EirGrid Evidence Based Environmental Studies Study 8: Noise

Literature review and evidence based field study on the noise effects of high voltage transmission development

---

May 2016

EIRGRID

The current. The future.

This document has been prepared by EirGrid plc with the assistance of RPS Group.

The evidence contained in this study has been provided by RPS Group.

May 2016

SUMMARY

This is an evidence-based study carried out by experts in noise. The research looks at the actual noise effects of the construction and presence of high voltage transmission infrastructure in Ireland. Such projects include overhead lines and substations. Underground cables have been excluded from the study as they do not create any significant noise. This document is intended for use by professionals working in the area if environmental impact assessment for transmission lines. It is also intended to inform best practice in future planning of this infrastructure.

The purpose of this study has been to:

- Review literature on the noise effects of transmission infrastructure.
- Report on and discuss noise surveys of existing overhead lines and substation transmission infrastructure of different voltages across the country – 110 kV, 220 kV and 400 kV.
- Present conclusions and recommendations in relation to noise for the future design and siting of transmission infrastructure projects.

In addition to the survey work completed as part of this study, EirGrid separately commissioned a long term noise survey at the existing Dunstown-Moneypoint 400kV overhead transmission line in Cloney, Co. Kildare. This work was completed by AECOM and supplements the work completed as part of this study, feeding into the overall discussion, conclusions and recommendations.

There are a number of ways in which noise can be generated from electricity infrastructure. Generally, these fall within four categories of noise:

- audible noise associated with “Corona Noise” from high voltage transmission lines – generally heard as crackling and hissing;
- audible noise associated with dirty, damaged or cracked insulators;
- audible noise associated substation equipment;

- audible noise associated with wind blowing through electricity infrastructure – this is called “Aeolian Noise”.

The literature review confirms that the level of noise impact likely from electricity transmission lines increases with the increase of the voltage strength of the line. Much of the literature indicates that “Corona Noise” only becomes a significant issue from 350-500 kilovolts (kV) and above. This would suggest that significant “Corona Noise” impacts may not be likely for 110 kV and 220 kV transmission lines and that the potential for more significant impacts may only relate to 400 kV lines.

Noise surveys (measuring noise over a period of time) were carried out at locations along existing 110 kV, 220 kV and 400 kV overhead lines in Ireland, and at substations of the same voltages. The approach was to survey when the line was in operation (“on”), and when it was switched out (“off”), say for routine maintenance, and to compare the noise recorded at these two different survey times.

It wasn’t possible to switch off any substation, so the overall noise environment of the operating substation was surveyed. In addition, it was decided not to carry out noise surveys of any substations under construction. This would be similar to any construction project, rather than specific to a transmission substation development.

The results of the surveys were compared with the information contained in the literature, and with information from the separate AECOM survey.

The results from the 110 kV and 220 kV overhead line surveys present strong evidence that these lines are not likely to result in a significant noise impacts in their vicinity. On this basis, the planning of 110 kV and 220 kV lines should not be significantly constrained on the basis of potential noise issues.

The noise study on the 400 kV overhead line (OHL) provided evidence which showed that these lines do produce significant corona noise effects under certain conditions (especially at night under humid or wet conditions). This evidence is consistent with the literature review which shows that corona effects start to become significant in noise impact terms at voltages in the range of 350-500 kV. There is potential for noise impacts from such corona effects on properties located very close to such infrastructure in quiet rural locations. On this basis, in the design and siting of new

400 kV overhead lines it may be appropriate to seek a separation distance of 200m between any property and a 400 kV tower, and 100m between any property and the OHL.

Noise measurement surveys completed at 110 kV, 220 kV and 400 kV substations recorded steady state noise levels in the vicinity of the boundaries of these substations. To avoid any noise impacts at sensitive receptors, it is recommended that in the design and siting of new substations: a minimum distance of 5m is maintained between a 110 kV substation and the land boundary of any noise sensitive receptor. A distance of 20m is to be maintained between a 220 kV substation and the land boundary of any sensitive receptor. A minimum distance of 150m is to be maintained between a 400 kV substation and the land boundary of any noise sensitive receptor.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 THE SCOPE OF THIS PROJECT

In April 2012, EirGrid published the *Grid25 Implementation Programme 2011-2016*, and its associated Strategic Environmental Assessment (SEA).

The SEA identified a number of Environmental Mitigation Measures expected to prevent, reduce and, as fully as possible, offset any significant adverse impacts on the environment of implementing the Implementation Programme.

Environmental Mitigation Measure (EMM) 3 concerns *Preparation of Evidence-Based Environmental Guidelines*. These are intended to be a series of authoritative studies which look at the actual effects of the construction and existence of transmission infrastructure in Ireland. The studies would provide benchmarks to facilitate the robust preparation of projects with an evidence-based understanding of likely environmental impact.

Three types of studies are envisaged under EMM3:-

- **Environmental Benchmarking Studies**: to determine the actual effect, in respect of a number of environmental topics, of the construction and existence of transmission projects in a representative range of Irish environmental conditions – typical, non-standard, and worst-case. The studies, while authoritative, are conceived as an ongoing body of work that can be continuously updated to take account of new information and/or developments in understanding arising from practice and research;

- **Evidence-based Environmental Design Guidelines:** deriving from the factual basis and evidence contained in the initial benchmarking studies, these will provide practical guidance to practitioners and consultants in the planning and design of transmission infrastructure from the perspective of a particular environmental topic. These might comprise new guidelines, or the updating of existing guidelines;

- **Guidelines on EIA for Transmission Projects in Ireland:** Accompanying, or incorporated into the design guidelines, these are intended to provide an agreed and authoritative format for the preparation of Environmental Impact Assessment (EIA) for transmission projects in Ireland, in respect of particular environmental topics.

This study is one of the Environmental Benchmarking Studies – to determine the actual effect of the construction and existence of transmission infrastructure in Ireland on its environment.

1.2 THE SCOPE OF THIS STUDY

The key aim of this study is to examine and benchmark the actual noise effects of the construction and operation of high-voltage transmission projects in Ireland.

A review of available documentation and literature provides the basis for an assessment of noise in the context of the development of the transmission network.

Consideration was given to assessing the noise impact associated with the construction of electrical infrastructural projects; however this was scoped out, as it was considered that such noise would be consistent with any construction project, rather than specific to transmission infrastructure. As such, this study concentrates on the noise impacts associated with existing operational infrastructure.

Two separate survey strategies have been adopted for the purposes of investigating noise from overhead lines and noise from substations. For overhead lines, long term noise surveys have been completed adjacent to various infrastructural types (i.e. 110 kV, 200 kV and 400 kV) during time periods when the infrastructure is live (referred to as 'On' surveys in this report) and during periods of outage when the infrastructure is subject to maintenance work (referred to as 'Off' surveys in this report). By making direct comparison over a large sample period (e.g. 160 hours) and using an array of relevant noise parameters (i.e. L_{Aeq}, L_{A50}, L_{A5}, L_{A90}), the effect of corona, insulator or any other noise sources associated with overhead lines should become apparent as increased noise levels in the 'On' surveys.

In order to reduce the variability of factors influencing measured noise levels to enable more meaningful comparisons to be made, hundreds of datasets were created as part of the analytical process to isolate measured noise levels in different time periods (e.g. weekday, night, quiet day etc) and under different weather conditions (e.g. rain, no rain, wind below 10mph, wind below 5mph, wind = 0mph etc.). This was done for each noise parameter at each location for 'On' and 'Off' surveys.

In the case of the substation surveys, long term noise surveying was not adopted as it was not possible to complete surveys around the outage programme. While individual items of plant within a substation were subject to outage, an entire substation was not, and hence a direct comparison between 'On' and 'Off' conditions was not feasible.

The substation surveys were completed with a view to determining the typical noise levels associated with substations of each type (e.g. 110kV, 220kV and 400kV). It was difficult to incorporate sporadic effects such as corona into such a survey strategy, as the onset of these conditions cannot readily be predicted or planned for. Without an option for complete outage at substation sites, it is considered that a long term survey strategy could not isolate and illustrate corona effects from substations.

On the basis of the practical considerations discussed above, random and sporadic effects such as corona noise could not be fully explored for substation sites as part of the evidence based studies.

Underground electrical cables did not form a part of the current study as they are not considered to be a noise source. The soil covering any underground cable acts as a substantial insulator absorbing any potential noise energy produced by underground cables and preventing any significant emission of noise energy above ground.

In addition to the survey work completed as part of this study, EirGrid separately commissioned a long term noise survey at the existing Dunstown-Moneypoint 400kV overhead transmission line in Cloney, Co. Kildare. This work was completed by AECOM and supplements the work completed as part of this study, feeding into the overall discussion, conclusions and recommendations.

1.3 THE TRANSMISSION NETWORK AND NOISE

Electricity supply is an essential service in Ireland's economy. The transmission system is a meshed network of 400kV, 220kV and 110kV high voltage circuits, with 156 high voltage substations (see Figure 1.1). The transmission system therefore plays a vital role in the supply of electricity[1]. The development of the transmission network is the responsibility of EirGrid, the Transmission System Operator (TSO), under statutory instrument SI445/2000[2].

Grid development requires a careful balance between meeting the technical requirement for a project, the costs of that project, and the environmental impact of that project.

ESB, as the Transmission Asset Owner (TAO), is charged with constructing the transmission assets as specified by the TSO. ESB also has the role of Distribution System Operator (DSO) with which the TSO coordinates planning and development requirements. An overview of the primary types of transmission infrastructure, including an outline of construction methodology is set out in **Appendix A**.

EirGrid is committed to ensuring that transmission infrastructure development is undertaken in an environmentally sensitive manner, including in terms of impact from noise. The significance of any adverse effects of transmission infrastructure development depends on the location and scale of the proposed infrastructure and the potential for mitigation measures. This is why transmission infrastructure development is undertaken and constantly reviewed by suitably qualified experts as the design of a scheme progresses.

---

[1] Transmission Development Plan 2008-2012 EirGrid

[2] SI445/2000, entitled European Communities (Internal Market in Electricity Regulations, 2000)

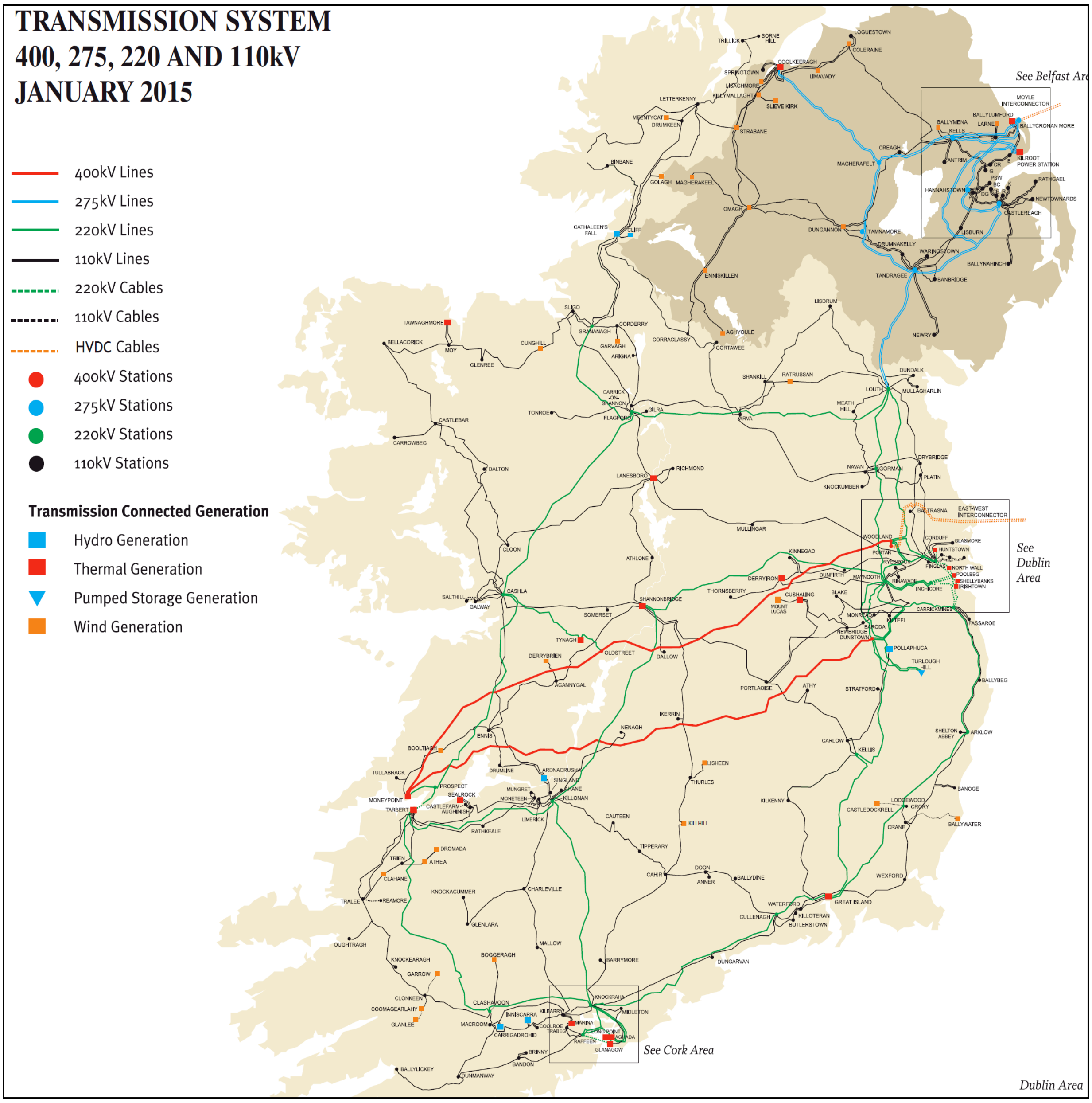


Figure 1.1 EirGrid and SONI's Transmission System Map (January 2015)

There are a number of ways in which noise can be generated from electricity infrastructure. Generally, these fall within four categories of noise, namely:

- audible noise associated with **Corona Discharge** from high voltage transmission lines;
- audible noise associated with dirty, damaged or cracked insulators;
- audible noise associated substation equipment such as transformers, quadrature boosters and mechanically switched capacitors;
- audible noise associated with wind blowing through electricity infrastructure - **Aeolian Noise**.

1.4 STUDY LAYOUT

Chapter 2 sets out a literature review relating to the noise effects of transmission infrastructure development. At the outset, it is clear that Aeolian Noise is not as common as Corona Noise, as the conditions that give rise to it (high winds and a very specific angle of incidence) do not occur regularly. Furthermore, such conditions that give rise to Aeolian Noise also assist in masking it (Cigre, 2009). In addition, the literature evidence does not provide any standard method for measuring and analysing Aeolian Noise from existing infrastructure - any work in this area has been by means of wind tunnel experiments (Akagi *et al*, 1998). On account of the practical difficulties associated with measuring Aeolian Noise and the fact that Aeolian Noise has generally not been perceived of as presenting a very significant noise impact at sensitive receptors (e.g. Cigre, 2009, DECC, 2011), it does not form a significant part of the evidence based studies included in this report.

Chapter 3 sets out the methodology undertaken for site survey of noise. As noted above, two separate survey strategies have been adopted as part of the evidence based surveys for noise for the purposes of investigating noise from overhead lines and noise from substations. Chapter 4 sets out the survey results for 110 kV, 220 kV and 400 kV overhead lines (underground cables having been scoped out of this study), and existing operation substations (substations under construction also having been scoped out of the study).

Chapter 5 discusses the separate AECOM survey work conducted at a location along the existing 400kV Dunstown-Moneypoint overhead transmission line in Cloney, Co. Kildare (also refer to **Appendix B**). Finally Chapter 6 sets out a discussion and conclusions in respect to the actual noise effects of transmission infrastructure development, and Chapter 7 sets out recommendations.

2 LITERATURE REVIEW

2.1 INTRODUCTION

2.1.1 Scope and Aims

There are a number of types of noise associated with high voltage electricity transmission infrastructure and these have been summarised in Chapter 1. The aim of this review is to examine literature relating to the topic of noise in the context of electricity infrastructure, and to summarise the evidence base under a series of headings that cover the different aspects of this topic.

