Part of Energy Queensland

Substation Standard

Standard for Audible Noise in Substations

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Abstract: The aim of this document is to establish a set of criteria and guidelines that can be referred to during substation design as to minimise the impact of noise on the surrounding environment and community

Keywords: Transformer, noise, sound

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1 Overview

1.1 Purpose

The purpose of this document is to provide a guideline to minimise noise disruptions from substations within communities in both Energex and Ergon Energy areas. These requirements are in part to ensure that noise generated by substation equipment satisfies the following objectives.

- Compliance with legislation and regulations
- Adherence to area noise restrictions

1.2 Scope

This standard provides a guideline on the requirements that need to be considered within substation designs to ensure Energy Queensland (EQ) adheres to its requirements in reducing noise caused by substation activity. The standard also describes the steps to minimise environmental nuisance caused by noise generation.

This standard guideline is applicable for the following:

- All new designed and constructed substation sites
- Existing substations where noise disruptions are high and need to be avoided.
- Existing substations where transformers will be upgraded.

This document does not intend to provide methods or guide to noise measurement, which are given in relevant Australian Standards and Manual published by Environment Protection Agency of Queensland Government.

2 References

2.1 Legislation, regulations, rules, and codes

Electrical Safety Code of Practice – Works, 2020 (Queensland Government)

Environmental Protection (Noise) Policy 2008. (Queensland Government)

Environmental Protection Regulation 2008. (Queensland Government)

Environmental Protection Act, 1994 (Queensland Government)

Queensland Electricity Act, 1994 (Queensland Government)

Queensland Electricity Regulation, 2006 (Queensland Government)

Queensland Electrical Safety Act, 2002 (Queensland Government)

Queensland Electrical Safety Regulation, 2013 (Queensland Government)

Queensland Noise Measurement Manual, 2020 (Queensland Government)

Queensland Work Health and Safety Act, 2011 (Queensland Government)

Queensland Work Health and Safety Regulation, 2011 (Queensland Government)

2.2 Energy Queensland controlled documents

Environment and Cultural Heritage P058 - 691101

Occupational Noise Management R078 - 690168

2.3 Energy Queensland other documents

Document number or location (if applicable)	Document Name	Document Type
Acoustic Amenity (noise)	Acoustic Amenity (Noise)	Factsheet

2.4 Other sources

AS 1055 (All) - Acoustics - Description and measurement of environmental noise.

AS 1633 – Acoustics – Glossary of terms and related symbols

AS IEC 61672 (All) – Electroacoustics – Sound level meters.

AS/NZS 60076.10 (All) -Power transformers. Part 10: Determination of sound levels. Definitions and abbreviations

IEEE 1127-2013 – IEEE Guide for the Design, Construction, and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility.

IEEE C57.136-2023 – IEEE Guide for Sound Level Abatement and Determination of Liquid-Immersed Power Transformers and Shunt Reactors Rated Over 500 kVA.

ISO 9613 (All parts) Acoustics – Attenuation of sound during propagation outdoors.

Michael Gange, "Low-frequency and Tonal Characteristics of Transformer Noise", Acoustics 2011 Conference Gold Coast, 2011

International Journal of Applied Acoustics Vol. 1, No. 2 1968 - Noise Reduction by Screens (Z. Maekawa)

3 Definitions and abbreviations

3.1 Definitions

For the purposes of this standard, the following definitions apply.

Sound power (W)	Rate at which airborne sound energy is radiated by a source. It is expressed in watts
Sound power level (L_w)	ten times the logarithm to the base 10 of the ratio of a given sound power to the reference sound power (W0 = 1 × 10–12 W). It is expressed in decibels
Sound pressure level (L_p)	ten times the logarithm to the base 10 of the ratio of the square of the sound pressure to the square of the reference sound pressure (p0 = 20 × 10–6 Pa). It is measured in decibels
Sound pressure (p)	fluctuating pressure superimposed on the static pressure by the presence of sound. It is expressed in pascals

A-weighted scale	The A scale - corresponding to loudness level 40 phon or 40 dB at 1000 Hz.

3.2 Abbreviations

This list does not include well-known unambiguous abbreviations, or abbreviations defined at their first occurrence within the text..

dB	decibel
N	Fresnel number = $\frac{2S}{\lambda}$
S	Difference in sound path diffracted vs straight line
λ	Wavelength of sound in air

4 Background Information

4.1 Substation audible noise sources

The most noticeable audible noise generated by normal substation operation consists of continuous audible discrete tones. Noise of this type is generated by power transformers, regulating transformers, reactors. Sometimes, noise from Audio Frequency Load Control Plant and air conditioners could also be objectionable.

While continuous radiated noise is generally the most noticeable to substation neighbour, significant values of impulse noise can also accompany normal operations such as switching of circuit breakers or transformer tap-changer operations. Normally this type of noise is not objectionable.

Equipment noise levels may be obtained from manufacturers, equipment tender documents (particularly transformers) or test results.

4.1.1 Transformer Sound Characteristics

Transformers noise will be transmitted and attenuated at different rates depending on the transformer size, voltage rating, and design.

The main sound sources in transformers are:

a) **Core sound** caused by very small change in its dimensions due to magnetostriction effects. The change occurs at twice the power frequency. Because the magnetostriction curve is non linear, higher-order even harmonics also appear. In addition, magnetic forces within the core due to flux transfer from the plane of one lamination to an adjacent plane or air gaps will also create vibration.

   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. Mechanical resonance of the core and tank walls can have significant influence on the magnitude of the transformer vibrations and consequently on the sound generated.

b) **Load sound** caused by electromagnetic forces in the windings, tank walls and magnetic shunts due to leakage flux associated with the load current. 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. In some cases, the natural mechanical frequency of winding system may tend to resonate with electromagnetic forces, thereby severely intensifying the load sound.
From experiences through several decades the contribution of the load sound to the total transformer sound has remained moderate.

Depending on the phase angle of the load current, i.e. load power factor, the total sound level may be higher or lower than the no-load sound level.

Increase in sound level can be expected from loading the transformer beyond the nameplate rating.

Harmonics in the load current have a larger impact on the sound level than might be expected.

c) **Cooling equipment sound** is caused by fans (aerodynamic and motor/bearing sound) and pumps (cavitation and motor/bearing sound).

Sound produced by cooling fans is usually broadband in nature. Fans usually contribute more to the total sound for transformers of small ratings. Factors that affect the total fan sound output include tip speed, blade design, number of fans and the arrangement of the radiators.

