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# The Sound of Silence:

## 'Silent Transformers' to Help Consolidated Edison Meet New York City's Ultrastrict Noise Ordinances

Silence is a source of great strength. Although these words were coined by the ancient Chinese philosopher Lao Tzu, they apply to modern transformers. These devices ensure our power supply, and it is important not to ignore the negative sides of their operation. Noise is a major issue.

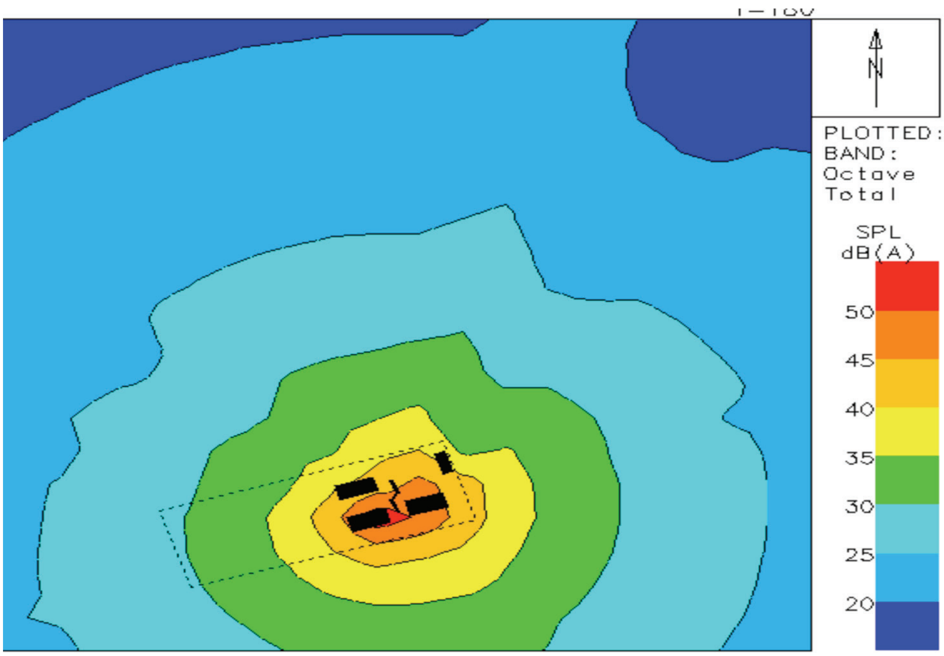
Transformers exhibit vibrations while operating, which generate a characteristic hum classified as noise. This noise is characterized mainly by four pure tones, the frequencies of which are in the range of human speech. The noise causes irritation and discomfort, so it is important to ensure residential areas are unaffected by noise of nearby transformer installations.

Probably the strictest noise ordinance in the world is in New York City. To fulfill the restrictions, it is necessary to understand the total process of sound generation, transmission and radiation. Such knowledge has enabled ABB to design and build quiet transformers for customers throughout the world. Most recently, ABB delivered ultralow-noise power transformers, referred to in this article as “silent transformers,” to the Consolidated Edison (ConEd) utility in the Manhattan borough of New York City.

## SOUND LEVEL UNITS

Sound-level limits typically are determined by the perception of the human ear to sound. For example, doubling the magnitude of the sound pressure is felt by the human ear as a small increase in sound level. The human ear is also 10 times more sensitive to a sound of 1,000-Hz frequency than it is to a sound of 100-Hz frequency. Sound, therefore, is measured in decibels (dB), and a decibel is 10 × Log10 (sound pressure). Sound levels typically are presented and specified in A-weighted decibels; dB(A), where the sound levels are attenuated according to their frequencies per an “A-filter,” which depicts the frequency response of the human ear.

NOISE LEVELS AROUND A SUBSTATION WITH TWO 40-MVA TRANSFORMERS 1



Industry standards, such as IEEE and IEC, specify how transformer noise is measured. Some customers, however, require reporting of the transformer’s total collective noise level in dB(A), while others require reporting of sound level of the transformer’s individual frequency components noise. Most customers require measurement of only the core and fan noise, but some require measuring the total noise level of the transformer, including noise generated from the load on the transformer, referred to as load noise.

## TRANSFORMER NOISE, CHARACTERISTICS

Three sources of sound and noise exist in power transformers: core noise, load noise and cooling system noise.

Core noise is caused by the magnetostriction property of core steel. Magnetostriction is a term for the small, mechanical deformations of core laminations in response to the application of a magnetic field. The change in dimension is independent of the direction of the flux, and hence it occurs at twice the supply frequency. Because the magnetostriction property is nonlinear, however, higher frequency harmonics of an even order are introduced at higher flux densities. Therefore, core noise has components at multiples of 100 or 120 Hz (for 50-Hz and 60-Hz transformers, respectively). The relative magnitudes of the noise at these different frequency components depend on core material, core type and operating flux density.

Load noise mainly is generated by windings vibrations caused by the electromagnetic forces as a result of the interaction of load current and leakage flux produced by this current. Another source of load noise is tank vibrations caused by the magnetic-pull forces exerted by the leakage flux. The main frequency of this sound, therefore, is twice the supply frequency. The level of load noise is determined by load current, winding design and the type of tank shielding used.

Cooling system noise is generated by the operation of the cooling equipment, fans and pumps.

This noise has a broad frequency spectrum with a peak at the blade passage frequency, the frequency at which the fan impeller blades pass some rigid disturbance in the air flow, and sometimes twice that frequency. Pumps also produce noise of a broad band nature and contribute to the total noise of the transformer.

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## DESIGNING LOW-NOISE TRANSFORMERS

Today's low-noise power transformers produce noise levels significantly lower than those built 20 or 30 years ago. Important contributors to achieving these low levels of transformer noise are: designing for low core noise, low load noise and low cooling system noise.

**Designing for low core noise.** In addition to using higher grades of magnetic orientation core steels with low magnetostriction and reducing the flux density in the core, core noise can be reduced by other measures, including:

1.) **Designing transformer cores to provide a more uniform distribution of magnetic flux** with a lower content of flux harmonics globally in the core and locally in the core joints. Detailed 2-D and 3-D magnetic field modeling optimize core designs to minimize core noise.

2.) **Calculating vibrations.** The core is held together by a clamping structure that provides uniform pressure on the core laminations while local deformations are avoided. ABB uses tools developed in-house to calculate the vibrations of the core considering modes of vibrations, as well as the complex forces exciting a three-phase transformer core.

3.) **Avoiding excitation of core mechanical resonances.** This necessitates accurately predetermining values of the different core resonance frequencies.

4.) **Decoupling of core vibrations from the tank.** New techniques reduce the transmissibility of the core vibrations to the tank and hence the resulting sound radiation. To get good results, it is necessary to consider carefully the dynamic properties of the core and tank. The vibration isolation elements must be designed properly.

5.) **Avoiding noise increase caused by its high radiation efficiency or tank mechanical resonance.** Acoustic simulations, verified by scale models and full-size experiments, provide the tools necessary to avoid tank resonances and reduce

TYPICAL FREQUENCY SPECTRUM OF
NOISE PRODUCED BY A POWER TRANSFORMER

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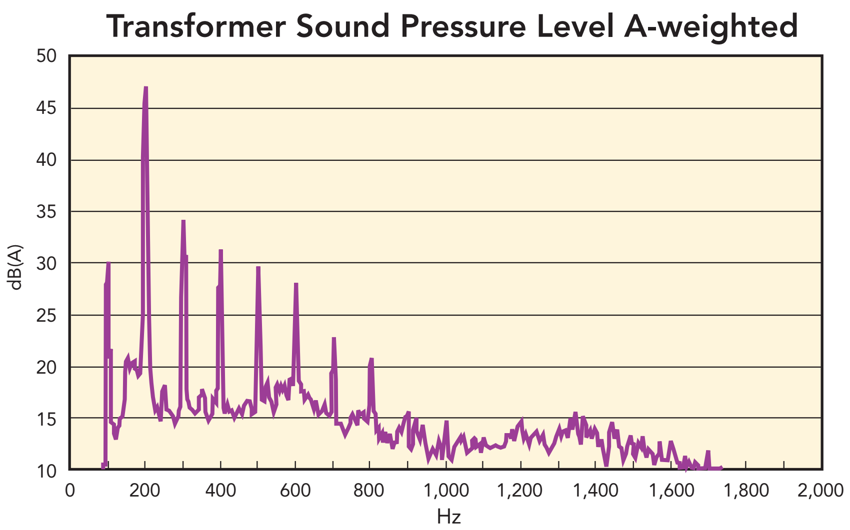
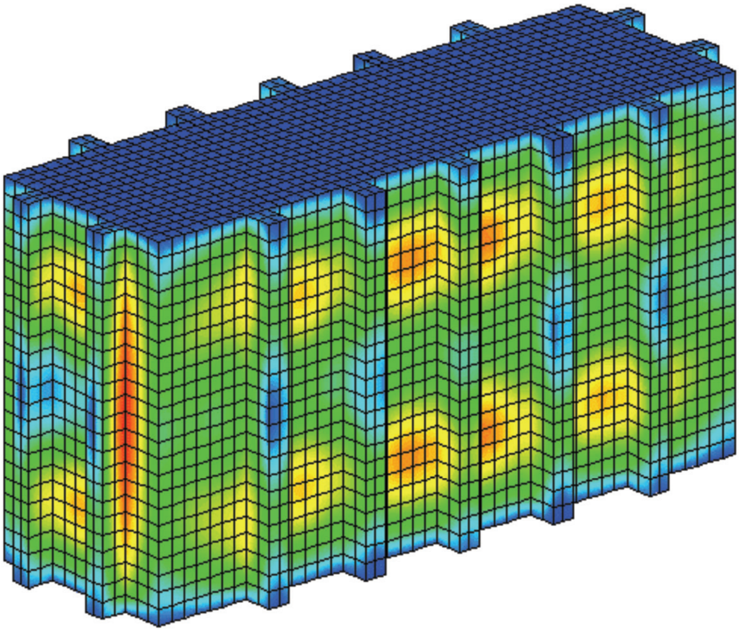


sound radiation.