There is a difference in the type and character of noise that is generated by different types of transmission infrastructure (overhead lines, underground cables and substations). This is further complicated by the strength of the voltage passing through the infrastructure. As noted in Chapter 1, underground cables are not identified as being a significant source of noise, as the ground covering the cable acts as an insulator absorbing a large proportion of the noise energy released prior to it propagating above ground. As such, it is not considered further in this literature review.

On account of the difference in the noise associated with overhead lines and substations, the noise associated with these two categories of infrastructure is discussed under separate headings (Section 2.2 and 2.3 below). These headings are supplemented with evidence under a number of other headings that relate to the overall topic of noise, including measurement of noise associated with electrical infrastructure and mitigation measures for noise associated with electrical infrastructure.

2.1.2 Noise Fundamentals

Sound is a sensation detected by the ear as a result of pressure variations set up in the air by a vibrating source. Noise is essentially unwanted sound or sound that is not desired by the recipient. Any sound that has the potential to cause disturbance, discomfort or psychological stress to a subject exposed to it, or any sound that could cause actual physiological harm to a subject exposed to it, or physical damage to any structure exposed to it, is known as noise (Environment Agency, 2004).

On account of the human ear's sensitivity to a wide range of fluctuations in pressure levels, sound is typically measured in terms of a logarithmic ratio of sound pressures. These values are expressed as sound pressure levels (SPL) in decibels (dB). In terms of sound pressure levels, audible sound ranges from 0dB (the threshold of hearing) to approximately 120dB (the threshold of pain). A doubling/halving of pressure equates to a 3dB increase/decrease in decibel level, which under normal circumstances is the smallest change in noise level that is noticeable to the human ear. A 10dB increase/decrease in sound level normally equates to a subjective doubling/halving of noise (EPA, 2012).

For a point source such as the fan of a chimney stack, the sound energy spreads out spherically, so that the SPL is the same for all points at the same distance from the source. The SPL decreases from a point source by 6dB per doubling of distance until ground and air attenuation noticeably affect the level. Items of plant within a substation are point sources. An overhead line is a line source, whereby the sound level spreads out cylindrically so the SPL is the same at all points at the same distance from the line. The SPL decreases from a line source by 3dB per doubling of distance until ground and air attenuation noticeably affect the level.

The frequency of a particular sound wave is the rate at which the sound wave oscillates. Frequency is measured in Hertz (Hz). Human hearing is not uniform across the frequency range, being less sensitive at very low and very high frequencies. In order for measured sound to relate more closely to the human hearing, a weighting (i.e. A-weighting) is commonly applied (EPA, 2012). Examples of some common sounds and their decibel ratings are listed below (Scottish Government, 2011):

- Unsilenced pneumatic drill (at 7m distance) - 95dB(A);
- Heavy diesel lorry (40km/h at 7m distance) - 83dB(A);
- Modern twin-engine jet (at take-off at 152m distance) - 81dB(A);
- Passenger car (60km/h at 7m distance) - 70dB(A)
- Office environment - 60dB(A);
- Ordinary conversation - 50dB(A);
- Quiet bedroom - 35dB(A).

2.1.3 Audible Noise from Corona Discharge

Audible noise associated with high voltage transmission lines usually occurs when the conductor surface electric stress exceeds the inception level for corona discharge activity, resulting in the release of acoustic energy which radiates into the air as sound. Conductors are designed to operate below the inception level for corona discharge; however surface contamination or accidental damage to the conductor can cause local enhancement of electrical stress, leading to the discharge activity and subsequent generation of noise (DECC, 2011).

Corona discharges are most often associated with rainy conditions, where water droplets collecting on the surface of the conductor initiate the discharge activity. The audible noise levels experienced are directly related to the level of rainfall - the higher the rainfall the higher the noise level. Fog will also give rise to corona noise, however the noise levels are generally lower than those experienced during rainfall. The build up of contamination or surface grease on conductors can give rise to or exacerbate corona discharge noise.

Corona discharges are perceivable as a broadband crackling and hissing noise in the frequency range of one to several kilohertz (Straumann and Fan, 2009).

2.1.4 Insulator Noise

Insulator noise is similar to corona noise with the one exception that it is not dependent on weather conditions. Insulator noise is caused by dirty, damaged or cracked insulators and is generally a feature of older ceramic or glass insulators. New polymer insulators have been found to minimise this type of noise emission from high voltage transmission systems. No specific literature was identified that explores any aspects of insulator noise and hence there is no specific section on insulator noise in this report. Much of the discussion on line transmission corona may be related to insulator noise also.

2.1.5 Substation Noise

Audible noise can be generated by substation equipment such as transformers, quadrature boosters and mechanically switched capacitors. Transformers typically generate a low frequency humming noise, the extent of which depends on the transformer type and the level of nose attenuation at the substation (DECC, 2011).

Transformer hum is the predominant noise generated at electricity substations and is associated with magnetic and electrical forces within the core of an electrical transformer. These forces generate vibrations in the core laminations within the transformer which generates noise. Typically, the noise level does not vary with transformer load as the core is magnetically saturated and cannot produce variations in the amplitude of the noise.

On account of the typically tonal nature of noise from substation plant, spectral analysis is commonly used to determine if a particular hum is due to noise at a distinct frequency.

Generally, modern transformers are manufactured with a specified and guaranteed emission level. Improvements in the manufacture of transformers have reduced the associated level of noise emission and hence modern transformers are typically quieter than equivalent capacity older transformers.

2.1.6 Aeolian Noise

The effect of wind blowing through electricity plant and its supporting structures can result in two types of noise - a general broadband turbulence noise and Aeolian noise. The general turbulence noise is no different for electricity infrastructure than it is for a wide range of physical structures in the environment and therefore this type of noise is not considered a nuisance. Aeolian noise, characterised by a series of tones and whistles that vary in frequency with the wind speed, is caused by vortex shedding (regular air fluctuations) across the surface of the item of infrastructure. This form of noise is independent of the infrastructure being energised or not.

Aeolian noise may become problematic at wind speeds higher than 10m/s; however it is often masked by the noise of the rain or by the wind itself (Cigré, 1999). Aeolian noise effects can be reduced by a range of infrastructure design techniques such as reducing the number of sub-conductors, increasing the spacing between sub-conductors, spiral wire wrapping and using composite insulators instead of glass or porcelain ones.

In general, Aeolian noise is not as noticeable as corona noise as the conditions that give rise to it (i.e. high winds at a specific angle of incidence) also help to mask its effects. It is also not as common as corona noise, as the conditions required to give rise to Aeolian noise do not occur regularly.

2.2 AUDIBLE NOISE FROM OVERHEAD TRANSMISSION LINES

2.2.1 Introduction

Corona from overhead transmission lines (OHL) refers to the discharge phenomenon produced by the ionisation of the air around the conductors, when the conductor surface potential gradient exceeds a critical value, namely, the corona onset gradient (Zhang *et al*, 2009). The corona characteristics of DC OHL are different from those of AC OHL mainly on account of the magnitude of environmental space charge arising from ionisation in the space between the two conductors of the lines and between each conductor and the ground.

It is generally recognised that audible noise from AC OHL is a concern in foul weather only, principally in rain. In the case of DC OHL, it is generally recognised that if there is any concern with audible noise, it is during fair weather (Task Force of the Corona and Field Effects Subcommittee, 1982) The cause of strong DC corona in fair weather is pollution on the conductors due to airborne particles and insects, which collect much more in the case of DC by being continuously attracted to the corresponding pole (Gela *et al*, 1993). As the Irish National Grid uses AC OHL, all of the background literature evidence outlined in this report relates to AC OHL.

There is no single standard guidance document that details the background, the requirements for measuring, assessing or predicting audible noise or that outlines mitigation measures for addressing audible noise on OHL. The consensus of authoritative evidence on the subject is derived from dedicated sub-sections within regional policy guidance documents on electricity infrastructure (DECC, 2011, Cigré, 2009) and international research papers

2.2.2 Measurement of Audible Noise from Overhead Transmission Lines

Corona noise is usually measured at the edge of the right away, or under the OHL as appropriate (Cigré, 2009). It can also be measured along a lateral profile. As one moves away from an OHL, the audible noise decreases approximately in inverse proportion to the square root of the distance, i.e. by approximately 3dB as the distance from the power line doubles (Cigré, 2009).

An example of a lateral profile of noise, averaged for the meteorological variation over one year, is illustrated in Figure 2.1. This profile was measured at 1.5m above ground, under a 400kV OHL (double circuit vertical configuration) with twin bundles of conductors of diameter 38mm and with distance between sub conductor of 40cm (Cigré, 2009).

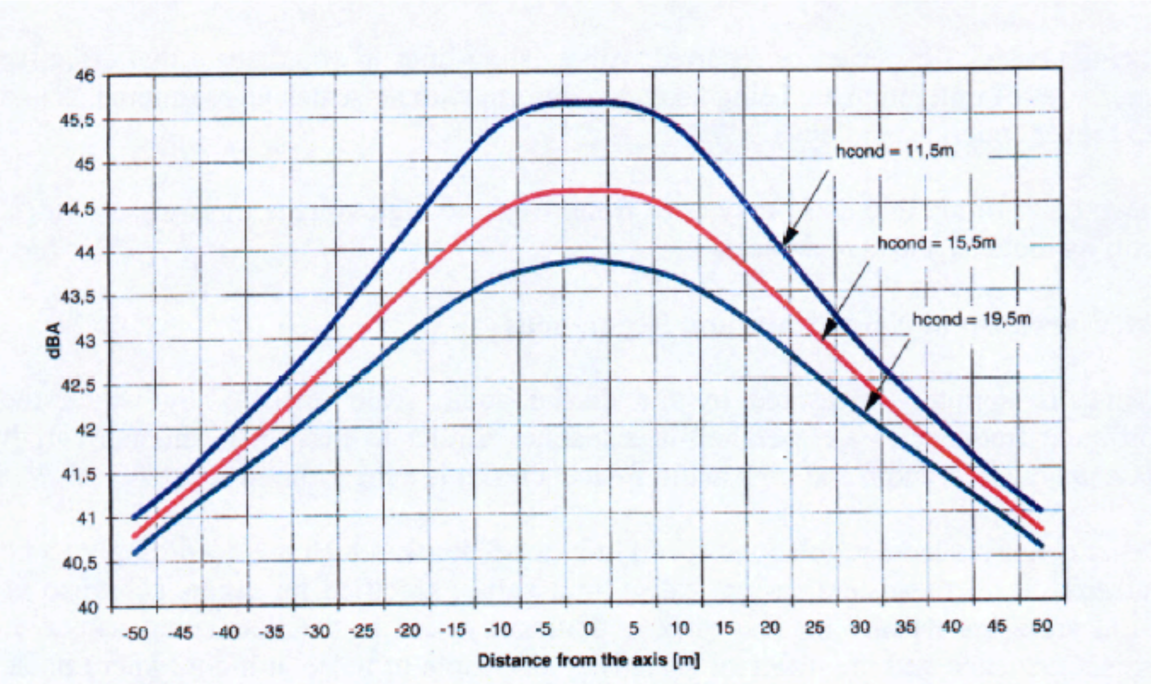


Figure 2.1: Typical Lateral Profile of Noise from a 400kV Transmission Line (Cigré, 2009)

Many noise measurements show evidence of higher noise levels near towers (especially near angle towers) than at mid-span on the transmission line. These higher noise levels are due to the presence of insulators and fittings on the towers, where corona discharges can occur when these items of equipment are dirty, wet or damaged (Cigré, 2009).

Corona discharge occurs on all types of OHL, but it becomes more noticeable at higher voltage (approximately 350kV and higher). Under fair weather conditions, audible noise from corona is minor and rarely noticed (Wordpress, 2011). On account of the fact that audible noise from corona discharge is more of an issue at higher voltage, much of the evidence base relates to measurement data from AC OHL at higher voltages (e.g. Zhang *et al*, 2009; Al-Faraj *et al*, 1997; Straumann and Fan, 2009; Task Force of the Radio Noise an Corona Subcommittee of the Transmission and Distribution Committee, 1975). There is literature that explores the measurement of audible noise from corona discharge at voltage levels between approximately 170 and 350kV (e.g. Chartier *et al*, 1995; Muhr *et al*, 2004), which is relevant to the OHL transmission network in Ireland (110kV, 220kV and 400kV).

In a review of previous measurement studies, Al-Faraj *et al* (1997) presented data from surveys completed by the Korean Electric Power Corporation (KEPCO) on the audible noise performance of a 6-rail conductor on a 765kV test line. The survey included experimentation with a number of different conductor bundle arrangements to determine which set up ensured the audible noise criteria of

50dB(A) for environmental protection of residential amenity was met. A 6-rail bundle conductor set up achieved an audible noise of 48.8dB(A) in rain at 15m from the outermost phase, compared with a measurement in fair weather of 42.1dB(A). The relationship between audible noise and voltage was also explored, demonstrating that an increase in voltage from 630kV to 800kV resulted in an increase in noise levels of 5.2dB(A).

Chartier *et al* (1995) completed long term measurements on an operating Puget Power 230kV line in USA in order to confirm the accuracy of the Bonneville Power Administration (BPA) audible noise calculation method. While the research team experienced partial contamination of the measurement data due to background noise at various stages of the survey, they were able to eliminate contaminated data and analyse the remaining data. Based on the analysis of the good data, the L_{50} levels during stable rain were 45.5 and 41dB(A) at 15m and 32.2m respectively.

The literature research detailed above provides good background information for the purposes of assessing the measured noise levels from the EirGrid study. Of particular interest to this study is the fact that the literature indicates that corona noise only becomes a noticeable phenomenon at approximately 350kV and above. The measured noise levels in the Chartier *et al* (1995) study appear to indicate a measureable difference in noise levels form a 230kV line; however these measurements are in the low 40s dB(A). The noise profile drawing shown in Figure 2.1 shows similarly low noise levels peaking in the mid 40s dB(A) for a 400kV overhead transmission line. Such low noise levels could easily be masked by other extraneous noise sources in a study area.

2.2.3 Factors Influencing Corona Discharge

The amount of corona produced by an OHL is a function of the voltage of the line, the diameter of the conductors, the locations of the conductors, the locations of the conductors in relation to each other, the elevation of the line above sea level, the condition of the conductors and hardware, and the local weather conditions. Power flow does not affect the amount of corona produced by an OHL (Wordpress, 2011).

Irregularities (such as nicks and scrapes on the conductor surface or sharp edges on suspension hardware) concentrate the electric field at these locations and thus increase the electric field gradient and the resulting corona at these locations. Similarly, foreign objects on the conductor surface (e.g. dust, insects etc.) can cause irregularities on the surface, thus giving rise to corona (Wordpress, 2011)

Corona also increases at higher elevations where the density of the atmosphere is less than at sea level. An increase in 1,000 feet of elevation will result in an increase in audible noise of approximately 1dB(A). Raindrops, snow, fog, frost and condensation accumulated on the conductor surface are also sources of surface irregularities that can increase corona, therefore during wet weather the corona effects are greater (Cigré, 2009; Wordpress, 2011). On account of the significant effect of rainfall on corona discharge, it is discussed in greater detail in Section 2.2.4.

Corona discharge has an inverse relationship with air density and with humidity at power frequencies (i.e. the frequency of oscillation of alternating current in an electric power grid). Corona will generally be greater on new conductors and will decrease to a steady-state value over a period of approximately one year in service (Wordpress, 2011). The trend towards compacting lines has a negative effect on audible noise, therefore there is a balance to be found between the positive and negative effects of compaction (Chartier *et al*, 1995: Cigre, 2009).

2.2.4 The Effect of Rainfall on Corona Discharge

Water droplets are elongated in the electrical field due to their dielectric behaviour. With the deformation of a water droplet, the electric field strength is increased again. Increase in the elongation of the water droplet to a certain extent leads to the formation of what is referred to as a Taylor-cone (Straumann and Fan, 2009). The subsequent instability created by the formation of the Taylor-cone results in a water jet being ejected from the tip of the water drop. With the excessive field strength in this process, corona discharges of various types may set in.

