Noise Level Assessment of Transformer Foundation Based on Nameplate Parameters

Zhengyang Wu1,*, Li Ma1, Dalong Jing1 and Qinghua Wang2

1Anhui Xiangshuijian Pumped Storage Co. LTD, Anhui Wuhu, China
2School of North China Electric Power University, Beijing, China
*Corresponding author: wangqher@ncepu.edu.cn

Abstract. The density and load of transformer are relatively high, and the noise signal is quite different between normal operation and fault state. With the increase of the service life of the transformer, the noise intensity of the transformer also changes. In order to quickly predict the operation status of transformer, it is necessary to evaluate the noise level of transformer foundation. In this paper, a dynamic evaluation method of transformer basic noise level based on nameplate parameters is proposed. The reliability and accuracy of the formula are verified by experimental measurement and calculation. It is of great significance to monitor the operation state of transformer, diagnose the fault quickly and improve the operation reliability of transformer.

1. Introduction

As one of the important power equipment, power transformer has a large number, long operation time and many specifications. The noise generated in the process of continuous operation of transformer is the most serious problem at present under the environment of increasing awareness of environmental protection, it has a great impact on people's daily life and production. At the same time, the operation noise signal of transformer also transmits the operation status information of transformer [1-3]. How to accurately identify the typical fault symptoms of transformer according to the sound pressure of transformer operation is of great significance to ensure the safe operation of transformer.

For the estimation of transformer noise level, reference [4] describes that BBN company has measured the transformer noise in operation in the substation of eseeeo company; In reference [5], Lorentz force is calculated by using three-dimensional equivalent magnetic circuit network. Considering the relationship between Lorentz force and sound pressure. The noise prediction formula proposed by Reiplinger for the first time predicts the change of load noise with the rated power of transformer [6] $L_{ma}=39+18\log_{10}(S_N/MVA)$, but only the rated power is considered and there is a large error. In reference [7], the relationship between noise, magnetic flux density and core clamping force of dry-type transformer is studied. It is found that the sound pressure level of old dry-type transformer is approximately linear with the square of magnetic flux density. However, the prediction formula of transformer noise is not obtained.

This paper studies the transformer name plate parameters and the transformer basic noise, establishes the relationship between the transformer name plate parameters and the noise, and considers the time factor, adds the dynamic estimation to the transformer basic noise estimation. Through the measurement
of the basic noise intensity of the same transformer with different operation years, the validity of the transformer dynamic noise formula based on the nameplate parameters is verified.

2. Influence factors of transformer foundation noise
The noise of transformer in operation is mainly composed of no-load and load. The no-load noise can be measured by open circuit test in factory acceptance test (FAT), which will magnetize the core, but will produce core or no-load noise.

In addition to the main core and winding, the clamping structure, winding machinery and materials, and transformer operation time are also included. The proposed parameters are benchmark tested to investigate. The design parameters weight the sound generated by transformer operation, and the noise formula based on transformer nameplate information and operation time is obtained. The design parameters are as follows:

2.1. Rated power of transformer
The rated power of the transformer is \( S_N \): \( S_N = I \times Z \). Where: \( S_N \) is the rated power, in MVA; \( Z \) is the transformer impedance.

2.2. Short circuit impedance
The load noise is affected by the same level of short circuit impedance \( u_k \) (%) and rated power. In the transformer, the reactance value is much larger than the resistance value. The magnetic energy in the transformer winding is the total magnetic volume between the high voltage winding and the low voltage winding and the main gap as shown in Figure 1. The leakage resistance expression [8]:

\[
X = 2\pi f \frac{\mu_0 \pi N^2}{H_{eq}} \sum_{i=1}^{n} ATD
\]

Among them:

\[
\sum_{i=1}^{n} ATD = \left[ \frac{1}{3} (T_{LV} + T_{HV}) + T_g \right] D_m
\]

In the above formula, \( D_m \) is winding diameter, \( N \) is winding turns, \( \mu_0 \) is permeability, \( H_{eq} \) is equivalent magnetic height, \( T_{LV} \) and \( T_{HV} \) are thickness of low voltage winding and high voltage winding respectively, \( T_g \) is air gap thickness.

