

## Analysis of Characteristics of Three Phase Transformer Using MATLAB

Fakhri Ramadhan<sup>1</sup>, Sari Novalianda<sup>2</sup>, Panangian Mahadi Sihombing<sup>3</sup>, Yoga Tri Nugraha<sup>4</sup>,  
Muhammad Irwanto<sup>5</sup>, Syahrin Nizam Md Arshad<sup>6</sup>, Mohd. Azlishah Othman<sup>7</sup>

<sup>1,2,3,4</sup>Department of Electrical Engineering, Universitas Al-Azhar Medan, Medan 20142, Indonesia

<sup>5</sup>Department of Electrical Engineering, Universitas Prima Indonesia, Medan 20118, Indonesia

<sup>6</sup>Department of Electrical Engineering, Universiti Malaysia Perlis (UniMAP), Perlis 02600, Malaysia

<sup>7</sup>Department of Electronic Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Melaka 76100, Malaysia

### ARTICLE INFO

#### Article historys:

Received : 18/01/2025

Revised : 30/01/2025

Accepted : 06/03/2025

#### Keywords:

Characteristic; Efficiency;  
Electromagnetic Field Radiation;  
MATLAB; Three Phase Transformer

### ABSTRACT

Three-phase transformers are integral components of modern electrical power systems, serving as the backbone of energy transmission and distribution networks. Their primary purpose is to step up or step-down voltage levels efficiently, enabling the transfer of electrical power over long distances with minimal losses. Due to their widespread use in industrial, commercial, and residential applications, understanding the operational characteristics of three-phase transformers is crucial for improving energy efficiency, ensuring reliability, and optimizing performance. The analysis of transformer characteristics, such as efficiency, voltage regulation, power losses, and behavior under varying load conditions. This research aims to analyze the characteristics of three-phase transformers using MATLAB. The results of the analysis obtained in the research of the characteristics of 3-phase transformers produce an active power (P) of 6183.42 W, a reactive power (Q) of 3832.14 VAR, an apparent power (S) of 7274.61 VA and a transformer efficiency of 97.75% with a time of 0.02 s and produces losses in copper of 81.65 W which produces electromagnetic field radiation, with a polar graph representing the radiation pattern of the magnetic field (H field) and electric field (E field).



This work is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/)

### Corresponding Author:

Sari Novalianda

Department of Electrical Engineering, Universitas Al-Azhar Medan, Medan 20142, Indonesia

Email: sarivaldano4@gmail.com

## 1. INTRODUCTION

Three-phase transformers are vital components in the electric power system that function to transform voltage and current according to the needs of the distribution and transmission system. However, in its operation, three-phase transformers face various technical problems that can affect its performance. One of the main problems is power losses, which consist of copper losses due to winding resistance and core losses caused by hysteresis and eddy currents. These losses contribute to the decline in transformer efficiency, which needs to be analyzed to improve the performance of the electric power system [1][2][3]. In addition, the distribution of current and voltage in a three-phase transformer is often uneven due to load imbalance. This condition can cause power distortion which has an impact on the quality of the electrical power supplied. Therefore, it is necessary to analyze the characteristics of the transformer under balanced and unbalanced load conditions to understand how the system works under various operational conditions [4] [5]. Furthermore, modeling the equivalent circuit of a three-phase

transformer becomes an important aspect in the analysis of its characteristics. The equivalent circuit is used to determine key parameters such as impedance, leakage reactance, and winding resistance. However, manual calculations are often complex and require a more efficient method. By utilizing MATLAB, transformer characteristic analysis can be done more accurately and systematically through numerical modeling-based simulations.

