Accurate Estimation and mitigation of Audible Sound using Novel Technique of Flux Density Reduction at Design Stage in Transformer

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Abstract

Transformer is the most vital equipment in transmission and distribution network, encompassing the entire network from generating station to user's premises. Till two decades ago, the sound produced by transformer was not attached any importance in public life. However, of late it is attracting attention as a result of the general public's growing concern about the environmental noise pollution. This is more so because, with the growing power demand, more number of power transformer are being installed in the close proximity of the populated rural, urban and suburban areas. In many countries, the local ordinances specify maximum allowable sound levels. As per Indian rules, there levels are specified area-wise, viz. residential, industrial, commercial, and silence zone. Consequently, transformers with low sound levels are being increasingly specified by the users. For this reason, the sound level of transformer becomes an important consideration in design, manufacturing, installation and operation.

During normal operation, it produces characteristic hum, the magnitude of which increases with increase in its capacity. The origin of the noise is the core vibration because of magnetostriction, which is a mechanical effect in core by the alternating flux. This paper presents the modification & validation of existing sound level calculation methods to estimate the accurate sound level at design stage, data of 26 Transformers was collected, ranging from 30 to 165 MVA rating. Existing method was modified by adding some factors. Also presents the outcomes of analytical study of sound level control technique, reduction of flux density by increasing yoke cross-sectional area of core through optimization using Memetic Algorithm. Optimum result was compared with Mgnetostatic analysis using Ansoft Maxwell 2D software.

Keywords— *Transformer, Sound level Reduction, Magnetostriction*

I. INTRODUCTION

Sound is defined as any pressure variation that the human ear can detect ranging from the weakest sound to the levels that could impair hearing. Frequency range of audible sound is 20 Hz to 20 KHz. As per Government of India rule declared by Ministry of Environment and Forest Notification in February-2000, acceptable sound levels are shown in Table I [1].

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

Growing demand for electrical energy is leading to more transformers being installed in close proximity of populated areas. So low noise transformer is required.

The sources of transformer sound are magnetostriction in core, winding vibration because of electromagnetic forces, tank walls, and magnetic shunts, cooling equipments. Magnetostriction was found to play the major part in noise production and it depends on flux density [2]. Magnetostriction is a term used for the small mechanical deformations of core laminations in response to the application of a magnetic field. The frequency of transformer sound is double of the supply power frequency [3].

Variation of 10 percentage in the flux density relative to the rated value produces on an average a difference of about 3 dB(A) [4].

Winding sound is only a few dB below that of core sound and may exceed it, if the design flux density at rated voltage is less than 1.4 T. [5]. Winding type, winding arrangement, current density, tank shielding/shunts, and tank design parameters have a significant effect on the magnitude of load sound level [6].

Transformer winding vibrates due to the radial and axial electromagnetic forces, which are produced by the current owing in the winding conductors. Generally axial vibration of windings contributes to sound but if winding diameter exceeds 6 m, then radial vibration of winding also generates significant sound.

II. ACCURATE ESTIMATION OF AUDIBLE SOUND AT DESIGN STAGE

The transformer designers use different empirical formulae for estimation of transformer sound level. Ideally, the basic empirical formulae should take into consideration parameters viz. flux density, core construction, core weight, CRGO grade, perimeter of sound measurement contour, cooling scheme etc, that have direct bearing on transformer sound level.

However, multitude of design variants makes it difficult to build-in the effect of all parameters to enable estimation of sound level accurately. Therefore, in order to calibrate the calculated results using the existing methods of sound levels calculation, the power transformer data such like, capacity (MVA), kV class, core diameter, flux density, CRGO lamination grade and thickness, core joint type, core weight and perimeter of measurement contour are collected and the tested results of 26 transformers of different ratings in the range of 30 to 160 MVA were compared with the estimated results (for Graphical representation Refer fig. 1), analysed the gaps and evolved some new constant factors to correct the existing empirical formulae.

