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A Study of Transformer Noise and Reduction Techniques of Transformer Noise

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Abstract—*Today, the world is showing increasing concern over environmental matters, and the minimization of noise in the vicinity of residential areas is one aspect that is growing in importance. Transformers should be dead silent; under no circumstances they should produce any noise. However, reality is totally different. This paper presents causes of noise generation in transformers and its reduction technique is discussed.*

The ministry of environment has specified noise level for different areas i.e. industrial, commercial and residential. In this paper three causes of noise generation in transformer i.e. core sound, load sound and sound by cooling fans & pumps are discussed and then technique to reduce these noise and those things which needs to take care in the installation are discussed.

1. INTRODUCTION.

Power transformers belong to the category of capital electric power equipment for each power system. There are several types of power transformers that determines their application: single phase and three phase power transformers, transformers with and without regulation, start up transformers and distribution transformers, transformers for voltage levels of 110 kV, 220 kV, 400 kV and higher voltage levels of above 1000 kV, transformers with power of 8 MVA, 12 MVA up to 725 MVA and 1000 MVA. Startup power transformers are mounted on hydro and thermal power plants and are directly associated with the generating aggregate, while distribution power transformers are installed in high voltage transformer substations like those of 400 kV/110 kV or 110 kV/35 kV.

Today, in addition to functional requirements, very high standards related to protection of human environment are being posed to power transformer’s constructors. Power transformers should be dead silent; under no circumstances they should produce any noise. However, reality is totally different! Transformers may suddenly become noisy. They begin to hum or buzz not because they are happy, but because they suddenly operate in a magnetic region where a transformer behaves as an acoustic transducer. This unpleasant feature is known worldwide, and has led to the need for the development of a new range of "low noise" transformers.

The primary source of acoustic noise generation in a transformer is the periodic mechanical deformation of the transformer core and the winding coils, under the influence of fluctuating electromagnetic flux associated with these parts [1]. The physical phenomena associated with this tonal noise generation can be classified as follows:

1. The material of a transformer core exhibits magnetostrictive properties. The vibration of the core is due to its magnetostrictive strain varying at twice the frequency of the alternating magnetic flux. The frequencies of the magnetic flux are equal to the power system supply frequency and its harmonics.
2. When there are residual gaps between laminations of the core, the periodic magneto-motive force may cause the core laminations to strike against each other and produce noise. Also, the periodic mutual forces between the current-carrying coil windings can induce vibrations if there are any loose turns of the coil.
3. Some of the other sources of noise in a transformer, such as the cooling fans and the pumps, are considered to be negligible contributors to the far-field noise [2].

2. SOURCES OF POWER TRANSFORMER'S NOISE

Power transformers as fundamental systems for transformation of electricity from one voltage level to another, in the phase of transmission or electricity generation, have several sources of noise. Out of which, the three basic sources of sound generation in power transformer are as shown in Fig. 1.

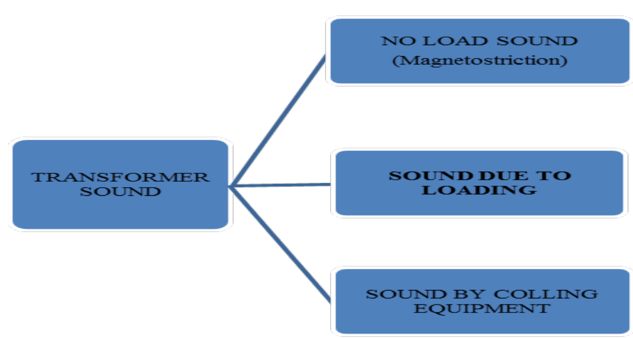

Fig. 1: Transformer Sound

2.1 No load noise (Magnetostriction)

Transformer noise is caused by a phenomenon which causes a piece of magnetic sheet steel to extend itself when magnetized. When the magnetization is taken away, it goes back to its original condition. This phenomenon is scientifically referred to as 'Magnetostriction'. A transformer when magnetically excited by an alternating voltage and current extends and contracts twice during a full cycle of magnetization. The changes are in terms of few μm/m for typical transformer's sheet. The value of magnetostriction depends on magnetic induction shown in Fig. 2, type of transformer's sheet and mechanical strains that arise due to the effect of electromagnetic forces.