To overcome these problems, validation is needed with simulation using MATLAB, which can help interpret the characteristics of three-phase transformers more effectively. MATLAB provides various functions and toolboxes for power system analysis, allowing modeling and simulation that are closer to actual operational conditions. Thus, this study aims to develop a more systematic analysis method in evaluating the characteristics of three-phase transformers and provide optimization recommendations based on simulation results [6][7][8]. This research aims to analyze the characteristics of three-phase transformers using MATLAB, focusing on theoretical concepts, simulation, and performance evaluation. By leveraging MATLAB's computational strengths, the research will explore key transformer characteristics, investigate the effects of operational conditions, and validate theoretical results through practical simulation models[9], [10], [11]. The insights gained from this research will contribute to a deeper understanding of transformer behavior and demonstrate the significance of computational tools in modern electrical engineering practices.

## 2. RESEARCH METHOD

A transformer is an electrical device that uses electromagnetic induction and magnetic coupling to change the alternating current voltage from one level to another. The primary coil and the secondary coil are the two coils that form the laminated iron core of the transformer. One of the main factors contributing to the widespread use of alternating current in the production and distribution of electricity is the ease and reliability of using transformers, which allows the selection of the most cost-effective and appropriate voltage for any need. This research uses an analytical approach and MATLAB-based simulation to analyze the characteristics of a three-phase transformer. The method used consists of several main stages, namely mathematical modeling, simulation of transformer characteristics, and validation of simulation results against theory and experimental data.

### 2.1 Voltage Transformation

The core principle of voltage transformation relies on electromagnetic induction. Alternating current (AC) produces a fluctuating magnetic flux in the core of a transformer when it passes through the primary winding. Depending on the turn's ratio, this flux causes a voltage to be induced in the secondary winding that may be more or lower than the primary voltage [12]. The relationship between primary and secondary voltages is given by the turn's ratio of the transformer can be calculate by equation 1 and despite changing the voltage, transformers conserve power (neglecting losses) between the primary and secondary circuits. This conservation of power is expressed as by equation 2.

$$\frac{V_{primary}}{V_{secondary}} = \frac{N_{primary}}{N_{secondary}} \quad (1)$$

$$V_{primary} \times I_{primary} = V_{secondary} \times I_{secondary} \quad (2)$$

### 2.2 Transformer Efficiency

A fundamental performance metric called transformer efficiency gauges how well a transformer minimizes losses when converting input electrical power into output electrical power. In an ideal transformer, the efficiency would be 100%, meaning that all the input power is transferred to the secondary side without any loss[13], [14]. The output power to input power ratio, represented as a percentage, is a transformer's efficiency ( $\eta$ ).

$$\eta = \frac{P_{output}}{P_{input}} \times 100\% \quad (3)$$

### 2.3 Voltage Regulation

Voltage regulation refers to the percentage change in the secondary voltage of a transformer as the load changes from no load to full load. It is an indication of how much the voltage varies with the change in load. Mathematically, voltage regulation ( $V_R$ ) is expressed as:

$$V_R = \frac{V_{no\ load} - V_{full\ load}}{V_{full\ load}} \times 100\% \quad (4)$$

## 2.4 Losses

In transformers, losses are inevitable due to the inherent properties of the materials and components used. Understanding these losses is essential for optimizing transformer design and improving efficiency. The primary losses in a transformer can be categorized into core losses (also known as iron losses), copper losses, and stray losses. Each of these losses occurs due to specific factors such as resistance, magnetic flux, and leakage inductance.

### A. Core Losses (Iron Losses)

Core losses, sometimes known as iron losses, occur in the transformer's magnetic core. The alternating magnetic field created by the current passing through the primary winding is what causes these losses. Energy is released as heat when the magnetic flow in the core shifts direction. Hysteresis loss and eddy current loss are the two primary components of core losses. As the transformer's alternating current (AC) reverses direction, the core material magnetizes and demagnetizes, causing hysteresis loss [15], [16]. The magnetic domains within the core material change direction in response to the applied magnetic field, which requires energy, causing heat to be generated. Circular currents called eddy currents are created inside the core material as a result of fluctuating magnetic flux. Energy losses result from the resistive heating caused by these currents flowing in loops within the core.