6.) **Using sound panels** or sound enclosures covering parts of the tank or the entire tank.

**Designing for low load noise.** Winding type, winding arrangement, current density, tank shielding/shunts and tank design parameters significantly affect the magnitude of load noise. Extensive development has resulted in the following measures for load noise reduction:

**3-D MODELING OF VIBRATIONS OF THE TANK OF A THREE-PHASE TRANSFORMER** 3



- Using winding designs, which generally results in lower magnitudes of leakage flux.
- Avoiding winding mechanical resonance.
- Improving tank shielding against leakage flux.
- Damping treatment of the tank.
- Improving tank design having lower sound radiation properties.
- Creating sound enclosures covering the entire tank.

**Designing for low cooling system noise.** Noise from cooling fans can be reduced by selecting low-speed fans or fans with sound-absorbing elements at the inlet and outlet. Other means include fan designs with improved noise performance. In cases where strict noise requirements apply, fan noise is eliminated by designing the transformer with radiators instead of fans. When cooling pumps are required, pumps with low-noise emission are adopted.

## CONED TRANSFORMERS DESIGN, PERFORMANCE REQUIREMENTS

To satisfy the New York City Noise Ordinance, ConEd's electric equipment department revised its noise specifications for new power transformers, requiring ultralow-noise transformers with the following requirements:

- 15- to 20-dB lower noise level than typical for these sizes of transformers.
- Guaranteeing noise levels at 100 percent voltage combined with full load.
- Guaranteeing noise levels at maximum overexcitation combined with 40 percent load.
- Noise level limits are to be met for each frequency component.

The maximum allowable limits of the frequency spectrum of the total noise of the transformer (sum of no-load and load noise) for the most important frequency components of the transformer noise are shown in the fact box.

These levels correspond to a total noise level of about 59 dB(A) at 116 percent voltage and 100 percent current. The corresponding value for the total dB(A) at 100 percent voltage and 100 percent current is in the 54 dB(A) range. In comparison, typical low-noise transformers of this size would have noise levels in the 60- to 65-dB(A) range for no-load noise alone (core noise + cooling system noise). This demonstrates the magnitude of challenge the ConEd noise requirements represent.

The ConEd requirements impose other design restrictions:

- Tight limits on weight, width and height to permit transportation in Manhattan.
- Tight limits on transformer impedance variation across the range of the tap-changer.
- Significant overload requirements (up to 200 percent).
- Limits on temperatures of hotspots in the windings at different loads.

The designs requested by ConEd were for their standardized 65-megavolt ampere (MVA) and 93-MVA network transformers.

## CONED TRANSFORMER SOLUTIONS

Designing a transformer for such ultralow-noise levels while satisfying all the other limitations is possible only if the transformer manufacturer is capable of the following:

- Accurate calculation of the noise level of the core vs. its flux density.
- Accurate calculation of load noise.
- Accurate calculation of resonance frequencies for the core, windings, tank plates and tank stiffeners.
- Accurate calculation of frequency spectrum of core noise vs. flux density.
- Effective means of reducing core and load noise for the different frequencies.
- Proper transformer mounting techniques.
- Accurate indoor measuring techniques of such low noise levels in the factory.

The more accurate all above calculations can be performed, the lower the margin of the resulting design would be, and the more feasible it becomes to satisfy the noise specifications.

## A CONSOLIDATED EDISON SUCCESS STORY

As of fall 2003, ABB had the technology to design low-noise power transformers, but not to the levels or details required by the revised specifications for the ConEd ultralow-noise transformers. The next four years, the ABB technology development team worked on the eight noise-related technology areas. As a result of first-year progress, ConEd in 2004 awarded ABB the contract to produce the first ultralow-noise 93-MVA transformers. These three transformers were successfully tested and delivered in 2005. The first was equipped with a sound enclosure. The second and third had only sound panels attached to the tank walls.

After delivery, ConEd awarded ABB an order for two similar 65-MVA transformers. These transformers were designed using the low-noise technology available at the time. The transformers were produced with no external sound enclosure or sound panels. The second unit was designed with 15 percent less winding weight while testing 4 dB lower load noise than that of the first unit. Frequency components of the total of core and load noise of this transformer were between 2 and 5 dB lower than the ultralow levels specified by ConEd.

## FACT BOX: FREQUENCIES

| **Octave Band Center Frequency, Hz** | **125** | **250** | **500** |
|---|---|---|---|
| **Permissible level, dB** | **71** | **64** | **57** |

As a result, ConEd awarded five more 93- and 65-MVA transformers for delivery in 2008 and early 2009. These transformers upgraded the design of the earlier transformers with 10-20 percent less weight in core and windings while satisfying the ConEd requirements. These transformers passed all tests and were delivered to ConEd. The ultralow-noise transformer technology resulting from this development is being used to produce optimum designs for low-noise transformers for metropolitan areas around the world. ●

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