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An Analysis Of Power Transformer Performance Reliability On The Effect Transient Recovery Voltage

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ABSTRACT

Technologies a power transformer is a crucial component in an electric power system that functions to change electric voltage from one level to another. Reliable transformer performance is essential to ensure the continuity of electricity supply and prevent significant losses. One phenomenon that can affect transformer reliability is Transient Recovery Voltage (TRV). This paper described the reliability of power transformer performance against the influence of TRV through simulations and experimental measurements. The research methodology includes literature review, mathematical modeling, simulation using electric power system analysis software, and laboratory testing. The research results show that TRV has a significant influence on transformer reliability, especially under conditions of major disturbances. Recommendations for mitigating the impact of TRV include the use of additional protective devices such as surge arresters and improving the quality of transformer insulation. By understanding the influence of TRV on transformer performance, it is expected to increase the reliability and operational lifespan of power transformers, as well as reduce the risk of economic losses due to transformer damage. This research makes an important contribution to the development of protection and maintenance techniques for power transformers in modern electric power systems.

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INTRODUCTION

A power transformer is one of the key components in an electric power system, which functions to change electric voltage from one level to another in order to distribute energy efficiently. Reliable performance of power transformers is very important to ensure continuity of electricity supply and stability of the power system. However, power transformers often experience various technical challenges that can affect their performance, one of which is the effect of Transient Recovery Voltage (TRV).

Transient Recovery Voltage (TRV) is a temporary voltage that appears after the fault current is cut off by a circuit breaker. TRVs can have high amplitudes and rise velocities, which can have a significant impact on the insulation of the transformer and other related components. These conditions can cause extreme electrical stress on the transformer, potentially causing damage to the insulation, reduced equipment life, and in severe cases, transformer failure.

Research on the influence of TRV on power transformers is very important to understand the mechanisms and factors that influence transformer reliability. With better understanding, mitigation strategies and techniques can be developed to increase the reliability and longevity of power transformers. The development of analytical models and computer simulations is also an important part of this research to predict transformer response to various TRV conditions and to design more effective protection systems.

In addition, analysis of the reliability of power transformer performance in the face of TRV has significant practical implications. In an operational context, electric utilities need to ensure that power transformers can operate safely and reliably under a wide range of grid conditions. This involves continuous monitoring, predictive maintenance, and improving the design of transformers and their protection systems.

In this research, an in-depth analysis will be carried out regarding the influence of TRV on power transformer performance, including identification of factors that influence TRV, evaluation of its impact on transformer insulation, and development of mitigation methods. The aim is to provide practical recommendations for improving the reliability and safety of power transformer operations, ultimately contributing to the stability and reliability of the electric power system as a whole.

In Indonesia, where energy needs continue to increase along with economic and population growth, the reliability of the electric power system is becoming increasingly critical. Power outages caused by transformer failure not only result in significant economic losses but also have a negative impact on people's social lives. Therefore, a deep understanding of the factors influencing transformer performance, including the influence of TRV, is essential for developing effective mitigation strategies.

The effect of TRV can vary depending on various factors, such as the type of fault, fault location, and circuit breaker characteristics. A high TRV can cause voltage spikes that exceed the design limits of the transformer, resulting in overvoltage that can damage the insulation. Damaged insulation can lead to leakage currents, overheating, and ultimately transformer failure. Therefore, detailed analysis and simulation of TRV conditions under various disruption scenarios is required to anticipate and mitigate these risks.

Additionally, new technologies such as advanced insulation materials and transformer designs that are more resistant to TRV need to be explored and implemented. Modern transformers must be designed to withstand higher electrical stresses without reducing their performance. Innovations in sensor technology and online monitoring also enable early detection of abnormal conditions, which can prevent transformer failure before more severe damage occurs.

This research also highlights the importance of strict standards and regulations in the design and operation of power transformers. Implementation of international standards and best practices can help ensure that transformers used in electric power systems have adequate resistance to TRV and other external factors.