Pump sound is normally not significant if the fans are running, although low-frequency sound may be present

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).

4.1.2 Shunt Reactor Sound Characteristics

Shunt reactors are usually a significant sound source. The sound is primarily caused by the magnetic “pull” effects of 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 creating vibration and hence sound. The frequency of this sound is normally twice the power frequency.

The appropriate mechanical design of the structural components of a reactor to avoid resonance at the exciting frequency is critical in minimising shunt reactor sound level.

4.2 Useful Sound Level Information

IEEE C57-136-2000 provides some useful sound level information, which includes:

- Sound pressure level
- Sound power level
- A-weighting sound scale
- Sound level calculations

Refer to Annex A for information extracted from the IEEE standard.

4.3 Queensland Government Environmental Protection (Noise) Policy 2019

This policy, established in 2019, aims to achieve the objectives defined in the Environmental Protection Act 1994 by:

1. Identifying environmental values to be protected or enhanced depending on stipulation.
2. Stating acoustic objectives for enhancing or protecting the environmental value, and
3. Providing a framework for making consistent, equitable and informed decision about the acoustic environment.

4.3.1 Management Hierarchy for Noise

Noise shall be dealt with in accordance to the following order of reference:

1. Firstly, avoid the noise entirely. An example being facing a part of an activity that makes noise away from a sensitive receptor.
2. Secondly, minimise the noise, in the following order.
    a. Firstly, orientate an activity to minimise the noise. (e.g. facing a part of an activity that makes noise away from a sensitive receptor)
    b. Secondly, use best available technology to minimise the noise:
3. Thirdly, manage the noise. (e.g. using heavy machinery only during business hours)

4.3.2 Management of Intent for Noise

The intent of this policy is:

1. To the extent it is reasonable to do so, noise mut be dealt with in a way that ensures:
    a. The noise does not have any adverse effect, or potential adverse effect, on an environmental value under this policy; and
    b. Background creep in an area or place is prevented or minimised.
2. If the acoustic quality objectives for an area or place are not being achieved or maintained, the noise experienced in the area or place must, to the extent it is reasonable to do so, be dealt with in a way that progressively improves the acoustic environment of the area or place.

4.3.2.1 Background Creep Management

The EPP states that to the extent that it is reasonable to do so, noise from an activity must not be:

1. For noise that is continuous noise measured by LA90,T – more than nil dB(A) greater than the existing acoustic environment measured by LA90,T
2. For noise that varies over time measured by LAeq,adj,T – more than 5dB(A) greater than the existing acoustic environment measured by LA90,T.

4.4 Local Council Laws on Noise Limits

Local councils can prescribe laws surrounding noise limits and standards for allowable noise. These may be intrusive noise limits, which relate to allowable limits above background sound levels, and acoustic amenity limits set for different periods of the day (eg day, evening and night) depending on the location of the activity.

The Brisbane City Council, as an example, has the Noise Impact Assessment Planning Scheme as part of Brisbane City Plan 2014 | Brisbane City Council for assessment criteria. Where increased noise has the potential to create an issue, local council guidelines shall be considered. Similarly, when a development application is put in for a new site the application will come back with conditions around noise levels.

4.5 Monitoring and Estimation of Noise Level

Measurements of background noise levels will not always be possible, particularly where operating plant and equipment is in place. At these times, estimated background noise levels presented in Table 1 may be used.

Table 1 - Estimate of background noise

Area	**Estimated Background Noise level (db(A))**		
	Day	**Evening**	**Night**
Rural or residential areas with traffic flows up to 5,000 vehicles per day	**40**	**35**	**30**
Residential areas with traffic flows of 5,000 to 15,000 vehicles per day or some commerce or industry	**50**	**45**	**40**
Areas in commercial districts or bordering industrial districts or with traffic flows of 15,000 to 30,000 vehicles per day.	**60**	**55**	**50**
Areas with predominantly industrial districts or with traffic flows above 30,000 vehicles per day.	**65**	**60**	**55**

Expected community response can be estimated from Table 2 below

Table 2 – Community Response Table

Amount in dB(A) by which the rating level exceeds the noise criterion	**Estimated community response**	
	Category	**Description**
0	None	No observed reaction
5	Little	Sporadic complaints
10	Medium	Widespread complaints
15	Strong	Threats of community action
20	Very strong	Vigorous community action

Source Bruel & Kjaer

4.5.1 Adjustment for Tonal Components

As per Clause 6.6.3 of AS 1055, Part 1, where the noise includes a significant tonal component eg transformer noise, an adjustment shall be made to the A-weighted sound pressure level.

Because the noise emanating from a transformer is tonal in character ie consists of one discrete frequency and its harmonics, it is more perceptible to the ear than a sound of the same pressure level which contains a wide spread of frequencies. A penalty of 5dB(A) is therefore added to the measurement of the noise due to the transformer(s) before comparing it to the background noise. Note that as the distance increases from the transformer tonality is less evident, so penalties may not apply in these circumstances.

4.5.2 Noise Annoyance

Where noise levels exceed the levels listed in Table 1 above, then annoyance due to this increased noise is likely to occur. Noise increases of greater than 5dB (A) above the figures given in Table 1 should be avoided. Noise levels of less than 5dB (A) may be of marginal significance.

4.6 Outdoor Propagation of Sound Attenuation

Propagation of sound in the atmosphere is affected by

- Frequency of sound
- Temperature
- Relative humidity
- Pressure
- Screening/Reflection
- Dimensional Orientation and Environmental Effects

Simplified calculations of attenuation is provided with examples in Annex B. The total attenuation caused within the outdoor environment should be the accumulation of all comparative components. This is defined by ISO 9613-1 which provides formulae and table for examining attenuation coefficient with ISO 9613-2 providing a summarised equation as defined below.

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{Misc}$$

Equation 1: Noise attenuation

Where,

A_{div} → attenuation due to geometric divergence

A_{atm} → attenuation due to atmospheric absorption

A_{gr} → attenuation due to the ground effect

A_{bar} → attenuation due to barrier

A_{misc} → attenuation due to miscellaneous other effects

4.7 Transformer sound power level to AS/NZS 60076.10:2023

Figure ZA1, Appendix ZA of AS/NZS 60076.10-2023, reproduced below, details the sound power levels applicable to transformers in accordance with AS/NZS 60076.1. Transformers manufactured prior to 2009 were made to older standards that allowed for higher sound levels. Modern manufacturing techniques have reduced sound levels appreciably.

