ISSN 2087-3336 (Print) | 2721-4729 (Online)

TEKNOSAINS: Jurnal Sains, Teknologi dan Informatika
Vol. 11, No. 1, January 2024, page. 201-208
http://jurnal.sttmcileungsi.ac.id/index.php/tekno
DOI: 10.37373

Advantage power transformer low losses with a case study on 30/60 MVA 150/20/10 kV transformers

Asep Saepudin*, Hilam Sholih

1* Mechanical Engineering, Sekolah Tinggi Teknologi Muhammadiyah Cileungsi. Jl. Orchid No. 25 Perum PTSC Cileungsi, Bogor, West Java, Indonesia

*✉ asep.saepudin@sttmcileungsi.ac.id

Submitted : 31/12/2023 Reviseded : 12/01/2024 Accepted: 24/01/2024

ABSTRACT

Transformers have a lengthy service life of 30 to 40 years and are used to transfer electrical power to distribution and transmission systems. The great efficiency and low losses of this static electricity machine are two of its advantages. can aid in lowering greenhouse gas emissions and protecting the environment. While transformers can experience several losses, two main types of losses typically arise: 1. Ohmic or copper losses; and 2. Core or iron losses. This study compares the benefits of low-loss transformers (143 kW) to high-loss transformers (258 kW). It focuses solely on the design and environmental aspects of copper losses (also known as load losses) and core losses (sometimes known as no-load losses). This study's methodology combines qualitative and quantitative methods with a case study of a 30/60 MVA transformer with a voltage rating of 150/20 kV and a mineral oil cooling system. The study concludes is that low-loss transformer design is important, this results in an efficiency increase from 99.57% to 99.80%, losses of 55.4% lower, and an approximate 25% increase in total weight. Environmentally speaking, it can reduce greenhouse gas emissions by approximately 31,347.87 tCO2e, making it more cost-effective, competitive, and environmentally friendly than transformers with 258 kW of total losses.

Keywords: Transformer; efficiency; losses; greenhouse gas emissions; environmentally friendly transformator

1. INTRODUCTION

Operating on static electromagnetic principles [1][2][3], the transformer increases voltage from high voltage to low voltage or vice versa, using the same frequency. Comparative analysis of transformations [4][5], where Figure 1 explains that the voltage ratio between the primary and secondary sides is directly proportional to the number of turns and inversely proportional to the current ratio. The power transformer idea [6][7].

A transformer is an apparatus that generates static electricity with an efficiency of better than 99% [8]. Generally speaking, load losses occur in the transformer windings and no-load losses occur in the transformer core in all power transformers, whether they are single-phase or three-phase converters [9][10].

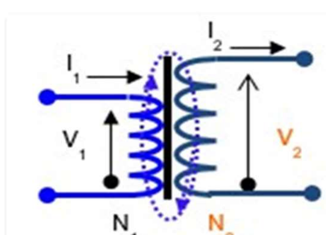

Figure 1. Power transformer concept [3]

Transformer models, this study makes use of a sample of a three-phase, 150/20/10 kV, 36/60 MVA power transformer with three cores, each of which contains the HV, FR, LV, and TV windings as well as all other transformer windings. The model utilized as the study subject is shown in Figure 2. This study is restricted to talking about the transformer's core and windings' optimal utilization as primary materials.