### B. Copper Losses (Winding Losses)

The resistance in the transformer's primary and secondary windings is what causes copper losses. When current flows through the winding, energy is dissipated in the form of heat due to the resistance of the copper wire (or aluminum wire) used for the windings. These losses increase with the current, and therefore, are load dependent [17], [18]. The copper loss  $P_{copper}$  in either the primary or secondary winding is given by:

$$P_{copper} = I^2 R \quad (4)$$

Copper losses are higher when the transformer is fully loaded and smaller when it is lightly loaded or not loaded at all because they are proportional to the square of the current. The resistance of the windings as current passes through them causes copper losses in transformers. The square of the current and the winding's resistance determines the copper loss exactly. The amount of copper loss in a transformer depends on a number of parameters. These variables mostly have to do with the transformer's windings' properties and the current passing through them.

## 2.5 Power Handling

The ability of a transformer to transfer electrical energy effectively and efficiently from the primary (input) side to the secondary (output) side is known as power handling. In AC circuits, transformers are used to increase or decrease voltage while maintaining power. However, its design, size, insulation, temperature limitations, and the load it handles are some of the elements that affect its power handling capacity. The voltage rating, current rating, frequency, and other characteristics of a transformer all affect how much power it can handle. The power handling capacity of a transformer is commonly measured in megavolt-amperes (MVA), kilovolt-amperes (kVA), or volt-amperes (VA). A transformer's ability to handle power is determined by its voltage and current ratings. The product of the maximum voltage and current determines the maximum power the transformer can handle.

$$S_{max} = V_{rated} \times I_{rated} \quad (5)$$

### A. Active Power (P)

Active power in a transformer is the power used to do real work, that is, the power that can be used to drive a load connected to the electrical system, such as a motor, heater, or other electronic device. In a transformer, active power is calculated based on the relationship between voltage, current, and power factor, which reflects how the voltage and current are in phase with each other [19], [20], [21]. In a three-phase transformer, active power can be calculated using the equation:

$$P = \sqrt{3} \times V \times I \times \cos(\theta) \quad (6)$$

**B. Reactive Power (Q)**

Reactive power is the power component that does not do any actual work but is needed to support the operation of the transformer and inductive loads (such as electric motors, the transformer itself, and other inductive devices). This reactive power is important for maintaining the magnetic field in the transformer and other inductive devices. Reactive power in a three-phase system is calculated by

$$Q = \sqrt{3} \times V \times I \times \sin(\theta) \tag{7}$$

**C. Apparent Power (S)**

Apparent power is the total power supplied by an electrical system, which includes both active power (which does real work) and reactive power (which does no real work). In the context of transformers, apparent power describes the total amount of power received and used by the transformer to drive the load and maintain the magnetic field in the system. Apparent power in a three-phase system is calculated by

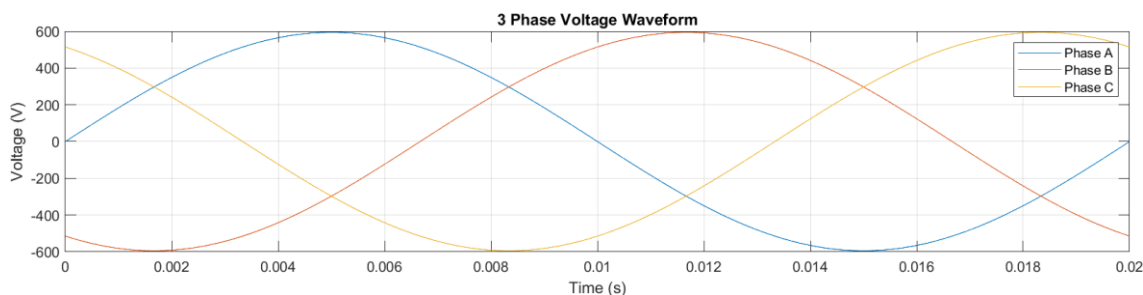
$$S = \sqrt{3} \times V \times I \tag{8}$$

