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Effect of No-load and Load Condition on Transformer Sound

Dr. Hitesh Paghadar
Associate Professor, Electrical Engineering Department, OM Engineering College, Junagadh, Gujarat, India

ABSTRACT

Increasing environment noise pollution is a matter of great concern and of late has been attracting public attention. Sound produces the minute oscillatory changes in air pressure and is audible to the human ear when in the frequency range of 20Hz to 20 kHz. The chief sources of audible sound are the magnetic circuit of transformer which produces sound due to magnetostriction phenomenon, vibration of windings, tank and other structural parts, and the noise produced by cooling equipments. This paper presents the validation for sound level measurement scale, why A-weighted scale is accepted for sound level measurement, experimental study carried out on 10MVA Power Transformer. Also presents the outcomes of comparison between No-Load sound & Load sound level measurement, experimental study carried out on different transformer like - 10MVA, 50MVA, 100MVA Power Transformer, to define the dominant factor of transformer sound generation.
Keywords : Transformer Sound, Load sound, No-load Sound, Measurement Scale

I. INTRODUCTION

The term 'Sound' is the detection at the human ear, which is nothing but the interruption in the air in which an elementary portion of the air transfers momentum to an adjacent elementary portion, so giving that elementary portion motion. When a vibrating solid object comes in to the contact with the air, it will be in motion and finally a 'wave' flow start in to the air. Any movement of a solid object produces the sound and the intensity and frequency sound can be detected by human ear [1].

Sound pressure level measurements have been developed to quantify pressure variations in air that a human ear can detect. The perceived loudness of a signal is dependent upon the sensitivity of the human ear to its frequency spectrum. Modern measuring instruments process sound signals through electronic networks, the sensitivity of which varies with frequency in a manner similar to the human ear. In many countries, there are local ordinances that specify maximum permissible sound levels at industrial, commercial, residential areas and silence zone. As per Government of India rule declared by "Ministry of Environment and Forest Notification in February-2000", acceptable sound levels are shown in Table 1 [2].

TABLE I
AMBIENT AIR QUALITY STANDARD IN RESPECT TO SOUND

Category of Area/Zone	Limits in dB(A)	
	Day Time	Night Time
Industrial Area	75	70
Commercial Area	65	55
Residential Area	55	45
Silence Zone	50	40

II. BASIC THEORY OF SOUND

Some parts of electro-magnetic machinery give the sound energy through vibration and radiation. Rate of energy radiation, called the sound power level (energy per unit time) and rate of energy flow through a unit area, called the sound intensity. The direction of flow must be integrated for the illustration of this flow rate. Finally sound intensity is a vector quantity and sound pressure is the scalar quantity, which have only magnitude [1].

A. Sound Pressure Level

For description of the sound, measurement of sound pressure is generally used. A healthy human ear can detect has an amplitude of 20 millionths of a pascal (20 μPa). A change in pressure of 20 μPa is too slight that it causes the eardrum to deflect a distance less than the diameter of a single hydrogen molecule. Amazingly, the ear can tolerate sound pressures more than a million times higher. Thus, if we measured sound in Pa, we would end up with some quite large, unmanageable numbers. To avoid this, another scale is used — the decibel or dB scale.

The dB is not a complete unit sound measurement because it is a ratio between a measured sound and reference level of sound. The dB scale is logarithmic and uses the hearing threshold of 20 μPa as the reference level, which takes as 0 dB. A sound pressure level can be defined as:

$$Lp = 10 \times \log(P/Po)^2$$

Po = 20 microPa (Reference sound pressure)
P = sound pressure at the measuring points

The perception of loudness depends not only on the sound pressure but also on the frequency of sound waves [4].

B. Sound Intensity Level

Rate of energy flow at unit area, called sound intensity. The unit of sound intensity is watts/ m2. Sound intensity measures of direction, as there will be energy flow in some directions but not in others, that why it is vector quantity. It has direction as well as magnitude also. Further, sound pressure measures magnitude only, that's why it is a scalar quantity. Generally we are measuring the intensity of sound energy flow in a normal direction (at 900) to a defined unit area [3].