In the event of a corona-discharge occurring, two clear regions can be observed: the ionisation region and the drift region. Figure 2.2 illustrates the location of these two regions in a schematic representation of the corona discharge.

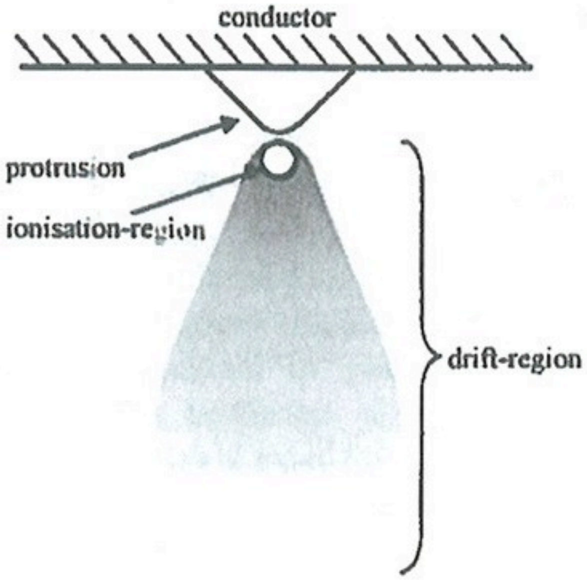


Figure 2.2: Schematic Representation of Corona Discharge (Straumann and Fan, 2009)

Negative ions are formed in the drift region, which drift together with the positive ions in the electric field E. Starting from the conductor, ions can drift over distances of several decimeters during a half-wave. Within the drift zone, there is a build-up of collisions between the ions and the neutral gas. The movements and collisions of ions with neutral gas within the drift zone creates energies and forces that can give rise to the sound emissions typical of corona discharge.

The effect of rainfall on the measured audible noise can be clearly illustrated by the data retrieved from the KEPCO surveys discussed in Section 2.2.2 of this report. Table 2.1 presents the correlation between the rainfall intensity and the measured AN (Al-Faraj *et al,* 1997).

Table 2.1: Relationship between Rainfall Intensity and Measured AN in KEPCO Surveys (Al-Faraj, 1997)

Rainfall Intensity (mm/hour)	**0.1**	**0.5**	**0.9**	**2.3**	**6.6**	**31.9**
Audible Noise [dB(A)]	41.3	43.4	44.2	44.9	48.1	52.0

The study concluded that at higher rainfall intensities, the nuisance effect of corona noise for residents living near the line will become less as the noise from corona discharge is masked by the noise created by the falling rain. Measurement data from the study indicates that audible noise reaches a saturation point at a rain intensity of approximately 30mm/hr.

Measurement of audible noise from a Puget Power 230kV compact line between Sedro Woolley and March Point substations in the USA demonstrated a relatively small difference in the measured L_{50} between heavy rain conditions and wet conductor conditions, a conclusion which contradicted some of the prediction models in standard use (e.g. EPRI, HVTRC) (Chartier *et al*, 1995).

2.2.5 Character of Audible Noise from Corona Discharge

Audible noise from corona discharge has two different character components: broadband noise which is subjectively observed as a frying, cracking or hissing noise; and tonal noise which contains pure tone components at a number frequencies (generally 120Hz and multiples). The pure tone component can be discerned as a noticeable 'hum' which is superimposed on the broadband noise. The broadband noise is caused by a random sequence of pulses produced by partial discharge in the area at the surface of the conductor (Al-Faraj *et al*, 1997).

While much of the literature evidence on the topic of audible noise from corona discharge relates to broadband noise, some research has been undertaken on the tonal aspects of audible noise from corona discharge. Straumann and Fan (2009) completed a theoretical comparison of broadband noise and tonal components from corona audible noise. The basis for their work was the fact that a significant tonal component from corona audible noise (i.e. the 2f component, which is twice the main frequency) had not been adequately investigated in previous studies which concentrated on broadband noise. Standard assessment criteria throughout the world use the A-Weighting noise level for assessing broadband noise as it reflects the sensitivities of the human ear. However, the use of the A-weighting scale results in a much reducing representation of the 2f component in the overall noise level (i.e. it is reduced by 19dB at 100Hz due to the use of A-Weighting).

Despite its reduced representation in the A-weighting, the 2f emission has the potential to present a significant problem as low frequency noise is less likely to be attenuated by building structures and tonal noise is in general perceived of as being annoying. This latter fact is highlighted by the fact that most national regulations add an additional noise penalty where tonal noise is involved (e.g. 5dB penalty in Irish NG4 and UK BS4142:1997 guidance documents) (EPA, 2012; BS4142:1997).

Figure 2.3 shows the lateral profile near the ground of the A-weighted tonal component (100Hz) for the line design investigated in the study with new conductor cables and under moderate rain (Straumann and Fan, 2009). Although the effect of the ions on the gas is small, it is still high enough to evoke a significant tonal emission. The levels included in Figure 2.3 were calculated for new cables, a substantial reduction in this cables is expected with the ageing of the conductors.

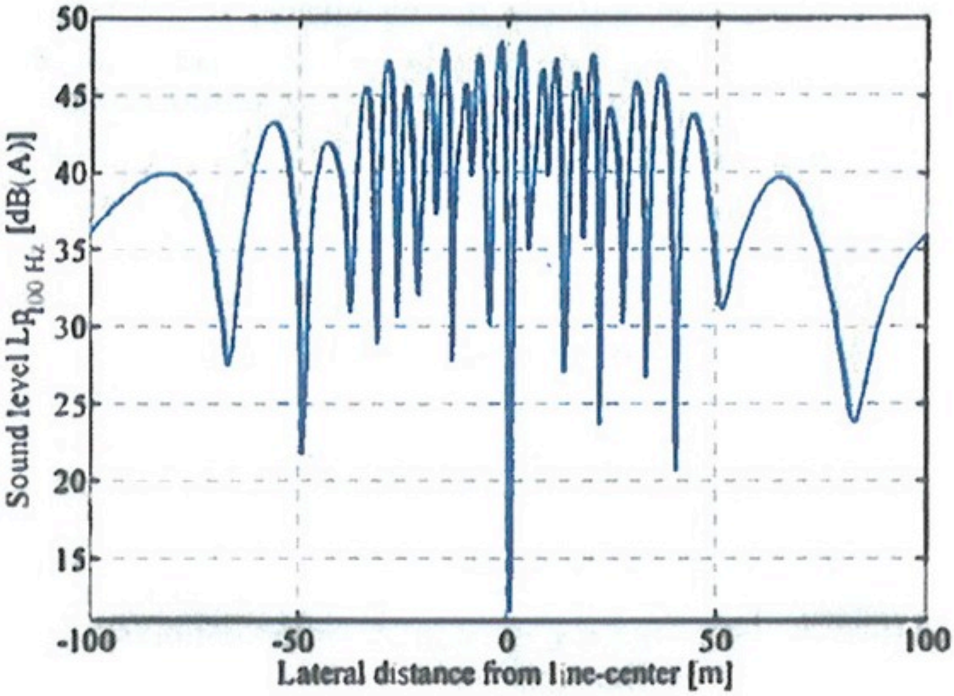


Figure 2.3 Lateral Profile of A-weighted Tonal Component (100Hz) (Straumann and Fan, 2009)

Muhr *et al* (2004) used a narrowband analysis method to analyse the acoustic spectrum of dry and wet conductors as opposed to the usual octave and one-third octave analyses. Energised overhead lines with high AC voltages show a typical acoustic pattern, whereby a double frequency of the supply voltage is noticeable as a 'hum' which is supplemented by broadband noise at the upper frequencies.

The 'hum' effect changes if the line is affected by rain, snow or fog. Figure 2.4 displays a typical frequency spectrum of a transmission line audible noise wet with 40, 50 and 60Hz supply voltage.

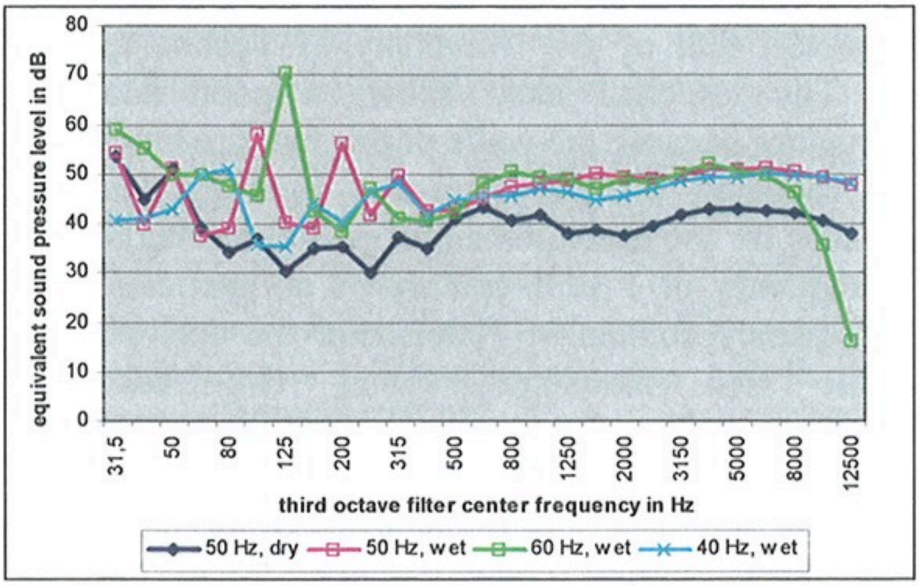


Figure 2.4: Typical Frequency Spectrum of Transmission Line AN Wet with 40, 50 and 60Hz Supply Voltage (Muhr *et al*, 2004)

Figure 2.5 shows the discrete frequency spectrum of a wet overhead transmission line at a voltage from 100kV to 320kV in 20kV steps, the frequency of the supply voltage being 50Hz. The figure illustrates that the even numbered harmonics show a higher sound pressure level than non even numbered harmonics if this spectrum is compared to the equivalent spectrum under dry conditions (see Figure 2.6).

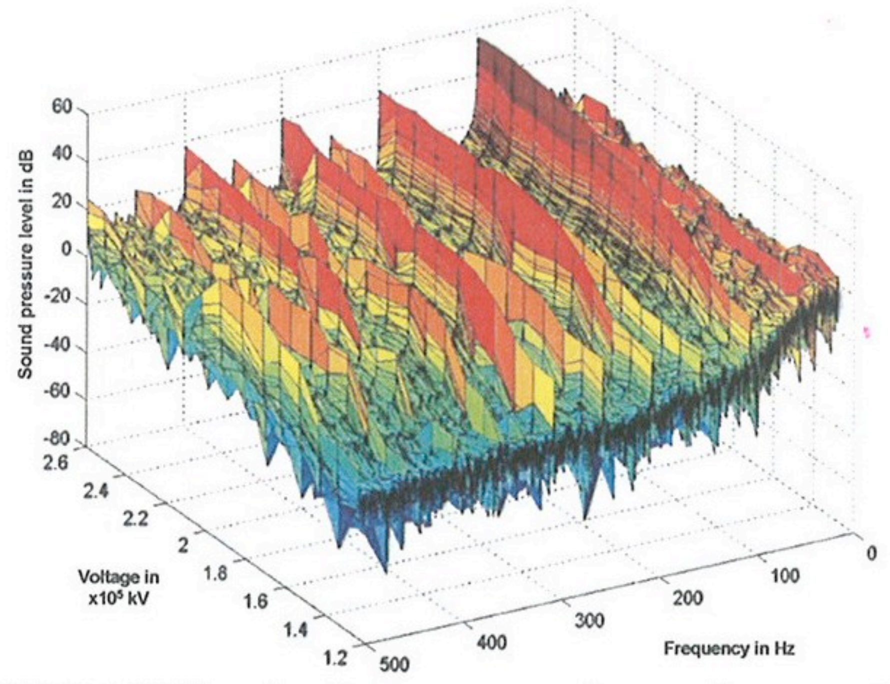


Figure 2.5: Discrete Frequency Pattern of a Wet Overhead Transmission Line (Muhr *et al*, 2004)

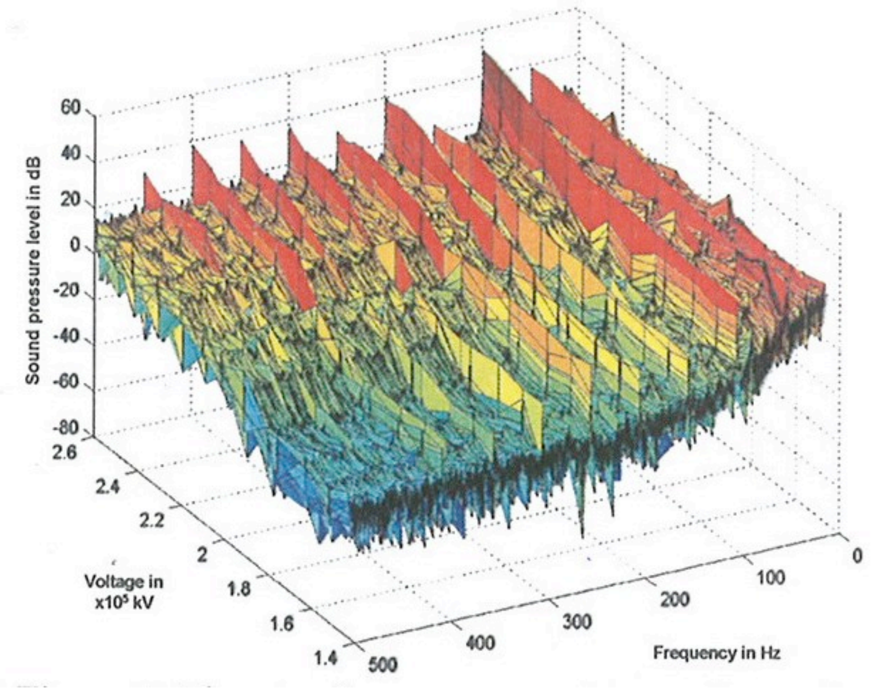


Figure 2.6: Discrete Frequency Pattern of a Dry Overhead Transmission Line (Muhr *et al*, 2004)

2.2.6 Methods for Calculating Audible Noise of High Voltage Transmission Lines

In 1982, subsequent to the emergence of audible noise as a critical design consideration for high voltage transmission lines in USA, the Task Force of the Corona and Field Effects Subcommittee (a subcommittee of the IEEE Transmission and Distribution Committee) published a paper comparing the different methods for calculating audible noise from AC and DC lines. A total of nine methods for AC lines and four methods for DC lines were applied to 4 different bipolar line geometries.

It was not the intention of the paper to recommend a particular calculation method over any other but to provide an objective comparison between methods available at that time. The general conclusion of the paper was that most AC calculation methods give acceptable results for transmission line voltages up to 765kV and a number of conductors per phase of 4 or less. For higher voltages and greater numbers of sub-conductors, fewer methods appear reliable.

More recent use of calculation methods and comparison with measured noise levels has consolidated the view that there is generally good agreement achieved with the standard AC methods. For example, Chartier *et al* (1995) compared the Electrical Power Research Institute (EPRI) and Bonneville Power administration (BPA) methods and found that predicted L_{50} audible noise levels using both methods, were in good agreement with the measured audible noise levels.

2.2.7 Mitigation Measures for Corona Discharge Audible Noise

There are many ways in which corona discharge can be reduced or avoided. One way is by minimising the voltage stress and electrical field gradient, which can be achieved by maximising the distance between conductors that have large voltage differentials, using conductors with large radii and avoiding parts that have sharp points or sharp edges (Wordpress, 2011).

Corona inception voltage can in some instances be increased by using a surface treatment such as semiconductor layer, high voltage putty or corona dope. Usage of a good homogenous insulator, such as a prepared silicone and epoxy potting material, can work well also.

When one is limited to using air as your insulator, geometry is the key factor. In such instances, steps should be taken to reduce or eliminate unwanted voltage transients, which can initiate corona. Using multiple conductors per phase helps reduce resistance and hence corona loss. The use of corona rings help to distribute charge across a wider area, thereby reducing the electric field and the resulting corona discharge.