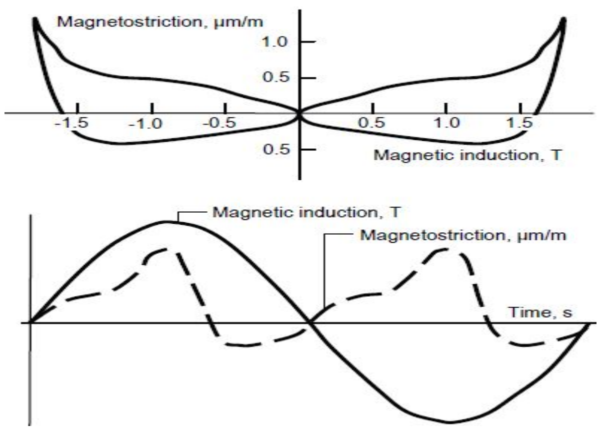

Fig. 2: Correlation of magnetic induction and magnetostriction

Inside a transformer, the core, which is made in the form of laminated sheets, also undergoes expansion and contraction due to the changing magnetic flux. This expansion and contraction occurs twice in an AC Cycle. Hence, the fundamental frequency of the noise or vibration is double that of the frequency of the power supply. Thus, a supply with a frequency of 50 Hz will cause noise or vibration whose fundamental frequency is 100 Hz. Besides the first harmonic, there are significant amounts of higher order harmonics which results as multiplication of pitch frequencies with even numbers of frequencies of distribution network (200, 300, 400 [Hz]). Noise level of magnetic core is calculated using the following empirical expression:

$$L_{wa}(core) = k1 \log \mathrm{GFe} + k2.B + k3$$

Where,

GFe is the mass of magnetic core,

B is induction inside the core,

k1, k2 are empirical coefficients,

k3 is Empirical coefficient that takes into account the type of transformer's sheet, type and construction of the core, frequency, design of transformer's tank.

2.2 Load noise

Load noise is caused by vibrations in tank walls, magnetic shields, and transformer windings due to the electromagnetic forces resulting from leakage fields produced by load currents. These electromagnetic forces are proportional to the square of the load currents. These forces inside winding conductors, produce axial and radial winding vibrations with pitch frequency twice the frequency of electrical distribution network (i.e. 100Hz for network of 50Hz. Winding noise level for certain load can be calculated using empirical expression:

$$L_{wa}(winding) = k1 + \mathrm{k2} \log \mathrm{Sr} + +40 \log \alpha$$

Where,

Sr is nominal power of transformer,

k1 and k2 are empirical coefficients,

α represents relative load (load Current / nominal current).

The load current noise level is strongly dependent on the transformer load. Reducing the current by 50 percent provides a reduction of the load current noise by 12 dB.

2.3 Noise by cooling equipment

The frequency character of fan noise is different from the sound from the core and windings. Standard sizes of fan used are 18 & 24 inch with speed of 900-950rpm and their sound level is in the range of 64-65dB. It does not have discrete tones but covers a broad frequency band with a peak at the "blade passage" frequency, which is the frequency at which the fan impeller blades pass some rigid disturbance in the air flow – and sometimes at twice that frequency.

Pumps also produce noise of a broad band nature and contribute to the total noise of the transformer.

Transformer's noise level resulting from the fan noise can be calculated according to the formula:

$L_{WA}(\mathrm{fan}) = L_{WA,0} + 10 \lg n$

$$L_{wa}(fan) = L_{wa,0} + +10 \log n$$

Where, $L_{wa,0}$ – is the noise level of one fan (determined under real operating conditions - the fan on the cooler) while and n - is the number of fans.

2.4 Noise by reflection

These voices become more when installation is near to any sounds reflecting or at any narrow place. Transformer noise contains discrete tones that are affected by room acoustics, room geometry, and reflecting objects. IEC Standards, Ref. [3] provides the following calculation formula to account the effect of these sound reflections.

$$K = 10log10\left(1 + \frac{4}{A/_S}\right), A = \alpha Sv$$

K= Environmental factor

α= Average Acoustic Absorption coefficient

S_V= Total Area of the Surface of the Test Room

S = Transformer Measurement Surface Area

The maximum value allowed for this environmental factor correction is 7 dB, otherwise measurements would be considered invalid.

The total transformer's noise level is calculated by adding the noise from all sources with the assumption that all noise sources are independent.

3. PERMITTED NOISE LEVEL

Transformer's noise is very important operational characteristic of power transformers, which is measured in any final test with methods prescribed by the standards IEC 60076-10 (2001)[4] and IEEE Std C57.12.90 (2006)[5], and at the same time the recommended values of the permitted noise levels by NEMA National Electrical Manufacturers Association Standards TR1 1998 must be met. NEMA Standard TR1 defines noise levels for applicable transformers used by the power industry. This standard includes tables of sound levels as test points, but significant study of the standards will be necessary to apply these values due to the impact of measurement distances. Table I is being provided as "typical" of the kinds of limits defined in this standard at a measuring distance of 2 meter.

