Low-frequency and Tonal Characteristics of Transformer Noise

Michael Gange

Senior Engineer, Renzo Tonin & Associates, Sydney, Australia

ABSTRACT

Electricity substations and their associated transformers are necessary for community power needs. In NSW these substations are often located in rural areas where background noise is low. Noise 'hum' from the transformers can be an issue for residents located nearby to the substation, and the tonal and low-frequency nature of the noise can add to the annoyance. The NSW Industrial Noise Policy applies penalties for these noise characteristics when assessing such sources. This paper analyses noise measurements of substations in rural areas. One-third octave band noise measurements were conducted both close up to the transformers, and also in the residential community. The measurement results show that although tonal and low frequency characteristics might be evident close up to the transformers, these characteristics dissipate over distance and the INP penalties do not necessarily apply at the residential receiver.

INTRODUCTION

The electricity used by households and businesses in NSW is generated at power stations then transmitted through high voltage transmission lines to substations. The substation performs the task of stepping down the voltage suitable for domestic and commercial distribution. There are approximately 91 large zone substations in NSW and many more smaller distribution substations.

Since substations are often located in rural areas, the nearest residential receivers are commonly isolated dwellings on large lots. Background noise is therefore usually very low due to the lack of other industrial development and low levels of traffic noise. Occasionally medium density residential areas on the edge of towns abut the substation land holding.

Since transformers generate noise emissions with a distinct tone at a relatively low frequency, it is sometimes assumed that these characteristics will also be evident at the residential receiver, to the point that a tonality penalty and/or a low-frequency penalty is automatically applied during an assessment. Particularly when utilising noise modelling say during the planning phase of a substation, the tones and harmonics the substation source are strongly evident in the predicted results at the receiver.

However, since tonality is assessed by determining the emergence of a particular tone above the noise level of the adjacent frequency bands, the background noise in an area plays a significant part in determining whether a noise source will be tonal or not. Even where the tone of a substation may still be somewhat audible, it may be that the tone has 'blended' enough with the background noise so that the tone is no longer inherently annoying.

This paper analyses the results of noise measurements conducted in rural areas, in the vicinity of substations, with the aim of determining typical distances from substations beyond which tonal and low-frequency penalties would no longer apply according to the INP.

ELECTRICITY SUBSTATION TRANSFORMERS

Zone substations typically contain at least two step-down transformers. These transformers operate with a distinct 'hum' which is generated by the periodic mechanical deformation of the transformer core and the winding coils, under the influence of fluctuating electromagnetic flux. The vibration of the core is at twice the frequency of the alternating magnetic flux. Since the line supply frequency is 50Hz, the noise emissions from these transformers are typically characterised by tonal spikes at 100Hz, and also at the 200Hz and 400Hz harmonic frequencies.

Figure 1 Typical substation transformer

During a transformer's operation, the vibrations from its core and windings get transmitted to the transformer tank surface through air-borne transmission (the air surrounding the core), and by structure-borne transmission at points where the mounting of the core structure is attached to the tank. The vibrating tank surface eventually radiates noise into the exterior air.

Some of the other sources of noise associated with transformer operation, such as cooling fans and pumps, are usually negligible contributors to the far-field noise.

NSW INDUSTRIAL NOISE POLICY

General Criteria

The NSW Industrial Noise Policy (INP) is generally used for setting noise goals in substation noise assessments in NSW.

The assessment procedure for the Industrial Noise Policy has two components:

- Controlling intrusive noise impacts in the short term for residences
- Maintaining noise level amenity for particular land uses for residences and other land uses.

In setting the project specific noise levels, the more stringent of the intrusive and amenity criteria is adopted. In general, the intrusive criterion tends to be the controlling criterion for substations as there is often little other industrial development in the regional areas where the substation is located.

Penalties for Low-frequency and Tonal Sources

Where a noise source contains certain characteristics (i.e. if it has an inherently tonal, low frequency, impulsive or intermittent character), then it can cause greater annoyance than other noise at the same level. According to the INP an adjustment of 5dBA for each annoyance aspect, up to a total of 10dBA, is to be added to the measured value to penalise the noise for the additional annoyance caused.

The INP provides definitive procedures for determining whether a penalty or adjustment should be applied for increased annoyance.

Tonal noise is defined as noise containing a prominent frequency and characterised by a definite pitch. A one-third octave (or narrow band analysis) is required and a 5dBA penalty is applied to the measured or predicted level when the level of one-third octave band exceeds the level of the adjacent bands on both sides by:

- 5dB or more if the centre frequency of the band containing the tone is above 400 Hz
- 8dB or more if the centre frequency of the band containing the tone is 160 to 400 Hz inclusive
- 15dB or more if the centre frequency of the band containing the tone is below 160 Hz.