For the 345-400kV voltage level, bundles of two to three conductors are generally considered sufficient. For voltages exceeding this level, the number of sub-conductors increase and levels of 765kV may require bundles of up to 6 sub-conductors to meet the noise design requirements (Cigré, 2009).

Different types of corona noise countermeasures are being tested in Japan on very high tension overhead lines. One of the most promising methods was the artificial ageing of the conductors by sandblasting and coating with a thin porous boehmite film. Measurements have shown that in the case of new conductors, corona noise levels equal or are even lower than those of equivalent conductors whose surface has become adequately saturable (Cigré, 2009).

Straumann and Weber (2010) have more recently demonstrated that hydrophilic coating of new conductors can cause substantial reduction of audible noise. Hydrophilic coating of well aged conductors was found to be superfluous, as ageing of conductors results in a comparable effect to the hydrophilic coating process. The paper concluded that hydrophilic coating produced the optimal hydrophilicity, but did not explore if hydrophilic coating produced a superior noise reduction in comparison to sandblasting.

2.2.8 Discussion

From reviewing the literature, it is clear that the level of impact likely from electricity transmission lines increases with the increase of the voltage strength of the line. Much of the literature (e.g. Zhang *et al*, 2009; Al-Faraj *et al*, 1997; Straumann and Fan, 2009; Task Force of the Radio Noise an Corona Subcommittee of the Transmission and Distribution Committee, 1975) indicates that corona noise only becomes a significant issue from 350-500kV and above. In terms of this study, this would suggest that significant corona noise impacts may not be likely for 110kV and 220kV transmission lines and that the potential for more significant corona noise impacts may only relate to the 400kV lines. The field surveys set out in Chapter 4 and 5 of this study address this in some detail.

As outlined in Section 2.2.2, many measurement surveys of transmission lines have used the lateral profile method of survey (e.g. Figure 2.1, Cigré, 2009). This was not the approach used in the field surveys for this study, which used a single monitoring location under the transmission lines but with surveys completed both with the line energised and during outage. The lateral profile is a method that can be used when the line is energised and there is no prospect of an outage for the line.

By completing the lateral profile, with distance the noise levels drop to the ambient noise level on either side of the line. As there was the option to complete surveys during outage for this study, this methodology gave an attractive opportunity to make direct comparisons of noise levels under the line during periods of energised and outage at the same location. The predominant use of the L_{50} and L_5 parameters for assessing corona noise was noted in the literature and are incorporated into the analysis of the field survey contained in the subsequent sections of this study.

2.3 AUDIBLE NOISE FROM SUBSTATIONS

2.3.1 Introduction

Audible noise effects can arise from a number of substation equipment such as transformers, quadrature boosters and mechanically switched capacitors (Cigré, 2009). Transformer acoustic noise is a hum characterised by special spikes at harmonics of the fundamental frequency (100Hz/120Hz) which is twice the line supply frequency. The transformer's low frequency tonal noise components are the most likely source of annoyance to nearby residents from substation noise (Masti *et al*, 2004). Figure 2.7 illustrates a typical noise spectrum of a standard transformer (Chang *et al*, 2009).

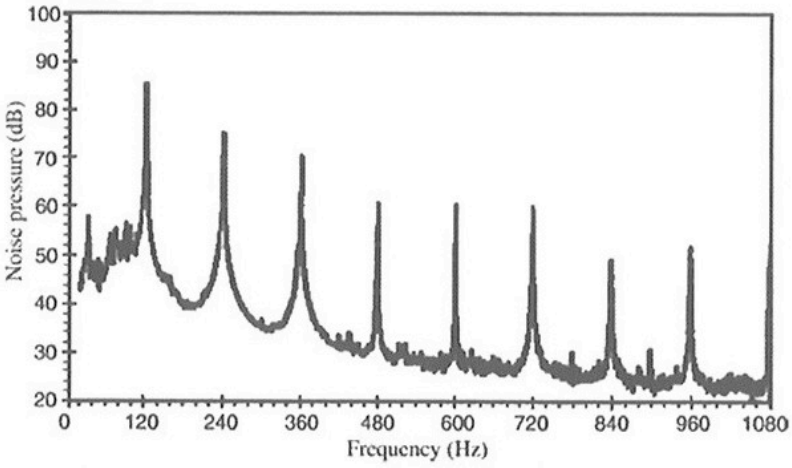


Figure 2.7: Typical Noise Spectrum of a Transformer (Chang et al, 2009)

2.3.2 Source of Noise in Substations

2.3.2.1 Transformers

The primary source of acoustic noise generation in a transformer is the periodic mechanical deformation of the transformer core and the winding coils, under the influence of fluctuating electromagnetic flux associated with these parts (Masti *et al*, 2004). The physical phenomena associated with this tonal noise generation can be classified as follows:

- The material of a transformer core exhibits magnetostrictive properties. The vibration of the core is due to its magnetostrictive strain varying at twice the frequency of the alternating magnetic flux. The frequencies of the magnetic flux is equal to the power system supply frequency and its harmonics.
- When there are residual gaps between laminations of the core, the periodic magneto-motive force may cause the core laminations to strike against each other and produce noise. Also, the periodic mutual forces between the current-carrying coil windings can induce vibrations if there are any loose turns of the coil.

During a transformer's operation, the vibrations from its core and windings get transmitted to the transformer tank surface through transmission through the air surrounding the core. Additional vibrations can be transferred through the structure at the points where the core mount is attached to the tank. The vibrating tank also radiates noise into the exterior air. Taken as a whole, there is a complex set of vibro-acoustic interactions that occur during the standard operation of the transformer and this is presented in a schematic format in Figure 2.8.

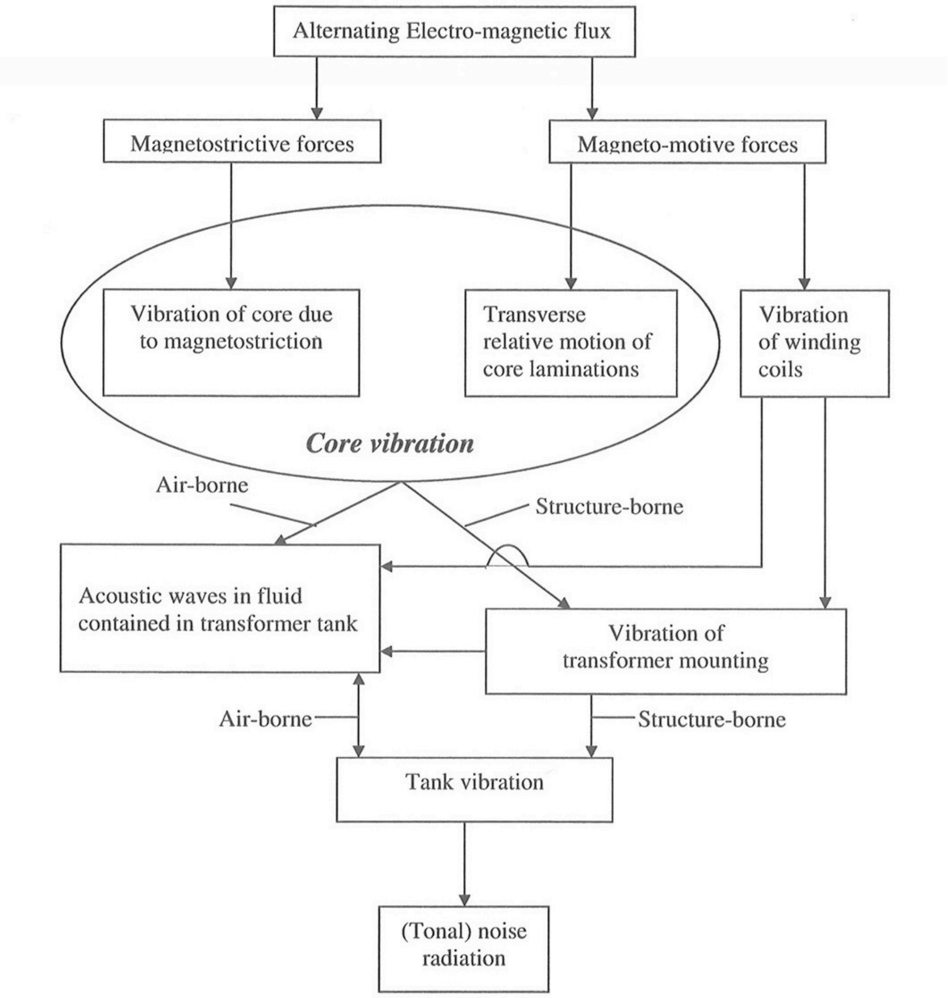


Figure 2.8: Schematic View of Noise Generation and Transmission in a Power Transformer (Masti *et al*, 2004)

Figure 2.9 is photograph of a typical transformer core (400kVA). The yokes and the legs of the core have stepped cross-sectional areas formed by a stacked arrangement of thin laminations. Although clamped, there is scope for relative in-place motion over the remaining interface areas. Laminations do not always have good matching flat surfaces and therefore residual gaps between the laminations can occur. Magneto-motive forces acting across these air gaps can set up relative transfer motions between the laminations.

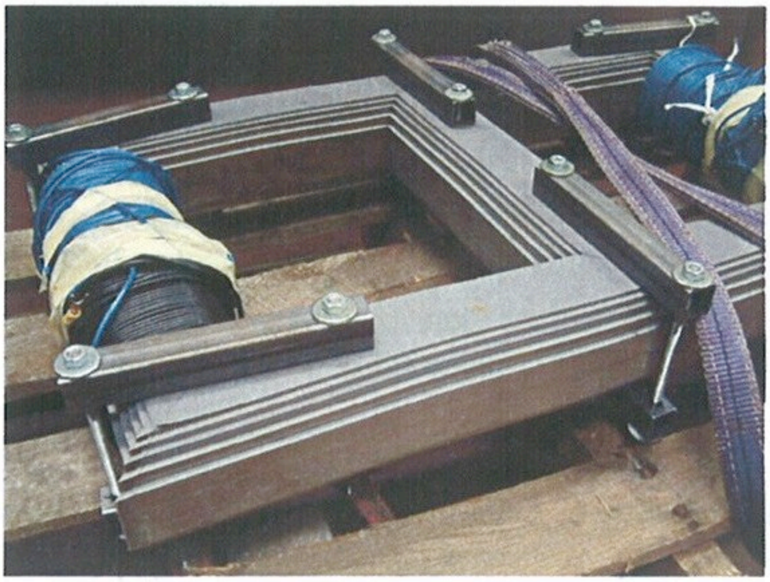


Figure 2.9: Photo of Typical Transformer Core (Masti *et al*, 2004)

2.3.2.2 Other Sources of Noise Within Substations

There is very limited discussion in the literature relating to other specific noise sources from substations other than transformers. One reference has indicated that audible noise effects can arise from quadrature boosters and mechanically switched capacitors, however this is not elaborated upon further (Cigre, 2009). Alternatively, Medeiros and Kroeff (1998) state that there is strong evidence that the only relevant noise sources are the power transformers and associated cooling systems. They state that other sources exist such as infrequent events (e.g. switching operations) of low intensity events (e.g. corona), but these are masked by the transformer noise.

2.3.3 Noise from Substations

There is limited literature available which illustrate direct measurements of audible noise (broadband or narrowband) from substations. Chang *et al* (2009) completed broadband noise measurements of low-noise power transformer design at manufacture stage and in-situ in a location in Austria. The design noise testing which was completed in a noise-isolated room (i.e. background 32dB) and resulted in a noise level of less than 48dB(A) with the transformer operating with inductance of 1.3(T). The exact distance between transformer and measuring point is not stipulated, however it is assumed to be short range. The value of the outdoor measurements completed in-situ are of unknown value as there appears to be significant contamination from other noise sources (especially road noise) in the measured results.

Medeiros and Kroeff (1998) explore aspects of substation noise, including the main considerations for the acoustic modelling of substation noise. Sample models of a typical substation are illustrated, showing predicted noise levels of over 60dB approximately 20 metres from the substation. No substation noise measurements are included in the paper.

Masti *et al* (2004) completed detailed experimentation on the core of the substation transformer using various lamination settings and clamping pressures and the effects the alternative set ups would have on the fundamental frequency. The ultimate objective of the paper was to present the optimum arrangement of lamination and clamp settings to produce the lowest noise output from the transformer. At this stage of development in the project, no noise monitoring had been completed.

2.3.4 Effect of Impulsive Substation Noise on Wireless Communications Systems

A number of papers have reviewed the character of substation impulsive noise and the possibility that impulsive noise from substations has the potential to degrade the performance and reliability of wireless communications systems (Bhatti *et al*, 2009; Shan *et al*, 2009a; Shan *et al*, 2009b; Shan *et al*, 2009c). Typical wireless transceiver designs are based on assumptions that noise is additive, white and Gaussian. These transceivers perform fine in normal environments but their applicability in noise intensive electricity substation environment is not fully understood (Bhatti *et al*, 2009).

Bhatti *et al* (2009) demonstrated that narrowband impulsive noise is more benign than additive white Gaussian noise in both moderately and highly impulsive environments (i.e. environments where impulsive noise events are common, e.g. electrical substations) for low signal to noise ratio (SNR) values but for high SNR values, it substantially degrades the bit error rate (BER) of both IEEE 802.11b and IEEE 802.11a WLAN receivers.

Shan *et al* (2009c) developed a system for the measurement of impulsive noise covering a total frequency range from 716MHz to 5GHz. The system was deployed in a 400kV electricity transmission substation for the characterisation of the substation noise environment at frequencies higher than has previously been attempted. The paper includes an experiment to determine the degrading effect of substation noise on the performance of ZigBee technology, concluding that there was no significant adverse impact on the technology.

2.3.5 Mitigation Measures for Substations

As outlined in Section 2.3.3, Masti *et al* (2004) experimented with various lamination and clamping set ups to derive the optimal set up of the transformer core. They illustrated how the dynamic interaction of the core structure with the surrounding fluid and the core mounting can have significant impacts on the overall generation of noise from the transformer. This paper clearly demonstrated the significant potential for noise reduction at source with transformers.

Belardo *et al* (2006) examined a number of different noise control measures for power transformers. The first part of the paper describes the methods and results of using dynamic vibration absorbers (DA) for the purposes of noise reduction. The principle is to transfer the vibration from the transformer panel to the DA, which has minimal acoustic coupling with the air. The results indicated that DA can reduce the vibration and the sound radiation of the transformer tank panels, but also identifies that there is potential for further improvements as part of further investigations. These include:

- optimising the size and fixing point of the DA on the panel by taking into consideration the coincidence of the wavelength of the panel flexural vibrations and the wavelength of sound in air;
- cancelling the damping of the dynamic absorber;
- fine tuning the natural frequency of the dynamic absorber.

The second part of this paper examined the use of acoustic active cancelling (effectively an 'anti-noise' wave) for transformer noise. The experiments concluded that active noise control is a viable solution for noise related problems generated by large power transformers, especially for control of the first harmonics contained in the noise. Active Noise Cancelling (ANC) works by introducing a cancelling wave through an appropriate array of secondary sources, which are interconnected through an electronic system using a specific processing algorithm for the particular cancellation scheme. Reductions in sound pressure levels up to approximately 20dB may be achieved as long as the phase errors remain considerably small.

Medeiros and Borges (2005) examined ANC with a view to determining the efficiency of a system by means of the attenuation coefficient. A typical application of such a system is the control of the noise emitted by electrical transformers in substations. The various analyses presented in the paper illustrate that an incorrect evaluation of the relationship between local and global attenuation coefficients can lead to an improper estimation of the performance of a system. This work provides a valuable supplement to work on active noise control by highlighting potential stumbling blocks in the design of active noise control systems.

2.3.6 Discussion

The literature review of substation noise has provided a valuable backdrop to the sources of noise from substations and the significant potential for noise reduction at source in substations. Mitigation measures at source should be the first consideration in terms of trying to reduce the potential noise impact associated with any new substation. There is a limited amount of measurement data relating to substation noise, the field surveys of this study provide a valuable source of new data in this regard.

Masti *et al* (2004) indicated that the transformer's low frequency tonal noise components are the most likely source of annoyance to nearby residents from substation noise. The substation noise surveys completed as part of this study included spectral analysis to determine if there were particular tonal features at specific frequency ranges.

