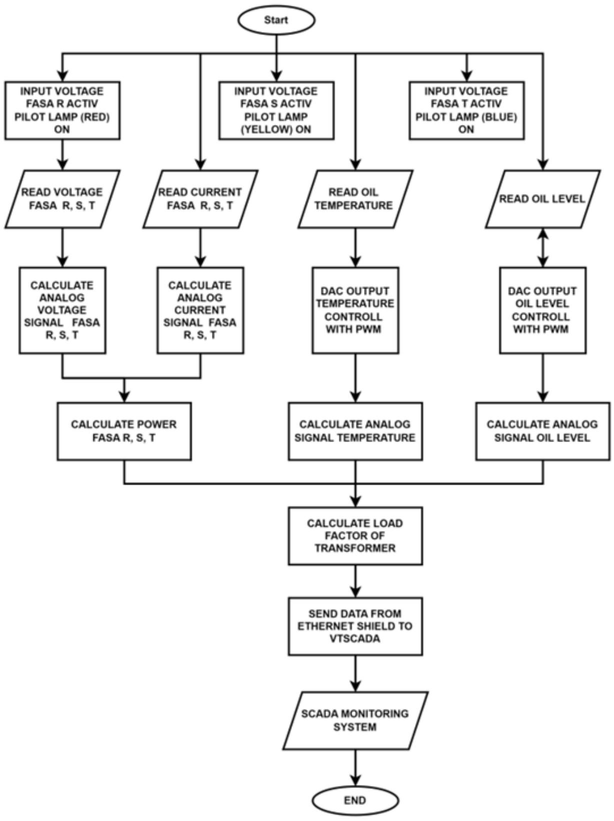

Fig. 3. Monitoring process flowchart.

be carried out on the original and the working transformer because the transformer can not be temporarily deactivated to install monitoring equipment. Therefore the equipment testing is carried out on a generator, with the load used in the experiment being the three-phase asynchronous motor with a capacity of 1500 watts. The monitoring is divided into two parts, the electrical and the mechanical. The electrical indicator (voltage, current, power, and transformer load) uses a generator that has an output of 220/380 V with a capacity of 250 kVA. The mechanical one uses an oil level on the generator and the temperature. The results were obtained in the form of data on whether the equipment can truly be used and reliable to monitor the performance of three-phase transformers or not.

Fig. 3 is a flowchart for the monitoring process of a three-phase distribution transformer. Inputs that are processed are voltage, current, oil temperature, and transformer oil level. This input will be processed to calculate the transformer loading factor, oil temperature, and transformer oil level. This data will be sent to VTSCADA via the ethernet shield network by the router to be displayed by the SCADA system.

Trihedral Engineering released version 11, and the VTS and VTSCADA products were merged into one product which is now known as VTSCADA. VTSCADA can connect a large number of I/O devices. Trihedral Engineering has developed a VTSCADA of more than 100 I/O drivers that can be used to interact with I/O devices. The following is a list of drivers available by VTSCADA [31].

Fig. 4 shows a wiring diagram when testing monitoring equipment with a load of more than 30 A so that CT is needed to reduce the high current with a certain ratio and then connected to the ACS712 current sensor. In this way, adjusting the CT ratio in the programming code on Arduino IDE is necessary. Whereas in Fig. 5, the load is less than 30 A so that it can be directly connected in series with the current sensor, and neither CT nor ratio adjustment is needed.

Fig. 6 shows the documentation of monitoring activities for three-phase distribution transformers carried out at the Semarang State Polytechnic Powerhouse starting from installing voltage and current sensors, oil temperature, and transformer oil level.

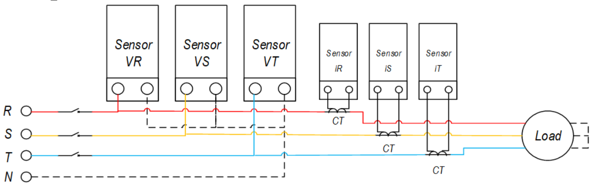

Fig. 4. Circuits with loads of more than 30 A.