Sound intensity gives the result of time-averaged rate of energy flow per unit area. Energy may be traveling back and forth during measurement at some points. In the measurement direction, if there is not enough energy flow then it will be not recorded enough intensity. Sound pressure level and sound intensity level (LI) can be measured with the unit of dB scale, where the measured intensity I in W/m2 is expressed as a ratio to a reference intensity level I0 as follows:

$$Li = 10 \times \log(I/Io)$$

$Io = 10^{-12}\ W/m^2$ (Reference sound Intensity)
I = sound pressure at the measuring points

C. Sound Power Level

Radiation of any sound source is in terms of energy, and outcome of that is in terms of sound pressure. Radiated energy of sound is the cause and outcome of that like, sound pressure is the effect. Rate of energy radiation at per unit time, called sound power. The sound pressure can be measured by microphone as well as human hearing but its quantity is depends on the distance between the sound source and microphone measurement point or human hearing point at sound field in which sound waves are present. This in turn depends on the room area and the sound absorbing capacity wall surfaces. Measurement of sound pressure level can not give the exactly quantity that how much sound is generated from the machine or sound source. That's why measurement of sound power is required because it does not depend on the environment and it is also unique descriptor of the sound of a sound source [3]. A sound power level can be defined as:

$$Lp = 10\log(P/Po)$$

$Po = 10^{-12}$ watt (Ref. sound power)
P = sound power (watt)

Sound power level is ten times the logarithm to the ratio of a given sound power to the reference sound power [3].

Sound power level could be calculated by sound pressure level or sound intensity level.

$L_{WA} = L_{PA} + 10 \log (S)$

$L_{WA} = L_{IA} + 10 \log (S)$

L_{WA}=A-weighted Sound Power level

L_{PA}=A-weighted Sound Pressure level

L_{IA}=A-weighted Sound Intensity level

S=area of radiating surface (m2)

III.SOURCES OF TRANSFORMER SOUND

There are three sources of sound generation in power transformers: (1) No-Load sound, caused by magnetostriction in transformer core. (2) Load sound, caused by winding vibrations due to electromagnetic forces and vibrations in structural parts due to leakage flux associated with the load current. (3) Sound generated by the operation of the external cooling fans and pumps [7].

A. No-load Sound

The vibration and sound of transformer core is due to magnetostriction and the magneto-mechanical effects of attraction (cross fluxes). Magnetostriction is a term used for the small mechanical deformations of core laminations in response to the application of a alternating magnetic field. The magnitude of the magnetostriction increases with the flux density, until the material becomes saturated. A transformer core is magnetically excited by an alternating voltage, causing extension and contraction of laminations twice during a full cycle of magnetization. As the change in dimension is independent of direction of flux, it occurs at double the supply frequency, i.e. the fundamental frequency of magnetostriction is 100Hz.

B. Load Sound

Load sound is mainly generated by the interaction of the load current in the windings and the leakage flux produced by this current. The main frequency of this sound is twice the supply frequency, i.e. 100 Hz for 50 Hz and 120Hz for 60 Hz transformers. If the load current contains significant harmonics, e.g. in rectifier transformers, the forces will contain higher frequency harmonics. These additional harmonics are a significant source of sound that must be considered when the transformer is ordered. Load sound level depends on the load current and is caused by transformer winding and vibration in structural parts due to leakage flux produced, by this current i.e. tank walls and magnetic shunts.

C. Cooling Equipments

The other major source of transformer sound is the transformer cooling equipment like, cooling fans and oil pumps. Cooling fans produce sound in the range of 500-2000 Hz, a frequency band to which the human ear is more sensitive than the 100 Hz fundamental frequency produced by the magnetostriction effect in core [5].

IV.MEASUREMENT SCALE OF SOUND LEVEL

There are three types of scales for sound level measurement: (1) A-weighting scale (2) B-weighting scale (3) C-weighting scale. The typical frequency response waveforms for the above weighting scales are represented in Fig.1 [5].