2.4 AEOLIAN NOISE FROM ELECTRICAL INFRASTRUCTURE

2.4.1 Introduction

Aeolian noise may occur when wind blows over conductors and insulators or through lattice towers or hollow components like arcing horns. Aeolian noise is independent of the line being energised or not. The noise caused by wind blowing over the electrical infrastructure results from the shedding of air vortices. This noise may become noticeable when wind speeds approach and exceed 10m/s and may become very prominent as wind speeds rise further. The noise however, in many cases will be masked by the noise from rain, if any, or by the wind itself (Cigré, 2009).

2.4.2 General Mechanism of Aeolian Noise

In order to discuss the mechanism of Aeolian noise generation, an example of a conductor is presented in this section. Figure 2.10 shows a model of fluid flow around a cylindrical conductor. A boundary layer, which is significantly affected by viscosity, exists on the surface of the cylinder. The fluid flow is separated from the surface of the cylinder in a region where pressure increases within the boundary layer, thus creating eddies rearward of the cylinder (Akagi *et al*, 1998).

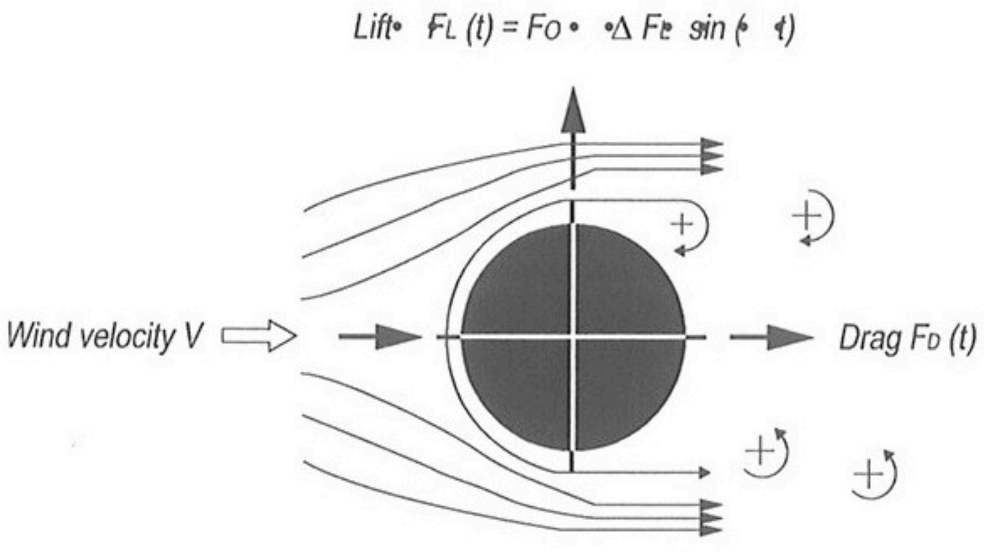


Figure 2.10: Generation Mechanism of Aeolian Noise (Akagi et al, 1998)

The separation of the fluid flow creates areas of lift and areas of drag in the vicinity of the cylinder and it is the interaction between these areas that creates the Aeolian noise. In order to reduce Aeolian noise, it is the lift that must be reduced. The boundary layer flow on the surface ranges from laminar to turbulent depending on the roughness of the surface. The laminar boundary-layer flow on a smooth surface with less surface roughness has a wide range of pressure fluctuation at which separation of flow occurs and the generated Aeolian noise level increases. On the other hand, when turbulence is enhanced by a rough surface, the point of flow separation moves rearward of the conductor and the region of varying separation point becomes narrow, thus decreasing the Aeolian noise levels.

2.4.3 Aeolian Noise Characteristics

Akagi *et al* (1998) conducted wind tunnel experiments on various sized conductors to determine the extent and characteristics of the Aeolian noise. The spectral analysis of Aeolian noise generated from a 4-bundle conductor (ACSR 410mm^2) system produced a predominant spectrum in a low frequency range from 50Hz to 250Hz. Figure 2.11 shows a spectral analysis of Aeolian noise from an 8-bundle conductor system (LN-ACSR 960mm^2) at a 20m/s wind velocity. The graph shows the significant reduction in noise level at the predominant frequency (i.e. more than 10dB) when compared with a standard conductor system, the ACSR 810 mm^2. The graph also illustrates that this reduction using the 8-bundle conductor is similar to the reduction achieved by the standard ACSR 810 mm^2 using spiral rods (See Section 2.4.4) (Akagi *et al*, 1998).

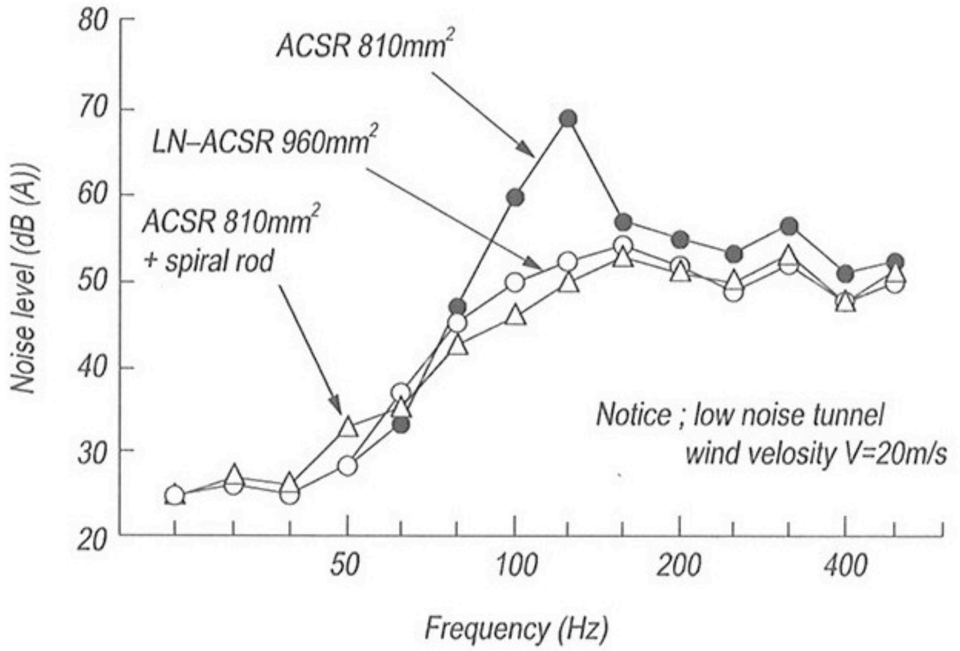


Figure 2.11: Aeolian Noise Characteristics of an 8-Bundle LN-ACSR 960 mm^2 Conductor (Akagi *et al*, 1998)

2.4.4 Mitigation Measures

Section 2.4.3 has highlighted the significant attenuation that can be achieved by using alternative sized conductor bundles and by using spiral rods instead of the standard straight rods with the conductors (Figure 2.11). Figure 2.12 shows a photograph of the spiral road method, an effective countermeasure to reducing Aeolian noise. In this method, aluminium wires are wound around the conductor. The outer diameter and the pitch of spiral rods have been optimised by experiments in a low-noise wind tunnel. As a result of the use of the spiral rod method, Aeolian noise can generally be decreased in the predominant frequency band range by 10dB or more.

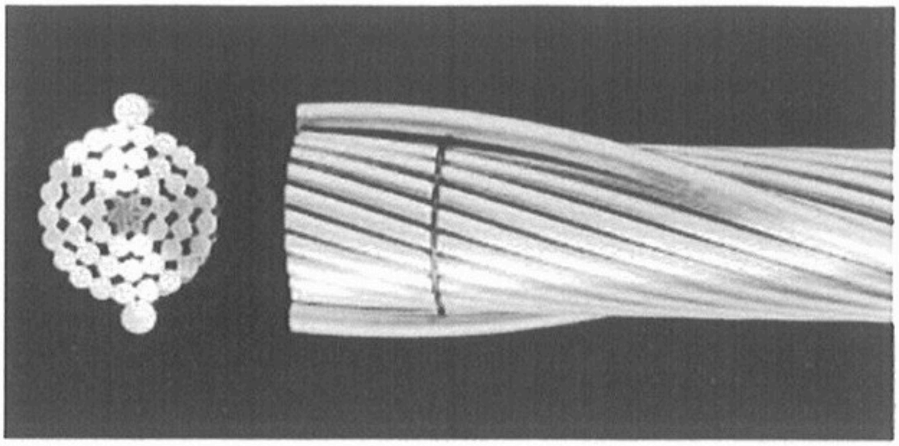


Figure 2.12: The Spiral Rod Method (Akagi *et al*, 1998)

Aeolian noise generated from a conductor is a phenomenon in which pressure fluctuation in a domain (i.e. where the air separates from the conductor surface) propagates as noise. Therefore, the pressure fluctuations can be reduced by changing the boundary-layer flow on the conductor surface to a turbulent state. The conductor surface has a certain roughness, so to create increased turbulent flow over the surface, coarser roughness (protrusions) can be added to the surface.

Akagi *et al* (1998) completed various experiments measuring Aeolian noise on conductor systems with various heights and angles of protrusions. Figure 2.13 shows the behaviour of Aeolian noise characteristics by applying a protrusion height of 1.5mm and a protrusion angle of 20-120 degrees, giving a 15dB noise reduction for this particular single conductor system. In the case of multi-bundle conductor transmission lines, Aeolian noise can be problematic as the effect of turbulence on the windward side conductors may influence the surrounding state of the leeward-side conductors. Experiments completed on the two conductor system model concluded that the optimum protrusion height was 2.5mm and protrusion angle approximately 45 degrees for such a system.

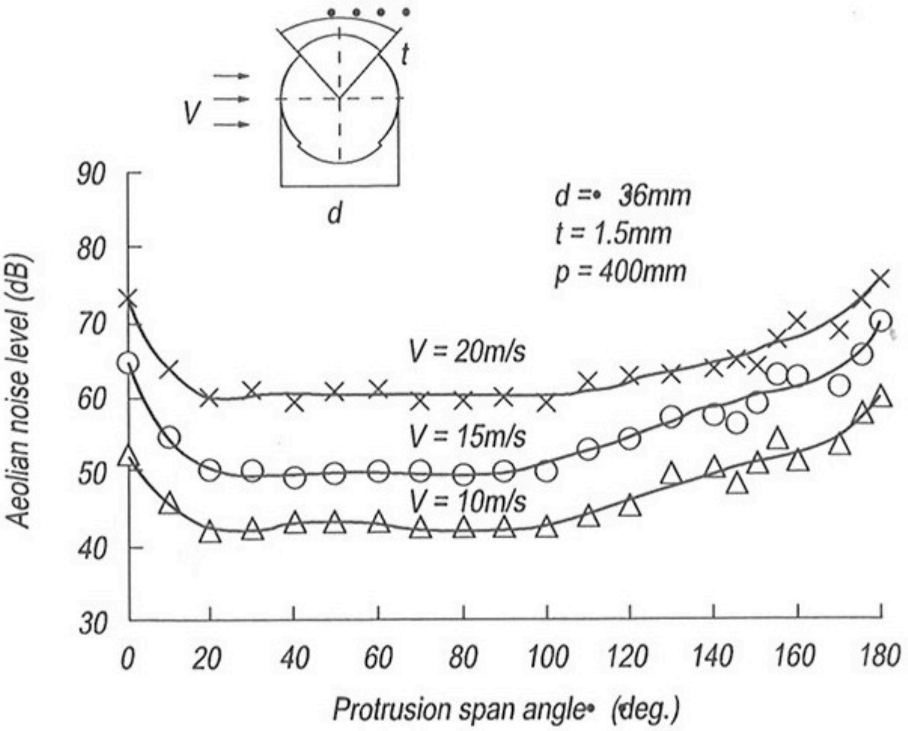


Figure 2.13: Relationship Between Protrusion Height and Aeolian Noise Level in a single Conductor System (Akagi *et al*, 1998)

Aeolian noise around insulators may occur also at high wind speeds for certain insulator configurations and designs. The occurrence of this type of noise is difficult to anticipate but it can be reduced by using composite insulators instead of glass or porcelain insulators, by changing the rib profile or the type of insulators in the string or by introducing a number of different profile insulators in the string (Cigre, 2009)

2.4.5 Discussion

Aeolian noise is very different to the other noise sources associated with electricity infrastructure, most notably because it does not relate to whether the infrastructure is energised or not. As the conditions required to generate Aeolian noise are very specific in terms of requiring high wind speeds at very specific angles of incidence, it is not as common as the other sources of noise associated with electricity infrastructure. The conditions that give rise to Aeolian noise (i.e. high wind speeds) will in most instances also mask the Aeolian noise. For the reasons stated above, Aeolian noise has generally not been perceived of as presenting a very significant noise impact at sensitive receptors (e.g. Cigré, 2009, DECC, 2011).

In terms of measurement of Aeolian noise, any significant measurement data and analysis in the literature relates to wind tunnel experiments (e.g. Akagi *et al*, 1998). Attempting to measure Aeolian noise along existing electricity infrastructure is fraught with difficulty on account of the not being in a position to anticipate its onset. The literature evidence would suggest that there is no standard or practical method for measuring and analysing Aeolian noise from existing infrastructure. On the basis of this, the measurement and analysis of Aeolian noise has not formed a significant consideration in the field surveys of this study.

The review of literature on Aeolian noise does demonstrate that there is significant potential for the reduction of Aeolian noise by applying a number of different mitigating measures as detailed in Section 2.4.4 of this report. The construction of any new electrical infrastructure on the EirGrid network should be done with full consideration of the mitigation measures available for the reduction of Aeolian noise.

2.5 HEALTH EFFECTS OF NOISE

In 1999, the World Health Organisation (WHO) published a report on the effects of environmental noise on human communities (WHO, 1999). This report outlined the research and consolidated views with regard to the health effects that environmental noise was known or suspected to cause on human communities. The most significant health effects were identified as hearing impairment, interference with speech communications, sleep disturbance, cardiovascular and physiological effects, mental health effects, effects on performance and effects on residential behaviour and annoyance.

The most prominent noise sources specifically referred to were industrial, transportation, construction, building services, domestic and leisure activity noise. No specific reference was made to noise from electricity plant or equipment.

The WHO 1999 Guidelines set threshold limits for moderate and serious annoyance (i.e. 50dB and 55dB $L_{Aeq\ 16hrs}$) and a range of internal room noise thresholds based around the requirements for speech intelligibility and sleep disturbance for various room types. While this study has illustrated the potential for noise impacts from electrical infrastructure under various conditions, such noise sources have had little literary review in terms of health effects, as noise from electrical plant and equipment is generally considerably less significant than noise from other sources (e.g. industry, road, rail, airports).

In 2009, the WHO published an additional report aimed specifically at examining the health effects from night-time environmental noise (WHO, 2009). No specific discussion of noise from electrical plant or equipment was included in this report; however noise threshold limits for night-time were included which illustrated where environmental noise was known to cause effects. Table 2 includes a summary of effects and threshold noise levels for effects where sufficient evidence is available. These threshold limits apply to all environmental noise sources, including noise from electrical plant and equipment.

While the literature base shows very limited reference to the health effects associated specifically with electrical plant and equipment, it is clear from the threshold limits outlined in Table 2.2 below that there is the potential for noise from electricity infrastructure to exceed these threshold limits under various scenarios, and hence contribute to the health effects discussed in the WHO Night Noise Guidelines.

Table 2.2: Summary of Health Effects and Noise Threshold Limits (WHO, 2009)

Effect		Indicator	Threshold (dB)
Biological Effects	EEG Awakening	$L_{Amax, inside}$	35
	Motility, Onset of motility	$L_{Amax, inside}$	32
	Changes in duration of various stages of sleep, in sleep structure and fragmentation of sleep	$L_{Amax, inside}$	35
Sleep Quality	Waking up in the night and/or too early in the morning	$L_{Amax, inside}$	42
	Increase average motility when sleeping	$L_{night, outside}$	42
Well-being	Self-reported sleep disturbance	$L_{night, outside}$	42
	Use of somnifacient drugs and sedatives	$L_{night, outside}$	40
Medical Conditions	Environmental insomnia	$L_{night, outside}$	42

The WHO published a further report in 2011 outlining in detail the synthesised reviews of evidence on the relationship between environmental noise and specific health effects (WHO, 2011). As with the 2009 report, the aim of this report was to supplement the 1999 guidelines and incorporate all of the most recent developments in the research of the health effects of environmental noise. Noise from electrical plant and equipment was not discussed directly, but this source of noise is assumed under the heading of environmental noise.