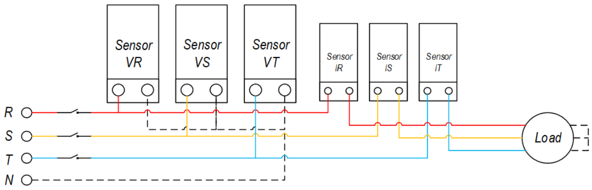

Fig. 5. Circuits with loads of less than 30 A.

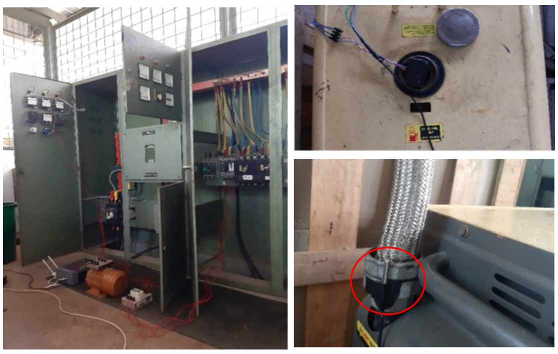

Fig. 6. Testing monitoring equipment.

From the results of the experiments conducted, we get data with an accuracy level that follows the characteristics of the sensors and transducers used. The sensors used include:

1) Voltage sensor module ZMPT101B is a voltage sensor made of a voltage transformer. ZMPT101B has excellent performance with high voltage accuracy and consistency.
2) Current sensor module has been equipped with an operational amplifier circuit so that the current measurement sensitivity increases and can measure small changes in current.
3) Temperature sensor using the DS18B20 sensor, which can measure temperature from -55 °C to +125 °C with +-5 % accuracy.
4) Level sensor HC SR04 ultrasonic has the transmitter and receiver rangefinders labeled T and R, respectively. You can control the levels. The rangefinder produces sound waves with a frequency of 40 kHz.

IV. Discussion

The test is carried out by applying the wiring diagram shown in Fig. 5. The circuit was chosen because the load on the experimental test was less than 30 A. The experimental test results are divided into two indicators, *i.e.*, electrical indicators shown in Table 1 (voltage, current, power, and transformer load) and mechanical indicators (oil level on generator and temperature) shown in Table 2.

From the measurement results in Table 1, it is found that the voltages in the R, S, and T phases are those standardized by PT. PLN (Persero), namely +5 % and -10 % of the nominal voltage of 220 V. while the transformer loading, apparent power, current and loading ratio in each phase are relatively the same.

Table 2 shows that the oil level is in the range of 72 % and the oil temperature is around 25 °C, and the highest is 41 °C.

Fig. 7. Data shown in SCADA.

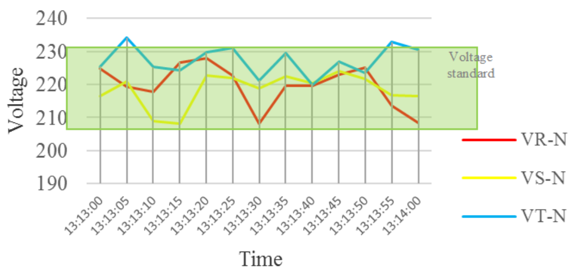

Fig. 8. Voltage monitoring data.

The result of the monitoring process is shown in Fig. 8. The phase voltage R-N ranges between 208,491 – 226,636 V, phase S-N voltage ranges from 208,008 – 223,986 V, and phase T-N voltage has a range of 219,972 – 234,073 V. The various voltage data are caused by the alternate current sinusoidal wave that converted to DC wave is not perfect. The low