Through this comprehensive research, it is hoped that practical and technical recommendations can be produced that can be adopted by the electric power industry in Indonesia. Implementation of the results of this research is expected to increase the operational reliability of power transformers, reduce the frequency and duration of power outages, and increase the efficiency and stability of the electric power system as a whole.

Literature Review

Source Electrical.

The electrical power generated at power plants must pass through several distribution stages before reaching consumers. This centralized generation and distribution of power enable electricity to be produced in one location and used at another distant location at any time. Due to various technical constraints, power generation occurs in specific areas, while consumers are dispersed across various locations. Transmitting electric power from the generation site to customers necessitates various technical measures.

For the transmission of very large amounts of electrical power over long distances, using high voltage is the most efficient method. High voltage is employed in transmission lines to minimize power losses.

Figure 1. Source Electrical Step

The electric power system can essentially be divided into two parts:

a. Primary Network System
Also known as the medium voltage network (JTM), the primary network system plays a crucial role in distributing electric power to users in a specific area. Utilizing a medium voltage system as the main network helps to avoid distribution losses and ensures that the voltage quality requirements are met. PT PLN Persero, as the main business authority, must adhere to the quality standards set by the Electricity Law No. 30 of 2009.

b. Secondary Network System
Referred to as the low voltage network (JTR), the secondary network system is the downstream component of the electric power system. This network distributes electric power directly to consumers or electricity customers. It functions to transmit electrical

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voltage from distribution substations to low voltage consumers. The low voltage levels used by PT. PLN (Persero) are 127/220 V and 220/380 V.

Protection Quality Step

In planning an effective protection system, several key requirements must be considered:

a. Selectivity and Discrimination, The effectiveness of a protection system is determined by its ability to isolate only the part of the system experiencing a fault.
b. Stability, This characteristic ensures that the protection system remains inactive if disturbances occur outside the protective zone (external disturbances).
c. Speed of Operation, The longer the fault current continues to flow, the greater the damage to the equipment. It is crucial to isolate the faulted sections before the synchronously connected generators lose synchronization with the rest of the system. Typical fault clearance time in high voltage systems is 140 ms, which is expected to be reduced to 80 ms in the future, necessitating very high-speed relaying.
d. Sensitivity, This refers to the amount of fault current required for the protection device to operate. It can be expressed as the amount of current in the actual network (primary current) or as a percentage of the secondary current (current transformer).
e. Economic Considerations, While the economic aspect often takes precedence, ensuring that basic safety requirements are met, technical aspects are paramount in transmission systems. Protection is relatively expensive, but so is the system or equipment being protected. Ensuring the continuity of system equipment is vital, often necessitating two separate protection systems: primary protection (main protection) and backup protection.
f. Reliability, The reliability of the protection system is critical, as the main cause of circuit outages is often the failure of the protection system to operate correctly (maloperation).
g. Supporting Protection, Backup protection is a completely separate system that functions to isolate the faulted section if the primary protection fails.

Figure 2. Electric Power Protection System

In an electric power distribution system, the level of reliability is crucial in determining system performance. This reliability is measured by the extent to which the supply of

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electric power remains continuous for consumers. The most fundamental issue in the electric power distribution system concerns the quality, continuity, and availability of electric power services to customers.

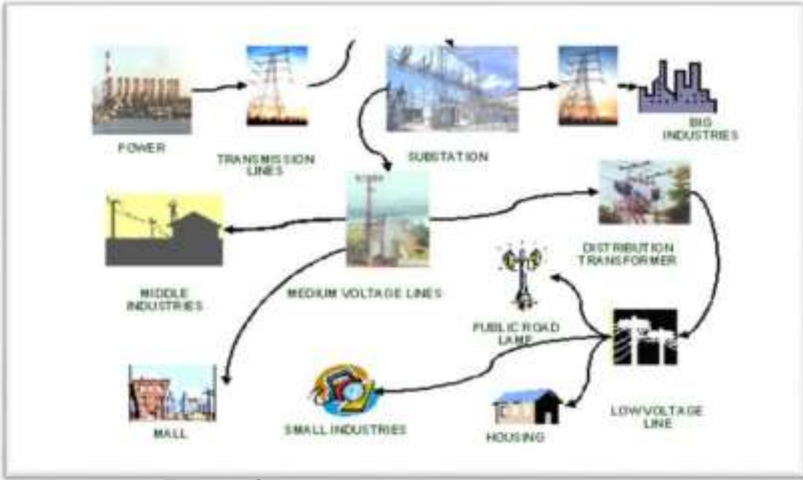

Figure 3. Source System Distribution.