In addition to the broad ranging coverage of the health effects from environmental noise in the WHO reports, additional reports and research papers have been published covering various aspects of the health effects associated with environmental noise. One example is a UK government sponsored review document into low frequency noise and its effects (Leventhall, 2003). This document includes a section on the health effects associated with low frequency noise exposure for humans which can be directly related to the various low frequency noise impacts from electrical plant and equipment as outlined in this literature review under the headings for corona, substation and Aeolian noise.

Meyer et al (1989) includes a review of published data in relation to the potential for physical agents such as noise and electromagnetic fields to provide an adverse impact on reproductive outcomes. The paper presents published data on possible biological mechanisms, considerations for exposure assessments and suggestions for further epidemiological research.

3 METHODOLOGY

3.1 SITE SELECTION

3.1.1 Site Selection Criteria

The general rationale for site selection in respect of this noise study was that representative noise data could be measured for each of the principal types of infrastructure associated with the Irish electricity transmission network. The four principal types of infrastructure considered in the studies were substations, 110kV OHL, 220kV OHL and 400kV OHL.

There is a 275kV double circuit OHL between Louth and Tandragee (Northern Ireland) substations. This was not included in the site selection process as there are no plans to use this infrastructure type in the future on the Irish electricity network. Again as previously noted, underground cables were not considered in the site selection process as they are not a source of significant noise emissions.

The initial concept for the site selection process was to select a relatively large number of sample locations (e.g.100) over a wide range of different land use types (e.g. urban, suburban, agricultural, forest, open, wetland, coastal etc.). Consideration would also be given to topography (i.e. upland, lowland etc.), the sensitivity of the landscape and the presence of specific ecological designations (e.g. Special Areas of Conservation, Special Protection Areas, National parks, Nature Reserves etc.). The site selection process would also build in the effect of distance between the relevant electricity infrastructure and the respective sensitive location/land use.

As the site selection process developed, the key emerging issue was how noise monitoring surveys could isolate and record noise from electricity infrastructure and ensure that the noise measurements were not contaminated with any number of other noise sources in the respective study area. After further consideration of this issue, it was clear that only a survey strategy that was based around the EirGrid outage programme could achieve an effective means of recording the noise levels associated with the live infrastructure.

Based on this new approach, the focus in the site selection process shifted from choosing a large number of sample locations in varied environments to selecting a smaller number of locations where more extensive surveys could be arranged around the outage schedule. By measuring noise levels in close proximity to the relevant infrastructure for a sufficient period of time with the infrastructure live, and then again during a period of outage, the variation in noise levels during different periods of the day and different weather conditions could be established for both scenarios. Analysis of the datasets would reveal how the noise levels compared for both scenarios at the same time of day under the same weather conditions.

By focusing surveys around the outage programme, it would be possible to determine if certain types of electrical infrastructure produced an audible noise that could be directly observed as an increase in the measured noise levels and to what extent the noise levels increased (i.e. what decibel level). This strategy would produce very clear evidence on whether various types of infrastructure did or did not result in elevated noise levels. The previous strategy of using a large number of sample points in various locations was flawed in that there was no means of determining whether the measured noise levels were or were not linked to the electrical infrastructure.

Having established the strategy to be adopted for the surveys, EirGrid's outage programme was reviewed. A record was made of all OHL (110kV, 220kV and 400kV) that were scheduled for outage for a period of time that would enable a sufficient sample of noise levels to recorded (i.e. approximately one week). This list of OHL was reviewed with a view to determining which of these were most suitable for the purposes of the noise surveys. OHL that had sections of line that were a significant distance from other noise sources (e.g. roads, industries, running water etc.) were sought.

The number of sites used for each type of infrastructure as part of the study reflects the relative prevalence of each type of infrastructure in the transmission network. This was also reflected in the number of each type of infrastructure that was included in the outage programme. For this reason, more surveys were completed on the 110kV overhead line network, followed by the 220kV network and lastly the 400kV network. For the purposes of reference in this document, all surveys completed on overhead lines while infrastructure has been live are referred to as 'On' surveys, while all surveys completed on overhead lines during periods of outage are referred to as 'Off' surveys.

While the outage programme presented a direct means of determining what noise emission were associated with OHL, this strategy was not practical in terms of surveying substations. While various items of plant in substations were scheduled for outage, no overall existing substation was scheduled for outage at one time. Leaving aside potential corona noise, substations typically produce a steady state noise level (or hum) which could be recorded by short-term noise measurements. For these reasons, the noise surveys completed for substations involved short-term measurements in the vicinity of the boundaries of the substation sites.

3.1.2 Outline of Sites Selected

On the 110kV overhead line network, surveys were completed during live periods and during outage periods at the following locations:

- Golagh Tee - Letterkenny 110kV overhead line;
- Cathleen's Fall (C'Fall) Golagh Tee - Letterkenny 110kV overhead line (1)
- Cathleen's Fall (C'Fall) Golagh Tee - Letterkenny 110kV overhead line (2)
- Cathleen's Fall (C'Fall) - Srananagh - 110kV overhead line.

The locations of the four monitoring points for the OHL listed above are illustrated in Figures 3.1 to 3.4.

Figure 3.1: Noise Monitoring Location on Golagh Tee - Letterkenny 110kV OHL

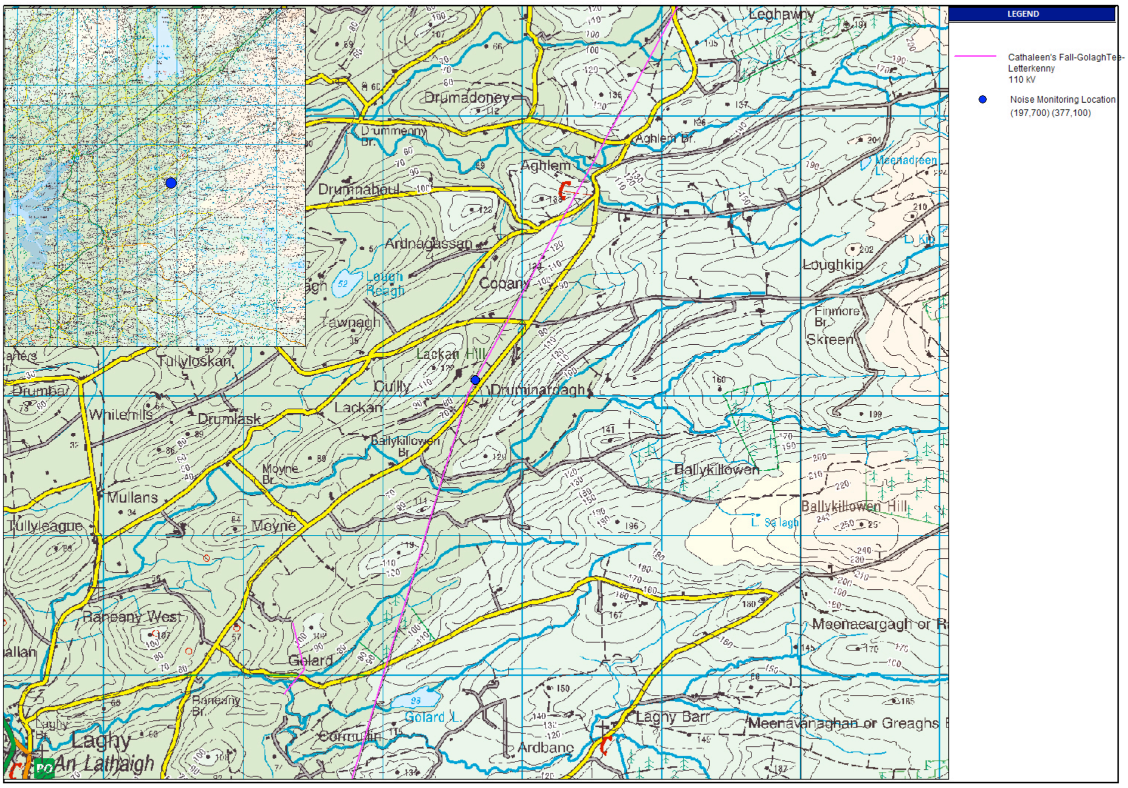


Figure 3.2: Noise Monitoring Location on C'Fall Golagh Tee - Letterkenny 110kV OHL (1)

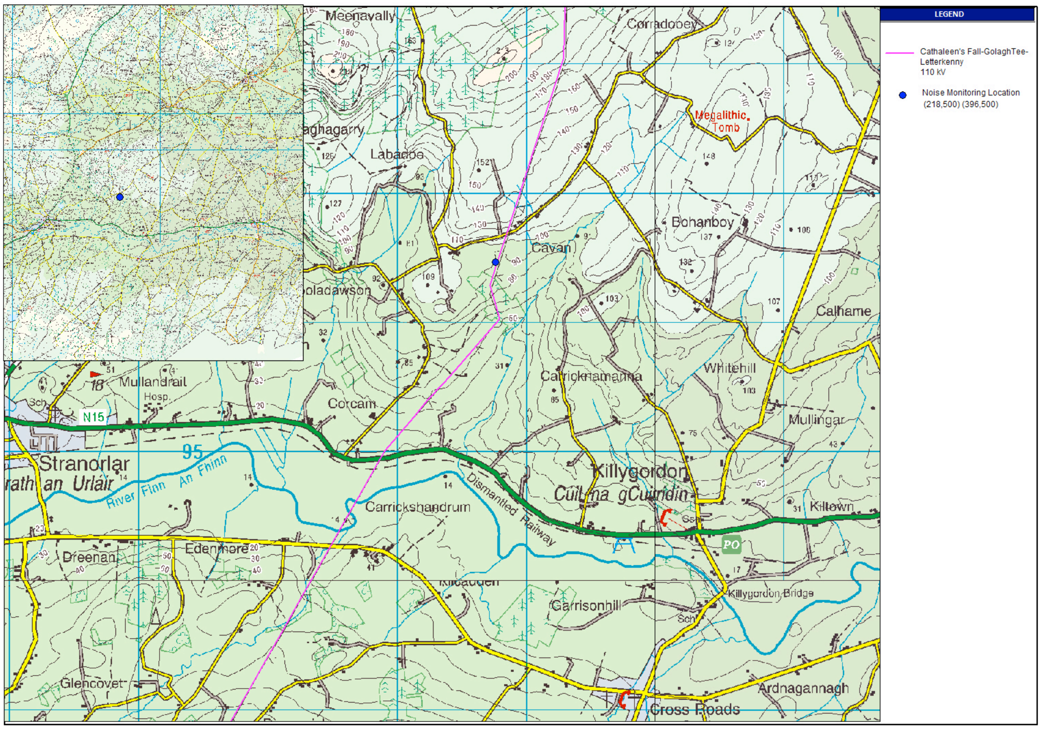


Figure 3.3: Noise Monitoring Location on C'Fall Golagh Tee - Letterkenny 110kV OHL (2)

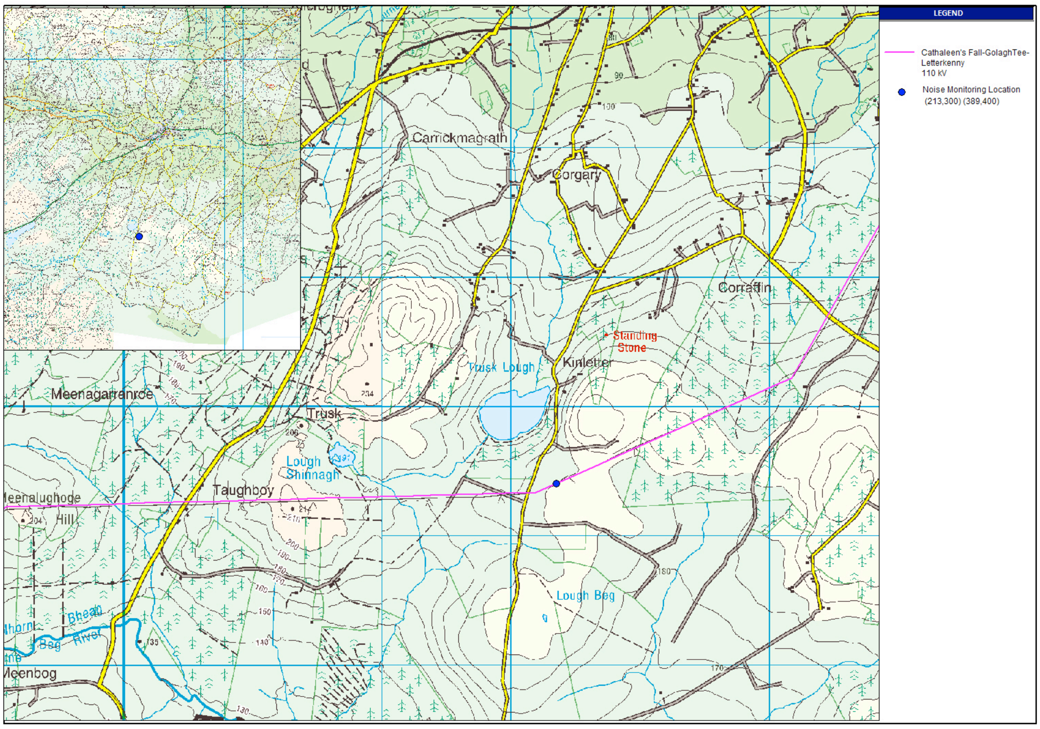
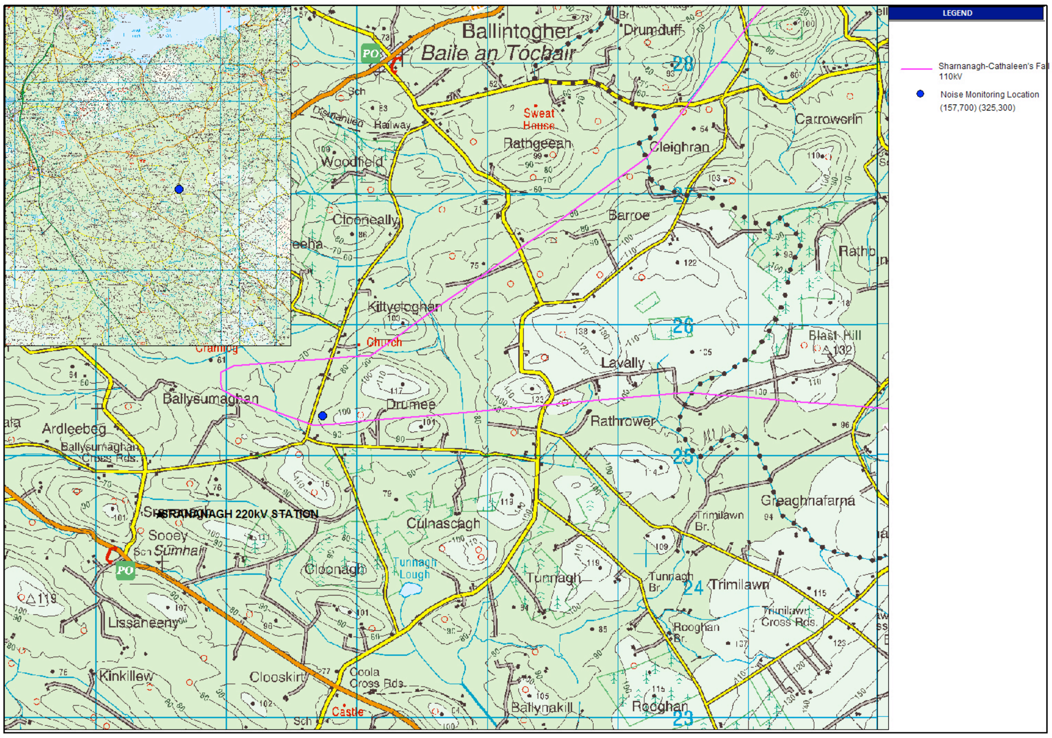


Figure 3.4: Noise Monitoring Location on C'Fall - Srananagh 110kV OHL



On the 220kV overhead line network, surveys were completed during live periods and during outage periods at the following locations:

- Dunstown - Maynooth 220kV overhead line (Betaghstown);
- Dunstown - Maynooth 220kV overhead line (Currabell);
- Dunstown - Maynooth 220kV overhead line (Thomastown);

The locations of the three monitoring points on the Dunstown - Maynooth 220kV overhead line are illustrated in Figures 3.5 to 3.7.

Figure 3.5: Noise Monitoring Location on Dunstown - Maynooth (Betaghstown) 220kV OHL

Figure 3.6: Noise Monitoring Location on Dunstown - Maynooth (Currabell) 220kV OHL

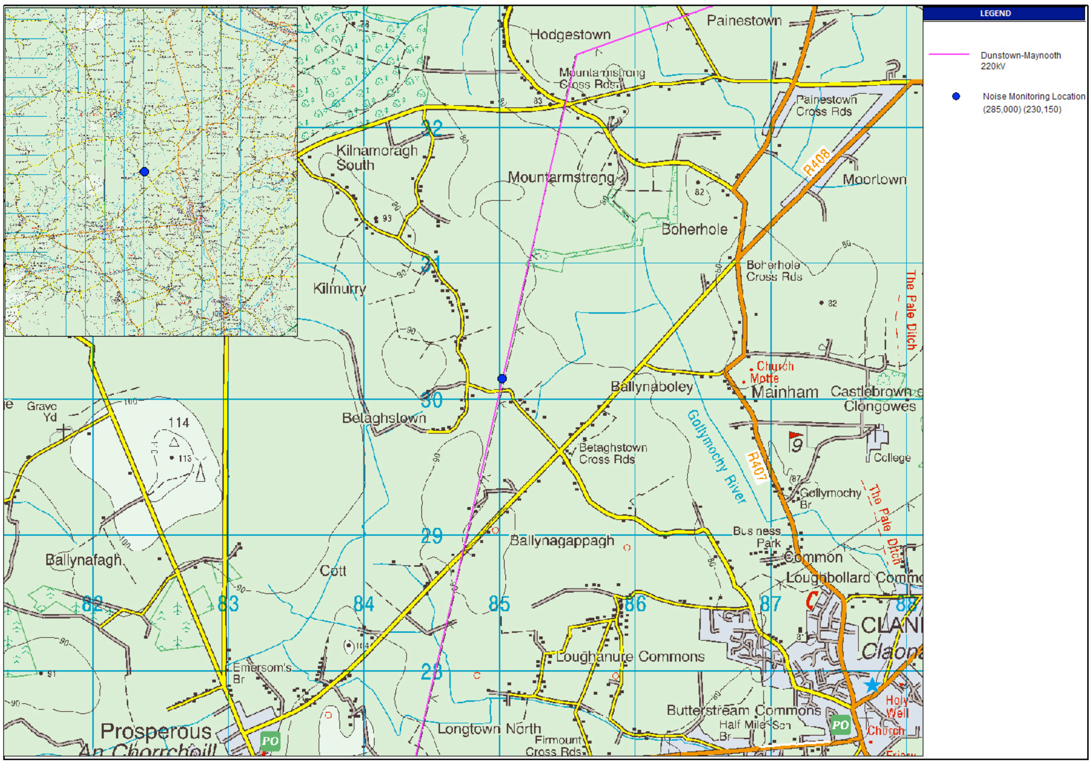


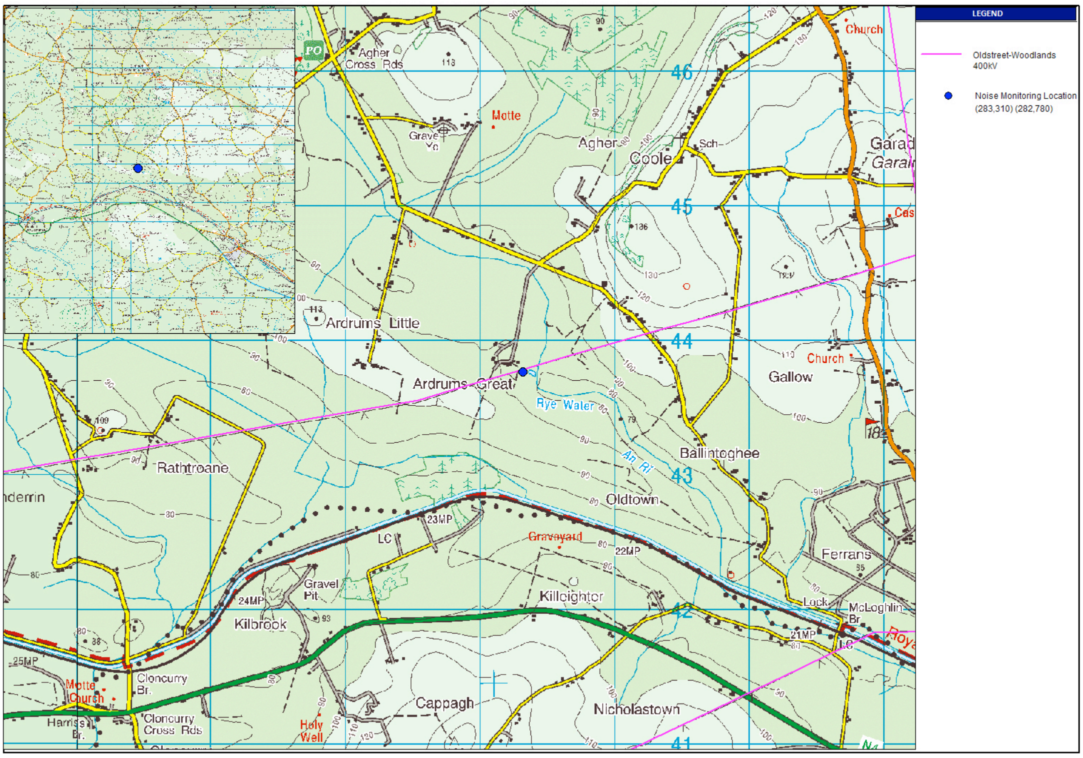
Figure 3.7: Noise Monitoring Location on Dunstown - Maynooth (Thomastown) 220kV OHL

On the 400kV overhead line network, surveys were completed during live periods and during outage periods at the following location:

- Oldstreet - Woodland 400kV OHL (Ardrums Great).

The location of the monitoring point on the Oldstreet - Woodland 400kV overhead line is illustrated in Figure 3.8.

Figure 3.8: Noise Monitoring Location on Oldstreet - Woodland (Ardrum Great) 400kV OHL



Noise measurement surveys were completed at the following substation sites:

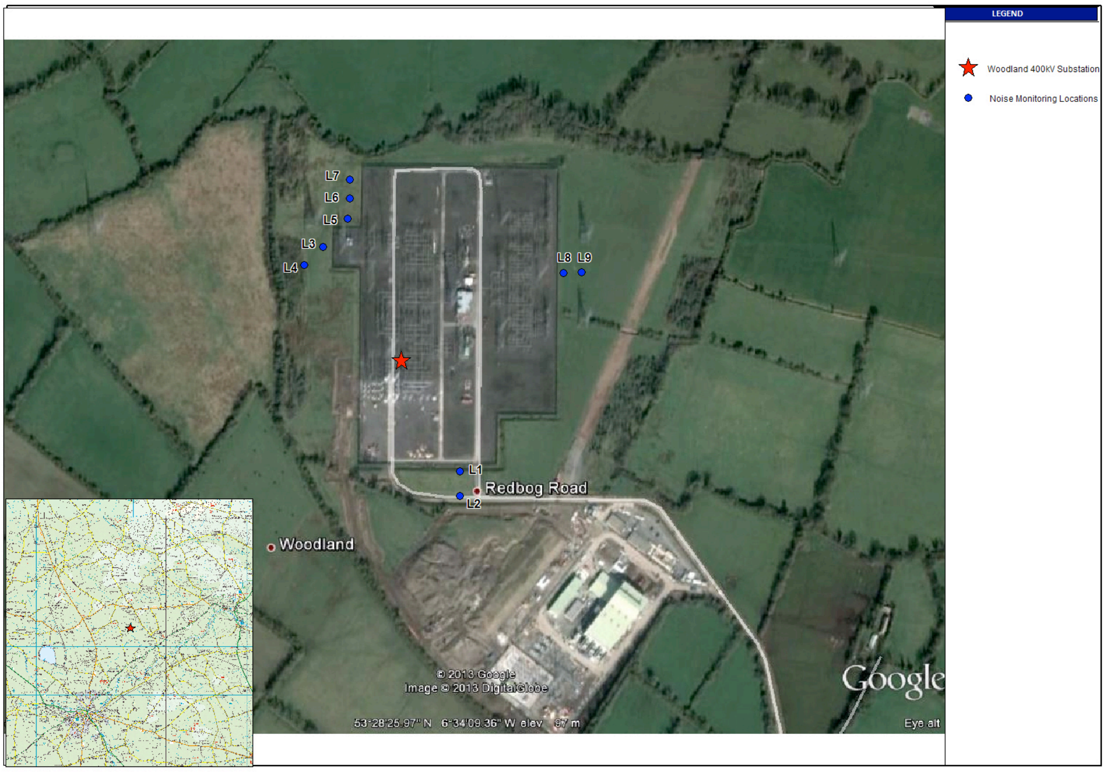
- Dunfirth 110kv Substation;
- Gorman 220kV Substation;
- Woodland 400kV Substation.

The locations of the monitoring points at the substations listed above are illustrated in Figures 3.9 to 3.11.

Figure 3.9: Noise Monitoring Locations at Dunfirth 110kV Substation

Figure 3.10: Noise Monitoring Locations at Gorman 220kV Substation

Figure 3.11: Noise Monitoring Locations at Woodland 400kV Substation



3.1.3 Limitations to Site Selection Process

On account of the survey strategy being worked around the outage programme, the most obvious limitation to the site selection process was the availability of suitable sites that were scheduled for a period of outage during the relevant survey window.

As the majority of the OHL transmission network consists of 110kV lines, there was a significant number of 110kV lines included in the outage programme. It was a relatively simple task to identify suitable locations along the 110kV network for undertaking site surveys.

The number of 220kV lines that were included in the outage programme was more limited and therefore the process of identifying suitable survey locations were more constrained. On account of the significant timeframe which the Dunstown-Maynooth 220kV line was scheduled for outage, multiple locations along this line were selected.

The number of opportunities for completing surveys during periods of outage on the 400kV network was very limited and this was reflected in the fact that only one survey could be completed on the 400kV network.

The choice of substation sites was not limited to the outage programme, and therefore there were more options available in determining which substation sites would be used for the surveys.

3.2 NOISE SURVEY METHODOLOGY

3.2.1 Survey Equipment - Overhead Lines

All noise monitoring surveys were completed using outdoor unattended noise monitoring kits. All of the noise monitoring kits used conformed to the requirements for integrating averaging sound level meters (Type 1) as specified in BS EN 60804. All noise monitoring equipment was accurately calibrated before use. All measurements were made at a height of 1.2 - 1.5m above ground level and all meters were placed directly in the path of the overhead line.

Noise measurements at all of the monitoring locations were recorded using the following noise monitoring equipment:

1. Rion NL-32 Class 1 Sound Level Analyser; Outdoor kit enhanced NL-31/32; Rion WS-03SO1 Windscreen head assembly (inc WS-03051); Rion EC-04 2m Extension Cable (7 Pin) and Rion NC-74 Class 1 Acoustic Calibrator.

2. Brüel & Kjær Type 2250 (BZ7224 Version 1.4.) with Brüel & Kjær Type 4189 0.25” microphone, mounted on an UA1404 weatherproof environmental kit. The monitoring kit was powered by 2 no. fused 12 volt valve regulated lead acid batteries and housed in a sealed iM2700 Stormcase.

Weather data was recorded at each site using a Davis Vantage Pro2 Met Station with Davis Weather Envoy logger and Meteovue GPRS Modem. The met station was equipped to measure wind speed, wind direction, rainfall, temperature and humidity. All measurement periods for the weather station were synchronised with the measurement periods for the noise monitoring equipment.

The met station was configured to log data to a server via GPRS so as weather conditions could be observed remotely in real time. On a number of occasions however, the GPRS modem failed to connect and transmit this data to the server. It is not clear as to whether this was an intermittent fault with the modem, the server or the local mobile network. As highlighted in Section 3.2.3 and 4.3.1 some of the weather data for the 400kV Oldstreet- Woodland survey was lost on account of this.

3.2.2 Survey Methodology - Overhead Lines

Section 3.1 outlines the site selection strategy and lists the sites where noise monitoring was completed. Section 3.2.1 gives details of the noise monitoring equipment and the weather recoding equipment used for the surveys. The general strategy for each location was to obtain approximately one week of data when the infrastructure was live and one week of data during the period of outage. There was some variation on this during the surveys as conditions arose which altered the length of surveys in particular instances.

At each location, the noise meter and the weather station were synchronised to record in short logging periods of either 15 minutes or 30 minutes. During each logging period, a range of noise parameters were recorded including L_{Aeq}, L_{Amax}, L_{Amin}, L_{A5}, L_{A10}, L_{A50} and L_{A90}. The parameters that were extracted for the purposes of analysis are listed below with a brief explanation regarding the relevance of the parameter:

- **L_{Aeq}** The continuous equivalent A-weighted sound pressure level. This is an “average” of the sound pressure level for the relevant measurement period

- **L_{A5}** This is the A-weighted sound level that is exceeded for 5% of the sample period and is commonly used in the literature relating to noise from electrical infrastructure.

- **L_{A50}** This is the A-weighted sound level that is exceeded for 50% of the sample period and is commonly used in the literature relating to noise from electrical infrastructure.

- **L_{A90}** This is the A-weighted sound level that is exceeded for 90% of the sample period and is commonly used as a reference for recording the 'background' noise level.

Parameters such as L_{Amax}, L_{Amin} and L_{A10} were not used in the analysis of the datasets as they did not offer any insight in terms of establishing what noise levels are associated with electrical infrastructure.

3.2.3 Problems Encountered During Surveys - Overhead Lines

During the 'On' survey at Cathleen’s Fall Golagh Tee - Letterkenny 110KV (2), livestock were introduced into the field that contained the noise and weather monitoring equipment. The dataset that was retrieved for this survey showed a substantial difference to the measured noise levels for the 'Off' survey completed at the same site. These substantial differences were not observed in the other 110kV or 220kV survey results, and therefore the only conclusion to be drawn was that the dataset was subject to significant contamination from the animals in the field during the 'On' survey. This dataset was therefore not used for the purposes of drawing conclusions based around the survey findings in the noise study.

During the 'Off' survey on the Oldstreet - Woodland 400kV OHL, a weather station malfunction meant that a portion of weather data for this survey was not recorded. The loss of this data meant that the analysis of the two datasets for this line was completed with more emphasis on the entire dataset and the use of graphical representations to illustrate analytical conclusions. Further discussion of this data deficiency is included in Section 4.3.1 of this report.

3.2.4 Survey Equipment - Substations

Noise measurements at all of the substation monitoring locations were recorded using a Brüel & Kjær Type 2250 (BZ7223 Version 1.5) with Brüel & Kjær Type 4189 0.25” microphone mounted on an UA-0801 Lightweight tripod.

3.2.5 Survey Methodology - Substations

Completing long-term noise surveys at substations was not a practical consideration for this study as the outage programme did not allow for an entire substation to be scheduled for outage at one time. The outage programme only allowed for individual items within a substation to be scheduled for outage, therefore there was no means of getting direct comparable data for complete substations in 'On' and 'Off' modes.

The primary purpose of the substation noise surveys was to record the steady state noise level (or 'hum') associated with substations of varying voltage (i.e. 110kV, 220kV or 400kV). By completing noise measurements at varying distances from the substation boundaries, the noise levels associated with the substation could be determined.

The same parameters as were used for the overhead line surveys were recorded for the substation surveys, namely L_{Aeq}, L_{A5}, L_{A50} and L_{A90}. In addition to this, spectral analysis was completed at all of the substation sites between frequencies 12.5Hz and 20kHz.

3.3 METHODOLOGY FOR ANALYSIS OF DATA

3.3.1 Overhead Lines

Sections 3.1 and 3.2 outlined the site selection process and the survey methodology used for the evidence based noise studies. Based on the strategy used for the surveys, large datasets (>100 hours in most instances) were recorded at each measurement location for the two principal scenarios (i.e. with infrastructure live and during outage).

The main aim of the analysis process was to determine if there was any clear difference between the data for both scenarios which would provide evidence that the live infrastructure is producing noise emissions that are detectable. In order to do this, it was imperative to remove all other noise sources from the datasets to ensure that a like for like comparison could be made. For ease of reference in this report, the survey with the infrastructure live will commonly be referred to as the 'On' survey while the survey completed during the period of outage will be referred to as the 'Off' survey.

The first part of this process of removing other noise sources from consideration was covered in the site selection process. As far as reasonably practicable, quiet survey locations were selected on the basis of their distance from all obvious noise sources in the study area (e.g. roads, industry, running water etc.). It was understood as part of this process that there was no guarantee in avoiding certain potential noise sources (e.g. animal noises, agricultural plant etc.). However, the data analysis did include a mechanism for extracting random noisy periods from the dataset, as further elaborated upon in the text below.

The second part of this process was to refine all of the datasets so that like for like comparisons could be procured For every dataset, all of the recorded noise parameters (L_{Aeq}, L_{A50}, L_{A5}, L_{A90}) were synchronised in 15 or 30 minute logging periods with the weather data. Each dataset was divided up into four different datasets based on different time periods as follows:

- All data for the survey period;
- Data during weekdays only (i.e. Monday to Friday, 08:00 - 18:00 hours);
- Data during night time only (i.e. every day, 23:00 - 07:00 hours);
- Data during quiet daytime periods only (i.e. Monday to Friday 18:00 - 23:00 hours, Saturday 13:00 - 23:00 hours, Sunday/Bank Holidays 07:00 - 23:00 hours).

For each survey location and survey strategy (i.e. infrastructure live or outage), separate datasets were created of synchronised noise and weather data for each noise parameter (i.e. L_{Aeq}, L_{A50}, L_{A5}, L_{A90}) for each of the time periods listed above (i.e. 16 datasets, e.g. L_{Aeq} - All, L_{Aeq} - Weekday, L_{Aeq} - Night, L_{Aeq} - Quiet Day etc.). Each of these datasets was put through a series of further refinements as described in the bullet points below:

- Deletion of all data during periods of rain (including the data periods that immediately preceded and followed periods of rain);
- Deletion of wind affected data in a graded manner (e.g. deletion of all data with wind speeds greater than 3mph, 5mph, 10mph etc.). There was some variation on how this was applied to different datasets based on the extent to which the dataset was impacted by the wind;
- Deletion of all data where wind speeds were greater than 0 mph;
- Deletion of 'outlier' data, which is defined as any measurement period where the measured noise level was 10dB(A) or greater above the measurement period which directly preceded it and the measurement period that followed it. Removing these outliers enables random sources of noise (e.g. animal noises, agricultural plant etc.) to be removed from the dataset which prevents these from skewing the overall trend for the survey period. The removal of outlier data was not required for every dataset.

Based on the refined analysis completed on the datasets as described above, a series of greater than 60 datasets were created for each survey location and for each survey strategy period. For each of these datasets, the average noise was calculated for the respective noise parameter. In the case of the L_{A5}, L_{A50} and L_{A90} parameters, the arithmetic average was calculated. In the case of the L_{Aeq} parameter, the logarithmic average was calculated. The calculated averages derived from each dataset were used for purposes of comparison between each survey strategy (i.e. infrastructure live and outage) at each location.

The refinement process that was applied to the analysis of the datasets resulted in certain datasets being reduced to a low sample rate. Where the refined dataset has fallen below 2.5 hours worth of data, this has been highlighted in Section 4 of this report. Interpretation of survey results included a consideration of the sample sizes.

The analytical process described above was completed for all of the survey locations selected and described in Section 3.1.2 of this report.

3.3.2 Substations

As short-term measurements were taken at the substation sites, the extent of data available for analysis is substantially lower for the substation surveys and hence there is no requirement for the extensive set of analyses that was conducted for the overhead lines. The analysis of this data was by means of review of the small datasets to determine the noise level associated with each substation type and to determine if there were any particular tonal features distinctly visible in the frequency analysis.

4 SURVEY RESULTS

4.1 SURVEY RESULTS FOR 110KV OVERHEAD LINES

4.1.1 Cathleen’s Fall (C’Fall) Golagh Tee - Letterkenny 110kV OHL (1)

Table 4.1 below includes a summary of all averaged data from the analysis of the synchronised noise and weather data at Cathleen’s Fall (C’Fall) Golagh Tee - Letterkenny 110kV (1). For each noise parameter, the averaged noise levels for the survey with the infrastructure live (i.e. 'On' in the table) has been placed beside the averaged noise levels for the survey completed during the period of outage (i.e. 'Off' in the table). This enables direct comparison to be made between 'On' and 'Off' surveys for each of the time periods and weather conditions.

The 'On' survey produced a dataset of approximately 166 hours for the purposes of analysis, while the 'Off' survey produced a dataset of approximately 118 hours. For each broad dataset included in the table below (e.g. all noise, weekday, night and quiet day), the dataset has been put through a series a refinements to delete perceived extraneous source noisy periods during the survey period.

Each subsequent entry includes the refinement made in the previous step of the data analysis. Therefore, the '0mph' entry includes all of the deletions to the dataset from the '- Rain Data', '<3mph wind speed' and 'outlier' steps.

In the table below, some of the entries measured noise levels show no change when the dataset is refined to omit perceived noisy periods during the survey (e.g. during rain and windy periods). This is the case as the original dataset did not contain these conditions.

Table 4.1: Comparison of Averaged Data from 'On' and 'Off' Surveys at C'Fall Golagh Tee - Letterkenny 110kV OHL (1)

Dataset	Averaged Noise Levels dB(A)							
	L_{A5}		L_{A50}		L_{A90}		L_{Aeq}	
	On	Off	On	Off	On	Off	On	Off
All Noise Data	39.9	46.7	34.3	40.0	32.0	37.3	41.5	51.3
- Rain Data	39.6	45.9	33.6	39.6	31.4	36.8	40.7	51.2
< 3mph wind speed	39.1	38.9	33.6	34.2	31.5	32.4	40.5	38.2
Outliers	39.0	38.6	33.6	34.2	31.4	32.4	38.4	38.2
0mph	35.2	39.4	30.8	34.8	29.3	33.0	34.0	37.2
Weekday	43.1	51.4	36.1	43.8	33.1	40.6	43.9	53.2
- Rain Data	41.1	51.9	36.1	44.2	33.1	40.6	43.6	53.2
< 3mph wind speed	43.1	42.8	36.1	37.4	33.1	35.0	43.3	39.6
Outliers	43.1	42.4	36.1	37.4	33.1	35.0	40.7	39.6
0mph	37.9*	42.9*	36.1*	38.9*	33.1*	37.2*	39.3*	39.9*
Night	34.5	43.5	30.2	37.7	28.5	35.1	33.6	50.5
- Rain Data	34.4	43.3	30.1	37.6	28.5	35.0	33.1	50.6
< 3mph wind speed	33.4	35.9	29.8	31.9	28.3	30.3	32.4	34.6
Outliers	33.2	35.9	29.8	31.9	28.3	30.3	32.4	34.6
0mph	31.6	36.5	29.3	32.0	28.2	30.3	30.9	33.7
Rain (<5m/s Wind) [2 Hours Dataset for 'On' & 'Off']	40*	47*	32*	40*	29*	37*	37*	43*
Quiet Day	42.3	45.8	37.0	39.6	34.7	36.9	42.7	50.3
- Rain Data	44.0	45.5	35.0	39.2	33.3	32.6	41.3	51.3
< 3mph wind speed	39.9	41.1	34.9	35.8	33.3	33.7	41.4	40.0
Outliers	39.9	41.1	34.9	35.8	33.3	33.7	40.8	38.4
0mph	33.8*	41.3*	30.5*	37.3*	29.4*	34.6*	31.3*	38.5*
Rain (<5m/s Wind)	50	49	42	42	37	40	45	46

* Small dataset, i.e. less than 2.5 hours of data

The comparison of the averaged noise levels for all parameters included in the table above demonstrate that measured noise levels during the 'On' survey are less than those measured for the 'Off' survey for all analysis scenarios investigated.

When all of the noise data is compared between the 'On' and 'Off' surveys before any refinement of the data was undertaken, there is a significant difference between the averaged noise levels for all of the parameters. All parameters were recorded as 5-10d(A) greater during the 'Off' surveys. The process of deleting rain and wind affected data reduces the difference between the noise parameters for both datasets generally into the 2-4dB(A) range.

The data in Table 4.1 provides strong evidence that live 110kV overhead lines do not produce significant noise levels that contribute to increasing the background (i.e. L_{A90}) or ambient (L_{Aeq}) noise level in the vicinity of the lines. The fact that the 'Off' survey is producing marginally higher measured noise levels than the 'On' survey is simply a factor of the natural variation in the noise from other sources in the study area during the respective measurement periods.

Figure 4.1 below includes a typical cross-section of data points for the background noise level (i.e. L_{A90}) for both 'On' and 'Off' surveys during the night-time period only. This dataset has been refined to exclude all rain and wind affected measurements. The y axis has been altered to give a simple numerical value to represent the passage of time as opposed to having a date and time. This has been done for ease of reference and because two datasets are being represented which have different measurement dates and times.

In the figure below, the background noise levels are quite similar with the 'Off' survey measuring marginally higher noise levels. The night-time period is the quietest period of the day and therefore, if the live infrastructure was producing any significant noise, it would be most noticeable as an elevated background noise level during the 'On' survey at night. The figure below clearly illustrates that there is no elevated background noise levels at night for the 'On' survey.

Figure 4.1: Comparison of Background Noise Levels (L_{A90}) for 'On' and 'Off' Surveys at Night (C'Fall Golagh Tee - Letterkenny 110kV OHL)

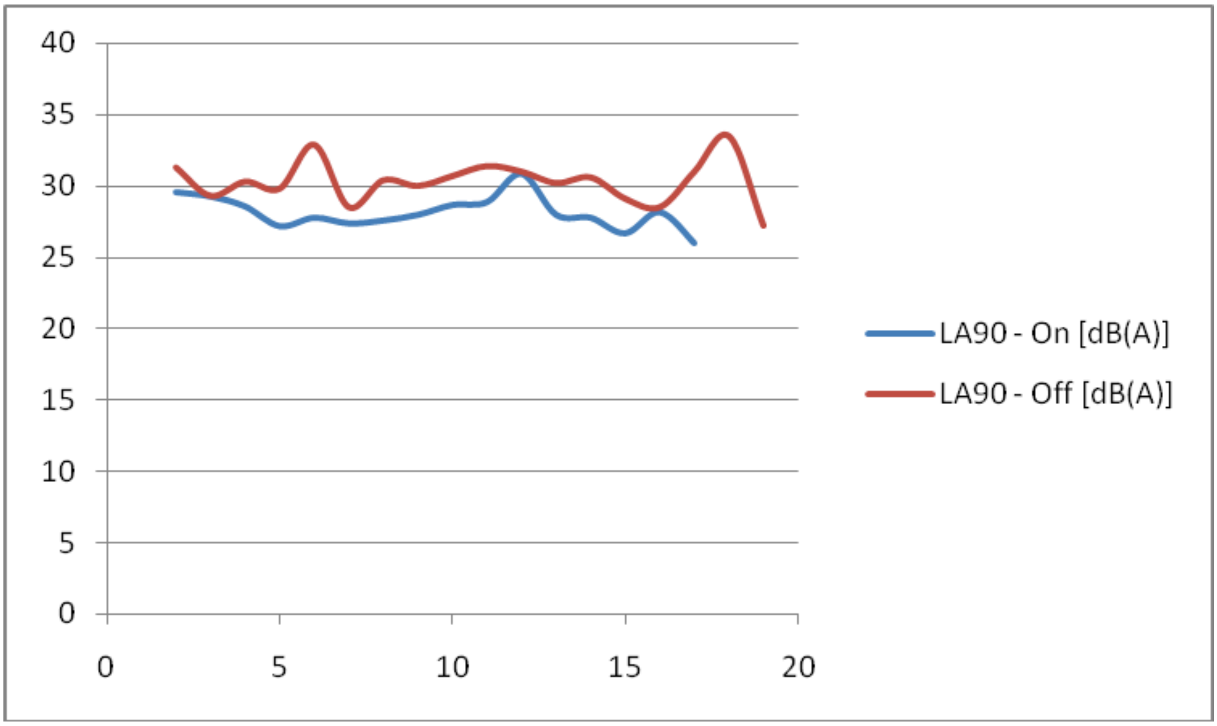


Figure 4.1 illustrates that during the quietest periods when all other rain and wind affected data has been removed, the steady state background noise level in the vicinity of the overhead line is not higher when the infrastructure is live as when compared with a period of outage.

Presenting the data in this way does not account for potential random and sporadic corona discharge events during the survey period. The L_{A90} parameter omits the top 10% of noisy activities during a measurement period (i.e. hence it is a record of the background noise level) and therefore omits any likely occasional events such noisy corona discharges.

The L_{A5} parameter records the top 5% of noisy activity within a given measurement period. One would expect that significant increases in random corona activity when comparing the 'On' survey with the 'Off' survey would result in a significant increase in the L_{A5} parameter for the 'On' survey as compared with the off survey. Table 4.1 illustrates that for all weather conditions and during all time periods, the L_{A5} parameter is similar or even lower during the 'On' survey as compared with the 'Off' survey. This indicates that either random corona discharges were not frequent enough throughout the 'On' survey to register a noticeable change in the recorded noise level or that if they were relatively frequent, they were not of sufficient noise energy as to register a change in the overall L_{A5} measurements. Either way, the data does not give any evidence that random corona discharge is a significant noise impact from 110kV overhead lines.

As random corona discharge is often linked to wet weather conditions, a further exercise was undertaken to refine the analysis to compare the measurements for all parameters during the 'On' and 'Off' surveys for periods of rain only. There was a reasonable sample size of rain affected data for both 'On' and 'Off' surveys during the quiet daytime and night-time periods, with average measured noise levels for all parameters being either similar or marginally less during the 'On' survey as compared with the 'Off' survey. The higher measured levels during the 'Off' survey may have been a factor of marginally higher average wind speeds for some of the data.

Overall, there was no evidence from these measurements during rainy conditions of significant recordable corona effects from the 110kV overhead line.

The weather-adjusted noise levels included in Table 4.1 are below the daytime WHO threshold limits for serious annoyance (55dB L_{Aeq}) and moderate annoyance (i.e. 50dB L_{Aeq}) for outdoor living areas and the night-time free-field threshold limit of 42dB (L_{Aeq}) for preventing negative effects on sleep.

A review of this data in the context of all 110kV survey data is included in Section 6.1 of this study.

4.1.2 Cathleen's Fall (C'Fall) Golagh Tee - Letterkenny 110kV OHL (2)

Table 4.2 below includes a summary of all averaged data from the analysis of the synchronised noise and weather data at C'Fall Golagh Tee - Letterkenny 110kV (2).

For each noise parameter, the averaged noise levels for the survey with the infrastructure live (i.e. 'On' in the table) has been placed beside the averaged noise levels for the survey complete during the period of outage (i.e. 'Off' in the table). This enables direct comparison to be made between 'On' and 'Off' surveys for each of the time periods and weather conditions.

The 'On' survey produced a dataset of approximately 167 hours for the purposes of analysis, while the 'Off' survey produced a dataset of approximately 166 hours.

Table 4.2: Comparison of Averaged Data from 'On' and 'Off' Surveys at C'Fall Golagh Tee - