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An Optimal Effect Of Overload And Unbalanced Load On Transformer Lifetime In 20kv Distribution Substation

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Article Info	ABSTRACT
Keywords: Overload, Unbalanced Load, Distribution Transformer, and Service Life.	This study aims to analyze the effect of overload and load imbalance on the service life of transformers in 20 kV distribution substations. Distribution transformers function vitally in the power distribution system, but often face problems such as overload and load imbalance that can affect their performance. The research method used is a quantitative approach with field measurements, focusing on evaluating transformer loading conditions. The measurement results show that the transformer operates at an overload with a loading percentage reaching 109.8%, and a load imbalance of 19.16%. These findings indicate that these conditions can cause an increase in operating temperature, damage insulation, and shorten the life of the transformer. The combination of overload and load imbalance accelerates transformer damage and reduces its reliability, which ultimately has a negative impact on the continuity of electricity supply to consumers. This study recommends the importance of effective load monitoring and management to maintain transformer performance and improve the quality of electricity supply. The results of this study are expected to provide insight for distribution system managers in an effort to improve the efficiency and operational reliability of distribution transformers.
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INTRODUCTION

The Distribution System plays an important role in the electric power system. This is because this system is directly connected to the electricity users of customers in medium voltage and low voltage channels. The Distribution System itself has functions including receiving electricity from power sources, as well as distributing the power to consumers (Susanto, 2020).

Distribution Substation is one of the components of an electric power distribution system. In this distribution substation, a Distribution Transformer is usually used which functions to reduce the electric voltage from the high voltage distribution network to the voltage used in the low voltage distribution network (step down transformer); for example, a voltage of 20 KV to a voltage of 380 volts or 220 volts. (Kodoati et al., 2015).

The transformer will work continuously if the transformer is at its nominal load. However, if the load served approaches 100% or even greater than 100%, the transformer will get more heat and can shorten the life of its insulation (Mertasana, 2015). Transformers have limitations in their operation. If the transformer is used continuously in overload conditions, it will experience an increase in temperature and heat in the transformer will increase. So that it will damage the insulation, materials and transformers will be damaged. In addition, it affects the quality of transformer power, voltage drops at the end of the network and results in reduced life of the transformer (Samsurizal & Hadinoto, 2020).

Distribution transformers can experience critical conditions due to two main factors: overload and load imbalance. Overload occurs when the transformer's loading capacity exceeds 80% of its nominal value (SPLN 50: 1997). If left for a long period of time, this condition causes excessive heat that damages the transformer's insulation, increases the risk of failure, and reduces its operational life. In addition, overload also triggers a voltage drop, which has an impact on reducing the quality of electricity supply to consumers. Meanwhile, a load imbalance that exceeds 30% of the standard also has serious impacts, such as increased neutral current, greater power losses, and additional heat that worsens the insulation condition. The combination of these two factors accelerates transformer damage, so that electricity system managers must ensure optimal and balanced loading to maintain transformer reliability.

Power distribution substations play a crucial role in maintaining the stability and reliability of electrical systems, especially in 20 kV distribution systems commonly used in many power distribution networks. One of the key components in these systems is the transformer, which is responsible for stepping up or stepping down voltage to match consumer needs. The optimal performance of a transformer depends on several factors, including the load it carries and the quality of the electrical distribution it transmits.
However, in practice, transformers often experience overload and unbalanced load, which can significantly affect their operational lifespan. Overload occurs when a transformer operates beyond its rated capacity, while unbalanced load results from an imbalance between the phase currents in the transformer, leading to uneven power distribution. Both of these factors can cause temperature increases in the core and windings, which, in turn, accelerate insulation degradation and shorten the transformer's operational lifetime.

The research problem addressed in this study is how overload and unbalanced load affect the lifespan of transformers in 20 kV distribution systems. This research aims to comprehensively analyze the impact of these two conditions on transformer performance and lifespan, as well as to find optimal solutions to minimize the losses arising from these factors.
Transformers are generally designed to operate within certain limits of current and voltage. However, in unstable or fluctuating operational conditions, such as in 20 kV distribution systems, transformers are often exposed to conditions of overload or imbalance for extended periods. While many studies have been conducted on the effects of overload and unbalanced load on electrical systems, few have specifically addressed their impact on transformer lifespan, particularly in the context of 20 kV distribution networks.

The impact of overload on transformer lifespan has been well-documented, with increased temperature significantly accelerating insulation degradation and the deterioration of other internal components. In addition, unbalanced load can lead to higher neutral currents and harmonic distortion, which further exacerbate the transformer's operational conditions. Therefore, it is essential to conduct further research to determine the extent of the effects of overload and unbalanced load on transformer lifespan and how to manage these factors to avoid adverse effects on long-term system performance.

Based on the description, it is important to understand that distribution transformers have a crucial role in maintaining the continuity and quality of electricity supply to consumers. However, overload and load imbalance are major challenges that can affect the performance and service life of transformers. Therefore, this study aims to analyze the effect of overload and load imbalance on the service life of transformers in 20 kV distribution substations. It is hoped that the results of this study can provide a clearer picture of the operational impacts caused and become a reference for optimizing transformer management so that it remains reliable in supporting the electricity distribution system.