**2.6 MATLAB**

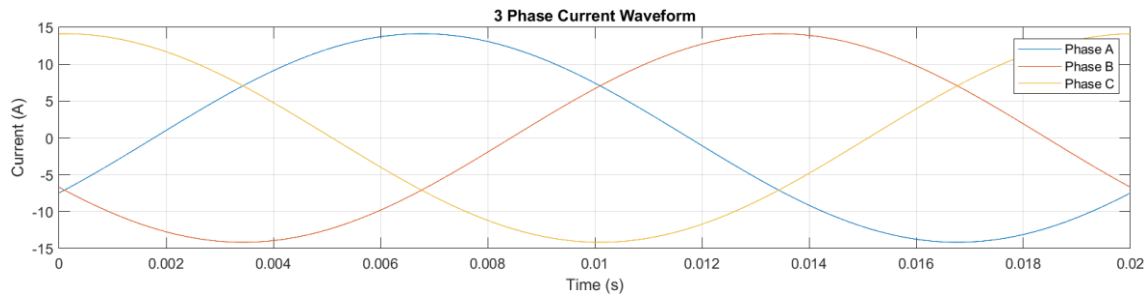
MATLAB is a technical computing high-performance programming environment that is frequently used for method creation, data analysis, simulation, and numerical computing. It provides a vast range of tools and functions to help engineers, scientists, and researchers model systems, visualize data, and solve complex mathematical problems. For analyzing 3-phase transformers in MATLAB, MATLAB provides an easy interface to model and simulate electrical systems such as transformers. The analysis of 3-phase transformers typically involves simulating key characteristics like voltage regulation, load effect, efficiency, and losses.

**3. RESULTS AND DISCUSSION**

The results and discussion of the MATLAB simulation-based examination of a three-phase transformer's properties are presented in this part. The analysis involves computing and visualizing several key parameters of the transformer such as power, voltage regulation, efficiency, and losses. These results are obtained using MATLAB's built-in functions and custom code to model and simulate the behavior of the transformer under various operating conditions that can be seen in Figure 1 shows the three-phase voltage waveforms obtained from the MATLAB simulation. In this graph, there are three sinusoidal curves that represent the voltages of each phase (Va, Vb, and Vc). The three waves have a phase angle difference of 120°, which is a typical characteristic of a three-phase power system. From this waveform, it can be observed that the voltage amplitude remains stable, indicating that the transformer is operating under normal conditions without any significant disturbances. If there is a change in the load or an imbalance in the system, the voltage waveform may experience distortion or amplitude shift. The MATLAB simulation allows for accurate monitoring of these changes, which is useful in transformer performance analysis, and Figure 2 shows the three-phase current waveforms generated from the MATLAB simulation. Just like the three-phase voltages, the three-phase currents (Ia, Ib, and Ic) have a phase angle difference of 120° between each other, indicating that the system is operating under balanced load conditions.