Disturbances System

Disturbances an electrical equipment are an inherent part of the operation of electric power systems, affecting everything from generators and transmission lines to load centres. These disturbances in the distribution system can trigger the feeder safety relay to open the circuit breaker at the substation, resulting in a power outage. The reliability of the distribution system is its ability to consistently and stably deliver electric power to customers, especially large power users who require uninterrupted service. Interruptions in electricity supply can disrupt the production processes of these major consumers. The structure of the medium voltage network is crucial in ensuring the reliability of power distribution, as a well-designed network allows for voltage maneuvers by isolating disturbances and rerouting loads through alternative pathways.

METHOD

In this research, switching overvoltage modelling will be modelling using ATP-Draw software simulation. Transient overvoltage that occurs due to the process of providing power to a transmission line depends on the characteristics of the transmission line used. Overvoltage disturbances in the transmission and distribution of electric power systems are usually caused by two types of surge voltage, namely lightning surges and circuit surges which have amplitudes greater than the nominal peak voltage value. One source of circuit surge overvoltage is the opening and closing of circuit breakers. The magnitude of the voltage amplitude during load shedding always correlates with the system voltage and the oscillation frequency which is influenced by the system impedance. The phenomenon of circuit surges on transmission lines can be resolved by creating a single phase equivalent circuit. So each phase is assumed to be able to stand alone, this applies if the power cut-off on each phase closes simultaneously. The simulation that will be carried out is by providing a three-phase fault trigger to the ground with the assumption that an opening is carried out circuit breaker.

This voltage consists of high frequency components that are superimposed on the normal system voltage and the total is called restriking voltage and forms a switching surge, when the circuit restriking voltage can reach a maximum value that is twice the peak value of the system recovery voltage. For system modelling, 3 different types of power transformer winding connections are used,

1. The power transformer uses a Delta – Wye type winding.
2. The power transformer uses a Wye – Delta type winding.
3. The power transformer uses a Delta – Delta type winding.
4. The power transformer uses a Wye – Wye type winding.

The simulation was carried out using the type of power transformer winding connection intended to find out the differences in the resulting transient recovery voltage. So the characteristics of the traveling waves that occur are also known. Transient Recovery Voltage generated during the circuit breaker disconnection process will be analysed using waves with the input parameters being VL–Peak on the secondary side of the power transformer which differs based on the type of winding connection.

Once the characteristics of the reflected wave are known, the results will be compared with the Transient Recovery Voltage. Based on the single line circuit diagram of 20 kV medium voltage transmission and modelling the circuit is equipped with a trigger in the form of a switching which is then connected to ground as a model of the short circuit system. This circuit modelling consists of main components such as a 150 kV voltage source, resistors, capacitors, nonlinear inductors, circuit breakers, power transformers with circuit parameters shown in Table 1. Circuit modelling is carried out in the Alternative Transient Program or ATP-Draw. The aim of modelling this transient recovery voltage circuit is to determine the differences in transient voltage response when switching a medium voltage circuit breaker and determine the differences in traveling wave response which will be analysed using the lattice Bewley diagram method using MATLAB software.

The research began with a literature study to understand the basic theory of Transient Recovery Voltage (TRV), power transformers, and electrical power system reliability. Relevant literature from scientific journals, textbooks, and industry standards will be reviewed to gain a comprehensive understanding. Mathematical modelling is carried out to describe the TRV phenomenon and its interaction with power transformers. Differential equations and other analytical methods are used to predict the transformer response to TRV. This modelling includes the electrical and mechanical characteristics of the transformer as well as the fault conditions that trigger the TRV.