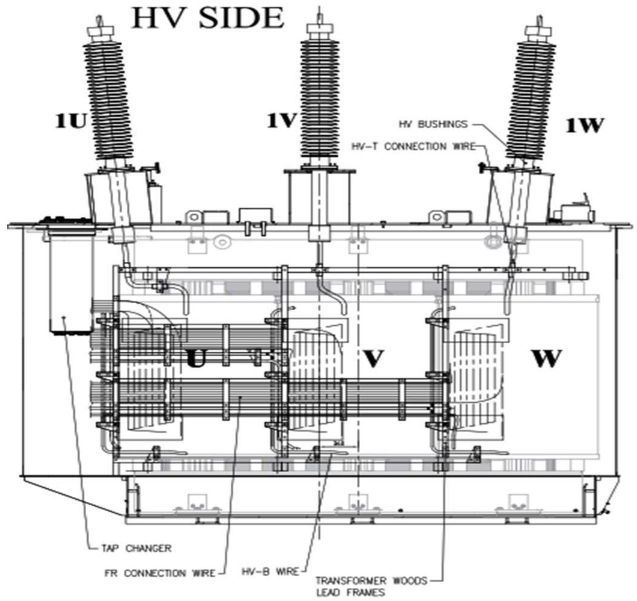

Figure 2. Three-phase power transformer model

The structural portion of the study is restricted to the losses of core and winding in Figure 3 describes for the transformer windings and core

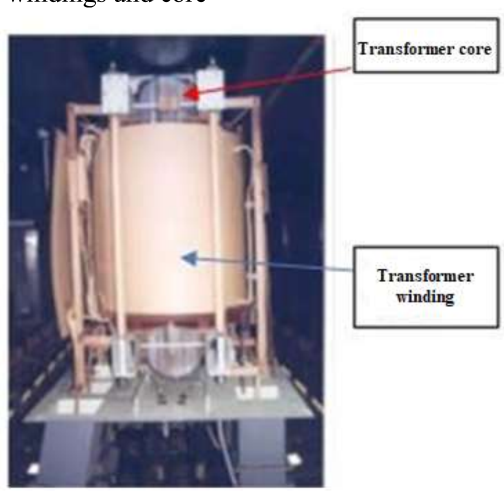

Figure 3. Transformer core and winding structure

Prior studies did not assess the benefits of low losses or the amounts of carbon emissions produced; they merely examined and quantified the emissions. This study is interesting in that it compares the carbon emissions from a case study of constructing a 60 MVA 150/20/10 kV transformer compared transformers with high and low losses.

2. METHOD

Two three-phase power transformers were sampled for this study using both qualitative and quantitative methods: sample 1 was a 60 MVA, 150/20/10 kV power transformer with large losses, and sample 2 was a 60 MVA, 150/20/10 kV power transformer with minimal losses.

Two samples of 60 MVA power transformers with nearly identical specs were used in this study: sample 1 is a losses power transformer with a 60 MVA power, 150/20 kV system voltage, and 50 Hz frequency. Data on a 60 MVA loss power transformer meant for PLN-Indonesia consumers can be found in Table 1.

Table 1. Information on significant losses in a 60 MVA power transformer

High losses power transformer		
Customer		PLN-Indonesia
Sample		1
Power Rating	MVA	60
HV/LV/TV Voltage Rating	kV	150/20/10
BIL	kV	650
Frequency	Hz	50
Loss without burden	kW	38
Burdened loss	kW	220
Transformer core inductance	T	1.606
Efficiency	%	99.57
Active part weight	kg	44500
Oil weight	kg	22500
Tank & Fittings weight	kg	20500
Total Weight	kg	87500

That is an example of two low-loss power transformers with a system voltage of 150/20 kV, a frequency of 50 Hz, and a power of 60 MVA [11]. Data on lost power transformers with a 60 MVA rating for PLN-Indonesia clients can be found in Table 2.

Table 2. Data on losses power transformer 60 MVA [12][13].

Low losses power transformer		
Customer		PLN-Indonesia
Sample		2
Power Rating	MVA	60
HV/LV/TV Voltage Rating	kV	150/20/10
BIL	kV	650
Frequency	Hz	50
Loss without	kW	28
Burdened loss	kW	115
Transformer core inductance	T	1.6887
Efficiency	%	99.80
Active part weight	kg	69000
Oil weight	kg	22600
Tank & Fitting Weight	kg	18400
Total Weight	kg	110000

Types of losses and their distribution in 60 MVA power transformers. The two components of the most popular transformer are load loss and no-load loss. When load loss (Pcu) makes up about 80% of the overall losses in the transformer, and no-load loss (Pcore) makes up about 20% [14][15]. No-load losses are primarily found in the transformer core and are commonly referred to as iron losses, whereas load losses are primarily found in the transformer windings and are generally dubbed copper losses. This is how the overall transformer loss is calculated [16].