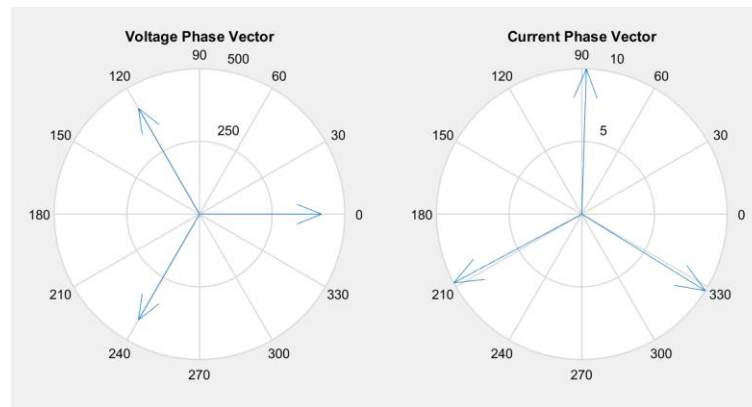


**Figure 1.** 3-phase voltage waveform



**Figure 2.** 3-phase current waveform

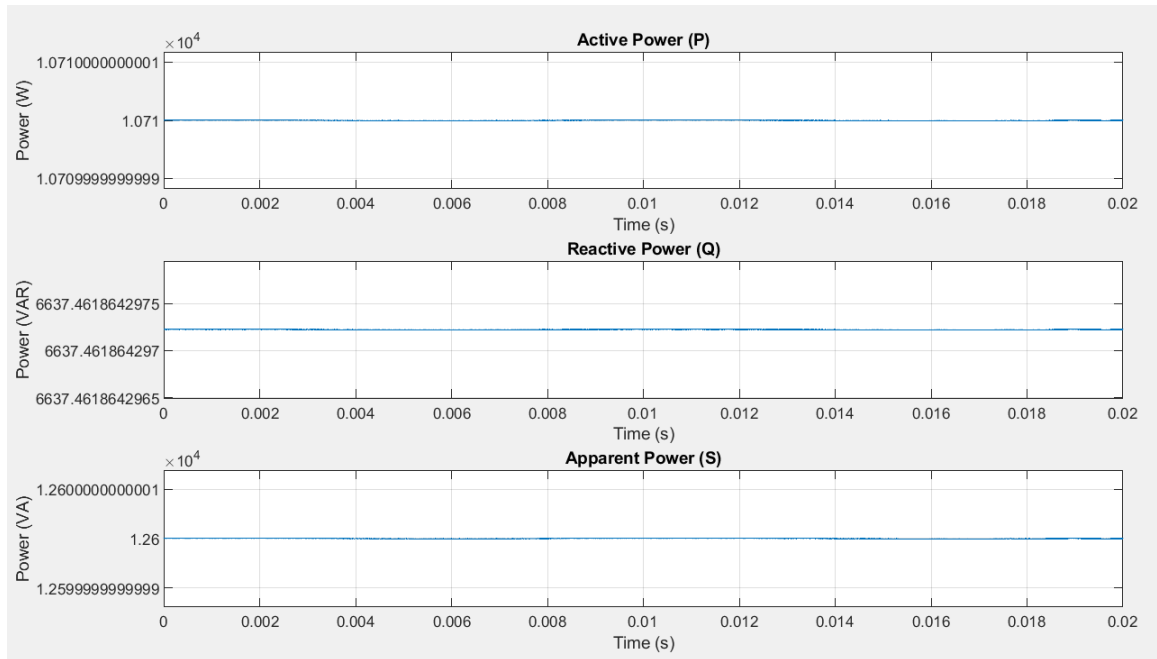
In a three-phase transformer, there are three main channels for voltage and current, each of which has a different value and phase. The three-phase system can be described by the interconnected voltage and current vectors shown in Figure 3 where the three voltage vectors (A, B, and C) will be distributed at an angle of 120 degrees, forming a triangle on the phasor diagram, and the currents on the primary and secondary sides will describe a similar relationship, but with the influence of the turns ratio. Phase differences between voltage and current can occur, depending on the load impedance.



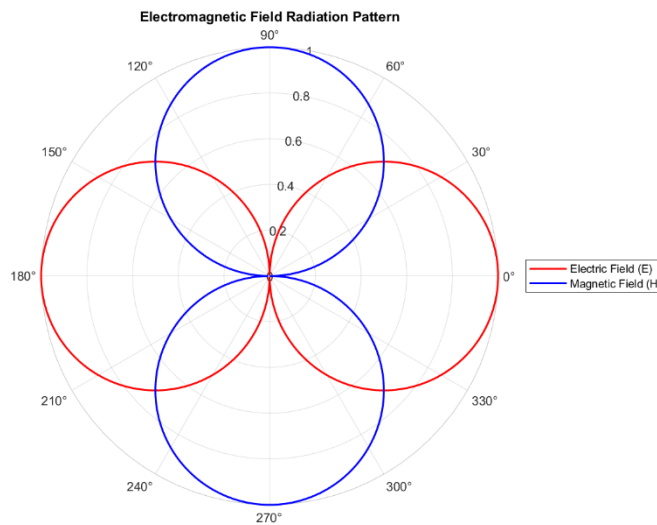
**Figure 3.** Vector on a 3-phase transformer (voltage and current)