Figure ZA1 can be applied to all conditions of cooling by choosing the sound level for each cooling condition based on the rated MVA for that cooling condition. For auto-transformers, the equivalent double-wound transformer MVA rating shall be used to select the limit.

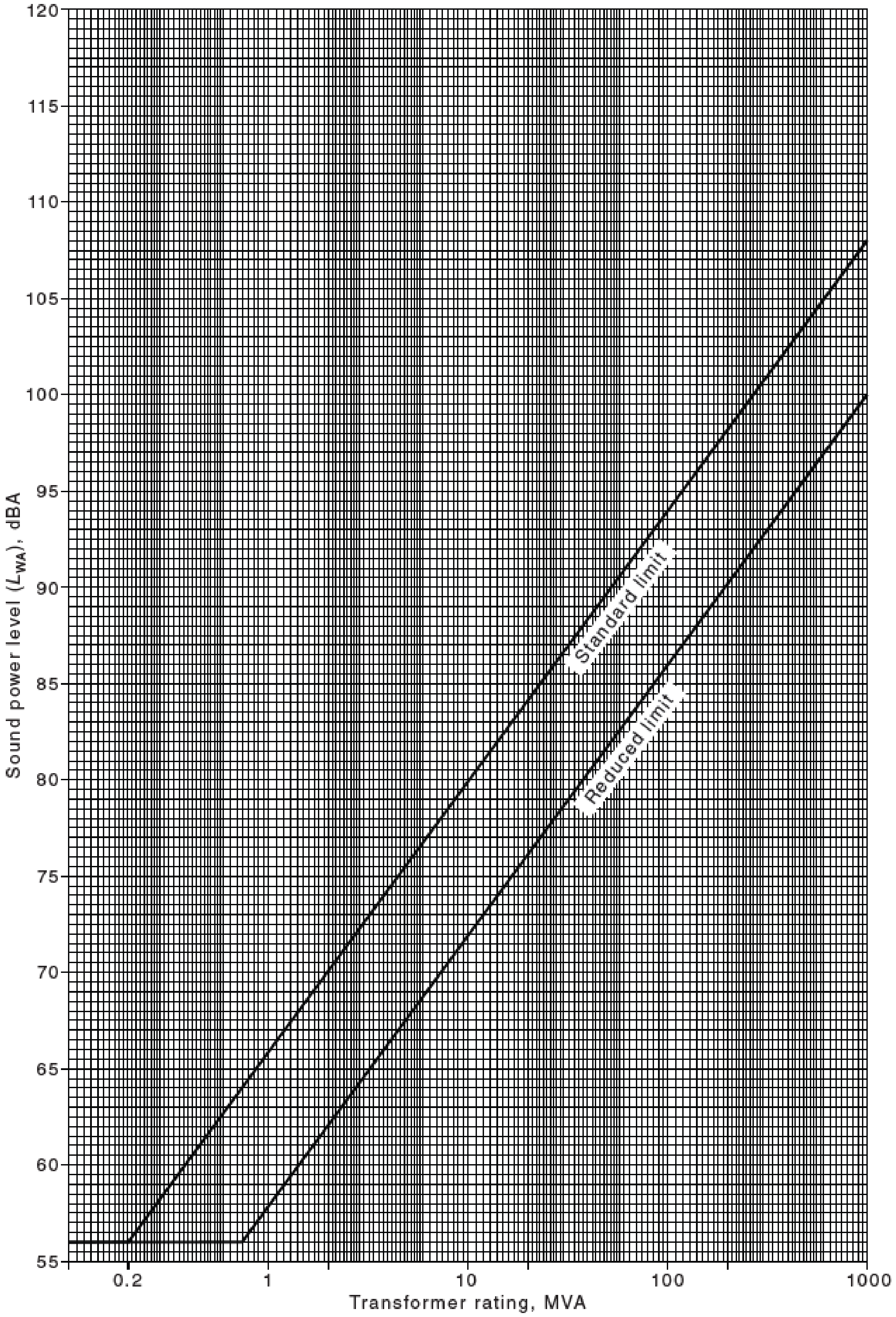
The graph is derived from the formulae:

$LWA(Standard\ Maximum) = 66 + 14 \times \log(MVA)$ for transformers >0.2 MVA and is constant at 56 dB(A) for all 0.2 MVA and smaller transformers.

Equation 2: Standard limit

$LWA(Standard\ Maximum) = 58 + 14 \times \log(MVA)$ for transformers >0.75 MVA and is constant at 56 dB(A) for all 0.75 MVA and smaller transformers.

Equation 3: Reduced limit



NOTE Measurements are done with the transformer operating at rated voltage and with all ancillary devices operating but without any load current.

Figure 1 - AS60076.10 Appendix ZA Figure ZA1

4.8 Occupational Noise Sources Within Substation Buildings

Another source of noise reported by operational staff is fan noise from large secondary systems equipment. This can include network servers in communications and security panels. These fan speeds are required to keep equipment cool for effective operation, so replacing with solid doors or lining cubicles with noise absorbent material may not be an appropriate solution.

Sound pressure limits from this equipment shall in no cases exceed 85dB(A) at locations where an employee may work, which is the 8 hour continuous A-weighted noise exposure limit beyond which a low risk of hearing loss can occur.

Figure 2 - Ciena rack doors (left) and MPLS door (right) – Beenleigh Substation

5 Design Methodology & Assessment Structure

Manual calculations can be done with methods and steps described in Section 5. For complex sites computer analysis is required.

5.1 Design Criteria

Noise Criteria from local council regulations shall be used to make assessments. In the absence of this information during planning and preliminary design, noise sensitive areas shall be assessed against the noise criteria detailed in Table 3 below.

Table 3 - Noise Criteria for New Plant/Facilities

Time of Day	Maximum Noise Level for Steady State Noise		
	Noise Sensitive Place	**Commercial Place**	**Industrial Place**
0700 hrs - 2200 hrs	Background + 5 dB(A)	55 dB(A)	65 dB(A)
2200 hrs - 0700 hrs	Background + 3 dB(A)	55 dB(A)	65 dB(A)

In multiple transformer substations the maximum noise level shall be evaluated in normal operation conditions (with all transformers are in service with load below their rating) and abnormal conditions (one transformer is out of service, the others are possibly loaded over their rating). Information on acoustic objectives for more sensitive sites can be found in Table 4.