A-Weighted Scale:

A-weighted scale is generally accepted for measurement of transformer sound because the purpose is to measure the sound level frequency within the band, which can be sensed by the human ear. Sound measurements made with the A-weighting scale are designated as dB (A).

B-Weighted Scale:

It is used to predict the performance of loudspeakers and stereos, but not industrial sound.

C-Weighted Scale:

The C-weighting scale includes the sound at low frequency range than the A and B scales.

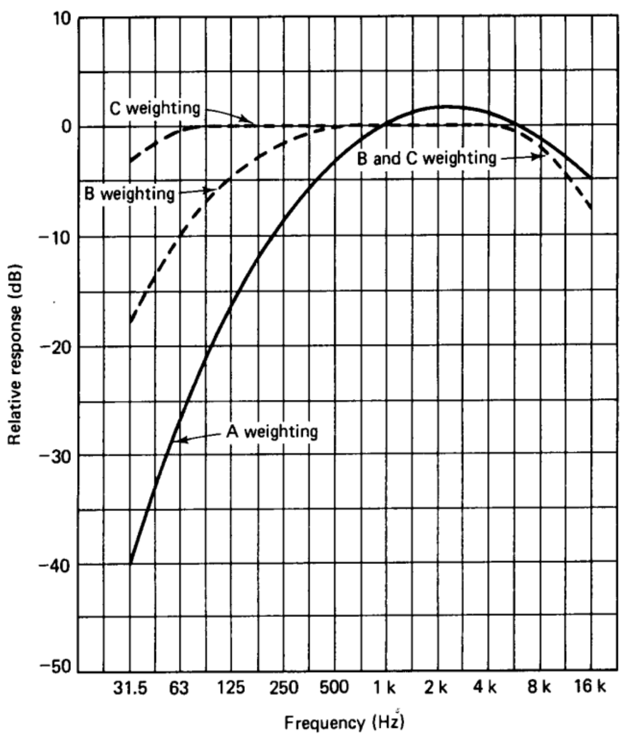

Figure 1: Frequency response for the A, B & C weighting networks

V. EXPERIMENTAL STUDIES

A. Sound Level Measurement with Different Scale

In order to understand the difference and verify the explanation given earlier as to why sound level measurements are specified according to A-weighted scale, a measurements of sound level with A and C-weighted scales were carried out on a 10 MVA, 110/33/11kV, 3-Phase, 50 Hz Power transformer.

TABLE III.

SOUND LEVEL MEASUREMENT WITH DIFFERENT SCALE

Test	Measured Sound level
Background	60.8 dB(A)
No-Load Condition	63.4 dB(A)
No-Load Condition	72.4 dB(C)
Load Condition	61.8 dB(A)

From the above experimentation, it is inferred that, (a) sound level is high on Cweighted scale as compared to that on A-weighted scale, because C-weighted scale includes sound at lower frequency, which can not be sensed by the human ear. (b) Aweighted scale is generally accepted for measurement of transformer sound because the purpose is to measure the sound level frequency within the band, which can be sensed by the human ear. (c) The sound level under load when excited at impedance voltage during works testing is significantly lower than no-load sound level.

B. Comparison Between No-load and Load Sound Level

Measurement of Load and No-load sound level was carried out on different transformer to find out the influence of load & No-load sound level on the overall transformer sound level.

Figure 2: No-load and load test of transformer at industry

TABLE IIIII

MEASURED NO-LOAD AND LOAD SOUND LEVEL

MVA Rating	Measured Load Sound Level dB(A)	Measured No-Load Sound Level dB(A)
50MVA, 132/33 kV	63.48	74.16

100MVA, 230/110/11 kV	64.21	75.66
10MVA, 110/33/11 kV	61.8	63.4

It is observed from the Table III that, Load sound level is lower than No-load sound level and No-load sound level (Core sound) gives the major effect on overall transformer sound.

VI.CONCLUSION

From the foregoing, it could be concluded that, A-weighted scale (dB(A)) is the acceptable scale for the measurement of transformer sound level, which can detect by the human ear. No-load sound is the dominant factor for the transformer sound generation, due to the magnetostriction effect in the transformer core. No-load sound is always more than load sound.

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