$$P_T = P_{Cu} + P_{Core} \tag{1}$$

Load loss is the loss of power absorbed when the transformer is loaded. It is a loss that happens in the transformer winding and is dependent on the resistance and square of the current that occurs. The load loss in a three-phase transformer is calculated as follows [16]:

$$P_{Cu} = 3 * ((I_{HV})^2 * R_{HV}) + (I_{LV})^2 * R_{LV}) \quad (2)$$

Where:
P_{Cu} = Loaded loss (copper loss) (Watts)
I_{HV} = Primary side current (Amperes)
R_{HV} = Resistance on the primary side (Ohm)
I_{LV} = Secondary side current (Amperes)
R_{LV} = Resistance on the Secondary side (Ohms)

No-load loss, also known as core loss, is the loss that happens in a transformer's core. It is also known as power loss absorbed by the transformer while it is not under load, and it includes hysteresis loss (P_H) and eddy current loss (P_E) [15]. No-load losses in a transformer are calculated as follows [16]:

$$P_{Core} = P_H + P_E \quad (3)$$

Hysteresis losses are caused by repeated changes in flux that hit the transformer core and cause heat. Hysteresis loss can be formulated as follows [16]:

$$P_H = k_s * B^{1.6} * f \quad (4)$$

Where:
P_H = Hysteresis loss (Watts)
k_s = Coefficient on core material
$B^{1.6}$ = Maximum magnetic flux density (Tesla)
f = Frequency (Hz)

Eddy current loss is caused by a circuit current that is induced in the transformer core due to changing flux and this current causes heat in the transformer core. Eddy's current losses can be formulated [16]:

$$P_E = k_e * B^2 * f * d^2 * 10^{-3} \quad (5)$$

Where:
P_E = A roaring eddy current (Watt)
k_e = Eddy current constant
B^2 = Maximum magnetic flux density (Tesla)
f = Frequency (Hz)
d^2 = Transformer core lamination thickness (mm)

Figure 4 source of carbon emissions in a 60 MVA power transformer, taking into account emissions from losses that happen and materials that are utilized in the transformer that release emissions and assuming a 40-year transformer life [12].

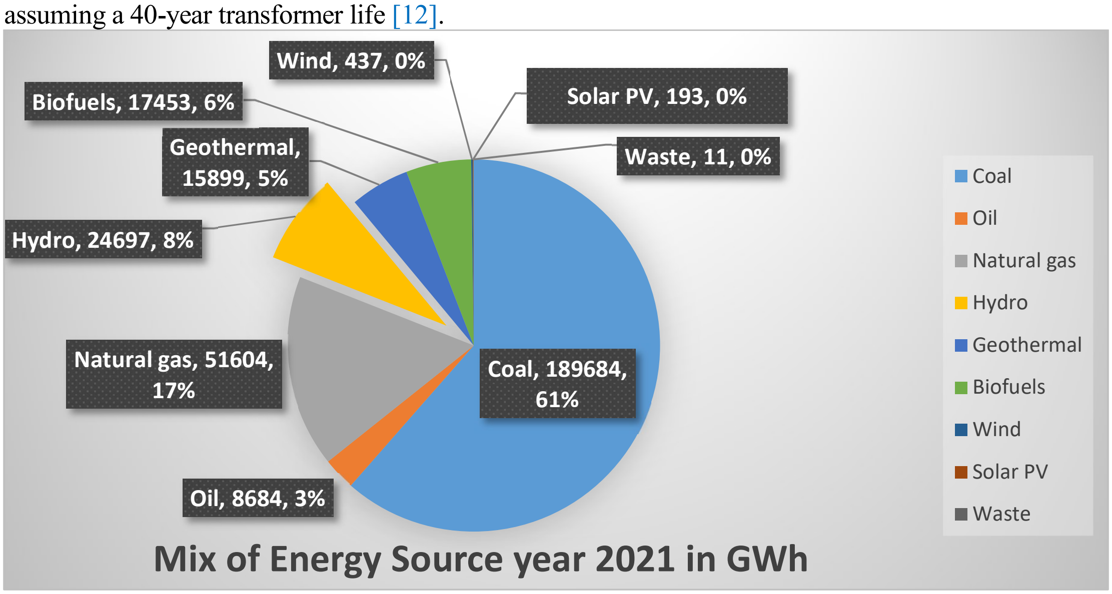

Figure 4. Indonesia's mixed energy generation in 2021 [17].