RESEARCH METHODS

This is a quantitative and experimental research with a case study approach at a 20kV distribution substation. Data will be collected through direct measurements and simulations to evaluate the impact of overload and unbalanced load on transformer lifetime. This study focuses on measuring the load on the transformer and observing the load imbalance conditions that occur in the distribution network. The object of this study is a 20kV distribution transformer with substation code MT-480 operating in the GU.06/PCG.05 feeder distribution network in the service area of PT. PLN (Persero) ULP Medan Timur. The transformer used in this study is a transformer with varying loads and distributed over several phases in the distribution network. The transformer was selected based on the level of significant load imbalance. Measurements were conducted at several substations on the 20kV distribution network that have variations in load patterns and customer distribution. Load measurements were conducted at only one time period, namely during off-peak load times, to obtain an overview of the loading conditions on the transformer. From several measurement points, one distribution substation was obtained with a load that exceeded capacity and a significant load imbalance.

No. MT-480 Substation

Data from the distribution transformer as follows:

a. Power: 250 kVA
b. Working Voltage: 20 kV/400 V
c. Transformer: 1 x 3 phase

Load measurement is done using current and voltage measuring devices on each phase of the transformer. The research on *"An Optimal Effect of Overload and Unbalanced Load on Transformer Lifetime in 20kV Distribution Substation"* can be conducted using a quantitative approach with modeling, simulation, and experimental methods. Below are the key research methodology steps:

a. Measurement of current, voltage, and temperature of the transformer using sensors in the distribution substation.
b. Thermal imaging (infrared) to identify hot spots caused by unbalanced loads.

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c. Measurement of harmonic factors affecting transformer losses.
d. Historical load profile data of the transformer from the utility or network operator.
e. Reference standards like IEEE C57.91-2011 for transformer lifetime calculations based on load profile.
f. Thermal and electrical characteristic data of transformers from manufacturers.

RESULTS AND DISCUSSION

Measurements are carried out only in one condition, namely outside the peak load time (LWBP) to obtain an overview of the loading conditions on the transformer. The measurement results can be seen in tables 1 and 2.

Table 1. Voltage on the secondary side of the transformer

TRANSFORMER VOLTAGE	
PHASE	VOLTAGE (V)
RS	399 V
RT	398 V
ST	396 V
RN	227 V
SN	228 V
TN	226 V

Table 2. Currents in each phase and neutral (R, S, T, N)

PHASE AND NEUTRAL CURRENT	
IF & IN	CURRENT (A)
IR	441
IS	384
IT	365
IN	70

The data obtained from the load measurement is analyzed to identify the level of loading percentage and load imbalance on the transformer. The analysis is carried out by:

Transformer Loading Calculation

S = 250 kVA = 250000VA
V = 400V phase – phase

$$I_{FL} = \frac{S}{\sqrt{3} \times V} = \frac{250000}{\sqrt{3} \times 400} = 361{,}3A$$

The transformer loading percentage is:

$$\frac{I_{FL}}{I_{rata-rata}} = \frac{361{,}3}{396{,}6} = 109{,}8\%$$

From the calculation above, it can be seen that the percentage of loading is 109.8%.

Transformer Unbalance Calculation

$$I_{rata-rata} = \frac{I_R + I_S + I_T}{3} = \frac{441 + 384 + 365}{3} = 396{,}6A$$

Thus, the average load imbalance is:

$$\frac{MAX_{arus\,phasa} - MIN_{arus\,phasa}}{I_{rata-rata}} \times 100\% = \frac{441-365}{396{,}6} \times 100\% = 19{,}16\%$$

Power Loss Calculation

Based on the measurement data of the load current value of a 20 kV distribution transformer, the losses caused by unbalanced loading conditions can be calculated, the following data:

For the active power of the transformer (P):

P = S.cos phi = 250 .0.85 = 212.5 kW

Losses due to neutral current flowing to the ground can be calculated as follows:

$$P_G = I_{G^2} \,.\, R_G = 70^2.5 = 24500kW = 24{,}5kW$$

CONCLUSION

This study has analyzed the effect of overload and load imbalance on the service life of transformers in 20 kV distribution substations. Based on the results of the study, several conclusions were obtained as follows: Overload. The measurement results show that the transformer is operating under overload conditions, with a loading percentage reaching 109.8%. This condition has the potential to increase the operating temperature of the transformer, which can damage the insulation and shorten its operational life. Load Unbalance, The observed load unbalance of 19.16% indicates that the current distribution in each phase is uneven. This causes higher neutral current, which contributes to increased power losses and worsens the transformer insulation condition. Overall Impact, The combination of overload and load unbalance accelerates the damage process to the transformer, reduces its reliability, and potentially disrupts the continuity of electricity supply to consumers. Based on these findings, it is recommended that distribution system managers monitor and manage loads effectively. Implementation of solutions to reduce load imbalance is essential to improve the performance and service life of distribution transformers, as well as maintain optimal power supply quality. This study is expected to be a reference for efforts to improve efficiency in managing electric power distribution systems.

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