Computer simulations are carried out using electrical power system analysis software such as MATLAB/Simulink or PSCAD. The mathematical model that has been developed is implemented in simulation to predict TRV behaviour and its impact on the transformer. Various fault scenarios and operating conditions are tested to evaluate transformer reliability. and Experimental testing is carried out in the laboratory to validate the simulation results. The necessary test transformers and measuring equipment are prepared to replicate

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TRV conditions. Data obtained from these tests are used to calibrate and verify the simulation model. and Data from simulations and laboratory tests are analysed to evaluate the effect of TRV on transformer performance. Performance parameters such as voltage, current, temperature, and insulation conditions are evaluated. Statistical analysis was carried out to identify patterns and relationships between TRV and transformer damage.

Based on the analysis results, a mitigation strategy was developed to reduce the negative impact of TRV on transformers. These recommendations include the use of protective devices such as surge arresters, improving insulation quality, and preventative maintenance procedures. and Proposed mitigation strategies are tested and validated through additional simulations and field testing where possible. Implementation of this strategy is expected to increase the reliability and operational life of power transformers. It is hoped that this structured research method will provide an in-depth understanding of the influence of TRVs on power transformers and produce practical recommendations for increasing the reliability of electric power systems.

RESULT

Result Of Data Substation.

The number of disturbances that occurred at the substation power transformer.

Table 1. Disturbances in the Substation Power Transformer Area Protection System

No	Year	Causes of Disorders			Frequency
		Technical	Non technical	No Is known	Disturbance
1	2018	3	-	-	3
2	2019	2	-	-	2
3	2020	-	-	-	-
4	2021	-	-	1	1
5	2022	1	-	-	1
6	2023	1	-	-	1
		Number of Interruptions			8

Calculation of the percentage of frequency of disturbances that occur in the Substation Power Transformer area.

Table 2. Percentage of Disturbances in the Substation Power Transformer Area Protection System 2018-2023

No	Year	Interruption Frequency Time	Percentage of Disorders %
1	2018	3	37.5 %
2	2019	2	25 %
3	2020	-	-
4	2021	1	12.5 %
5	2022	1	12.5 %
6	2023	1	12.5 %
	Amount	8	100%

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The number of various disturbances at the Substation from 2018-2023 was minimized with a protection system to minimize the occurrence of disturbances in the transformer area can be seen in Table 3. below.

Table 3. Substation 150 KV Power Transformer Area Protection System 2018-2023

No	Transformer Protection Relay Power	Protection Relay Performance		Number of Interruptions Time
		Capable Secure	Unable Secure	
1	REF	2	-	2
2	OCR/GFR	2	-	2
3	OLTC	1	-	1
4	BHUCOLZT	1	-	1
5	SHUDDEN PREASURE	1	-	1
6	PMT 150KV	1	-	1
7	PMT 20KV INCOMING	3	-	3
8	PMT 20KV FEEDER	-	1	1
	AMOUNT	11	1	12

Calculation of the percentage of reliability of the protection system on the transformer, the calculation results are in Table 4.

Table 4. Percentage of Reliability of the Kalibakal 150 KV Substation Power Transformer Area Protection System 2018 - 2023

No	Protection Relay Power Transformer	Protection Relay Performance		Amount Disturbance Time	Level Success
		Capable Secure Disturbance	Unable Secure Disturbance		
1	REF	2	-	2	100%
2	OCR/GFR	2	-	2	100%
3	OLTC	1	-	1	100%
4	BHUCOLZT	1	-	1	100%
5	SHUDDEN PREASURE	1	-	1	100%
6	PMT 150KV	1	-	1	100%
7	PMT 20KV INCOMING	3	-	3	100%
8	PMT 20KV FEEDER	-	1	1	0%
	Amount	11	1	12	91.67%

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Analysed Faults and Performance of Transformer Protection Systems

The disturbances that arise can be classified into 3 types of disturbances where the first is a technical disturbance, the second is a non-technical disturbance and the third or last is a disturbance whose cause is unknown. By using 2012 disturbance data and the percentage description analysis formula, the 2012 disturbance percentage was obtained at 37.5%.

