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Addressing the Complexities, Limitations and Benefits Involved in Conducting Near-Field Sound Power Measurements of Large Electrical Transformers

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ABSTRACT

The industry-standard method for quantifying the sound emission levels of electrical transformers is outlined in IEEE Standard C57.12.90, which details a procedure requiring sound pressure measurements at specified near-field distances and elevations surrounding a transformer. Despite widespread use of these measurement methods throughout the industry, recent field experience has shown that measurements of sound pressure levels conducted at these specified measurement distances can result in overestimated sound power levels, as determined by far-field sound measurements. Sound intensity measurements of transformers were also employed, using methods from ISO Standard 9614-1, which have also verified that the near-field sound pressure measurements can result in overestimated sound levels. This is thought to be a result of the acoustic reactivity in the near-field of the transformer tank. To improve the accuracy of acoustical measurements of transformers, ISO Standard 9614-2, along with elements from IEC Standards 60076-10 and 60076-10-1 have been employed, and have shown improved results. This paper presents a case study summarizing the complexities and limitations associated with near-field sound measurements of transformers, and outlines the benefits of sound intensity measurement methods and offset sound pressure measurement methods.

Keywords: Transformer, Near-field, Intensity

1. INTRODUCTION

The standard most commonly used in industry to measure sound emissions of transformers is IEEE Standard C57.12.90 [1]. The measurement locations specified in [1] are relatively very close to the transformer tank (0.3 metres in the absence of cooling fans). Presumably this close offset distance was chosen to minimize potential interference from background sound and room reverberation in situations where the transformer would be measured indoors – perhaps in the manufacturer's plant. However, the findings of this study indicate that the measurement positions specified in [1] may be too close, tending to result in overestimates of sound emissions, because of near-field acoustic reactivity. The acoustic near-field is the zone around a sound source where the distance to the radiating surface of the source is less than the wavelength of sound [2]. In this zone, the sound field is complex, and there are "reactive" components of sound pressure which do not propagate to the far field.

In the past five years, the authors have had the opportunity to conduct acoustical measurements of more than 100 large electrical transformers throughout the province of Ontario. In general, sound intensity measurement techniques have been utilized to measure the at-source sound levels of the transformers and any other sound producing equipment within the stations, and sound pressure measurement techniques have been used to measure far-field sound levels for verification purposes.

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The specific measurement data addressed herein resulted from circumstances in which the IEEE near-field sound pressure method [1] was used by others to measure the *in-situ* sound emissions of two large 750 MVA transformers. The results of these measurements seemed at odds with a series of far-field measurements. In order to investigate this discrepancy, the authors had the opportunity to re-measure the sound emissions of the transformers using both sound pressure and sound intensity methods from ISO Standard 9614-1 [3] simultaneously at the near-field locations specified by [1], and far-field locations suggested by IEC Standard 60076-10-1 [4].

A comparison of the various measurement results indicates that sound pressure measurements in the near-field tend to overestimate the sound power emission levels of the transformer by as much as 10 to 12 dB, whereas the near-field intensity measurements and far-field pressure and intensity measurements do not. Therefore, sound pressure measurements conducted according to [1] should be treated as suspect, and used with caution. It is preferable either to use sound intensity methods for near-field measurements, or to select measurement locations further from the transformer, as per [4], if sound pressure methods are to be used.

2. STANDARD MEASUREMENT PROCEDURES

2.1 Overview of IEEE Standard C57.12.90

IEEE Standard C57.12.90 titled *IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers* [1] is the most common procedure manufacturers use to quantify sound power levels of electrical transformers, for the purpose of publishing a sound level as a technical specification. Generally, the standard outlines methods for testing and quantifying several properties associated with electrical transformers, including the A-weighted, one-third octave, and discrete frequency sound pressure levels of transformers located within laboratories, factories, or outdoor electric substations. Specifically, for measurements made in the absence of forced air cooling auxiliaries, the prescribed contour is 0.3 metre away from the principal radiating surface (tank or enclosure), and when the forced air cooling system is in operation, the prescribed contour is 2 metres from any portion of the radiators, coolers, or cooling tubes cooled by the forced air. For transformers with a tank height of 2.4 metres or greater, two prescribed contours are used which are on horizontal planes at one-third and two-thirds of the tank height. Horizontal spacing of the measurements is 1 metre, with a minimum of 4 horizontal positions. These levels are used to determine the overall sound power level of the transformer by calculating an energy average sound pressure level of all the measured sound pressure levels, and applying a factor for the radiating surface area.

2.2 Overview of ISO Standards 9614-1 & 9614-2

Both ISO Standard 9614-1 titled *Acoustics -- Determination of sound power levels of noise sources using sound intensity -- Part 1: Measurement at discrete points* [3] and ISO Standard 9614-2 titled *Acoustics -- Determination of sound power levels of noise sources using sound intensity -- Part 2: Measurement by scanning* [5] specify methods for measuring the component of sound intensity normal to a measurement surface which is chosen so as to enclose the noise source(s) of which the sound power level is to be determined. Part 1 outlines methods for positioning an intensity probe at discrete points at specific, representative intervals, so to wholly envelope the sound source, while Part 2 instructs to subdivide the measurement surface into contiguous segments, and to scan an intensity probe over each segment along a continuous path.