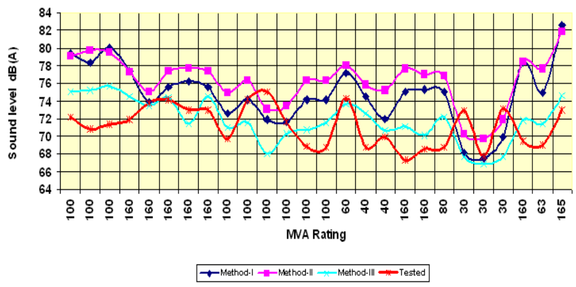

Fig. 1 Comparison Between Existing Method-I, II, III and Tested Results

We observed that, method-III is in good agreement with the tested result than method-I & II. In order to modify the existing method-III, the various transformer design parameters that are likely to have impact on sound level were studied. Based on that, the empirical formulas were modified so as to take into account the impact of core joint (Mitered, Step-lap), CRGO grade (M4, MOH) and perimeter of measurement contour. The sound levels were recalculated using the modified empirical formula and the results were found reasonably closer to the tested results within the tolerance of 1.5 to 2 dB(A) (for Graphical representation Refer fig. 2).

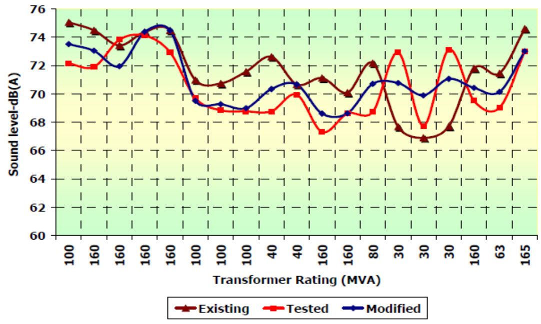

Fig. 2 Comparison Between Existing Method, Modified Method and Tested Results

From the foregoing, it could be concluded that the modified method of calculation of sound level gives fairly accurate results and could be used as a reliable tool to estimate the sound levels for meeting contractual requirements.

III. MITIGATION OF TRANSFORMER SOUND USING NOVEL TECHNIQUE OF FLUX DENSITY REDUCTION AT DESIGN STAGE

Flux density could be reduced by increasing cross sectional area of core with constant volt/turn or reducing volt/turn with constant core area. Thickness of lamination sheet could be increased to reduce the magnetostriction effect. Most of the sound transmitted from a core comes principally from the yoke region because the sound from the limb is effectively damped by the surrounding windings (copper and insulation material) around the limb.

Winding diameter will increase with the increase in core diameter and if winding diameter exceeds 6m, then radial vibration will come in picture [7]. Based on the above, an analytical study is carried out by increasing top and bottom yoke cross-sectional area and results are compared with the software analysis. It is novel technique for controlling sound level at design stage.

A. Analytical Study

For the purpose of carrying out analytical study, a 100 MVA, 220/66 kV, 3-Phase, 50 Hz Power transformer is identified..In order to study influence of change in flux density by changing the top and bottom yoke cross-sectional area on the sound level, novel technique is chosen. Analytical studies are carried out by increasing 8% to 13% of C/S area of top & bottom yoke with the change in lamination sheet thickness and core material grade to reduce the flux density and effect of magnetostriction, refer Table-II.

TABLE III : COMPARISON BETWEEN DIFFERENT METHODS

Sr. No	Design Parameter	Reference Design	Modified					
			8%	9%	10%	11%	12%	13%
1	Core dia. (cm)	80	83.2	83.6	84	84.4	84.8	85.2
2	Flux density (T)	1.6	1.472	1.456	1.44	1.424	1.408	1.392
3	Volt/turn (volt)	165	165	165	165	165	165	165
4	No. of turn in HV wdg.	1340	1340	1340	1340	1340	1340	1340
	No.of turns in LV wdg.	402	402	402	402	402	402	402
5	Material Grade	M4	M6	M6	M6	M6	M6	M6
6	Thickness (mm)	0.27	0.3	0.3	0.3	0.3	0.3	0.3
7	Core weight (kg)	55442.77	60223.9	60836.8	61453.12	62072.8	62696	63322.5
8	Specific loss (W/kg)	1	1	0.94	0.9	0.89	0.86	0.85
9	No-load loss (kW)	55.44	60.223	57.19	55.3	55.24	53.91	53.82
10	Change in sound level dB(A)	-	2.32	2.63	2.95	3.26	3.59	3.92

