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Design of Load Unbalance on Neutral Current and Losses in Distribution Transformer Using IoT

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ABSTRACT

This study examines the current leakage in the neutral in the electricity distribution system, which can cause energy waste and potential safety hazards. This study develops an IoT-based device using the PZEM-004T current sensor to monitor the current in real-time and calculate the financial loss due to current leakage. Tests were conducted under full load and no load conditions for the performance of the device. The results showed that the device is able to detect current leakage with high accuracy, as well as an effective warning system in preventing the risk of electrical accidents. These findings are expected to improve the efficiency and safety of electricity distribution.

1. INTRODUCTION

Electricity distribution is a system that regulates the flow of electricity from the energy source to the customer. It includes a series of cables, transformers, and other equipment required to deliver electricity safely, efficiently, and reliably. Electricity distribution systems are designed with the need to ensure a safe supply of electricity to customers in mind.

The PZEM-004T sensor enables real-time monitoring of leakage current, enabling immediate detection and response. Chen et al. (2023). Integration with a cloud platform facilitates data transmission and alerts, enhancing user awareness and management capabilities. Zhihui, (2019). Tests conducted under full-load and no-load conditions demonstrated the high accuracy of the device in detecting leakage current, Chen et al. (2023). The system’s ability to provide alerts significantly reduces the risk of electrical fires and electric shocks, which are common consequences of leakage. Yang et al. (2022). The device quantifies the potential financial loss due to leakage, emphasizing the economic benefits of implementing such a monitoring system. Chunlei et al. (2018). By preventing energy waste, the system contributes to overall efficiency in Electricity distribution. Zifeng, (2017).

In the use of electrical energy, it must also be balanced with the use of renewable energy sources and the use of sufficient electrical energy in order to achieve efficiency in its use, which aims to save costs that must be paid to the State Electricity Company (PLN), which is a state-owned enterprise, also known as BUMN. Although savings efforts have been made to the maximum, there are factors that cause customers' electricity bills to remain high, namely current leakage. This current leakage can cause electricity bills to continue to run even though the customer is not using any electronic devices. In the distribution system, current leakage can occur when the current in each phase, namely R, S, and T, does not have the same current, which causes current leakage to neutral. This current leakage in neutral can result in an increase in electricity usage bills that are not used by customers. Current leakage occurs when there is an imbalance in cross-phase current (R, S, T), causing excess current to flow to neutral. This leakage can cause electricity bills to increase because customers are charged for energy that is not actively consumed, Hasibuan et al. (2022). Shifting to renewable energy sources, such as solar power, can reduce dependence on PLN and reduce overall electricity costs, Juliawan et al. (2022). Therefore, this study was conducted to provide an understanding of the current leakage in the neutral in the distribution system and the losses that must be paid due to losses caused by current leakage in the neutral. From this background, the design of the tool "Design Of Load Unbalance On Neutral Current And Losses In Distribution Transformer Using Iot" was carried out.

ISSN : 3032-2642

2. METHODOLOGY
2.1. Research Design

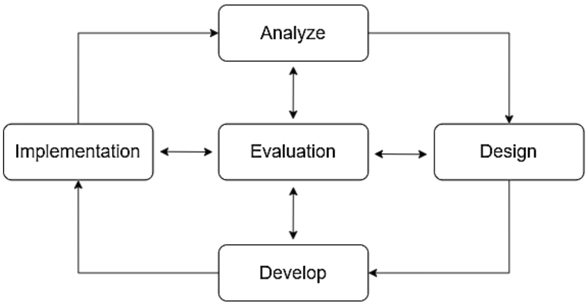

Figure 1. Research Design

2.1.1. Analyze

At this stage, it begins with an analysis of the potential of the problem. With the potential of the problem, an analysis can be carried out on the need to develop a new product, be it a model, method, or teaching material. The product development process can be started if a problem arises, whether it already exists or has been implemented previously. The purpose of this step is to collect data and information needed for research, which will then be analyzed further in order to strengthen the basis of the research being carried out.

2.1.2. Design

In the ADDIE model, the design stage is a systematic process that begins with the design of a product concept that has been determined and will be used. At the design implementation stage, each design concept is explained very clearly and accurately. The product design at this stage is conceptual, which will be the basis for the next concept development process.

