Prediction formula development of power transformer no-load noise

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Abstract. Power transformer noise is one of the contributors to noise pollution in the environment. The dominant component of power transformer noise is no-load noise, which is a noise that appears when a power transformer is connected to a voltage source and is not connected to other electrical loads. The amount of no-load noise must be predicted at the design stage so that the noise does not exceed consumers' standards or criteria. In this study, the prediction of no-load noise was conducted involving rated power, magnetic flux density, and geometry factor. Based on the measurement results from industrial testing and the multiple linear regression method, no-load noise prediction formula results with better accuracy are obtained.

1. Introduction
ANSI/IEEE defines a transformer as a static electrical device consisting of a single-coil, two or more with or without a magnetic core, as a standard connection between electrical circuits. Power transformers are used in electric power systems to transfer power with electromagnetic induction in the same frequency. At the different voltage and current levels, a power transformer is an essential tool in the electric power system. In operation, the power transformer will cause noise in the form of sound or buzz. Noise is unwanted noise from a business or activity at a certain level and time that can cause human health problems and environmental comfort. According to the World Health Organization [1], noise levels above 41 dB can cause hearing damage, although not too severe.

Total noise is the sum of the no-load noise, load noise, and noise due to the cooling system. According to real loading conditions, noise testing is difficult for the power transformer industry because of the limited electrical energy source and the type of load. Therefore, testing of various types of noise is required before the power transformer is delivered to consumers. To ensure that no-load noise, load noise, and total noise must comply with consumers' criteria or standards.

The primary sources of noise in the power transformer are the magnetic core, winding [2,3], and cooling system [3–5]. Noise due to the magnetic core is called no-load noise, and the winding is called load noise. No-load noise has a dominant portion of the total power transformer noise. Therefore, efforts to predict the amount of no-load noise accurately since the design process is needed.

In this paper, we will present a formula development to predict the amount of no-load noise better. This paper is organized as follows. The second part discusses the causes of no-load noise.
The third part discusses the no-load noise prediction method and its results, and the last part will be the conclusions and opportunities to improve the prediction results.

2. Sources of power transformer no-load noise

No-load noise emanating from the power transformer core is caused by Maxwell force [6,9] and magnetostriction [2,8].

2.1. Magnetostriction

Magnetostriction is a mechanical deformation process of core lamination in response to a magnetic field [4,8]. When connected to an AC voltage source, the power transformers will produce a magnetic flux that changes according to the input voltage frequency. The core of the power transformer in the form of a sheet will contract a few micrometers with a frequency twice the source voltage frequency. [4,6]. Magnetostriction has the most considerable portion in generating no-load noise in the power transformer [6]. The magnetostriction is greatly influenced by the magnetic flux density [4,9].

Figure 1 shows the relationship between magnetic induction and magnetostriction. Magnetostriction varies with magnetic flux density changes. Figure 2 shows the magnetostriction frequency’s relationship twice the magnetic induction frequency.

![Figure 1: Relationship between magnetic induction and magnetostriction [10]](image1)

![Figure 2: Magnetostriction Frequency is twice more significant than the magnetic induction frequency [10]](image2)

This magnetostriction will cause vibrations in the transformer core. The beat at the center is one of the sound sources of noise [11].

2.2. Maxwell force

Maxwell force is generated by magnetic flux passing in the air gap between the power transformer’s core laminates. This event mainly occurs at the corner of the transformer core. In this area, the magnetic field changes direction with a high anisotropy of the core material, causing the magnetic field to be disconnected. The magnetic field can exist on the same sheet or transfer to another sheet, depending on the permeability conditions [7].
The joints at the power transformer core corners are an area of particular concern. It is due to two phenomena coinciding in the angular joint: the change in the core sheet and the change in the direction of the joint’s magnetic field.

3. Development of no-load noise formula

Prediction of no-load noise rests more on changes in magnetic flux density and weight of transformer cores. Until recently, the noise and vibration caused by magnetostriction were determined experimentally [12–15]. The absence of a complete physical model hinders the analysis and quantification of these physical phenomena. Another way that can be conducted to determine noise and vibration from the core is by numerical modeling with the help of the finite element method (FEM) [6,10,17–25].

