

IEEE Guide for Sound Level Abatement and Determination for Liquid-Immersed Power Transformers and Shunt Reactors Rated Over 500 kVA

Sponsor

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Abstract: Guidelines are provided for the selection of suitable sound reduction methods in oil-immersed power transformers and shunt reactors over 500 kVA. Sound-producing sources within transformers and reactors are discussed. Sound abatement procedures are described for achieving various levels of sound reduction in transformer and shunt reactor installations.

Keywords: liquid-immersed power transformers and shunt reactors, sound, sound abatement, sound reduction methods

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Introduction

(This introduction is not part of IEEE Std C57.136-2000, IEEE Guide for Sound Level Abatement and Determination for Liquid-Immersed Power Transformers and Shunt Reactors Rated Over 500 kVA.)

This introduction provides some background information to aid in the understanding and usage of this guide.

The proximity of residential areas to some substations and the increasing prevalence of local ordinances specifying property line sound levels have made sound radiation from transformers a factor of increasing significance. Thus, it is of considerable importance that information be available regarding the choice and design of effective methods of sound abatement, which provide a reasonable margin of safety and minimize the probability of community complaints.

In some cases, even recently installed transformers may require the use of sound reduction methods due to residential complaints or changes in the residential zoning codes.

The principal sources of sound radiated by transformers are

- a) The core,
- b) The windings (and tank), and
- c) The cooling equipment.

The core sound, primarily consisting of a double power frequency tone and its harmonics, is generally dominant in overall level. However, on some transformers with forced air cooling, the cooling equipment sound can dominate.

Once the sound levels have been determined at locations of concern, there are various sound level measurements and data manipulation techniques for calculating the desired sound levels to accurately define the problem areas.

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IEEE Guide for Sound Level Abatement and Determination for Liquid-Immersed Power Transformers and Shunt Reactors Rated Over 500 kVA

1. Scope

This document is intended to provide guidelines for selecting suitable methods for sound reduction in liquid-immersed power transformers and shunt reactors rated over 500 kVA.

Many sound abatement procedures are described that are presently available for achieving various levels of sound reductions in transformer and shunt reactor installations. For background information, this guide will also discuss the sound-producing sources within transformers and reactors.

2. References

This guide should be used in conjunction with the following publications:

IEEE Std C57.12.00-2000, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.¹

IEEE Std C57.12.90-1999, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.21-1990 (Reaffirmed 1995), IEEE Standard Requirements, Terminology, and Test Code for Shunt Reactors Rated Over 500 kVA.

NEMA TR1-1993, NEMA Standard Publication on Transformers, Regulators, and Reactors.²

¹IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

²NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

3. Sources of sound

3.1 General characteristics

Sound coming from the transformer itself, as opposed to cooling fan or pump sound, is tonal in nature, consisting of even harmonics of the power frequency. The predominant source of transformer sound is the core. The low-frequency, tonal nature of this sound makes it harder to mitigate than the broad-band, higher frequency sound that is produced by cooling fans, pumps, and other sources. Not only do low frequencies propagate farther with less attenuation, but also tonal sound is more annoying to the public even in a high sound level ambient. This combination of low attenuation and high perception makes tonal sound the dominant problem in the neighboring community around the transformer. To address this problem, most community sound ordinances impose penalties or stricter requirements for tonal sound. A site may be in compliance with overall sound levels, but out of compliance with tonal levels.

In siting a transformer it is, therefore, critical to consider the dominant tones in the sound spectra, and not just the overall sound levels. These tones will not only dictate the severity of the problem, but also the type of sound mitigation approach that is necessary. For example, if low-frequency tones such as the second and fourth harmonics of the power frequency are present, these are difficult to attenuate with simple sound abatement methods such as a single side wall. In this case an active control system or a full enclosure may be necessary. If very high frequency tones, such as the tenth or twelfth harmonics of the power frequency, are present in the near field, there is a chance that they will attenuate naturally, and no treatment may be necessary if the nearest neighbor is far enough away.

Tones are best measured on a narrow-band spectrum (1-2 Hz bandwidth). Although strong tones are noticeable on one-third or octave band spectra, at higher frequencies two or more tones will always be added together in the same band, making their relative contributions indistinguishable.