From Figure 1 to Figure 3 above, it can be seen that the research of the characteristics of the 3-phase transformer produces an active power (P) of 6183.42 W, a reactive power (Q) of 3832.14 VAR, an apparent power (S) of 7274.61 VA and a transformer efficiency of 97.75% with a time of 0.02 s and produces losses in copper of 81.65 W can be seen in Figure 4 shows the simulation results of the power generated by a three-phase transformer under various operating conditions. In a three-phase power system, the power transferred can be calculated in several main forms, namely active power (P), reactive power (Q), and apparent power (S). This shows that the 3-phase transformer has met the applicable international standards.

In a 3-phase transformer, it produces an electric field (E-field) and magnetic field (H-field) radiation pattern in the form of a polar graph. The electric field pattern (E-field) shows a cosine-based distribution, with maximum intensity on a certain axis and minimum intensity in other directions. The magnetic field pattern (H-field) shows a sine-based distribution, with maximum intensity in different directions from the electric field, indicating an orthogonal relationship between the E-field and H-field. The operating frequency (50 Hz) produces a radiation pattern with low frequency properties, where the effects of electromagnetic waves are still dominant at close range around the transformer. The field distribution shows a relationship between the intensity of the electric and magnetic fields with the angular position to the transformer core as shown in Figure 5 shows the electromagnetic field distribution generated by a three-phase transformer during operation. This electromagnetic (EM) field radiation occurs due to the electric current in the transformer windings, which produces a magnetic field around the core and windings. Electromagnetic field radiation can be analyzed to understand its impact on transformer efficiency, power losses, and potential electromagnetic interference (EMI) that can affect other electrical equipment in the vicinity.



**Figure 4.** Power generated by a 3-phase transformer



**Figure 5.** Electromagnetic field radiation in 3 phase transformers

#### 4. CONCLUSION

The MATLAB-based analysis conducted in this study aims to provide a comprehensive understanding of the operating characteristics of a three-phase transformer, especially in relation to the voltage, current, and power generated. With this approach, various key parameters of the transformer can be accurately evaluated, allowing the identification of factors that affect efficiency and power losses. The results of the analysis show that the active power (P) generated by the transformer is 6183.42 W, which is the real power used by the load. The reactive power (Q) generated is 3832.14 VAR, which reflects the energy circulating in the system due to the inductive or capacitive components of the load and the transformer itself. The apparent power (S) generated is 7274.61 VA, which represents the vector combination of active power and reactive power in a three-phase system. With a transformer efficiency reaching 97.75%, it can be concluded that the transformer operates with high performance and only experiences minimal power losses. One important aspect in this analysis is the calculation of copper losses of 81.65 W, which occurs due to resistance in the transformer windings. These losses contribute

to the dissipation of energy in the form of heat and generate electromagnetic field radiation. The study of these radiation patterns shows that the electric field (E field) and the magnetic field (H field) form a polar graph, which describes the distribution of the direction and intensity of the fields in space. The electric field (E) distribution shows a cosine-based pattern, with maximum intensity in certain directions and minimum intensity in other directions. Meanwhile, the magnetic field (H) distribution shows a sine-based pattern, with maximum intensity in different directions from the electric field. This indicates that the electric and magnetic fields have an orthogonal relationship with each other, as expected in the electromagnetic wave theory. With this understanding, it can be concluded that MATLAB-based analysis not only allows the evaluation of the operational parameters of the transformer but also provides deep insight into the interaction of electromagnetic fields generated during operation. These findings emphasize the importance of maintaining an ideal power factor to optimize transformer performance and minimize energy losses, so that the power system can operate more efficiently and stably.

