Design And Development of An IoT-Based Automatic Magnetic Balance Testing Device for Three-Phase Transformers at PT. Bambang Djaja

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Abstract – Magnetic Balance testing on three-phase transformers that are still done manually has the potential to cause human error and delays in defect identification. This research aims to develop an automatic Magnetic Balance testing tool based on the Internet of Things (IoT) using Arduino Mega 2560 microcontroller and Wemos D1 mini (ESP8266) connected to Google Spreadsheet as an online data logger. Voltage regulation on each phase is done automatically through a relay, while the measurement results are displayed on the LCD and recorded in real-time to the Spreadsheet. Based on the test results, the device functions properly and meets the Magnetic Balance testing standards, this is evidenced when we test one of the phases, the voltage value read in the other two phases when summed is close to or in accordance with the phase that is given a voltage. The successful integration of the system with Spreadsheet allows remote monitoring of test results and supports early detection of potential transformer damage.

Keywords: Arduino Mega 2560, Google Spreadsheet, Internet of Things, Magnetic Balance, Wemos D1 mini ESP8266.

I. INTRODUCTION

A transformer is a crucial component in electrical power systems, functioning to increase or decrease AC voltage [1]. One method of transformer maintenance is magnetic balance testing, which aims to detect imbalances in the magnetic field between phases. In several companies, this method is still performed manually, making it prone to human error and limitations in data recording. To address this issue, an innovation is needed in the form of an IoT-based automatic testing device capable of recording and displaying data in real-time. The use of Arduino Mega 2560 and Wemos D1 Mini microcontrollers based on the ESP8266 module offers a solution for automatic control and wireless connectivity. Google Spreadsheet is chosen as the data storage medium due to its ease of access and integration with Google Apps Script.

II. LITERATURE REVIEW

A. Magnetic Balance

The magnetic balance test is an important diagnostic tool because it can detect internal faults in a transformer without the need to dismantle the device. This method operates based on the principle of magnetic field distribution. The magnetic balance test can be used to analyze and identify internal transformer faults, including determining the type and location of damage with high accuracy [2].

Essentially, this test largely relies on comparing the voltages generated in each phase, with the ideal magnetic field distribution being symmetrical. Any imbalance in voltage or magnetic field indicates that the transformer's core or windings may be damaged or deformed. The magnetic balance test is known for being quick, simple, and capable of being performed on-site without disassembling the transformer.

In magnetic balance testing, calculations are needed to ensure that the test complies with the standard.

$$\text{Fasa R (R-N)} = \text{S-N} + \text{T-N} \quad (1)$$

$$\text{Fasa S (S-N)} = \text{R-N} + \text{T-N} \quad (2)$$

$$\text{Fasa T (T-N)} = \text{R-N} + \text{S-N} \quad (3)$$

From equation 1, when we test in Phase R, the voltage read in Phases S-N and T-N when summed up the results must be close to or according to the input voltage in Phase R (R-N), and equation 2, when we test in Phase S, then the voltage read in Phases R-N and T-N when summed up the results must be close to or according to the input voltage in Phase S (S-N), and in equation 3, when we test in Phase T, then the voltage read in Phases R-N and S-N when summed up the results must be close to or according to the input voltage in Phase T (T-N).

B. Three-Phase Transformer

There are various types of transformers, depending on their operating voltage, phase configuration, and intended application. One type that will be discussed here is the three-phase transformer, which typically operates at high voltages and is usually found in substations. Its main function is to step down transmission voltage (high voltage) to distribution voltage (medium voltage).

A three-phase transformer is used to transfer electrical energy from high to low voltage or vice versa. As the name suggests, a three-phase transformer operates on a system with three phases. In principle, a three-phase transformer works similarly to a single-phase transformer; however, the fundamental difference lies in the electrical system used single-phase versus three-phase. A three-phase transformer can be connected in star (wye), delta, or zig-zag configurations. Three-phase transformers are widely used in electrical power transmission and distribution systems due to economic considerations. Additionally, they reduce the weight and size of the framework, making them more cost-effective compared to combining three single-phase transformers with the same power rating [3].

C. Internet of Things

The general definition of IoT (Internet of Things) is a network of wirelessly connected devices, and its potential to develop integrated smart solutions for smart homes, smart cities, and Industry 4.0 is becoming increasingly tangible. The use of IoT offers the advantage of being accessible anytime, anywhere, on any device, by anyone, and for various purposes [4].

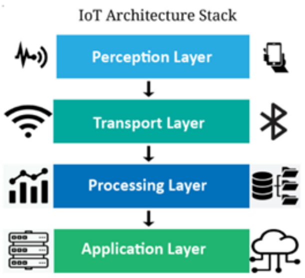


Figure 1. Layer of IoT

Based on Figure 1, the layers can be described according to their functions as follows:

1. Perception Layer
   This is the physical layer responsible for collecting data from the environment using sensors and actuators. In this study, the perception layer consists of:
   a) Relay: Functions as an automatic switch that alternately controls the input voltage.
   b) Sensor: The sensor used is the PZEM 004T, which measures voltage and current.
   c) Microcontroller: The microcontroller used is the Arduino Mega 2560, which acts as the main controller managing various components such as the relay, LED, sensor, push button, adjuster, and potentiometer.
2. Transport Layer
   This layer is responsible for transmitting data from the perception layer to the processing layer. In this study, the communication network used is the Wemos D1 Mini (ESP8266 WiFi Module), which enables data transmission from the Arduino Mega 2560 to a cloud platform or Google Sheets.
3. Processing Layer
   This layer processes, stores, and analyzes the received data. In this study, processing occurs at two levels:
   a) Arduino Mega 2560: Performs initial processing of sensor data before transmission.
   b) Google Sheets: Functions as a cloud-based data logger for storing measurement results in real-time.
4. Application Layer
   This layer serves as the user interface for accessing measurement data. In the designed system, the application used is Google Sheets, which allows real-time data monitoring via computer or mobile devices.

D. Google Spreadsheet

Google Sheets is a software developed by Google that can be used to create tables, process data, and perform simple calculations. This cloud-based application relies on an internet connection to support communication and collaboration among its users. Google Sheets is also frequently used in various programming tasks. It is often utilized as a database in programming projects due to its advantages in accessibility and integration capabilities [5].

E. Apps Script

Apps Script is a platform used to extend the functionality of Google Sheets. In various programming applications, Google Apps Script is used to create programs that connect, send, and store specific data in Google Sheets. Additionally, Apps Script can be used to create web pages using HTML as a user interface to present data from Google Sheets in a more visually appealing way.

F. Arduino Mega 2560

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 chip. It features 54 digital input/output pins (15 of which can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

Figure 2. Arduino Mega 2560

In the implementation of the magnetic balance testing device, the Arduino Mega 2560 serves as the main control unit that manages the entire testing process. This board collects data from various sensors that measure parameters such as voltage and current. The acquired data is then processed and analyzed to determine the magnetic field balance within the transformer. In addition, the Arduino Mega 2560 can communicate with communication modules such as the Wemos D1 Mini to transmit data in real-time to an Internet of Things (IoT) platform for remote monitoring.

G. Wemos D1 Mini

The WeMos D1 Mini is a microcontroller module based on the ESP8266 that features built-in Wi-Fi connectivity. This module supports IoT systems by providing an affordable wireless interface for remote communication and device control [6].

Figure 3. Wemos D1 Mini

The integration between the Arduino Mega 2560 and the Wemos D1 Mini enables the system to wirelessly monitor and control the testing process. The Arduino Mega 2560 acts as the main controller, collecting data from various sensors that measure parameters such as voltage and current. The Wemos D1 Mini functions as the Wi-Fi interface, allowing the data gathered by the Arduino Mega 2560 to be transmitted to an Internet of Things (IoT) platform or other remote monitoring applications.

H. Sensor PZEM 004T

The PZEM-004T sensor is a module designed to measure electrical parameters in alternating current (AC) systems, such as voltage, current, active power, energy, frequency, and power factor. The PZEM-004T was chosen due to its high accuracy compared to other sensors with similar functions. This is evidenced by its testing accuracy: 99.90% for voltage measurement, 98.63% for current, 98.90% for power factor, and 99.56% for power measurement [7]. In the implementation of the magnetic balance testing device, the PZEM-004T sensor plays a crucial role in monitoring relevant electrical parameters.

Figure 4. PZEM-004T Sensor

In this system, the PZEM-004T sensor measures electrical parameters and sends the data to the Arduino Mega 2560. The Arduino then processes the data and, via the Wemos D1 Mini module, transmits it to a web-based monitoring platform or mobile application. This allows users to monitor the magnetic balance condition in real-time and take preventive action if any anomalies are detected.

III. METHODS

The research was conducted at PT. Bambang Djaja and the Electrical Energy Conversion Laboratory of Universitas Negeri Surabaya. The research model used was Research and Development (R&D). The main components of the system include the Arduino Mega 2560 as the controller, the PZEM-004T sensor for measuring voltage and current, and the Wemos D1 Mini (ESP8266) as the WiFi module. Testing was carried out by alternately supplying voltage to each transformer phase through relays, with the results automatically recorded in Google Spreadsheet.

The block diagram facilitates the operation of the system by illustrating the integration of each component to ensure they function effectively.

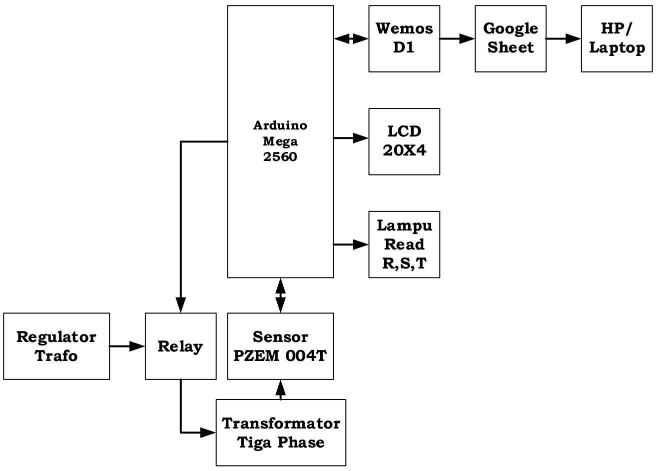


Figure 5. Diagram Block Syatem

IV. RESULT AND DISCUSSION

A. External Appearance of the Device

The developed device successfully automated the magnetic balance testing process. Test data is displayed in real-time on the LCD and transmitted to a Google Spreadsheet via a WiFi connection. The testing was conducted five times on two types of transformer vector groups (Yzn5 and Dyn5).

Figure 6. External View of the Device

Figure 6 shows the exterior of the automatic magnetic balance testin g device. On the outside, an identification sticker is attached to help users easily recognize the device and prevent it from being confused with other equipment.

B. Internal View of the Device

The internal part of the device is divided into two sections, with the first section being the device interface. Figure 7 shows the internal section or the interface of the device, which contains several indicators and buttons designed to assist the user in operating the device. These include a Push Button to start and reset the testing device, an MCB (Miniature Circuit Breaker) to connect the electrical current from the power source to the device, a Selector Switch to choose the device's operating mode, a Potentiometer to adjust the current and voltage protection settings, an LCD screen to display the test data, indicator lights to show which phase is being tested, and an Emergency Button to stop the device in case of an emergency.

Figure 7. Device Interface View

Figure 7 displays the interface section of the device. Following that, Figure 8 shows the innermost part of the device.

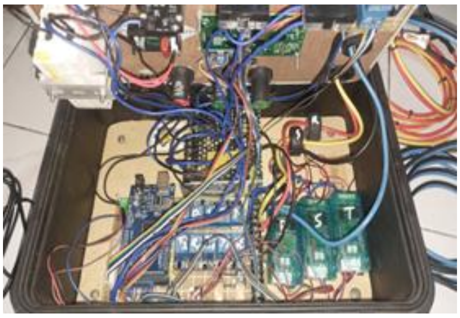
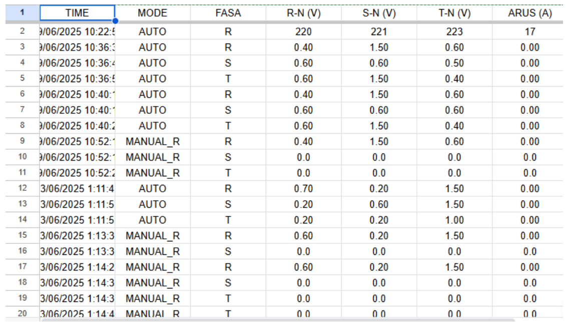


Figure 8. Innermost Layer of the Device

Figure 8 shows the internal layout of the automatic magnetic balance testing device. This section serves as the integration area for various components, including the Arduino Mega 2560, Wemos D1, PZEM sensor, relay, LCD, and several other components.

C. Google Spreadsheet Display

The spreadsheet shown in the figure represents the automatic recording results from the three-phase magnetic balance testing process carried out using a microcontroller-based system. This demonstrates that the testing device and the spreadsheet are well-integrated.



1	TIME	MODE	FASA	R-N (V)	S-N (V)	T-N (V)	ARUS (A)
2	9/06/2025 10:22:5	AUTO	R	220	221	223	17
3	9/06/2025 10:36:3	AUTO	R	0.40	1.50	0.60	0.00
4	9/06/2025 10:36:4	AUTO	S	0.60	0.60	0.50	0.00
5	9/06/2025 10:36:5	AUTO	T	0.60	1.50	0.40	0.00
6	9/06/2025 10:40:1	AUTO	R	0.40	1.50	0.60	0.00
7	9/06/2025 10:40:1	AUTO	S	0.60	0.60	0.60	0.00
8	9/06/2025 10:40:2	AUTO	T	0.60	1.50	0.40	0.00
9	9/06/2025 10:52:1	MANUAL_R	R	0.40	1.50	0.60	0.00
10	9/06/2025 10:52:1	MANUAL_R	S	0.0	0.0	0.0	0.0
11	9/06/2025 10:52:2	MANUAL_R	T	0.0	0.0	0.0	0.0
12	3/06/2025 1:11:4	AUTO	R	0.70	0.20	1.50	0.00
13	3/06/2025 1:11:5	AUTO	S	0.20	0.60	1.50	0.00
14	3/06/2025 1:11:5	AUTO	T	0.20	0.20	1.00	0.00
15	3/06/2025 1:13:3	MANUAL_R	R	0.60	0.20	1.50	0.00
16	3/06/2025 1:13:3	MANUAL_R	S	0.0	0.0	0.0	0.0
17	3/06/2025 1:14:2	MANUAL_R	R	0.60	0.20	1.50	0.00
18	3/06/2025 1:14:3	MANUAL_R	S	0.0	0.0	0.0	0.0
19	3/06/2025 1:14:3	MANUAL_R	T	0.0	0.0	0.0	0.0
20	3/06/2025 1:14:4	MANUAL_R	T	0.0	0.0	0.0	0.0

Figure 9. Spreadsheet Data Display

The data displayed in this spreadsheet originates from the Arduino Mega 2560, which is connected to the Wemos D1 module. This module is responsible for transmitting the measurement data to Google Spreadsheet in real-time via a Wi-Fi connection. Each row in the spreadsheet represents one measurement session, including the timestamp, test mode, the phase being tested, as well as the measured voltage and current values.

D. Yzn5 Vector Testing

The first test was conducted on a Yzn5 vector transformer with a capacity of 160 kVA. This vector uses a Star-Zigzag configuration.

Table 1 Test of Vektor Yzn5

Test	Voltage (V)	Phase	R-N (V)	S-N (V)	T-N (V)	Current (A)
1	20	R	19,8	10,6	9,50	0,11
		S	10,5	20,1	9,60	0,11
		T	9,90	10,0	20,0	0,12
2	20	R	19,8	10,6	9,60	0,11
		S	10,5	20,1	9,60	0,11
		T	9,90	10,0	20,0	0,12
3	20	R	19,9	10,7	9,60	0,11
		S	10,6	20,2	9,60	0,11
		T	10,0	10,0	20,1	0,12
4	20	R	19,9	10,7	9,60	0,11
		S	10,6	20,2	9,60	0,11
		T	9,90	10,0	20,0	0,12
5	20	R	19,9	10,7	9,60	0,11
		S	10,6	20,2	9,60	0,11
		T	10,0	10,0	20,1	0,12

Based on Table 1, it is shown that the device functions properly and the transformer is in good condition with no detected faults. This is evidenced by the voltage readings of each phase, which do not differ significantly.

E. Dyn5 Vector Testing

The second test was conducted on a Dyn5 vector transformer with a capacity of 160 kVA. This vector uses a Delta-Star configuration.

Table 2 Test of Vektor Dyn5

Test	Voltage (V)	Phase	R-N (V)	S-N (V)	T-N (V)	Current (A)
1	20	R	19,9	15,8	6,70	0,23
		S	11,2	20,2	8,90	0,18
		T	7,50	14,5	20,0	0,25
2	20	R	19,9	15,7	6,90	0,23
		S	11,0	20,3	9,10	0,17
		T	7,50	14,5	20,0	0,25
3	20	R	19,9	15,7	6,80	0,23
		S	11,0	20,3	9,10	0,17
		T	7,50	14,6	20,0	0,24
4	10	R	10,4	8,40	3,20	0,13
		S	5,60	10,6	4,90	0,10
		T	3,50	8,00	10,5	0,14
5	10	R	10,6	8,00	3,40	0,14
		S	5,50	10,7	4,10	0,11
		T	3,80	7,40	10,6	0,17

Based on Table 2, it is shown that the device functions properly and the transformer is in good condition with no signs of damage. This is evidenced by the phase voltage readings, which show minimal variation.

F. Spreadsheet Testing

This test aims to verify whether the data displayed on the LCD matches the data shown in the spreadsheet. The following presents the results of the integration test between the Automatic Magnetic Balance Testing Device and Google Spreadsheet.

G. Phase R

The test on phase R is well-integrated, as evidenced by Figures 9 and 10, since the data displayed on both the LCD and the spreadsheet are identical. The recorded values for Phase R are: R-N: 10.4 V; S-N: 8.30 V; T-N: 3.20 V; and Current (A): 0.13.

Figure 10. LCD Display of Phase R

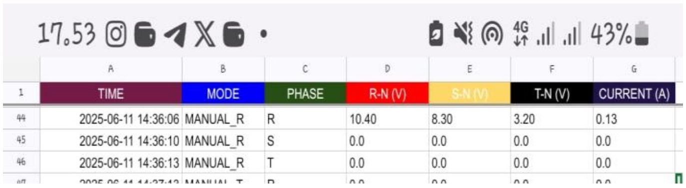


Figure 11. Spreadsheet Display of Phase R

H. Phase S

The test on phase S is well-integrated, as evidenced by Figures 11 and 12, where the data displayed on the LCD and the spreadsheet are identical. The recorded values for Phase S are: R-N: 5.60 V; S-N: 10.6 V; T-N: 4.90 V; and Current (A): 0.10.

Figure 12. LCD Display of Phase S

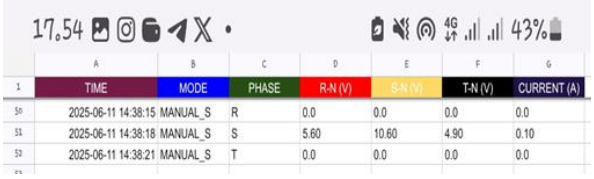


Figure 13. Spreadsheet Display of Phase S

I. Phase T

The test on phase T is well-integrated, as evidenced by Figures 13 and 14, where the data displayed on the LCD and the spreadsheet are identical. The recorded values for Phase T are: R-N: 3.40 V; S-N: 8.00 V; T-N: 10.5 V; and Current (A): 0.14.

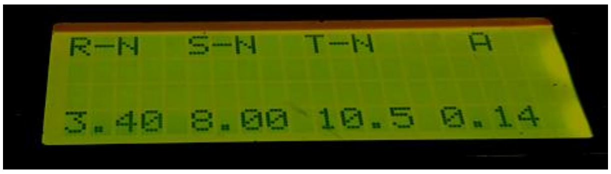


Figure 14. LCD Display of Phase T

Figure 15. Spreadsheet Display of Phase T

V. CONCLUSION

This research successfully designed and implemented an IoT-based automatic magnetic balance testing device. The device meets magnetic balance testing standards and is capable of recording results in real-time to Google Spreadsheet, thereby enhancing the efficiency of monitoring and enabling early detection of transformer faults.

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