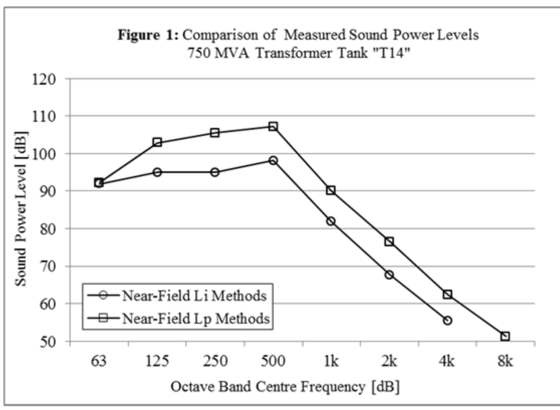
2.3 Overview of IEC Standards 60076-10 & 60076-10-1

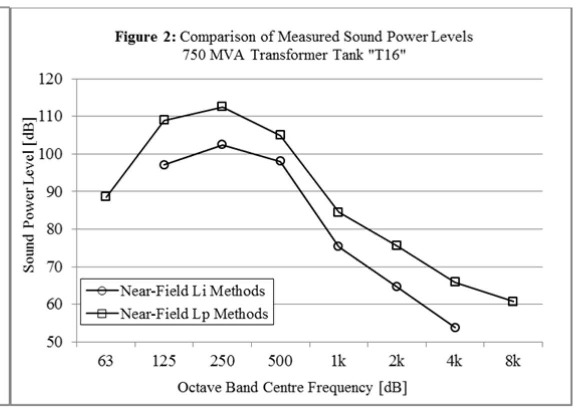
IEC Standard 60076-10 titled *Power transformers – Part 10: Determination of sound levels* [6] and IEC Standard 60076-10-1 titled *Power transformers – Part 10: Determination of sound levels – Application guide* [4] provide methods for quantifying the sound levels of a transformer similar to [1]. These standards include testing parameters such as the suitable environmental conditions (ambient sound levels, temperature), transformer position within the measurement environment, and transformer operating conditions (electrical load, voltage, etc.). The two procedures also prescribe similar physical microphone positions for measuring the reference sound-producing surfaces of a transformer, which generally follows the contour of a taut string stretched around the periphery of the transformer or integral enclosure.

However, [4], which functions as an addendum to [6], details a more robust measurement technique, and incorporates recommendations to incorporate sound intensity measurement techniques. This standard also provides further insight into the causes of acoustical near-field effects, and indicates that non-propagating sound energy within the reactive field close to a large sound source, such as a transformer tank, can result in significant variations in the near-field sound pressure levels, but not the far-field sound pressure, due to the sound pressure and particle velocity being out of phase. This is accounted for inherently by the intensity method of measuring sound.

3. IN-SITU MEASUREMENTS OF TRANSFORMER SOUND

The apparent discrepancy between near-field and far-field sound levels related to two 750 MVA transformers – designated as T14 and T16 – at a site in Ontario. In order to investigate this apparent discrepancy, the authors measured the sound power of the two transformers in four different ways by using sound intensity and sound pressure methods simultaneously, and at two different distances away from the transformer tank – near-field, according to [1] and far-field according to [4]. The measurements were conducted using a Hewlett Packard model 3569A Real Time Frequency Analyzer, equipped with an HP model 35230A sound intensity probe, following two prescribed horizontal contours at one-third and two-thirds of the tank height, with 30 measurement positions horizontally spaced at one metre along each contour. The results are summarized in Figures 1 and 2, below. Note that, in all figures below, sound power levels measured using sound intensity instrumentation and sound pressure instrumentation have been labeled as "Li" and "Lp", respectively.

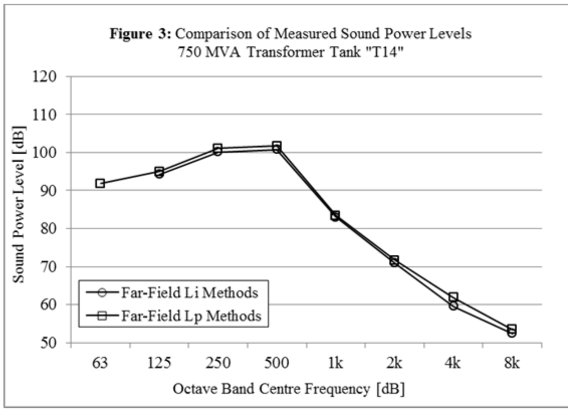


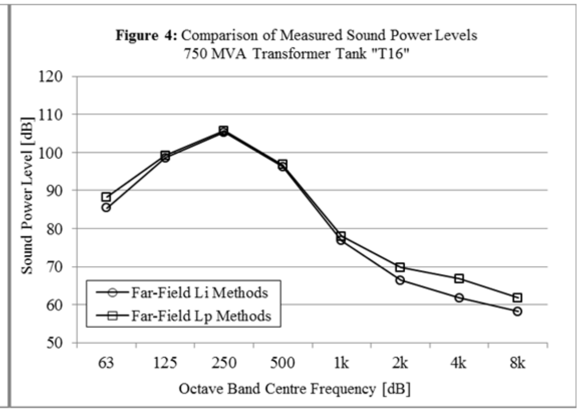


Figures 1 & 2 - Comparison of T14 & T16 transformer sound power levels measured using near-field sound intensity methods utilizing [1] and [3], and near-field sound pressure methods utilizing [1]

As depicted in Figures 1 & 2, above, it is evident that the sound power levels derived from the near-field sound pressure measurements are significantly greater than those derived from the near-field sound intensity measurements, with a difference of up to 12 dB in the 125 Hz octave band. While this was expected to some degree given the potential for influence due to the near-field effects on sound pressure levels, the magnitude of the discrepancy was surprising.

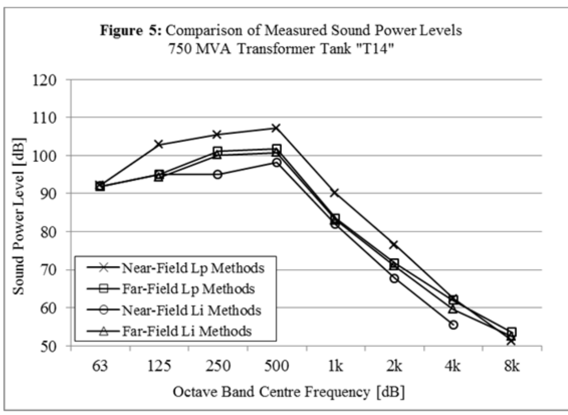
The far-field measurements were offset from the transformer tanks by approximately 2 to 3 metres (approximately half the length of the transformers' shortest side). The T14 and T16 sound power levels, derived from these measurements are depicted in Figures 3 and 4, below. The agreement between the sound power levels derived from intensity versus pressure agree much better in the far-field (Figures 3 & 4) than in the near-field (Figures 1 & 2).

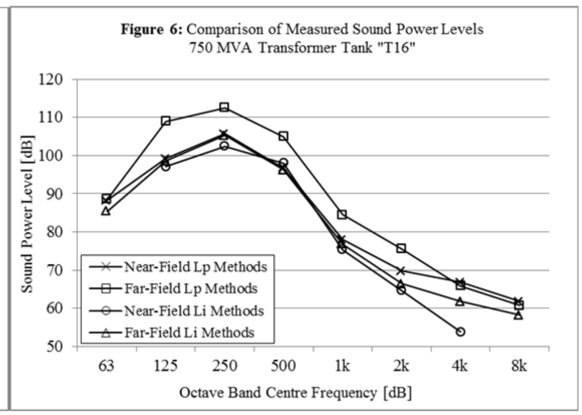




Figures 3 & 4 - Comparison of T14 & T16 transformer sound power levels measured using far-field sound intensity methods utilizing [5], and far-field sound pressure methods utilizing [4]

Figures 5 & 6, below, present an overall comparison of all sound power measurements conducted, and clearly illustrate the potential to overestimate sound power levels when using near-field sound pressure measurement techniques for in-situ transformers.





Figures 5 & 6 - Comparison of T14 & T16 transformer sound power levels measured using near-field & far field sound pressure and sound intensity methods

4. CONCLUSIONS

This study has contrasted methods for measuring the sound levels of electrical transformers, based on several published standards. Each of the methods were utilized in the field to measure the sound of energized, *in-situ* transformers for the purpose of quantifying environmental sound emissions of the electrical substations in which the transformers were located. The measurement results considered indicate that the sound pressure measurement methods outlined in [1] can result in octave band sound levels that are significantly inflated, presumably due to the field reactivity in the immediate near-field of a transformer tank and the inability of a sound level meter measuring sound pressure to compensate for this.

Generally, sound intensity measurement procedures have proven to be the most accurate for measuring the sound of *in-situ* transformers, as they require the least amount of correction due to environmental conditions and inherently account for the acoustical near-field effects on sound within a reactive field. The data outlined also indicates that when the measurement position recommendations outlined in [4] are applied to the measurement methods defined in [1], the influence of field reactivity is minimized and more accurate sound level data can be collected. While we acknowledge that under certain measurement conditions, factors such as background sound and reflections may factor into the accuracy of offsetting the sound pressure measurement locations described in [1], it has been found that the acoustical influence of the reactive field around a transformer tank can be dramatically influential on near-field, sound pressure levels, and in situations where sound intensity data is not available to verify the accuracy of the pressure levels, overestimated sound levels can go unnoticed. Therefore, an improvement over the methods in [1] would be either to use sound intensity methods, if near-field measurements are necessary, or to increase the measurement distance from the transformer, according to [4] if sound intensity methods are not available and if space and site conditions permit.

ACKNOWLEDGEMENTS

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