### Acknowledgments

We would like to express our deepest thanks to all parties who have helped in preparing the research and writing of this scientific paper, especially the electrical engineering department of Universitas Al-Azhar Medan in collaboration with Universiti Malaysia Perlis (UniMAP) and Universiti Teknikal Malaysia Melaka (UTeM).

### REFERENCES

- [1] C. Yan, W. Wang, P. Zhang, Z. Liu, J. Shu, and B. Zhang, "Coupled Field–Circuit Modeling and Analysis for Interturn Short–Circuit Faults in an Onboard Traction Transformer," in *2023 IEEE International Magnetic Conference - Short Papers (INTERMAG Short Papers)*, 2023, pp. 1–2. doi: 10.1109/INTERMAGShortPapers58606.2023.10228536.
- [2] J. P. Karunadasa, K. G. L. Navarathna, R. Abeyrathna, K. Perera, and K. D. N. Sandaruwan, "Novel Three Phase Transformer Model to Accommodate the Effects of Load Injected DC," in *2018 Moratuwa Engineering Research Conference (MERCon)*, 2018, pp. 138–143. doi: 10.1109/MERCon.2018.8421993.
- [3] J. Qin *et al.*, "A Three-phase Combined Transformer with Characteristics of Anti-leakage current and Anti-electromagnetic Interference," in *2021 6th Asia Conference on Power and Electrical Engineering (ACPEE)*, 2021, pp. 1184–1188. doi: 10.1109/ACPEE51499.2021.9437125.
- [4] H. S. Oztura and S. Polat, "A Symmetrical-Asymmetrical Fault Characteristics Analysis within Cogeneration Power Plant in Izmir, Turkey: An Experimental Assessment," *Gazi Univ. J. Sci.*, vol. 35, no. 2, pp. 524–540, 2022, doi: 10.35378/gujs.770814.
- [5] A. Kokor, S. Smaka, S. Grebović, and V. Helać, "Effects of Neutral Point Grounding Methods on Single-Phase Short Circuit Fault Characteristics," in *2022 21st International Symposium INFOTEH-JAHORINA (INFOTEH)*, 2022, pp. 1–6. doi: 10.1109/INFOTEH53737.2022.9751319.
- [6] I. Roza, Y. T. Nugraha, R. Rida, M. Irwanto, and M. A. Othman, "Modeling of Glugur Substation grounding systems using MATLAB graphical user interface," *Int. J. Electr. Comput. Eng.*, vol. 15, no. 1, pp. 15–23, 2025, doi: 10.11591/ijece.v15i1.pp15-23.
- [7] M. Irwanto, Y. T. Nugraha, N. Hussin, I. Nisza, D. Perangin-Angin, and H. Alam, "Modelling of Wireless Power Transfer System Using MATLAB SIMULINK," *2022 IEEE 13th Control Syst. Grad. Res. Colloquium, ICSGRC 2022 - Conf. Proc.*, no. July, pp. 21–24, 2022, doi: 10.1109/ICSGRC55096.2022.9845181.
- [8] C. Shambare, Y. Sun, and O. Imoru, "A Survey on Recent development of Asymmetrical Three-Phase Short Circuit Faults Computation in Power Systems," in *2019 6th International Conference on Soft Computing & Machine Intelligence (ISCMI)*, 2019, pp. 180–184. doi: 10.1109/ISCMI47871.2019.9004345.