3.2 Transformers

The principal sound sources in transformers are:

- a) Core sound caused by magnetostriction effects and inter-laminar magnetic forces,
- b) Load sound caused by electromagnetic forces in the windings, tank walls, and magnetic shunts due to leakage flux associated with the current, and
- c) Cooling equipment sound caused by fans (aerodynamic and motor/bearing sound) and pumps (cavitation and motor/bearing sound).

The frequency spectrum for the core and winding sound is markedly different from that of the cooling equipment. The latter dominates at the lower and higher ends of the frequency spectrum (depending on whether pumps or fans are involved), while the core and winding sound dominates the intermediate frequency range (between 100 Hz and 600 Hz).

3.2.1 Transformer core sound

When a strip of iron is magnetized, it undergoes a very small change in its dimensions (usually only a few parts in a million). This phenomenon is called magnetostriction. This change in dimension is independent of the direction of the flux; therefore it occurs at twice the power frequency. Because the magnetostriction curve is nonlinear, higher-order even harmonics also appear in the resulting vibration of the core at higher induction flux densities.

In addition to magnetostriction effects, magnetic forces within the core will create vibration and thus sound. These forces occur where the flux transfers from the plane of one lamination to the plane of an adjacent

lamination, or at other air gaps. Laminations that are not flat or that have non-uniform thickness or permeability will cause this effect, as will interleaved joints and bolt holes. These holes distort the flux locally, modifying the flux density and flux direction.

Factors influencing the magnitude and frequency components of the transformer core sound include: flux density, core material, core geometry, and wave form of excitation voltage. As in any other mechanical structure, the transformer mounting structure as well as the mechanical resonances of the core and tank walls can have a significant influence on the magnitude of the transformer vibrations and consequently on the sound generated.

3.2.2 Transformer load sound

Load sound is the sound emitted by a loaded transformer in addition to its no-load sound. It is caused by electromagnetic forces resulting from the leakage fields. These forces are proportional to the square of the load current and thus the load sound is proportional to the fourth power of the current (a doubling of the current increases the load sound level by 12 dB). The sources of this sound are the vibrations of tank walls, magnetic shields, and the windings themselves.

The load sound is predominantly produced by the axial and radial vibration of transformer windings. The frequency of this sound is usually twice the power frequency. The compressive electromagnetic forces produce axial vibrations and thus can be a major source of sound. In some cases, the natural mechanical frequency of winding systems may tend to resonate with electromagnetic forces, thereby severely intensifying the load sound.

If an appropriate mechanical design is used for laminated magnetic flux shields and their anchoring to the tank walls (avoiding resonance at the exciting frequency or its harmonics), the sound due to vibrations of these shields is usually of low intensity as compared to the winding sound. However, it is important to take into account the effects of loading beyond nameplate rating in order to avoid saturation of the magnetic shields during operation, which would cause additional sound.

Through several decades the contribution of the load sound to the total transformer sound has remained moderate. Nonetheless, in transformers designed with low induction levels and improved core designs for complying with low sound level specifications, the load sound can become a significant contributor to the overall sound level of the transformer. However, in the majority of these cases, the overall sound level will be determined by the cooling equipment sound level, which generally exceeds the load sound level (except in the case of natural cooling).

The transformer testing standards IEEE Std C57.12.90-1999 and IEEE Std C57.12.91-1999 specify that the sound level measurements on a transformer should be made under no load conditions. As users demand transformers with lower and lower sound levels, there will be a point at which the load sound will become comparable to the core sound. Therefore, when buying a very low sound level transformer, the users may choose to negotiate load sound test procedures with the manufacturers prior to placing their order.

3.3 Shunt reactors

Shunt reactors are usually a significant sound source. The sound is primarily caused by the magnetic “pull” effects of the leakage flux field. The magnetostriction effects of the core steel are not generally significant.

Leakage flux impinges on structural components of the reactor and produces forces acting on them. These forces create vibration and hence sound. The frequency of this sound is normally twice the power frequency.

For “air-core” iron-shielded reactors, forces act upon the parts of the shield that cover the ends of the reactor coil. These forces will act mainly to bend the laminations on edge and can be quite high. The resulting