Developing the no-load noise formula is statistically based on the design data and the measured noise data. The development of a procedure to predict no-load noise by considering several parameters significantly influences the amount of no-load noise. According to [26], based on the experimental methods, the main determinants of the amount of no-load noise are the rated power \( S \), magnetic flux density \( B \), diameter of column \( A_c \) and mass of the core \( W_c \). In this research, the main factors will be quantified by adding the geometry factor of the core \( GF \). \( GF \) is the ratio between this weight to the cross-sectional area of the core and the number of legs in the core. The method of quantifying the relationship between the main factor and good power used multiple linear regression based on design data and power measurement data.

4. Results and discussion

Based on multiple linear regression, an equation is obtained to predict no-load noise, as shown in equation (1).

\[
L_{NL} = a \log(S) + b \log(B) + GF
\]  

Where \( S \) is the rated power (MVA), \( B \) is the magnetic flux density (T), \( GF \) is the geometry factor. The \( a \) and \( b \) coefficients are 9.63 and 194.25. \( GF \) is the ratio of the core weight to the cross-sectional area and the number of legs to be written with equation (2).

\[
GF = c \log\left(\frac{W_c}{A_c}\right) + d \log(nl) + A
\]

where \( W_c \) is the core weight (kg), \( A_c \) is the limb diameter (mm²), and \( nl \) is the number of legs, and \( A \) represents the other factors (material type, standard type, etc.). The values of coefficients \( c \) and \( d \) are 44.13 and -11.8. The no-load noise prediction calculations for 26 power transformers based on equations 1 and 2 are shown in Table 1 and clarified in Figure 3.

These results indicate that the rated power aspects, the magnetic flux density, and the geometry factor significantly affect the generated no-load noise. The relation between some aspect elements (magnetic flux density, the core’s weight, and rated power) and no-load noise is not linear. The fact that the decibel is a base 10 logarithmic unit.

No-load noise measurements will be accepted if it has a tolerance of ±3 dB so that the prediction results using this formula have an accuracy of more than 90%. This formula is suitable for predicting no-load noise at the design stage without knowing the power transformer’s detailed physical dimensions and electrical quantities.

5. Conclusion

This study shows that no-load noise from a power transformer can be expected using a statistical approach. The main factors affecting no-load noise have been used. This work has presented...
Table 1: Result of predicted no-load compared to the measurement result

| No | Predicted (dB) | Measurement (dB) | Error       |
|----|----------------|------------------|-------------|
| 1  | 65.68951       | 66.7             | 1.010487    |
| 2  | 65.68951       | 66.8             | 1.110487    |
| 3  | 65.68951       | 66.9             | 1.210487    |
| 4  | 64.68616       | 64.5             | -0.18616    |
| 5  | 75.65048       | 75.2             | -0.45048    |
| 6  | 70.59858       | 70.8             | 0.201419    |
| 7  | 81.82443       | 82               | 0.175572    |
| 8  | 71.02192       | 72.2             | 1.178083    |
| 9  | 74.0511        | 70.4             | -3.6511     |
| 10 | 76.28313       | 76.9             | 0.616875    |
| 11 | 76.07337       | 76.9             | 0.826628    |
| 12 | 79.2264        | 79.1             | -0.1264     |
| 13 | 59.26402       | 58.6             | -0.66402    |
| 14 | 72.64415       | 71.5             | -1.1415     |
| 15 | 76.41755       | 77.5             | 1.082448    |
| 16 | 77.11424       | 77.9             | 0.785757    |
| 17 | 72.14105       | 70.8             | -1.34105    |
| 18 | 67.72593       | 67.2             | -0.52593    |
| 19 | 88.2           | 88.2             | 0           |
| 20 | 73.82857       | 75.07            | 1.241429    |
| 21 | 71.50405       | 72.4             | 0.895945    |
| 22 | 72.62373       | 72.4             | -0.22373    |
| 23 | 63.27134       | 62.4             | -0.87134    |
| 24 | 63.62782       | 64.3             | 0.672184    |
| 25 | 69.17583       | 68.5             | -0.67583    |
| 26 | 72.64761       | 71.5             | -1.14761    |

Figure 3: The plot of actual and predicted no-load noise
a novel way to predict power transformer no-load noise. The method’s advantage is that with simple data, a better predictive value of no-load noise will be obtained at the design stage without more detailed design data. The prediction results show better accuracy within acceptable limits.

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