- [9] M. Irwanto, Y. T. Nugraha, N. Hussin, and I. Nisja, "Effect of Temperature and Solar Irradiance on the Performance of 50 Hz Photovoltaic Wireless Power Transfer System," *J. Teknol.*, vol. 85, no. 2, pp. 53–67, 2023, doi: 10.11113/jurnalteknologi.v85.18872.
- [10] M. Irwanto, M. B. Ali, Y. T. Nugraha, B. Ismail, I. Nisja, and W. Z. Leow, "Analysis on the Effect of DC Current Changes on the Magnetic Field of Wireless Power Transfer," in *2023 IEEE 14th Control and System Graduate Research Colloquium (ICSGRC)*, 2023, pp. 186–191. doi: 10.1109/ICSGRC57744.2023.10215406.
- [11] M. Irwanto, H. S. Ibrahim, Y. T. Nugraha, and I. Nisja, "Performance analysis of photovoltaic powered half bridge inverter using sinusoidal pulse width modulation (SPWM) method," *AIP Conf. Proc.*, vol. 2991, no. 1, p. 20018, Jun. 2024, doi: 10.1063/5.0198660.
- [12] C. Martineac, P. C. Dărab, H. G. Beileu, and R. N. Hasanah, "Influence of Soil Resistivity on 110 kV Substation Grounding System," in *2020 International Conference and Exposition on Electrical And Power Engineering (EPE)*, 2020, pp. 715–720. doi: 10.1109/EPE50722.2020.9305645.
- [13] H. Alam, M. Irwanto, Y. M. Mashor, and M. Masri, "Design of multiple Pulse Width Modulation (MPWM) Transformerless Photovoltaic Inverter (TPVI) system," *J. Phys. Conf. Ser.*, vol. 1432, no. 1, pp. 0–9, 2020, doi: 10.1088/1742-6596/1432/1/012056.
- [14] K. Akom, T. Shongwe, M. K. Joseph, and S. Padmanaban, "Energy Framework and Policy Direction Guidelines: Ghana 2017-2050 Perspectives," *IEEE Access*, vol. 8, pp. 152851–152869, 2020, doi: 10.1109/ACCESS.2020.3018314.
- [15] Q. Wu, T. Hong, S. Jazebi, and F. de León, "Experimentally Validated Method to Measure the  $\lambda$  Characteristics of Asymmetric Three-Phase Transformers," *IEEE Trans. Magn.*, vol. 55, no. 4, pp. 1–9, 2019, doi: 10.1109/TMAG.2019.2897962.
- [16] T.-H. Han, S.-C. Ko, and S.-H. Lim, "Analysis on Three-Phase Ground Fault Current Limiting Operations of Three-Phase Transformer Type SFCL Using Two Superconducting Modules," *IEEE Trans. Appl. Supercond.*, vol. 32, no. 6, pp. 1–7, 2022, doi: 10.1109/TASC.2022.3181571.
- [17] S. Hardi, A. Nasution, F. Fahmi, and F. Purnamasari, "Efficient Design On The Substation Grounding Grid: A Case Study at 2x500MVA Galang," in *2020 4rd International Conference on Electrical, Telecommunication and Computer Engineering (ELTICOM)*, 2020, pp. 180–185. doi: 10.1109/ELTICOM50775.2020.9230492.
- [18] A. R. Soman, A. R. Deshmukh, A. D. Kulkarni, A. N. Kulkarni, and P. S. Nagdeote, "Design And Development of Three - Phase Transformer," *IJIREEICE*, vol. 12, no. 4, pp. 264–272, 2024, doi: 10.17148/IJIREEICE.2024.12441.
- [19] A. Ge, D. Xie, Z. Shi, G. Yu, and X. Zhang, "Analysis of Grounding Grids Connection Between Photovoltaic Farm and Its Substation," in *2020 IEEE International Conference on High Voltage Engineering and Application (ICHVE)*, 2020, pp. 1–4. doi: 10.1109/ICHVE49031.2020.9280034.
- [20] R. Rios, M. Quintana, M. Ramirez, E. Ortigoza, V. Oxilia, and G. Blanco, "Use of electric vehicles to achieve sustainable development goals in countries with surpluses of hydroelectricity: Case of Paraguay," *IEEE Chil. Conf. Electr. Electron. Eng. Inf. Commun. Technol. CHILECON 2019*, pp. 1–6, 2019, doi: 10.1109/CHILECON47746.2019.8988038.
- [21] T. Mushiri and C. Mbohwa, "Research on the use of matlab in the modeling of 3-phase power systems," *Lect. Notes Eng. Comput. Sci.*, vol. 2217, pp. 363–369, 2015.