![Figure 1. Equivalent leakage magnetic field and magnetic flux vector diagram.](image-url)
The short circuit reactive power $S_Nu_k$ of transformer can be expressed by formula (3):

$$S_Nu_k = S_N \frac{I_N X}{U_N} \times 100 = I_N U_N \frac{2 \pi f \mu_0 I_N N^2}{H_n U_N} \sum_{k=1}^{N} ATD$$  \hspace{1cm} (3)

2.3. Winding factors and operation time of transformer

The parameters of winding material have the information of equivalent mechanical properties of winding conductor. This includes the influence of different types of insulators on the mechanical properties of conductor materials. All transformers are mechanical structures, and the operation of transformers is accompanied by vibration, which leads to the aging and wear of transformer parts, and has a direct impact on the operation noise of transformers. Therefore, transformer noise is a dynamic process that changes with time.

3. Noise modeling of transformer foundation

According to the standards [9], [10], the load sound power level is calculated as:

$$L_{na} = 39 + 18 \log_{10} \left( \frac{S_N}{MVA} \right)$$  \hspace{1cm} (4)

This formula was first proposed by Reiplinger [4]. It predicts the variation of load noise with the rated power of transformer, but does not consider the design of winding, clamping and electromagnetic force in winding.

Comparing the sound level calculated by the formula with the measured values of various rated power, it can be found that the deviation is 5-10 dB. Therefore, different manufacturers recommend adding 10 dB to the estimated noise intensity. This shows that in addition to the rated power, other factors are also important factors to produce load noise, which need to be studied.

The sound formula of transformer can be expressed as:

$$E_0 = L_{db1} + L_f + L_0 + TF$$  \hspace{1cm} (5)

$L_{db}$ is the sound pressure level; $L_f$ is the conversion coefficient of frequency weighted frequency filter, generally, 50 Hz is 0 dB; $L_0$ is sound pressure caused by other factors, such as temperature, phase number of transformer, etc. $TF$ is the shell coefficient of the transformer:

$$TF = b \log_{10} S_b + c$$  \hspace{1cm} (6)

To sum up, the noise formula is deduced as follows:

$$E_0 = a \log_{10} (S_r \cdot u_k) + b \log_{10} S_b + c$$  \hspace{1cm} (7)

Among them : $S_b$ is the operating power of the transformer; $a$ and $b$ are weighting factors ; $c$ is the compensation factor.

Physically, the weighting factor $a$ must be less than or equal to 20. Therefore, the range of weighting factor is 17-19. For the current transformer range, it is found that the value of $a= 17.5$ can achieve the best trend and match with the mean value of the measurement point. At the same time, it is found that the weighting factor $b= 2.7$ and the offset factor $c= 15$ cover all possible ranges of the noise measurement contour path around the transformer shell.

$$E_0 = 17.5 \log_{10} (S_r \cdot u_k) + 2.7 \log_{10} S_b + 15$$  \hspace{1cm} (8)
Due to the different operation time of the transformer, the mechanical structure of the transformer will change slightly, and the noise level will also change. In order to reduce the judgment error of transformer operation state, a method considering transformer operation time noise is proposed:

\[ E(t) = E_0 \cdot e^{-\frac{t}{T}} \]  

Where: \( E_0 \) is the estimated noise level when the transformer leaves the factory; \( t \) is the service time of the transformer, in years; \( T \) is the decay time constant.

4. Experimental study
1. Estimation of initial noise of dry type transformer based on its nameplate parameters. The selected transformer model is ABB SF9-120000-220. According to its rated state, the initial noise of the transformer is calculated according to formula (8): \( E_0=40.46 \)

2. According to the test data, the attenuation time constant \( T \) considering the operation time of transformer is calculated.