2.1.3 Development

At the development stage, the design or product plan that has been made previously will be used as the desired product. At this stage, the help of tools is also needed to measure the performance of the conceptual framework for implementing the product that has been made previously.

2.1.4. Implementation

The purpose of the ADDIE development research model at this implementation stage is to be able to get feedback or responses to the product that has been designed or developed. Questions about product development goals can be used to obtain initial feedback, which is also an initial evaluation. The implementation process begins by referring to the previously designed product design.

2.1.5. Evaluation

The evaluation process is the final stage of development research conducted using the ADDIE method design. The purpose of this stage is to get feedback or responses from product users so that revisions can be made according to the evaluation results to determine whether the developer's goals have been achieved or not. before time.

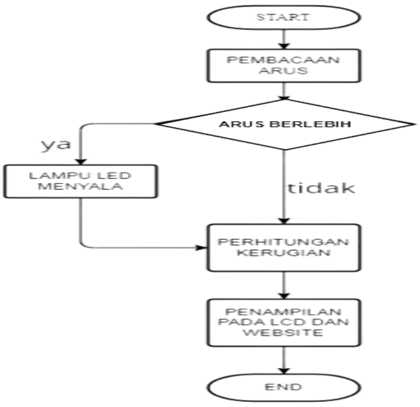

Figure 2. how the tool works

2.2. Tool Design

The way this tool design works is to find out the current leakage in the neutral in the distribution transformer, which is caused by the current imbalance in each phase R, S, and T.
In this design, there is a current sensor that aims to find out the current leakage in the neutral from the transformer, which is caused by the current imbalance in each phase R, S, and T. The concept of this tool is to find out how much loss the customer must pay due to the current leakage in the Neutral and to monitor the Neutral Current if it has exceeded the safe limit so that a check is carried out because if there is a current leakage in the neutral, it can cause an electric current to flow in the transformer body or panel body

2.3. Wiring Diagram

By using standard symbols to represent electrical components such as switches, lights, resistors, power sources, and cables, wiring diagrams show how components are physically connected to each other and how electricity moves through the system.

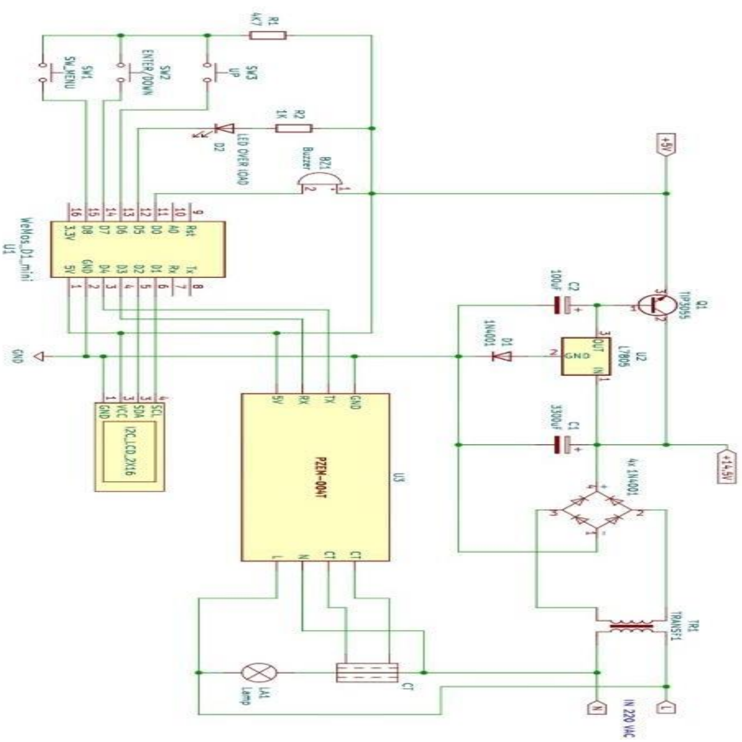

Figure 3. Tool wiring diagram

The design of this tool begins when the PZEM-004T current sensor detects a current in the neutral, which will then automatically calculate how much loss must be paid for the current that comes out of the distribution transformer neutral. The PZEM-004T sensor detects the current in the neutral line, providing real-time data on the leakage level, It calculates the financial impact of the leakage by assessing the current out, allowing users to understand the potential loss. Chen et al. (2023).