Low frequency noise is defined as noise containing major components within the low frequency range of 20Hz – 250Hz. Low frequency noise is considered to be evident where the difference between the measured A and C weighted levels is 15dB or more, and another 5dBA penalty may be applied.

MEASURED TRANSFORMER NOISE LEVELS

Near Field Noise Levels

Australian Standard 60076.10.1-2009 "*Power transformers – Determination of sound levels*" is the current standard for quantifying noise levels from transformers. The procedure in this standard calls for noise levels to be measured at a series of points around the tank of the transformer.

One-third octave band noise measurements have been conducted in accordance with the standard for the near field noise levels presented in this paper. A typical noise spectrum for these near field measurements is presented in Figure 2. The tone at 100Hz is distinct, being two times the electrical supply line frequency. There is also significant energy at the 200Hz and 400Hz harmonic frequencies.

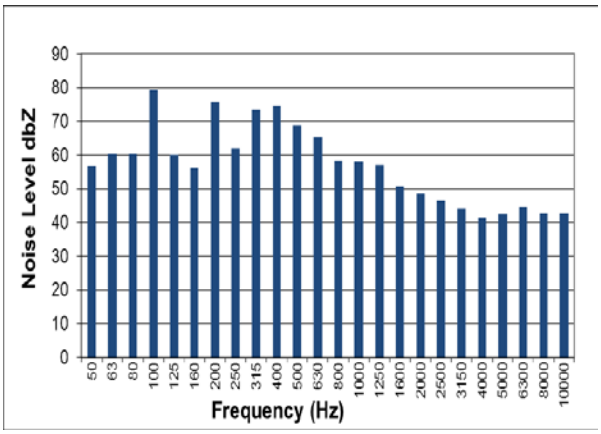

Figure 2. Typical Transformer Noise Spectrum

Noise Levels in the Community

The following three case studies are examples of where residences are affected by audible substation noise. Noise measurements have been conducted late at night at the residential boundaries in a low background noise environment to quantify noise emission levels and to determine whether tonal or low frequency characteristics exist. In each case, noise measurements have also been conducted close up to the transformers in the switchyard to quantify the character of the source.

Case 1

The substation was located in a rural area surrounded by grassy fields and farmland, and is approximately 2km from the main highway. Background noise levels were around 30dBA, although slightly less than 30dBA at some residential locations.

The graph in Figure 3 presents a comparison of measured noise levels both close up to the transformer in the substation, at the substation boundary, and at the residential boundary. The results are in one-third octave bands to enable analysis of tonality.

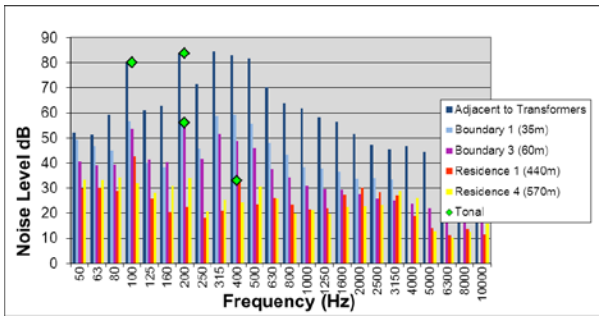

Figure 3. Measured Noise Levels (Case 1)

As shown by the arrowed notations, the following conclusions can be drawn for Case 1 according to the annoyance test procedures outlined in the INP

- Close up to the transformers, noise emissions are clearly tonal, with the obvious tones being at 100Hz, and at the 200Hz harmonic.
- Noise is still considered tonal at both the boundary locations (35m and 60m away), however the tones are only evident at 200Hz, but no longer at 100Hz.
- At the residential boundary 440m away, tonality was determined at 400Hz, but not at 100Hz or 200Hz
- At the residential boundary 570m away, noise from the substation was not considered tonal according to the INP procedures

Comparison of the A-weighted and C-weighted overall noise levels confirmed that a penalty for low frequency noise would not need to be applied at any residence.

Case 2

The substation was located in an area with farmland and some industry, and is approximately 400m from the main highway. Background noise levels were between 30 - 32dBA at night and truck traffic from the highway was audible at night.

The graph in Figure 4 presents a comparison of measured noise levels both close up to the transformer in the substation, at the substation boundary, and at the residential boundary.