Data on the percentage of disturbances in Power Transformer Area Protection System for 2012-2017 in table 2 above shows that the average percentage of disturbances each year is 12.5%. This 12.5% percentage of disruption occurred in 2015, 2016 and 2017, while in 2012 it was 37.5%, in 2013 it was 25% and in 2014 there was no disruption.

Based on table 3 above, it can be seen that the performance of the Kalibakal 150 KV Substation Power Transformer Area Protection System from 2012-2017 is included in the good category. This is proven by the fact that most of the disturbances in the power system can be resolved, where there is only one disturbance that cannot be resolved, namely the disturbance at the PMT 20 KV Feeder.

A relay is said to have good reliability if it has a reliability of 90% to 100%. To calculate the percentage of performance or reliability of a power transformer protection system, you can also use the percentage description formula using formula (2), So the percentage of reliability of the 2012-2017 transformer protection relay at the Kalibakal 150KV Substation is 91.67% and is stated to be quite good because it is more from 90%.

CONCLUSION

Based on the results of research conducted and analysis of transient recovery voltage (TRV) using traveling waves in medium voltage circuit breakers, the following conclusions are obtained: where is the peak TRV voltage value in the simulation with four variations of power transformer winding connections and The peak value of the TRV voltage and traveling wave at each power transformer winding connection varies due to differences in parameters, namely the peak voltage VL–N at each power transformer winding connection.

REFERECNES

[1] Aryza, S., Lubis, Z., Indrawan, M. I., Efendi, S., & Sihombing, P. (2021). Analyzed New Design Data Driven Modelling of Piezoelectric Power Generating System. *Budapest International Research and Critics Institute-Journal (BIRCI-Journal)*, *4*(3), 5537-5547.

[2] Aryza, S., Wibowo, P., & Saputra, D. (2022, July). Rancang Bangun Alat Pengontrolan Proses Pemanasan Produksi Biodisel Dari Minyak Jelantah Berbasis Arduino Mega. In *Prosiding Seminar Nasional Sosial, Humaniora, dan Teknologi* (pp. 121-127).

[3] Aryza, S., Wibowo, P., & Saputra, D. (2022). AN ENHANCE DESIGN HEATING BIODIESEL PRODUCTION FROM OIL BASED ON ARDUINO MEGA. *INFOKUM*, *10*(02), 1147-1155.

[4] Pradana, dkk. "Prototipe Pembangkit LIstrik Termoelektrik Generator Menggunakan Penghantar Panas Aluminium, Kuningan Daan seng." Jurnal teknik elektro 9.2 (2020).

Jurnal Scientia
Volume 13, Number 03, 2024, DOI 10.58471/ scientia.v13i03
ESSN 2723-7486 (Online)
https://infor.seaninstitute.org/index.php/pendidikan

[5] Puspita, Shanti Candra, Hasto Sunarno, and Bachtera Indarto. "Generator termoelektrik untuk pengisisan aki." Jurnal Fisika dan Aplikasinya 13.2 (2017): 84-87.
[6] Sasmita, Sandy Angriawan, et al. "Alternatif pembangkit energi listrik menggunakan prinsip termoelektrik generator." Tesla: Jurnal Teknik Elektro 21.1 (2019): 57-61.
[7] Sumarjo, dkk "Pemanfaatan sumber panas pada kompor menggunakan 10 termoelektrik generator dirangkai secara seri untuk aplikasi lampu penerangan." SINTEK JURNAL: Jurnal Ilmiah Teknik Mesin 11.2 (2017): 123-128.
[8] Tyas, Naufal Ridha. Uji Karakteristik Modul Termoelektrik Generator Seri 12705. Diss. Fakultas Teknik, 2017.
[9] Tharo, Z., & Hamdani, H. (2020). Analisis biaya pembangkit listrik tenaga surya (PLTS) atap skala rumah tangga. *Journal of Electrical and System Control Engineering*, *3*(2), 65-71.