Continuous neutral current monitoring helps identify when it exceeds a safe threshold, reducing the risk of electrical errors. Sofwan et al. (2018). The integration of high-precision sensors ensures accurate detection of leakage current, which can be as low as 1 mA. Chen et al. (2023). This system can be integrated with existing electricity meters, increasing its utility in various settings. Chen et al. (2023). Advanced sensors, such as those designed to measure neutral DC current, offer linear output characteristics, improving measurement accuracy, Tong et al. (2019).

3. RESEARCH RESULTS

Although the testing methods described are effective, they may not account for all potential hardware issues, such as sensor malfunctions or wiring errors, which can also cause differences in expected results. This highlights the importance of comprehensive testing beyond just code verification (Entienza, 2024) (Sumarah et al., 2024).
Tool Testing

ISSN : 3032-2642

Figure 4. tool testing

Testing the Arduino program is needed to ensure that no errors will occur when connected to hardware / tools. The programming language for this tool is attached in the attachment. Testing on the Arduino program is done by inputting all the coding that has been designed. Then analyze whether there are errors. If the coding runs but the tool does not function according to the programmer's coding command, it can be confirmed that the coding program has an error. Testing can be done in the following ways:

1. Connect the current sensor coil to the neutral cable.
2. Connect the adapter to a power source.
3. Turn on the wifi hotspot on the cellphone according to the SSID and password that have been set on the microcontroller.
4. The LCD lights up, and the sensor reads the current in the neutral.
5. Observing the values displayed by the LCD and Thingspeak

The current leakage data in the neutral will be read by the PZEM-004T current sensor, which will then be displayed in rupiah on the LCD display and also the Thingspeak website to be monitored remotely. This calculation uses the neutral current leakage formula caused by the current imbalance in the 3-phase R, S, and T systems. The formula has been entered into the program, allowing the data display on the LCD to show the leakage in Rupiah, which aims to provide more accurate and easily understood information by users.

4. DISCUSSION
4.1. Manual Data Collection

Figure 5. manual testing

The current leakage data in the neutral was tested for 5 days with 2 test samples, namely when the load was being fully used and when the load was not being used. The data obtained will be compared with the calculation using the tool to determine the difference between the tool calculation and the formula. For data collection, as follows:

Table 2. Testing 1

Day	Current Leakage
1	9,5 A
2	10,1 A
3	10,6 A
4	10,5 A
5	10,6 A

From the data above, it can be seen that there is a current imbalance that causes current leakage in the neutral. To ensure whether there is a current leakage in the neutral according to that displayed by the measuring instrument, a manual calculation is carried out using a formula using the first day's data sample. The calculation formula for current leakage is as follows:

$$I_n = \sqrt{I_r^2 + I_s^2 + I_t^2 - (I_r I_s + I_s I_t + I_t I_r)}$$

Known:
$I_r = 12{,}1$
$I_s = 11{,}4$
$I_t = 21{,}5$

Then :
$I^2_r = 12{,}1^2 = 146{,}41$
$I^2_s = 11{,}4^2 = 129{,}96$
$I^2_t = 21{,}5^2 = 462{,}25$

$$I_n = \sqrt{I_r^2 + I_s^2 + I_t^2 - (I_r I_s + I_s I_t + I_t I_r)}$$
$$I_n = \sqrt{146{,}41 + 129{,}96 + 462{,}25 - (137{,}94 + 245{,}1 + 260{,}15)}$$
$$I_n = \sqrt{738{,}2 - 643{,}19}$$
$$I_n = \sqrt{95{,}43}$$
$$I_n \approx 9{,}76 \text{ A}$$

From the calculation above, the current leakage in the neutral is approximately 9.76 A, while the leakage read by the measuring instrument is 9.5 A, so it can be concluded that there is indeed a current leakage in the neutral caused by the current imbalance in the R, S, and T phases. After testing when the load is fully used, testing is also carried out when the load is not in use to find out whether there is still a current leakage even though there is no load being used with the following data:

ISSN : 3032-2642

Table 2. Test 2

Day	Current Leakage
1	0,4 A
2	0,4 A
3	0,4 A
4	0,4 A
5	0,4 A

Known :
I_r = 0 A
I_s = 0A
I_t = 0,4A

Then :
$I^2_r = 0^2 = 0$
$I^2_s = 0^2 = 0$
$I^2_t = 0{,}4^2 = 0{,}16$

$$I_n = \sqrt{I_r^2 + I_s^2 + I_t^2 - (I_r I_s + I_s I_t + I_t I_r)}$$

$$I_n = \sqrt{0 + 0 + 0{,}16 - (0\ x\ 0 + 0\ x\ 0{,}16 + 0{,}16\ x\ 0)}$$

$$I_n = \sqrt{0{,}16}$$

$$I_n = 0{,}4\ A$$

From the calculation of current leakage when the load is not in use, it shows that there is still a current leakage of 0.4 A, while the leakage read by the measuring instrument also shows a current leakage of 0.4 A.

4.2. Data Collection Using Tools

Data collection using the design aims for efficiency because the tool can directly read the leakage in the neutral and can also be directly monitored remotely. This test was carried out for 5 days with samples when the load was fully used and also when the load was not in use. For data collection as follows:

Table 3 . Testing 2

Hari	Kebocoran Arus	Kerugian
1	10,06 A	Rp. 2.476.324
2	10,71 A	Rp. 2.460.005
3	10,64 A	Rp. 2.487.884
4	10,87 A	Rp. 2.477.884
5	10,5 A	Rp. 2.455.202

From the test conducted under fully used load conditions, the results showed a current leakage of approximately 10 A. This current leakage not only indicates a problem with the electrical installation but also has a significant impact on operational costs. In a month, financial losses due to this current leakage are estimated to reach approximately 2.4 million Rupiah.

Table 4. Testing 3

Hari	Kebocoran Arus	Kerugian
1	0.4 A	Rp. 94.320
2	0.4 A	Rp. 94.569
3	0.4 A	Rp. 94.300
4	0.4 A	Rp. 94.220
5	0.4 A	Rp. 94.910

Meanwhile, when the test was carried out when the load was not in use, there was still a current leakage of approximately 0.4 A, with losses caused by the leakage amounting to approximately 90 thousand Rupiah.

4.3. Neutral Overcurrent Warning Test

This test is carried out in order to ensure safety, because if there is a very large current in the neutral conductor, it can cause voltage to appear on the body panel. This situation has the potential to endanger human safety if the body panel is touched. Therefore, this test is very important to prevent the risk of electrical accidents and ensure that all components of the electrical system operate safely. There are 3 buttons to set when the warning will turn on if there is a large current in the neutral. The three buttons are red, yellow, and blue, each of which has its own function and use. The use of the buttons is as follows:

- The red button functions to display the main layer of current warning settings. When the tool is in this setting display, the user can set the current limit used to turn on the warning light
- The yellow button functions to lower the current in the settings.
- The blue button functions to increase the current in the settings.

Figure 6. Tool warning

The tool test results show that the current leakage is at 10 A, so for this overcurrent warning test it is set when the neutral current reaches 11 A. If the current exceeds 11 amperes, the green LED will light up, indicating a warning that the current has reached 11 A or more.

After testing, a current leakage of more than 11 A was found. When the transition when all loads are used will be turned off completely, this overcurrent leakage occurs because the loads are turned off alternately, which makes the current in the R, S, and T phases very unbalanced.

4. RESULTS AND DISCUSSION

Based on the results of the tests and research that have been carried out, several conclusions can be drawn as follows:

1. Current Leakage Occurs in Neutral
   Testing of the equipment on the R, S, and T phases found current leakage to the neutral caused by the current imbalance in the R, S, and T phases, causing significant financial losses.
2. Financial Losses
   The results of the current leakage measurement caused significant financial losses so that consumers had to pay bills that were not necessary because there was a current leak in the neutral, which caused the current to flow smoothly on the R, S, and T phases.
3. Financial Impact of Current Leakage:
   The detected current leakage can cause significant financial losses. In this study, the detected current leakage during full load ranged from 10 A, which can cause losses of up to IDR 2.4 million per month, while the current leakage under unused load conditions was around 0.4 A, which can cause losses of around IDR 90 thousand per month.

For further development of this design, there are several suggestions that can be considered, namely:

1. Internet Connection Optimization:
   Make sure the internet connection used for sending data to ThingSpeak is stable and fast to avoid delays or failures in sending data, especially if the data sending interval is set with a high frequency.
2. Sensor Accuracy Improvement:

Using a sensor with higher accuracy can improve the accuracy of leakage current measurements and provide more precise results.

3. Testing in Various Conditions:
   Testing the device under various load conditions and different environments can help ensure the consistency of the device in various real situations.

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