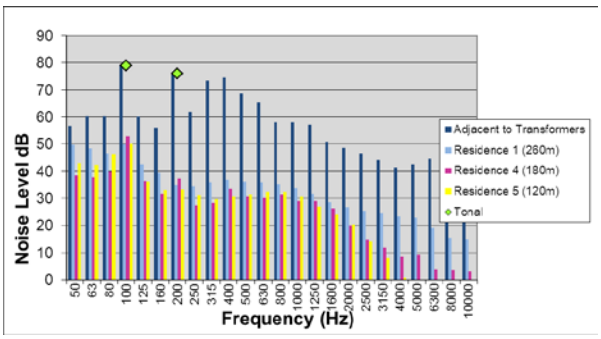

Figure 4. Transformer Noise (Case 2)

The following conclusions can be drawn for Case 2:

- Close up to the transformers, noise emissions are clearly tonal, with the obvious tones being at 100Hz and 200Hz.
- Noise is not considered tonal according to the INP at residences 120m, 180m or 260m away in any frequency.

Comparison of the A-weighted and C-weighted overall noise levels confirmed that a penalty for low frequency noise would not need to be applied at any residence.

Case 3

The substation was located in a rural residential with no industry. The nearest main road was approximately 1km away, and the nearest highway many kilometres away. Background noise levels were less than 30dBA at night.

The graph in Figure 5 presents a comparison of measured noise levels both close up to the transformer in the substation, at the substation boundary, and at the residential boundary.

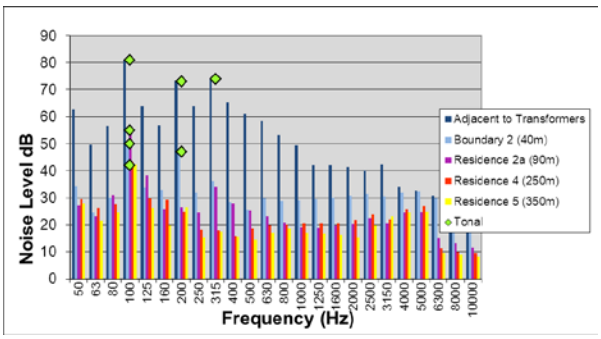

Figure 5. Transformer Noise (Case 3)

The following conclusions can be drawn for Case 3:

- Close up to the transformers, noise emissions are tonal at 100Hz, 200Hz and 315Hz.
- Tonality still exists at 100Hz at 40m and 90m. It is not calculated at 250m but is just triggered at 350m.

Comparison of the A-weighted and C-weighted overall noise levels confirmed that a penalty for low frequency noise would not need to be applied at any residence.

AUDIBILITY VERSUS INP PENALTIES

At each residential measurement location referenced in this paper, transformer hum could be described as being 'clearly audible' within the ambient noise. However, according to the INP procedures, penalties for tonality would not apply at all locations.

Table 1 summarises where tonality is evident for each case scenario, according to the INP procedures.

Table 1. Application of INP Tonality Penalty

Case	Receiver Distance	INP Penalty Applicable	Audibility of substation 'hum'
1	440m	Yes, tonal at 400Hz	Clearly audible
	570m	No	Clearly audible
2	260m	No	Clearly audible
	180m	No	Clearly audible
	120m	No	Clearly audible
3	90m	Yes, tonal at 100Hz	Clearly audible
	250m	No	Clearly audible
	350m	Yes, tonal at 100Hz	Clearly audible

Where a penalty for tonality is not required to be applied, the INP's 'background + 5dB' intrusiveness criterion is the remaining instrument for limiting noise impacts.

CONCLUSION

When acoustic engineers are planning for new substation installations in accordance with the NSW Industrial Noise Policy, the set of measured data in this paper suggests that:

- Where background noise levels are around 30dBA at night, application of the tonality penalty is appropriate for residences within about 500m of the transformers if the aim is simply to comply with the INP.
- Transformer hum can be clearly audible at a residential location without the INP procedures necessarily identifying that noise as being tonal. For additional protection of residences, particularly where background noise levels are below 30dBA at night, application of the tonality penalty for all receivers in the surrounding area may be appropriate, generating a more conservative outcome and additional mitigation measures so that that audible noise from the substation is reduced.
- Where receivers are exposed to existing traffic or industrial noise, or where background noise levels are greater than 30dBA, the INP penalty for tonality may not be triggered even for residences within a few hundred meters of the transformers.
- According to the INP procedures, an additional penalty for low-frequency noise is not warranted for substation installations.

REFERENCES

Australian Standard 60076.10.1-2009 "*Power transformers – Determination of sound levels*", Standards Australia, Sydney.

Jane Ann Verner, *Sound Tutorial*, March 2006

NSW Environment Protection Authority 2000, *Industrial Noise Policy*, EPA, Sydney.

Ravish S. Masti, Wim Desmet, Ward Heylen *Influence of core laminations upon power transformer noise,* K.U. Leuven, Department of Mechanical Engineering, Division PMA, Celestijnenlaan 300B, B-3001 Leuven, Belgium.