Indonesia's sources of mixed energy generation in 2021 are depicted in Table 3, with a total of 308662 GWh coming from these sources.

Table 3. CO2 emissions based on generator fuel source type [17].

Coal	Oil	Natural gas	Units
202	11	27	Mt CO2

The following formula can be used to get the average emission factor for the electrical network based on the source of energy generation and emissions based on the fuel used in generating [18]:

$$EF = \frac{\sum_{i=1}^{n}(E_i x\, EF_i)}{\sum_{i=1}^{n} E_i} \quad (6)$$

Where:
EF = Average emission factor on the electricity grid (tCO2/MWh)
EF_i = Emission factor for each generating source (tCO2/MWh)
E_i = Generating energy sources (MWh)

The average emission factor on the electricity network in Indonesia is as follows [18][19]:

$$EF = \frac{240\ x\ 10^6}{308662\ x\ 10^3} = 0.78 \text{ tCO2/MWh}$$

The amount of carbon emissions resulting from the production of each primary component used in power transformers, in Table 4, is known as the carbon emission factor in transformers.

Table 4. Average emission factors according to the primary material of transformers [18].

	Core steel	Copper	Paper	Steel	Pressboard	OLTC	Oil
EF (kgCO2/kg)	2.765	4.738	0.817	2.5	1.183	7.5	1.209

3. RESULT AND DISCUSSION

To do computations and comparisons between transformers with low and large losses, each transformer's data must be displayed. The specifications are needed for both high-loss and low-loss transformers.

1. Transformer efficiency.
2. Loss without load.
3. Expense loss.
4. Transformer core weight.
5. Weight of transformer winding.
6. The weight of the paper insulation used
7. The weight of the wood insulation used
8. Heavy metal part
9. OLTC weight
10. Weight of Oil used

The computation and comparison results will be derived from the equations that have been shown, the transformer data in Table 1 and Table 2, and all of the starting calculation data. Table 5 shows the primary materials used in the 60 MVA transformer with a high total loss of 258 kW, as well as a summary of the carbon emissions resulting from load losses and no-load losses.

Table 5. Data on carbon emissions for power transformers with large losses of 60 MVA

High losses power transformer			
Customer		PLN-Indonesia	
Sample		1	**CO2 (tCO2)**
Life time	Year	40	

High losses power transformer			
Customer		PLN-Indonesia	
Power Rating	MVA	60	
HV/LV/TV Voltage Rating	kV	150/20/10	
BIL	kV	650	
Frequency	Hz	50	
Loss without burden	kW	38	10.385,9
Burdened loss	kW	220	60.128,6
Transformer core inductance	T	1.606	
Efficiency	%	99.57	
Core bearing (steel core)	kg	27634	76,41
Winding bearing (copper)	kg	10104	47,87
Bearing metal part (steel)	kg	20500	51,25
Bearing insulating paper (paper)	kg	5400	4,41
Insulating wooden bearers (pressboard)	kg	1122	1,33
OLTC weight	kg	240	1.8
Oil Weight	kg	22500	27.20
Total	kg	87500	70.722,77

Table 6 lists the primary materials used in the 60 MVA transformer with a low total loss of 143 kW and summarizes the carbon emissions from load losses and no-load losses.

Table 6. Data on carbon emissions for low-loss power transformers with 60 MVA

Losses power transformer			
Customer		PLN-Indonesia	
Sample		1	**CO2 (tCO2)**
Life time	Year	40	
Power Rating	MVA	60	
HV/LV/TV Voltage Rating	kV	150/20/10	
BIL	kV	650	
Frequency	Hz	50	
Loss without burden	kW	28	7.652,74
Burdened loss	kW	115	31.430,88
Transformer core inductance	T	1.6887	
Efficiency	%	99.80	
Core bearing (steel core)	kg	34500	92,29
Winding bearing (copper)	kg	24000	113,71
Bearing metal part (steel)	kg	18400	46
Bearing insulating paper (paper)	kg	5400	4,41
Insulating wooden bearers (pressboard)	kg	4860	5,75
OLTC weight	kg	240	1.8
Oil Weight	kg	22600	27.32
Total	kg	110000	39.374,9

The carbon emissions from load losses and no-load losses, as well as the primary materials used in the 60 MVA transformer, are summarized in Table 7 between a low total loss of 143 kW and a high total loss of 258 kW.

Table 7. 60 MVA power transformers with high and low losses compared

Customer		PLN-Indonesia		
Losses		High losses	Low losses	Information
Sample		1	2	
Life time	Year	40	40	

Customer Losses		PLN-Indonesia High losses	Low losses	Information
Power Rating	MVA	60	60	
HV/LV/TV Voltage Rating	kV	150/20/10	150/20/10	
BIL	kV	650	650	
Frequency	Hz	50	50	
No Load Losses	kW	38	28	No-load losses are 10 kW lower
Load losses	kW	220	115	Lower load loss of 105 kW
Transformer core inductance	T	1.606	1.6887	
Efficiency	%	99.57	99.80	Better efficiency 0.23%
Beart inti (core steel)	kg	27634	34500	
Winding weight (copper)	kg	10104	24000	
Beart metal part (steel)	kg	20500	18400	
Weight of insulating paper (paper)	kg	5400	5400	
Weight of insulating wood (*pressboard*)	kg	1122	4860	
OLTC weight	kg	240	240	
Oil Weight	kg	22500	22600	
Total Weight	kg	87500	110000	The total weight of the transformer is 22500 kg
Total CO2 (Carbon dioxide)	tCO2e	70.722,77	39.374,9	Total carbon emissions are 31,347.87 lower

The total carbon emissions produced on a transformer with high losses, which is 70,722.77 tCO2e, and on a transformer with low losses, which is 39,374.9 tCO2e, differ by approximately 31,347.87 tCO2e, indicating that the transformer with low losses is more environmentally friendly. This is based on a comparison of samples 1 and 2, studied on a 60 MVA transformer, as shown in Table 7, Transformers with low losses are more efficient by design and will be more cost-effective and competitive in the long run than transformers with high total losses, specifically 258 kW. For no-load losses, they are 10 kW smaller, and for load losses, they are 105 kW smaller. The impact on transformer efficiency is better, at about 0.23%.

4. CONCLUSION

This study's 60 MVA 150/20/10 kV transformer with low losses—a total loss of 143 kW—shows that efficiency rises from 99.57% to 99.80%, losses are reduced by 55.4%, and the overall weight increases by approximately 25%. Additionally, it can reduce greenhouse gas emissions by approximately 31,347.87 tCO2e from an environmental standpoint. Low total loss transformers will be kinder, more efficient, and weigh more overall. They will also be more cost-effective and competitive in the long run. environment since it emits fewer greenhouse gases than transformers with large losses—that example, a total loss of 258 kW.

ACKNOWLEDGEMENT

We are grateful for the financing for internal research granted by LPPM STTM Cileungsi and Muhammadiyah Cileungsi College of Technology.

REFERENCE

[1] W. Nugraha, *Panduan Operator Distributed Control System Unit 1 dan 2*. 2021.
[2] F. Adzikri, D. Notosudjono, D. Suhendi, P. Studi, and T. Elektro, “Strategi Pengembangan Energi Terbarukan,” pp. 1–13, 2014.
[3] N. Zhu, J. Li, L. Shao, H. Liu, L. Ren, and L. Zhu, “Analysis of Interturn Faults on Transformer Based on Electromagnetic-Mechanical Coupling,” *Energies*, vol. 16, no. 1, pp. 1–13, 2023, doi: 10.3390/en16010512.

[4] H. U. Chirag Parekh, Chetan Kotwal, "Aspect of Power Transformer Design and Optimization," *Trends Electr. Eng.*, vol. 7, no. 1, 2017, doi: https://doi.org/10.37591/.v7i1.3242.
[5] A. Saepudin, "Optimalisasi Material Utama Pada Auto Transformator 100 MVA," *TEKNOSAINS J. Sains, Teknol. dan Inform.*, vol. 7, no. 1, pp. 1–7, 2020, doi: 10.37373/tekno.v7i1.2.
[6] T. McLyman, *Transformer and Inductor Design Handbook, Fourth Edition*. 2017. doi: 10.1201/b10865.
[7] Martin Heathcote, *J & P Transformer Book*. 2007. [Online]. Available: https://shop.elsevier.com/books/j-and-p-transformer-book/heathcote/978-0-7506-8164-3
[8] N. L. H.-T. Neisius, I. Dzafic, S. Henselmeyer, D. Ablakovic, "Modeling of auto-transformers for load flow calculations," 2012, doi: 10.1109/ISGTEurope.2012.6465850.
[9] M. C. Hlatshwayo, "The Computation of Winding Eddy Losses in Power Transformers Using Analytical and Numerical Methods," 2013.
[10] A. Saepudin, A. Dharmanto, and W. Wilarso, "The Pressure Relief Venting for Air Insulation Cable Box at Power Transformer," in *AIP Conference Proceedings*, 2022. doi: 10.1063/5.0116405.
[11] "Consultation on Tier 2 Fixed Loss Levels on Distribution and Power Transformers implementation," no. March, 2017.
[12] W. Wilarso, "Strength Analysis of Tubular Oil to Oil Cable Box Power Transformer GIS 60 MVA in the Case of Voltage Arc Energy Using the Finite Element Analysis Method," *J. Eng. Sci. Res.*, vol. 4, no. 2, 2023, doi: 10.23960/jesr.v4i2.111.
[13] A. Indarto, I. Garniwa, R. Setiabudy, and C. Hudaya, "Total cost of ownership analysis of 60 MVA 150/120 kV power transformer," *QiR 2017 - 2017 15th Int. Conf. Qual. Res. Int. Symp. Electr. Comput. Eng.*, vol. 2017-Decem, pp. 291–295, 2017, doi: 10.1109/QIR.2017.8168499.
[14] E. I. Amoiralis, M. A. Tsili, and A. G. Kladas, "Transformer design and optimization: A literature survey," *IEEE Trans. Power Deliv.*, vol. 24, no. 4, pp. 1999–2024, 2009, doi: 10.1109/TPWRD.2009.2028763.
[15] Z. Nadolny, "Determination of Dielectric Losses in a Power Transformer," *Energies*, vol. 15, no. 3, 2022, doi: 10.3390/en15030993.
[16] V. Saelee, C. Sinsukudomchai, and P. Khluabwannarat, "Losses Prediction in the Distribution Transformer Using Hierarchy Neural Networks," *J. Int. Counc. Electr. Eng.*, vol. 2, no. 4, pp. 384–390, 2012, doi: 10.5370/jicee.2012.2.4.384.
[17] "IEA Electricity Information." [Online]. Available: https://www.iea.org/countries/indonesia
[18] S. S. Prakash Deenapanray, "A Step-by-Step Calculation of the Combined Margin Grid Emission Factor of the National Electricity System of Mauritius," *Green Energy Technol.*, pp. 331–346, 2018, doi: DOI:10.1007/978-3-319-63612-2_21.
[19] K. Kulasek *et al.*, "Towards net zero emissions-The role of circularity in transformers," *Transform. Mag. | Vol. 7, Issue 4* |, pp. 51–58, 2020, [Online]. Available: www.transformers-magazine.com