The change in sound level with respect to flux density was calculated using equation-1.

$$\triangle_p = 10\log((\frac{B2}{B1})^8(\frac{W2}{W1})^{1.6}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

B1, W1= Reference Flux density and core weight
B2, W2= Desired Flux density and core weight

B. Result Optimization of Analytical Studies

Result optimization was carried out using Memetic Algorithm technique (refer fig.3) to find the optimum result, through C language Programming. It gives the 10% reduction of flux density is applicable for sound level reduction up to 3dB(A).

C. Magnetostatic Analysis using Ansoft Maxwell 2D Software

For the purpose of carrying out software analysis, a 100 MVA, 220/66 kV, 3-Phase, 50 Hz Power transformer is identified as a reference design, which is same as for Analytical study. In order to carried out the magnetostatic analysis, Ansoft Maxwell 2D version is chosen. Drawing model with dimension of transformer core and winding is shown fig 4.

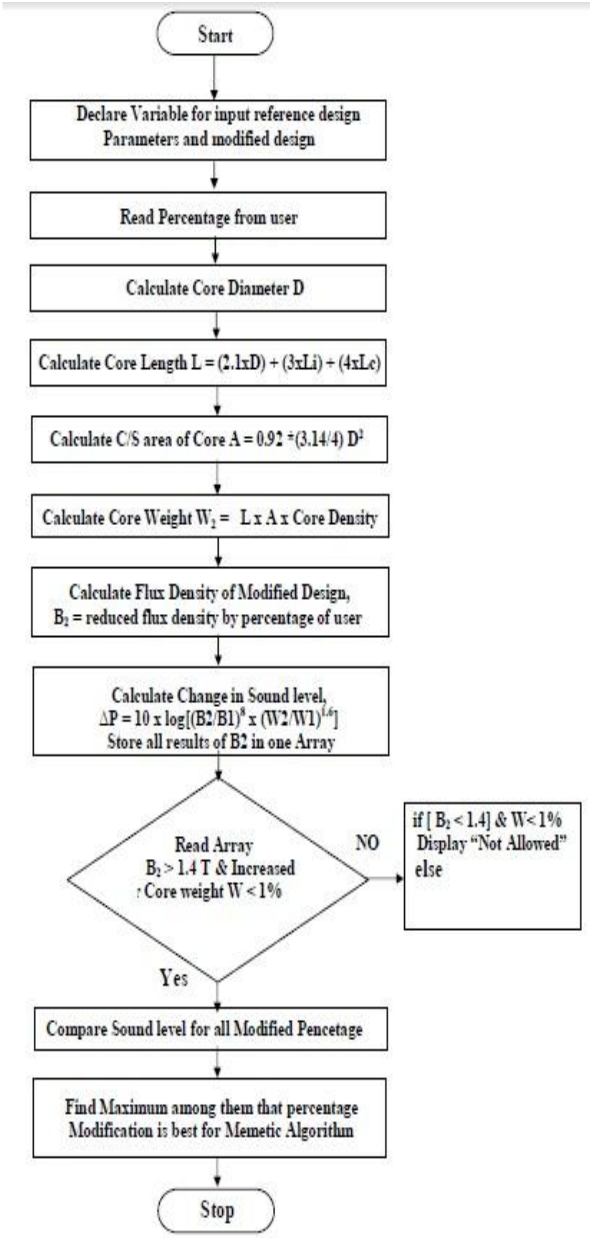

Fig. 3 Flow Chart of Memetic Algorithm

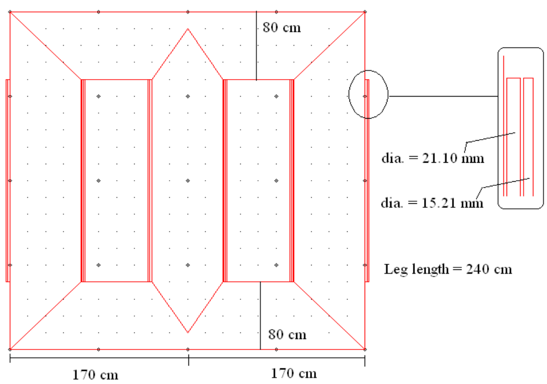

Fig. 4 Reference Design – 2D Drawing Model

Fig.5 shows the Magnetostatic analysis using Ansoft Maxwell 2D software with Reference design of Transformer. It gives 1.55 Tesla average flux density and found reasonably closer to the result of analytical study.

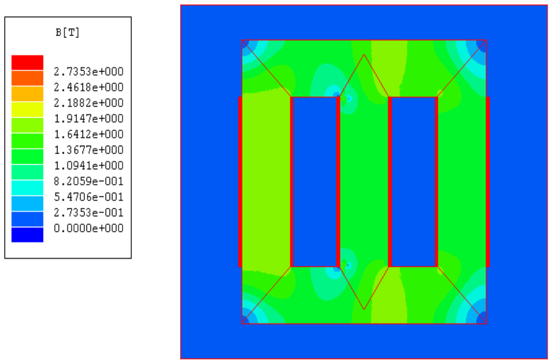

Fig. 5 Reference Design – 2D Magnetostatic Analysis using Ansoft Maxwell Software

Now, in order to reduce the flux density, C/S area of top and bottom yoke is increased, shown in fig. 6 and then again analysed with this modified design of Transformer like increased yoke C/S area, 0.30 mm lamination sheet thickness and M6 core material shown in fig.7. It gives 1.4 Tesla average flux density. Based on above results, Magnetoststic analysis gives 2.82 dB(A) sound level reduction, using equation-1.

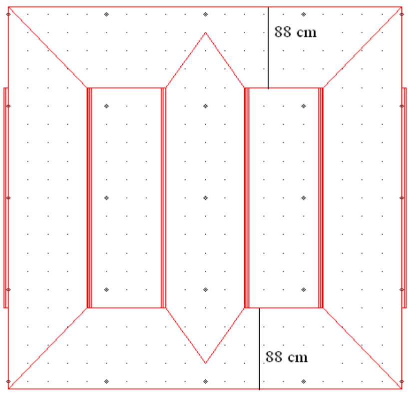

Fig. 6 Modified design – 2D drawing model

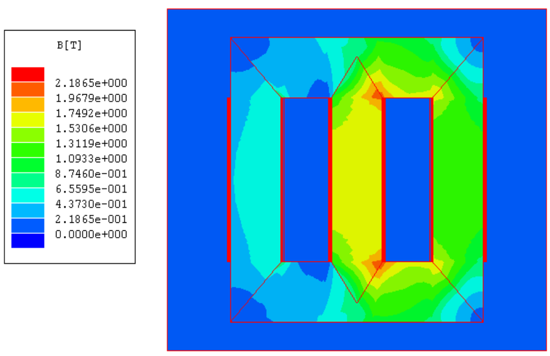

Fig. 7 Modified design – 2D magnetostatic analysis using Ansoft Maxwell software

D. Output

Analytical results are compared with the software results, given below in tabular form.

TABLE III : COMPARISON OF RESULTS

Analysis	Reference Design	Modified Design	Reduction in Sound level
Analytical	B = 1.6 T	B =1.44 T	2.95 dB(A)
Software	B = 1.55 T	B = 1.4 T	2.82 dB(A)

It is observed that, 10% reduction in flux density gives the maximum sound level reduction up to 2 to 3 dB(A).

IV. CONCLUSIONS

By the research work, following notification have been made, Empirical formulae used for the calculation of transformer sound level modified and validated; this can now be used to estimate sound level at design stage within an accuracy of 2dB(A).

Modified method of sound level reduction gives the economical design with 2 to 3 dB(A) low sound level, thick lamination sheet, low cost, 10% low flux density to meet the contractual requirements.

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