Table I: Audible sound level for liquid immersed distribution transformer

Equivalent two winding kVA	Average sound level in dB
0-50	48
51-100	51
101-300	55
301-500	56
750	57
1000	58
1500	60
2000	61
2500	62

Depending on the requirement of the transformer recommended permitted noise level is also change. With increase in size the permitted noise level is also increased table II showing the permitted noise level of 100MVA & 300MVA power tranformer with oil directed water forced ODWFcooling.

Table 1: Permissible noise level for 100 MVA transformers with ODWF cooling

Test voltage in kV	Permissible Noise dB	
	100MVA	300MVA
350	78	83
450	80	85
750	81	86
900	82	87
1175	83	88
1300	84	89

4. NOISE REDUCTION TECHNIQUE

4.1 Reduction in noise through design

Reduction in noise is possible by adopting some designing techniques they are given below.

4.1.1 Magnetic core design

No-load sound level of core mainly depends on Magnetostriction and magnetic forces. For every 0.1 tesla reduction in induction by magnetostriction, the noise of transformer's core reduces by 3 - 4dB. But the flux density is inversely proportional to the core weight. Therefore, if we reduce the flux density in order to reduce the sound, the core weight increases which in turn increases the cost. And also increasing or decreasing flux does not increase or decrease the magnetostriction by the same amount. Therefore, we can say that this relation is non-linear.

Now-a-days, standard solution of using step-lap mode of angular overlap of transformer's pillars and yokes while stacking the magnetic core is being implemented to minimize magnetization, idle current losses and also the noise level. Step-lap and classical method for stacking transformer's sheets and magnetic flux distribution at area of joints due to presence of air gaps is shown in the Fig. 3 below.

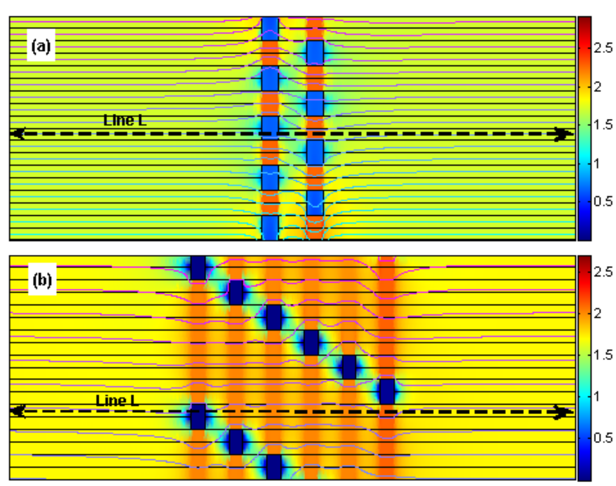

Fig. 3: Flux distribution at joint of two laminations a) Single Step Lap, b) Multi-Step Lap

Step-lap has several steps which reduces the noise of the magnetic core by up to 6 dB. And with lower flux value, even greater noise reduction can be achieved**.** Fig. 4 shows the magnetic force in area around the overlap of transformer by step lap method.

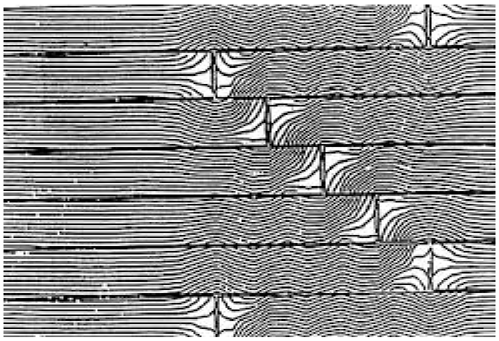

Fig. 4: Magnetic force by step lap method.

If the magnetic flux passes through the magnetic core then the vibrations in transformer's sheet occur which creates noise. For this, tightening of yokes with some non-ferromagnetic material screw has been done. One part of transformer's sheet on the upper surface remains untighten because of the yoke's circular cross section. For that untighten end, epoxy or wood glue is used to reduce the vibration [6]. Finally, fixing the transformer's sheets in yoke while tightening of pillars is done by polymer tapes. Half-polymerized poliglas tape is used for tightening the magnetic core, because, later while heating the magnetic core it gets fully polymerized and shortened, which leads to very strong tightening of transformer's sheets in pillars of magnetic core. Heating at 140 ^{0}C for 120 minutes polarizes the half-polymerized tape.

After this, the active part of the power transformer is placed in the transformer's tank and is further secured with anti-vibration elements that are placed between the magnetic core and the transformer's tank, which will reduce the noise up to 2dB.