Table 1. Electrical Monitoring Result

Date	Time	VR	VS	VT	IR	IS	IT	SR	SS	ST	%
Oct 5, 2020	13:13:00	224,697	216.542	225,384	2	2	2	634.098	618.01	598.392	0.0072
Oct 5, 2020	13:13:05	219.436	220.882	234.073	2	2	2	616.243	616.354	648.148	0.0072
Oct 5, 2020	13:13:10	217.836	208.87	225.301	2	2	2	611.159	592.639	666.699	0.0072
Oct 5, 2020	13:13:15	226.636	208.008	224.390	2	2	2	640.014	586.07	626.986	0.0072
Oct 5, 2020	3:13:20	228	222.829	229.650	2	2	2	646.391	626.993	652.487	0.0072
Oct, 5 2020	13:13:25	22.587	222.020	231	2	2	2	632.235	629.285	650.967	0.0072
Oct 5, 2020	13:13:30	208.22	218.68	221.195	2	2	2	587.277	626.315	623.038	0.0072
Oct 5, 2020	13:13:35	219.671	222.539	229.46	2	2	2	614.993	628.088	649.022	0.0072
Oct 5, 2020	13:13:40	219.619	220.275	219.972	2	2	2	608.524	623.320	620.003	0.0072
Oct 5, 2020	13:13:45	222.958	223.986	226.770	2	2	2	625.245	634.905	647.056	0.0072
Oct 5, 2020	13:13:50	225.146	221.792	223.403	2	2	2	626.542	618.531	626.255	0.0072
Oct 5, 2020	13:13:55	213.576	216.752	232.833	2	2	2	612.644	618.283	655.52	0.0072
Oct 5, 2020	13:14:00	208.491	216.594	230.419	2	2	2	591.376	608.134	649.865	0.0072

Table 2. Mechanical Monitoring Result

Date	Time	% Level	Temp. (°C)
Oct 5, 2020	12:40:00	72.3916	25
Oct 5, 2020	12:40:05	72	25.82615
Oct 5, 2020	12:40:10	72	23.9017
Oct 5, 2020	12:40:15	72.1018	30.7171
Oct 5, 2020	12:40:20	72.5146	33.44945
Oct 5, 2020	12:40:25	72	35.7476
Oct 5, 2020	12:40:30	72	38
Oct 5, 2020	12:40:35	72.0728	38
Oct 5, 2020	12:40:40	72.5292	38
Oct 5, 2020	12:40:45	72	39.30895
Oct 5, 2020	12:40:50	72	41
Oct 5, 2020	12:40:55	72.072	40.20519
Oct 5, 2020	12:41:00	72.3214	40
Oct 5, 2020	12:41:05	72	40
Oct 5, 2020	12:41:10	72	40
Oct 5, 2020	12:41:15	72.0698	41
Oct 5, 2020	12:41:20	72.1156	41
Oct 5, 2020	12:41:25	72	41
Oct 5, 2020	12:41:30	72	41
Oct 5, 2020	12:41:35	72	41
Oct 5, 2020	12:41:40	71.7874	41
Oct 5, 2020	12:41:45	72	41
Oct 5, 2020	12:41:50	72	41
Oct 5, 2020	12:41:55	72	41
Oct 5, 2020	12:42:00	72.0194	41

voltage, according to Indonesian Electrical Standard, has a maximum voltage rise of +5 % and a maximum voltage drop of -10 % [32]. Therefore, maximum rising voltage can be calculated, and the value is 231 V, then the maximum voltage drop is 209 V.

Then the current sensor indicates the load current has the same value in R-phase, S-phase, and T-phase, which is 2 A. Therefore, if using calculations, the three-phase 1500 W motor has a current [33]:

$$\begin{aligned} P_{3\sim}[W] &= 3 \times V \times I \times \cos\varphi \\ 1500[W] &= 3 \times 220[V] \times I \times 0.85 \\ I &= \frac{1500[W]}{220[V] \times 0.85} \\ I &= 2.7[A] \end{aligned} \tag{1}$$

The comparison between the monitoring equipment average data and the calculation in (1) also the calculation result can be seen in Fig. 9.

The calculation of the percentage difference between the three-phase currents in each phase is shown

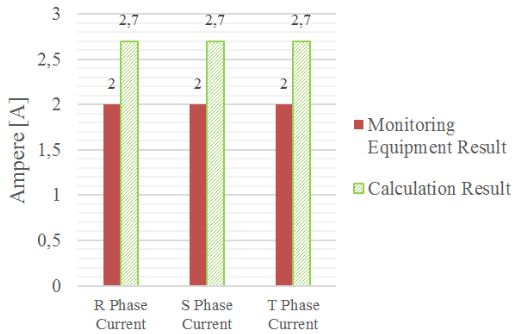

Fig. 9. Average current comparison data.

in (2).

$$\begin{aligned} [\Delta I\%] &= \frac{I_{monitoring} - I_{calculation}}{I_{calculation}} \times 100\% \\ [\Delta I\%] &= \frac{(27.2-2)VA}{2} \times 100\% \\ [\Delta I\%] &= 35\% \end{aligned} \tag{2}$$

Table 3. Average Current Comparison and % Difference

Phase	Result Avg. (A)		Diff. (%)
	Monitoring	Calculation	
R	2	2.7	35
S	2	2.7	35
T	2	2.7	35

From the measurement results in Table 3, the current flowing in the load for each phase is 2.7 A. Then the current for each phase displayed on the SCADA is 2 A. This 0.7 A difference is due to the use of the Modbus function, the medium of communication between the Arduino Mega 2560 and SCADA, not being able to use the comma (integer function) and the power factor $\cos\varphi$ on the motor, which is different from the calculation.

The power shown in SCADA has various values in each phase. For example, the R-phase has a value between 591.376 – 646.391 VA, the S-phase has a value between 586.07 – 634.905 VA, and the T-phase has a value between 620.003 – 628.148 VA. To calculate the power of a three-phase asynchronous motor for each phase (R, S, T), use (3) [31].

$$P_{3\sim}[W] = 3 \times S[VA] \times cos\varphi \tag{3}$$

$$S_{1\sim}[VA] = \frac{P_{3\sim}[W]}{3 \times \cos\varphi} \tag{4}$$

Fig. 10. Power monitoring data.

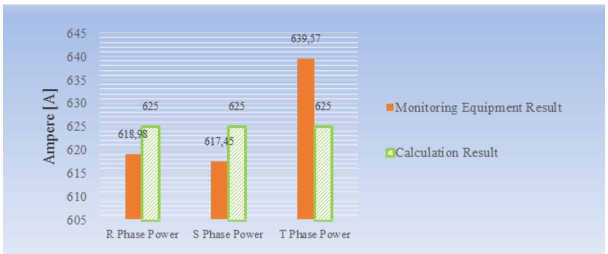

Fig. 11. Average power comparison data.

Fig. 10 shows the comparison between the monitoring result and calculation results for one minute. Fig. 11 shows the comparison between the monitoring result and calculation result by using the average data of each phase. Using (3), the calculation of a three-phase 1500 W motor (each phase) has the power:

$$S_{1\sim}[VA] = \frac{1500[W]}{3 \times 0.8}$$
$$S_{1\sim}[VA] = 625[VA]$$

The comparison between the monitoring equipment average data and the calculation in (5) also the calculation result can be seen in Fig. 12.

To calculate the percentage difference between apparent power and monitoring results, use (5):

$$[\Delta S\%] = \frac{S_{monitoring} - S_{calculation}}{S_{calculation}} \times 100\% \tag{5}$$

Table 4. Average Power Comparison and % Difference

Phase	Result Avg. (VA)		Diff. (%)
	Monitoring	Calculation	
R	618.98	625	0.96
S	617.45	625	1.20
T	639.57	625	2.33

The difference between the monitoring and power calculation results is caused by the calculation in the programming code where the power displayed on the SCADA is the product of the multiplication between the varying voltage (from the voltage sensor) and the constant current (from the current sensor).

The transformer load percentage has the same value, which is 0,0072 %. Therefore, the calculation of the transformer load with a power of 250 kVA and a load of 625 VA per phase based on (6) and the calculation results of the previously calculated power per phase are as follows:

$$\begin{aligned} \delta[\%] &= \frac{S_{3\sim}}{S_{nameplate}} \times 100\% \\ \delta[\%] &= \frac{3 \times 625[VA]}{250,000[VA]} \times 100\% \\ \delta[\%] &= 0.0075\% \end{aligned} \tag{6}$$

The calculation result of the transformer loading based on the data that has been displayed and calculated previously is 0.0075 %. Then the data displayed by the SCADA data logging averages 0.0072 %. Therefore, calculation and monitoring result loading has a difference of 0.0003 %.

The SCADA shows oil levels on various values but is still in the 72 % range. The temperature always seems to rise from 25-41 °C because the temperature sensor detected a temperature rise when the generator was started.

V. Conclusion

The three-phase distribution transformer monitoring equipment based on the IoT and SCADA is used to monitor the condition of the transformer, which consists of voltage with a ZMPT101B sensor. The sensor shows the results of the voltage monitoring, where it can read the phase-neutral voltage with variable measurement results but is still within the specified voltage standard range. The ACS712 current sensor shows the difference in electric current from the measurement results with the calculation results of 0.6 A with a percentage difference of 35 %. This difference will shrink if the measured current is large, since the calculation difference is only found in the comma (the integer function cannot read a comma). The power calculation shows a small percentage difference between the monitoring equipment and calculations. The difference in power in the R phase is 0.96 %, the S phase is 1.2 %, and the T phase is 2.33 %. And the transformer load has a very small percentage difference of 0.003 %. Temperature with DS18B20 sensor and oil level with HCSR04 sensor can show the values in SCADA obtained from the experimental results of monitoring generator mechanical indicators. However, the mechanical indicator monitoring equipment should be tested directly on the real transformer to determine the accuracy of the sensor readings. The result shows if this monitoring equipment can be installed on a new three-phase distribution transformer before it is installed on the network so that the condition and performance of the transformer can be identified and prevent detrimental damage. SCADA also allows the transformer to be monitored remotely and in real time. This equipment is used as the basis for whether the transformer needs to be maintained.

Fig. 12. Average transformer load comparison data.

ACKNOWLEDGMENT

The authors would like to thank the Semarang State Polytechnic and the Ministry of Research and Technology, who have supported this work through their polytechnic research fields. We express our deepest gratitude to all lecturers, students, and the Semarang State Polytechnic leaders for their support in carrying out our research. We would also like to thank everyone in the Electrical Department for their assistance in completing this research.

REFERENCES

[1] R. Syahputra and L. F. Arrozak, ”Power transformer loading analysis in order to improve the reliability of a substation,” *Journal of Electrical Technology UMY (JET-UMY)*, vol. 1, no. 4, pp. 165-175, 2017.

[2] U. Subha, N. Dinesh, T. S. Kumar, K. S. Kumar, G. B. Sampath Reddy, A. S. Kumar, ”Real time monitoring of a distribution transformer based on IoT,” *International Journal of Scientific Research in Science, Engineering and Technology*, vol. 7, no. 2, 2020.

[3] PT. PLN (Persero). 2007. Standar Perusahaan Perusahaan Listrik Negara D3.002-1: 2007 Spesifikasi Transformator Distribusi Bagian 1: Transformator Fase Tiga, 20 kV-400 V dan, Transformator Fase Tunggal, 20 kV-231 V dan 20/ $\sqrt{3}$ kV-231 V. PT. PLN (Persero).

[4] W. Sarimun, ”Buku Saku Pelayanan Teknik Edisi Ketiga”, Penerbit Garamond, 2012.

[5] IEC 60076 – 2 – 2011 - 5.1 Air cooled transformers. 2011.

[6] IEC 60076 - 1: 2011, ”Power Transformers – Part 1: General,” 2011.

[7] PT. PLN (Persero), ”Indonesia second power transmission development project (IPTD-2); The environmental management plan (EMP) Development Of Substation II,” 2016.

[8] PT. PLN (Persero), ”East Java – Bali power distribution; Strengthening project environmental & social management planning framework,” 2020.

[9] P. Suresh, J. V. Daniel, V. Parthasarathy, and R. H. Aswathy, ”A state of the art review on the internet of things (IoT) history, technology and fields of deployment,” in *2014 International Conference on Science Engineering and Management Research (ICSEMR)*, 27-29 November 2014, Chennai, India, 2014.

[10] M. Ramdham, S. Mahajan, P. Shivankar, M. Belpande, D. Raut, K. Wadatkar, B. Kumar, ”IoT based distribution transformer health monitoring system,” *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, vol. 10, no. VI, pp 3945-3950 2022.

[11] A. A. Sonune, A. A. Akotkar, M. S. Talole, P. S. Jaiswal, S. V. Sonkusale, V. N. Gayki, ”Condition monitoring of distribution transformer using IOT,” *International Journal of Engineering Research & Technology (IJERT)*, vol. 9, no. 6, pp. 335-338, 2020.

[12] Md. S. Hossain, M. Rahman, Md. T. Sarker, Md. E. Haque, and A. Jahid, ”A smart IoT based system for monitoring and controlling the sub-station equipment,” *Internet of Things*, vol. 7, pp. 56-59, 2019.

[13] M. J. Odhekar, R. G. Joshi, B. T. Deshmukh, ”Development of web based SCADA application for monitoring parameter of transformer,” *International Journal of Engineering and Technical Research*, vol. 4, no. 4, 2016.

[14] A. Sachan, ”Microcontroller Based Substation Monitoring and Control System with Gsm Modem,” *IOSR Journal of Electrical and Electronics Engineering (IOSRJEEE)*, vol. 1, no. 6, pp. 13-21, 2019.

[15] A. John, R. Varghese, S. S. Krishnan, S. Thomas, T. A. Swayambu, P. Thasneem, ”Automation of 11 kV substation using raspberry pi,” in *2017 International Conference on Circuit ,Power and Computing Technologies (ICCPCT)*, Kollam, India, 20-21 April, 2017.

[16] A. I. Tătaru and C. N. Drugă, “Designing and realization an ECG based the Arduino Mega 2560 development board,” in *IOP Conf. Series: Materials Science and Engineering 568*, 012081, 2019.

[17] D. Artanto, ”Interaksi arduino dan labVIEW,” Jakarta: Elex Media Komputindo, 2012.

[18] V. Miron-Alexe, “Comparative study regarding measurements of different AC current sensors,” in *2016 International Symposium on Fundamentals of Electrical Engineering (ISFEE)*, , Bucharest, Romania, 30 June 2016 - 02 July 2016.

[19] I. Abubakar, S. N. Khalid, M. W. Mustafa, H. Shareef, and M. Mustapha. “Calibration Of Zmpt101b voltage sensor module using polynomial regression for accurate load monitoring,” *ARPN Journal of Engineering and Applied Sciences*, vol. 12, no. 4, pp. 1076-1084, 2017.

[20] S. Nie, Y.-C. Cheng, and Y. Dai, ”Characteristic analysis of DS18B20 temperature sensor in the high-voltage transmission lines’ dynamic capacity increase,” *Scientific Research: Energy and Power Engineering*, vol. 5, no. 4B, pp. 557-560, 2013.

[21] V. A. Zhmud, N. O. Kondratiev, K. A. Kuznetsov, V. G. Trubin, and L. V. Dimitrov,"Application of ultrasonic sensor for measuring distances in robotics," in *IOP Conf. Series: Journal of Physics: Conf. Series 1015*, 032189, 2018.

[22] A. Kusniawan and A. A. Mujahidin, "LKP: Scada dan sistem proteksi pada PT.PLN Area Pengatur Distribusi Jawa Timur," *Repositori Universitas Dinamika*, 2012.

[23] S. Iwan, "Membangun jaringan komputer," Bandung: Informatika. 2008.

[24] IEC 60076 – 7: 2005, "Power Transformer – Part 7: Loading guide for oil-immersed power transformer," 2005.

[25] R. K. Chauhan, M. L. Dewal , and K. Chauhan, "Intelligent SCADA system," *International Journal on power system optimization and Control*, vol. 2, no. 1, pp. 143-149, 2010.

[26] R. K. Chauhan, K. Chauhan, M. L. Dewal, "Implementation of an intelligent system in process control," in *National Conference on Trends in Instrumentation and Control Engineering (TICE 2009)*, Thapar university, Patiala, 28-29 Oct 2009, pp.156-160.

[27] N. Goldenberg and A. Wool, "Accurate modeling of Modbus/TCP for intrusion detection in SCADA systems," *International Journal of Critical Infrastructure Protection*, vol. 6, no. 2, pp. 63–75. 2013.

[28] Elijah, "HCSR04 Ultrasonic Sensor", *J. Morgan.*, 2014.

[29] Nurpadmi, "Studi tentang modbus protokol pada sistem kontrol," *Swara Patra*, vol. 1, no. 2, 2011.

[30] Zuhal and Zhanggischan, :Prinsip dasar elektronika," Jakarta: PT. Gramedia Pustaka Utama, 2004.

[31] Trihedral Engineering Limited. 2017. Student Workbook VTScada Configuration Fundamentals Course. Bedford: Trihedral Engineering Limited.

[32] PT. PLN (Persero), Standar Perusahaan Perusahaan Listrik Negara T6.001: 2013 Tegangan Tegangan Standar. PT. PLN (Persero), 2013.

[33] M. Ramdhani, "Rangkaian listrik," Bandung: Sekolah Tinggi Teknologi Telkom, 2005.