5.2 Design Parameters

The following design parameters are critical as they form the basis for the assessment and assumptions which define the noise abatement system.

- Nature of the activity in the substation vicinity and types of sensitive receptors
- Sound source characteristics (penalties for tonal sounds).
- Distance of the sensitive receptor to noise sources
- Location and details of buildings/structures internal and external to the substation
- Other environmental and meteorological conditions.

5.2.1 Types of Sensitive Receptors and Nature of the Activity

Types of sensitive receptors and nature of the activity in the substation vicinity are criteria in determining background noise level and the maximum allowable noise level in the day. These are essential in the assessment of environmental noise associated with the substation and design of noise control system.

The background noise levels can be measured or estimated. For estimation refer to Table 1 of in clause 3.5.

5.2.2 Sound Sources Characteristics

Sound sources, sound levels and tonal components (measured or estimated) are used in the assessment to determine whether they present a noise nuisance for sensitive receptors in the neighbourhood. The required information should include dimensions of sound sources, which are used in the evaluation of sound level.

5.2.3 Distance from the Sound Sources to Sensitive Receptor

The distance(s) from the sound source to the sensitive receptor is/are important in calculating sound level attenuation and sound level at the receptor.

5.2.4 Location and Details of Buildings/Structures

Location and details of buildings/structures internal and external to the substation play an important role in reflection and absorption of sound/noise.

Information can be obtained from substation layout and detailed drawings, and vicinity maps of the substation. The drawings also provide other useful information for sound level evaluation, such as:

- Distance of the sensitive receptor to the noise sources
- Indication of orientation of the substation relative to the prevailed wind
- Location and dimensions of buildings/structures that may reflect or attenuate noises.

5.2.5 Other Environmental and Meteorological Conditions

For manual calculations environmental and meteorological conditions such as temperature, humidity, site topology, type of ground surface to determine sound absorption, trees, and hedges are not necessary. However they will be required as design inputs for rigorous analysis methods and computer modelling software.

6 Calculation of Sound Levels (IEEE C57.136-2023)

6.1 Step 1 - Determine Background Sound/Noise Level (LPBG)

The background sound/noise level at the sensitive receptor can be obtained either by measurement or estimated value from Table 1.

6.2 Step 2 – Determine transformer sound power level

The transformer sound power level L_w is provided in manufacturer's test results to AS60076.10. Use the A-weighted sound power level with all cooling on. In the absence of manufacturer's test results use the maximum allowable limits in AS60076.10 based on the standard in place at that time. (Note – don't confuse sound pressure level L_{pA} with sound power level L_{wA}.). See Section 3.7 for further details.

6.3 Step 3 – Calculate sound pressure level L_p

The calculated sound pressure level at a specific distance 'R' from the face of the transformer, assuming hemispherical sound wave radiation, is given by:

$$L_P = L_w - 10\log(2\pi R^2)$$

Equation 4 – Sound pressure at remote location

6.4 Multiple transformer installations

When several transformers contribute to the sound level at the remote point the distance-attenuated Sound Pressure Levels for each transformer may be added logarithmically to give a total Sound Pressure Level by the use of the following formula:

$$L_p(total) = 10\ \log \sum_{i=1}^{i=n} 10^{0.1\, L_p(i)}\ \text{dB(A)}$$

Equation 5 - Total Sound Pressure at Receptor

Where

$L_p(i)$ = The attenuated sound pressure level of the i_{th} source.

6.5 Sound Attenuation by Barriers or Enclosures

When reduction of transformer noise is necessary in order to abate a nuisance, and it is not feasible technically or economically to reduce the noise level at source, then the use of barriers or enclosures should be considered. Options include the placement of barriers between the transformers and the point at which the nuisance occurs, or to enclose the transformers either partly or completely by sound absorbing screens.

Barriers placed close to the source of the sound are very much more effective than barriers placed close to the receiver. However, if the barriers do not completely enclose the transformer they could increase the noise problem in the non-shielded directions due to reflections.

The effectiveness of partial barriers is largely determined by the diffraction of noise at the top and or sides of the barrier since this will greatly exceed the transmission of sound through a barrier with a suitable sound transmission loss. Details of the method of calculating the shielding effects of finite size barriers are given in Annex B.

7 Methods of Substation Noise Control

The following practices can be used to minimise noise levels created by transformers at substations. Additional information is included in Annex D.

7.1 Separation

Ideally, separation from sensitive receptors to limit noise levels to allowable levels is the preferred design.

7.2 Landscaping

Planting of grown trees on the outside of the fenceline in the direction of sensitive receptors can provide moderate noise reduction in marginal situations.

7.3 Transformer replacement

Standards have been updated in recent years to reduce the impact of noise from transformers, and manufacturers have made significant steps in recent years to reduce noise levels. Anti vibration pads are also fitted at site to reduce potential noise at the interface from tank to ground.

7.4 Block Wall Sound Barrier

A simple barrier around one or more sides facing a sensitive receptor may reduce noise levels by typically 8-13dB. Ensure adequate space between barrier and transformer for maintenance tasks.

7.5 Acoustic Barriers

An alternative to the simple barrier is an acoustic wall construction, which is a baffle resonant absorber solution. This system comprises two wall layers using customised spacing and setout of panels. The space between the two outer layers is filled with a sound absorption material to attenuate the noise from the transformer. The internal elements can be sized and spaced to tune for typical transformer generated frequencies.

7.6 Sound Enclosure

This enclosure is installed around all four sides of a transformer, and can be fitted with or without a roof. Adequate space must be allowed between the walls and transformer for maintenance activities. Coolers are installed outside the enclosure. Reductions of up to 20dB are possible.

7.7 Settings for Ventilation Fans

As indicated in Section 3.8, noise can be generated by ventilation fans on network servers and other auxiliary equipment. Some devices, like the Dell XR11 server have a setting called “SoundCap” that reduces fan speed and acoustic noise, at the expense of loss of processor performance, which may be an acceptable solution.

Another solution is to have air conditioning in the rooms housing this equipment to reduce the fan speed on these servers to acceptable acoustic levels.

8 Documentation Required

Documentation on the substation sound/noise design shall take the form of a design report and is to include, but not be limited to the following:

a) Environmental aspect identification.

b) Values for the critical design factors, and the methods used and assumptions made in ascertaining these values.

c) Details on calculations used in the design process.

d) A drawing or series of drawings detailing site plan, which indicate site boundary, surrounds with any significant sound sensitive characteristics, etc.

e) A drawing or series of drawings detailing the layout of the sound abatement system as applied.