In this example, the same transformer with different operation time is used for acoustic signal acquisition. The operation time of transformer is as shown in Table 1, two of them are used as attenuation coefficient calculation, and one is used as method verification. Finally, the average decibels of the three transformers are obtained as shown in Table 1:

| Transformer | 1     | 2     | 3      |
|-------------|-------|-------|--------|
| Noise(dB)   | 45.04 | 48.181| 51.026 |

Using operation sound pressure of transformers 1 and 2, the attenuation time constant of the transformer is calculated as (one decimal place is reserved): \( T = -18.5 \)

3. Noise estimation \( E_0 \) considering transformer operation time

Taking it into the noise estimation formula, the basic noise estimation result of transformer 3 is calculated as follows: \( E_0=50.23dB \). Using the Reiplinger noise formula, the noise level of the transformer is calculated to be 58.4 \( dB \), the error of the difference obtained by using the Reiplinger noise formula to predict the equation is 7.4 \( dB \), and the error obtained by using the improved equation is 0.77 \( dB \), which shows that it is reduced by 6.63 \( dB \). The improved equation is more accurate to predict the load noise.

5. Conclusion
Through research and analysis, the rated power, short-circuit impedance, winding factor, transformer shell and transformer operation time should be considered in the noise prediction of transformer, which should be applied to formulate the load noise formula of transformer. It is verified that, compared with the current standard rippling formula, the proposed basic noise level assessment method for dry-type transformer based on the nameplate parameters can calculate the load noise sound pressure and power level with high accuracy in one formula. It has guiding significance for the operation and maintenance of dry-type transformer.

Acknowledgments
This work was supported by the project of development and application of acoustic monitoring and diagnosis device for power transformer in Xiangshuijian hydropower station under Grants 52572920000a.
References

[1] Wang Fenghua, Wang Shaojing, Chen Song, Yuan Guogang, Zhang Jun. Transformer voiceprint recognition model based on improved MFCC and VQ[J]. Proceedings of the Chinese Society of Electrical Engineering, 2017, 37(05): 1535-1543.

[2] Hou Dong, Duan Lian, Cao Chuncheng, Bing Long, Ma Chaoqun, Chen He. Noise and vibration test of 35 kV oil-immersed distribution transformer[J/OL]. Applied Acoustics, 1-6[2021-03-10].

[3] Hu Jingzhu, Wang Yanzhao, Wang Jin, et al. Measurement and analysis of vibration characteristic of a 10 kV transformer tank[J]. Noise and Vibration Control, 2019, 39(6): 239-245.

[4] Ver, I. L, Andersen, et al. Field Study of Sound Radiation by Power Transformers[J]. Power Apparatus & Systems IEEE Transactions on, 1981.

[5] Kim D K, Ryu J Y, Kim D M, et al. Load Noise Prediction of High-Voltage Transformers by Equation Applying 3-D EMCN[J]. IEEE Access, 2020, 8(99): 130669-130677.

[6] E. Reiplinger, Study of Noise Emitted by Power Transformers based on Todays Viewpoint, CIGRE Session 1988.Power Apparatus Systems, 1981, 100(7): 3513-3524.

[7] Peng Wei, Tian Haoyang, Huang Hua, Li Minxian, Qu Junhua. Experiment on the relationship between noise and operation and process parameters of dry-type transformers[J]. Electrical Applications, 2015, 34(S2): 812-815.

[8] Fan Chao, Nie Jingkai, Xiao Weimin, Wang Guangzhou, Ji Shengchang, Yang Fuyao, Liu Yang, Du Pengyu. Research on the Vibration Characteristics of Power Transformer Core Tank and Its Correlation with Near Field Noise[J]. China Electric Power, 2020, 53(10): 34-41.

[9] IEC 60076-10, Power Transformers Part 101: Determination of Sound Levels, 2001.

[10] IEEE Standard C57.12.90-2010, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers, The Institute of Electrical and Electronics Engineers, Inc. New York, 2010.