4.1.2 Winding design

Electrodynamic forces in the windings are with very high intensity, and they create vibrations of conductors in windings. Even at short-circuit voltage, they can completely deform windings of the transformer. Fortunately with the development of modern methods of CAD, design analysis of Electrodynamics forces and other parameter of windings are being carried out. Modal analysis provides the definition of modal parameters of windings as a mechanical structure, information about the resonant frequencies, suppression and modal shapes [7]. Resonant frequency is the frequency at which the dynamic excitation creates a critical reaction of windings structure. So, it is very important to design power transformer by taking care of this resonant frequency. When core or tank resonance frequencies coincide with the exciting frequency, the noise level further increases. In some extreme cases like at short-circuit voltage, it may lead to breakage of conductor and total damage of the windings may occur. Fig. 5 shows the complete deformation of transformer winding. An appropriate mechanical design for these laminated magnetic shields can be helpful in avoiding resonance in the tank walls.

Fig. 5: Deformation of winding due to short circuit.

Reducing the noise in transformer's windings is the subject of many scientific research projects, which are being carried out in the development laboratories of large companies through researches based on sophisticated numerical methods of modelling like in the manufacturers of power transformers (Siemens, ABB, ABS Serbia).

Still there are a lot of phenomenological events that are not fully explored in the field of noise generation in the power transformer's windings, so they are still the subject of ongoing researches [8].

4.1.3 Noise by cooling equipment

The frequency character of fan noise is different from the sound from the core and windings. The fan noise is a function of speed and circumferential velocity. If the size of fans is reduced, number of fans increases. Therefore, it is better to increase number radiators. Therefore, ONAN cooling is preferred than ONAF cooling. Fig. shows the noise spectrum

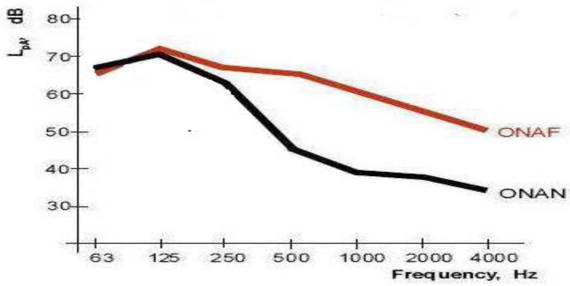

Fig. 6: Noise Spectrum.

In addition to this, reducing fan's noise can be achieved through balancing the rotating masses, quality bearing and stable structure for binding the fan with housing of the radiator for cooling.

4.1.4 Reduction in noise through installation

During installation of any transformer unit we should take care of the following points

1. If possible put the transformer unit in a room or indoor in which the wall, floor are massive enough to reduce the noise. Noise is also attenuated as it try to pass through the massive structure and that wall can be of bricks, steel concrete, lead, etc.
2. Try to keep unit inside an enclosure in which two thin plates are separated by a viscous rubbery type material. The noise hits the inner sheet and then gets lost in viscous material. The outer sheet will not vibrate and also will not produce any noise.
3. Do not make any reflecting surface near to the unit exactly with the dimension of half of the wavelength of the noise. Speed of noise is air is approx. 1130ft/sec. If the transformer is of 50Hz frequency, then transformer noise frequency is of 100Hz. Wavelength of frequency is 1130ft/100Hz is equal to 11.3ft. So, if a surface is near to unit with dimensions equal to half of this wavelength i.e. 11.3/2=5.65ft, then it will produce standing waves and these waves produce reverberations (echoes) and an increase the sound level.
4. Isolate the unit from the ground using anti vibration pad for installing a unit.

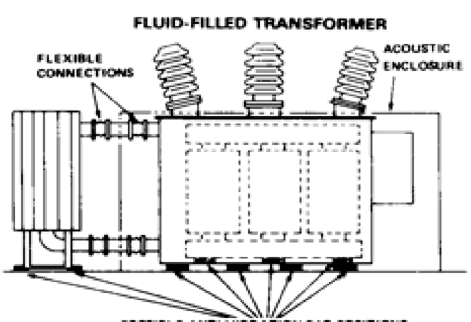

Fig. 7: Typical transformer connection for dry type transformer.

5. CONCLUSION

Transformer cores can make acoustical noise like humming and buzzing. The mechanisms of magnetostriction which produce changes in dimensions of the core when it is magnetized or demagnetized is studied Also, the other factor that causes noise inside the core have been explained. Knowledge of permitted level is also necessary. Permitted noise in liquid immersed distribution transformer is studied. It is impossible to make transformers without noise but reduction is possible by some proper design techniques and taking few steps. Some of these design techniquess and steps are explained.

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