Annex A

(Informative)

Audible Noise Background

A.1 Standard Definition of Intent

This section will enlist some fundamental principles reflecting the key assessed factors of this standard. The information provided is for reference and develops a foundation for standard implementation.

A1.1 Principle Source of Noise

Transformer noise is attributed to the effects of magneto-restriction in the laminations of the core within said transformers. With the change in magnetic flux within the lamination core, either positive or negative, the length of the lamination changes by a short amount. Furthermore, the alterations in permeability and thickness of said laminations can cause magnetic flux to pass through the residing air gaps, which in turn produce attractive or repulsive forces. The generated vibrations, lying within the range of 100Hz, will emanate off the walls of the tank via either mechanical coupling or indirectly via incompressible cooling fluid.

A1.2 Secondary Source of Noise

Secondary source of noise can be attributed to the generation and activity of oil pumps or air fans that are commonly associated within the cooling system of said transformers. These components emit noise which resonate of the tank walls leading to audible noise detection outside the enclosed transformer space.

A1.3 Primary Source of Noise Reduction

The process of reducing primary sources of noise within transformers are enlisted below, each pertaining to different interactions with noise source.

- Implementation of cold rolled grain orientated silicon steel for laminations
- Ground borne vibrations can be reduced by the insertion of anti-vibration rubber pads between the tank base and the foundation
- HI-B lamination coatings
- Isolation of the radiators from the tank using flexible rubber expansions joints rather than metal bellows
- Anti-vibration mountings between the core and tank
- Attention to the dimensions of the tank and stiffness of the tank walls to eliminate resonances.

A1.4 Secondary Source of Noise Reduction

The reduction of secondary noise source can be attributed to a few key motions, each negating the rise in secondary noise intensity.

- Use of larger diameter lower speed fans
- Attention to pipework
- Radiator design to mitigate resonance
- Lower speed higher volume oil pumps

Amendments as expressed above will result in the departure from optimum design implementation which will lead to an increase in cost premium per transformer construction.

A1.5 Shunt Reactor Sound Characteristics

Shunt reactors are commonly a significant sound source. The sound is primarily caused by the magnetic “pull” effects of leakage flux field. The magnetisation effects of the core steel are not generally significant. Leakage flux impinges on structural components of the reactor and produces forces acting on them creating vibration and hence sound. The frequency of this sound is normally twice the power frequency. The appropriate mechanical design of the structural components of a reactor to avoid resonance at the exciting frequency is critical in minimising shunt reactor sound level.

A1.6 Definition of Noise Measurements

To ensure that audible noise generated through transformer activity can be measured accordingly, the analysis of sound pressure, measured in pascals, will be undertaken. The process will be enlisted within this section of the annex.

The absolute magnitude of a given sound within the air medium is designated as sound pressure (P) and is found via the root mean square of the pressure variation about the mean. The measured range of said pressure lies within the minimum detectable limit of human ear hearing to maximum limit permissible by human ear. This pressure range resides in the region of micro pascals to megapascals. As such, due to this, the pressure range of the ear follows a logarithmic response. The level of the sound pressure is given as (Lp) and via the equation below.

$$L_p = 10 \times \log \frac{(P_{RMS})^2}{P_0} = 20 \times \log \frac{(P_{RMS})}{P_0}$$

Equation 6 – Sound pressure

Where P_0 is defined as reference (20 micro pascals)

A1.7 Definition of Phon and Application

To relate the sound pressure level encompassed from a sound wave to the complex response of the ear, a loudness level unit called a ‘phon’ is used. The loudness level of a pure tone in phons is numerically equal to the Sound Pressure Level in dB of a 1000 Hz note that is adjudged to be equally loud in free-field conditions.

To relate pressure level and loudness perceived by ear, a filter network is incorporated into the measuring instrument to give weight to certain frequencies. There are three levels normally used within this assessment being A, B and C scale.

- A scale → corresponding to loudness level 40 phone or 40dB at 1000Hz.
  - Used for transformer and background noise measurement.

- B scale → corresponding to loudness level 70 phon or 70dB at 1000Hz
    - Little used within this context.
- C scale → corresponding to loudness level 100 phon or 100dB at 1000Hz
    - Estimate frequency distribution of noise.

The A scale is predominantly used within audible noise assessment in transformers, in which the methods of measurement are done in accordance with individual sites. As the noise emanating from a transformer is tonal in character ie consists of one discrete frequency and its harmonics, it is more perceptible to the ear than a sound of the same pressure level which contains a wide spread of frequencies. A penalty of 5dB(A) is therefore added to the measurement of the noise due to the transformer(s) before comparing it to the background noise.

In case of adjusted sound pressure level exceeding the magnitude of the background sound pressure level by more than 5dB(A) or more then complaints associated to said transformer would be expected.

Annex B

(Informative)

Sound Barrier – Worked Example

Within this section, a working example will be provided on audible noise assessment. This example acknowledges the application of noise attenuating enclosures to the abatement of a noise issue. The attenuation of sound in this example is based only on geometric divergence (distance) and barrier effects from Equation 1.

The attenuation of the barrier is based on diffraction of the sound waves around an object. The amount of attenuation from a semi-infinite wall can be calculated from the Fresnel number:

$$N = \frac{2S}{\lambda}$$

Where S =difference in distance between diffracted path around barrier vs the straight line distance.

λ = wavelength of sound (for 100Hz sound wave in air = 3.4m)

Figure 5 and Figure 6 can then be used to determine the amount of attenuation can be achieved by the barrier. By calculating attenuation affects from top and sides and combining effects together an estimate of the total effect of the barrier can be calculated.

As a guide it should not be expected to achieve greater than 10dB(A) attenuation with 1, 2, or 3 sided barriers of practical height. For a 4 sided enclosure an attenuation not greater than 15dB(A) can be anticipated.

In designing such barriers it is essential to minimise the creation of standing waves by reflection of sound waves from transformer to barrier and from barrier to opposite barrier. To achieve this the distance between the tank and the barriers, and between opposite barriers should not be a multiple of the half wavelengths of 100Hz (1.7m) and 200 Hz (0.85m) + 75 mm. A suitable acoustic lining should be applied to the side of the barrier facing the transformer to provide good absorption of these frequencies. Helmholtz resonators may be used for this purpose and may be either standard hollow blocks drilled with holes in one wall or blocks specially designed to resonate at the desired frequencies.

When attenuations in excess of 15dB(A) are required it will be necessary to resort to full enclosure of the transformer, ie four walls and a roof enclosing the transformer tank but not the radiators. Improved anti-vibration couplings between the tank and radiators may be necessary if the attenuation of sound emission from the tank is not to be negated by sound emissions from the radiators.

Heavy concrete masonry enclosures with reinforced concrete roofs and acoustic block inner linings can achieve an average attenuation of 30dB(A).

When using any type of full enclosure it is necessary to consider the effect on the thermal rating of the transformer. Heat loss from the tank will be reduced and, unless the radiators have sufficient cooling capacity, allowable temperatures may be exceeded at full load. Depending on operating conditions it may be necessary to provide additional radiator area and/or oil flow.

B.1 Effect of distance

A substation consists of two x 25MVA power transformers, rated sound power level 72dB(A). One is located 20m from a boundary and one 30m from the boundary of a sensitive receptor.

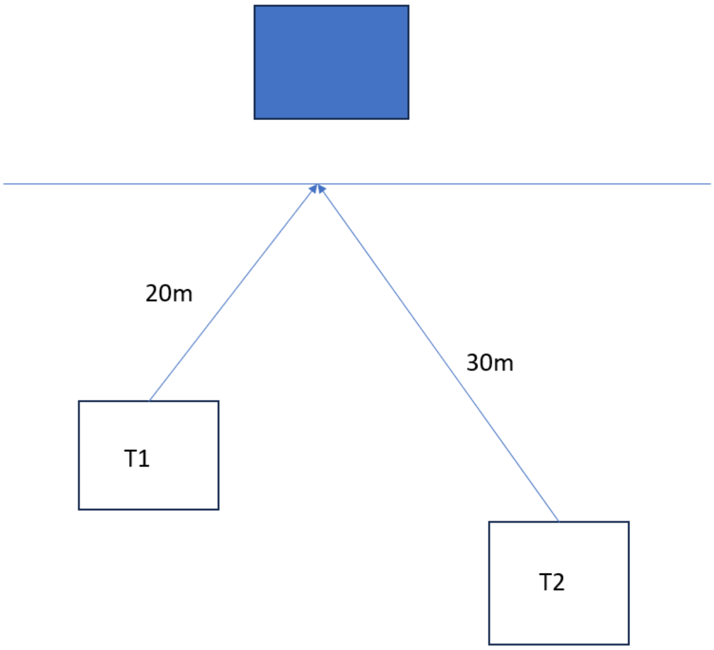


Figure 3 – Example

$$P_{t1} = 72 - 10\log(2\pi 20^2) = 38dB(A)$$

$$P_{t2} = 72 - 10\log(2\pi 30^2) = 34.5dB(A)$$

$$P_{bound} = 10\log(10^{0.1\times 38} + 10^{0.1\times 34.5}) = 39.6dB(A)$$

B.2 Effect of semi-infinite barrier

Consider T1 only. For a semi-infinite barrier what height is required to reduce background to 30dB(A)?

From C1.1 – distance effect = 38dB(A). Therefore reduction required is 8dB(A). From Figure 6, reading down N= 0.2. Therefore:

$$N = \frac{2S}{3.4}$$

$$0.2 = \frac{2S}{3.4}$$

S=0.34

Assuming 1.5m distance between transformer and barrier, and the source of noise as 2/3 of height of transformer tank = 2.5m.

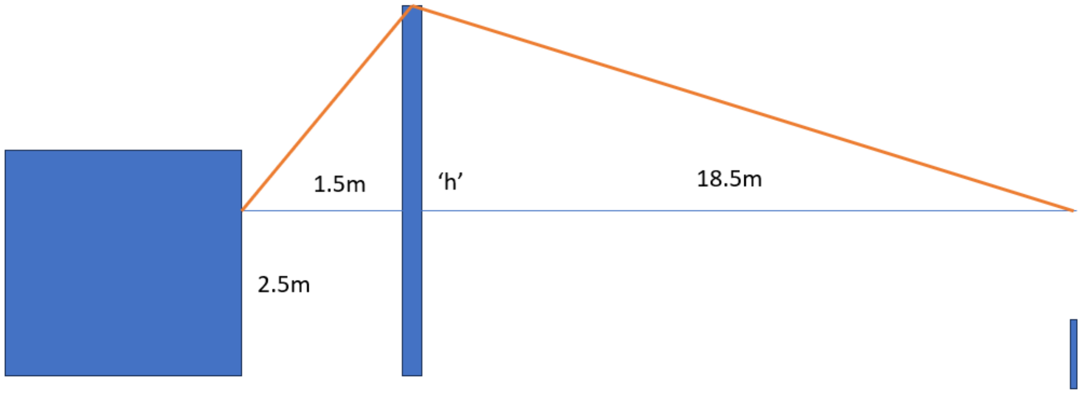


Figure 4 – Barrier

$$0.34 = \sqrt{}((1.5^2 + (h-2.5)^2) + \sqrt{}((18.5^2 + (h-2.5)^2) - 20$$

h = 3.5m

B.3 Effect of a finite barrier

S= barrier width of 5m. What is the total attenuation given diffraction around each side.

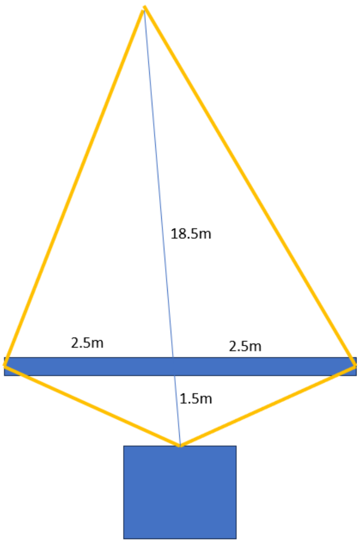


Figure 5 - Horizontal attenuation around barrier

S= 1.58m. N = 2S/3.4 = 0.93. From Figure 6 Attenuation = 13dB(A).

Total attenuation can be calculated from

$$Att = -10\ \log(10^{-0.1\times8} + 10^{-0.1\times13} +\ 10^{-0.1\times13})$$

= 5.9dB(A).

To increase attenuation back to 8dBA can increase height or add sides to barrier.

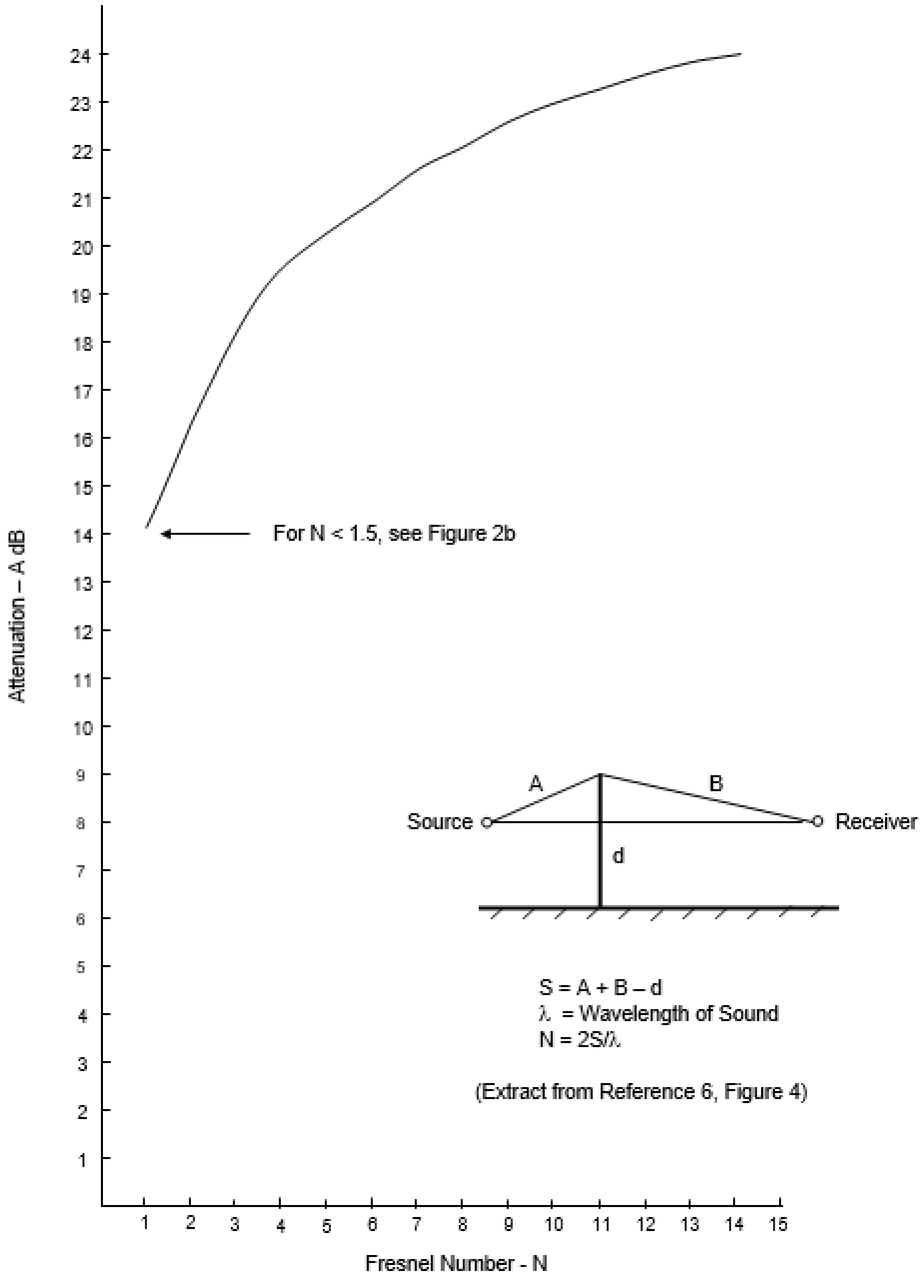


Figure 6 - Attenuation vs Fresnel No. for Barrier

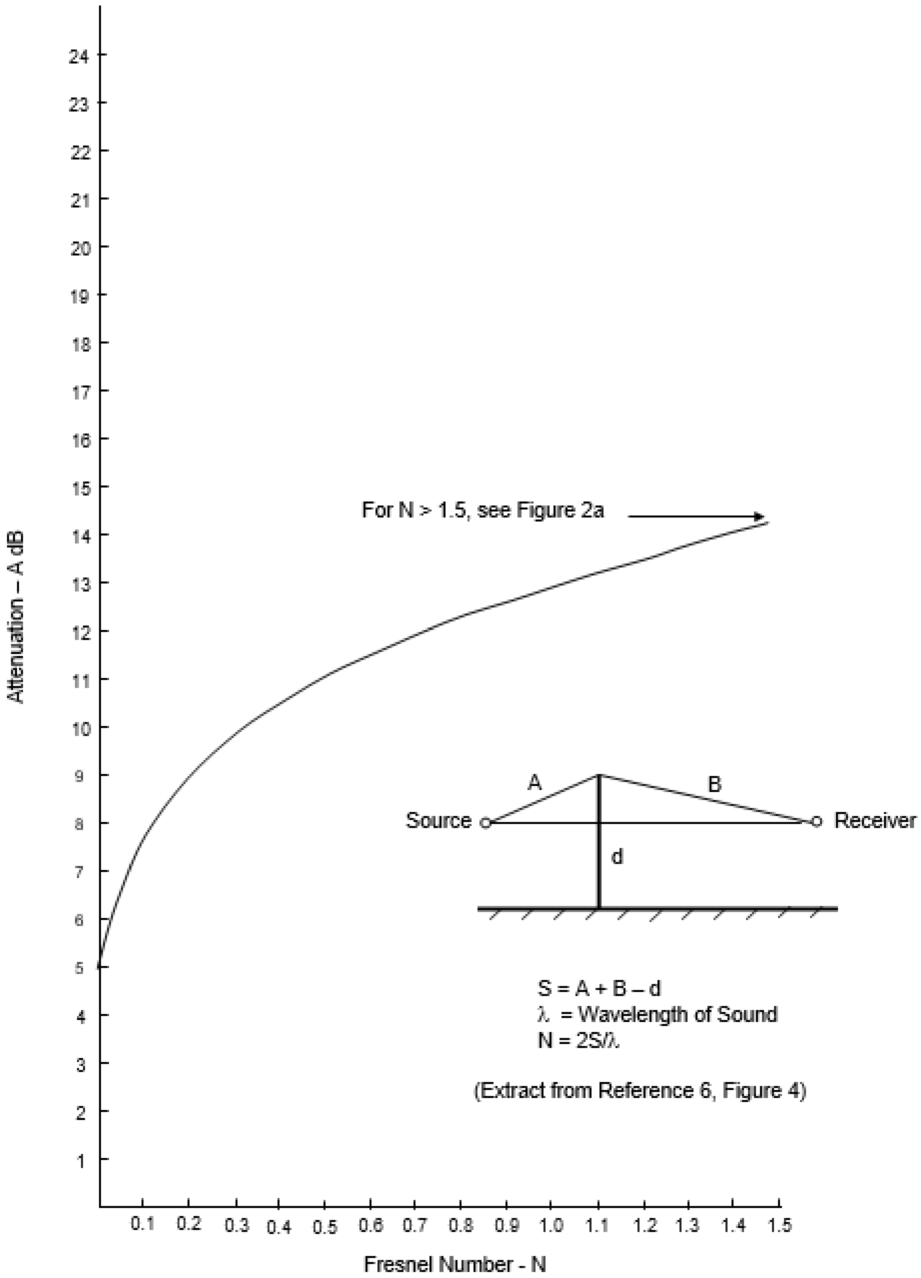


Figure 7 - Attenuation vs Fresnel No. for Barrier

Annex C

(informative)

Queensland Govt Acoustic Objectives

Extracted from Environmental Protection (Noise) Policy 2019

C.1 Acoustic Quality Objective Descriptors

To understand the given table of acoustic quality objectives, the descriptors referenced in Column 3 of the table are stated and explained below

1. $L_{Aeq.adj,1hr}$ → the A-weighted sound pressure level, adjusted for tonal character or impulsiveness, that is exceeded for 1% of a 1-hour period when measure using time-weighted "F".
2. $L_{A10,adj,1hr}$ → the A-weighted sound pressure level, adjusted for tonal character or impulsiveness, that is exceeded for 10% of a 1-hour period when measure using time-weighted 'F'.
3. $L_{A1,adj,1hr}$ → an A-weighted sound pressure level of a continuous steady sound, adjusted for tonal character, that within a 1-hour period has the same mean square sound pressure as a sound arise with time.

C1.1 Schedule for Acoustic Quality Objectives Table

Column 1	Column 2	Column 3			Column 4
Sensitive receptor	**Time of day**	**Acoustic quality objectives (measured at the receptor) *dB(A)***			**Environmental value**
		$L_{Aeq,adj,1hr}$	$L_{A10,adj,1hr}$	$L_{A1,adj,1hr}$	
residence (for outdoors)	daytime and evening	50	55	65	health and wellbeing
residence (for indoors)	daytime and evening	35	40	45	health and wellbeing
	night-time	30	35	40	health and wellbeing, in relation to the ability to sleep
library and educational institution (including a school, college and university) (for indoors)	when open for business or when classes are being offered	35			health and wellbeing
childcare centre or kindergarten (for indoors)	when open for business, other than when the children usually sleep	35			health and wellbeing
childcare centre or kindergarten (for indoors)	when the children usually sleep	30			health and wellbeing, in relation to the ability to sleep
school or playground (for outdoors)	when the children usually play outside	55			health and wellbeing, and community amenity
hospital, surgery or other medical institution (for indoors)	visiting hours	35			health and wellbeing

Column 1	Column 2	Column 3			Column 4
Sensitive receptor	**Time of day**	**Acoustic quality objectives (measured at the receptor) *dB(A)***			**Environmental value**
		$L_{Aeq,adj,1hr}$	$L_{A10,adj,1hr}$	$L_{A1,adj,1hr}$	
hospital, surgery or other medical institution (for indoors)	anytime, other than visiting hours	30			health and wellbeing, in relation to the ability to sleep
commercial and retail activity (for indoors)	when the activity is open for business	45			health and wellbeing, in relation to the ability to converse
protected area or critical area	anytime	the level of noise that preserves the amenity of the existing area or place			health and biodiversity of ecosystems
marine park	anytime	the level of noise that preserves the amenity of the existing marine park			health and biodiversity of ecosystems
park or garden that is open to the public (whether or not on payment of an amount) for use other than for sport or organised entertainment	anytime	the level of noise that preserves the amenity of the existing park or garden			community amenity

Table 4 - Acoustic Quality Objectives

Annex D

(informative)

Sound Abatement Techniques

Extracted from IEEE C57.136-2023

D.1 Description of Factory Techniques

The following table provides a description on the sound control techniques that can be implemented within the factory designation of transformer production. The list presented within the table enlist a collection of methods that can be incorporated within production to negate or reduce the magnitude of sound pressure level present within residential implementation.

Method of Limitation	Description
Lower Core Flux Density	Reducing core flux density is most effective in reducing core noise. The reduction is greatest at higher flux densities. Disadvantage however being that reducing core flux density results in increased size, weight, and cost of the transformer.
High Permeability Grain-Orientated Core Steel	Provide several dB lower sound levels of core noise compared to regular core steels. This is due to the core steels having a lower magnitude of magnetostriction than regular core steels. Disadvantage being cost and size of transformer development and construction.
Avoiding Core Resonance	Overlap between core vibration frequencies and resonance frequencies leads to increase in sound pressure levels by 2db to 5db. To mitigate this, reduction of core resonance is desired. Disadvantage being that the dimensions of the core will need to be modified as such fluctuating cost and build size.
Filling Tank Stiffeners with Sand	Can be effective in reducing sound generated by coil noise, which can range from 1dB to 4dB in noise reduction depending on the size and design of the inner core and tank.

D.2 Description of Core and Load Noise Techniques

This section will enlist the methodologies that can be administered to mitigate load noise with transformer operation, as such to reduce or eliminate sensitive audible noise generated.

Methods of Limitation	Description
Low Noise Tank Design	Entails avoiding tank mechanical resonance, using low sound tank stiffeners such as T- and L-shaped stiffeners, and using a tank design ith higher level of mechanical stiffeners.
Vibration isolation between active part and tank	Reducing transmission of vibrations formed through active parts to the tank using isolation can reduce both core and load noise.
External Sound Panels	Used to reduce transformer noise in the case of low and ultra-low noise transformers. These can be tank mounted sound panels, panels attached to tank wall stiffeners, or panels attached to tank wall stiffeners and tank cover.
Sound Enclosures	Typically, can be designed to significantly reduce both core noise and load noise and consist of two main types being Sound enclosure mounted on tank. Free standing sound enclosures Disadvantages are expense, extra real estate and reduction in cooling capacity of the transformer to some extent.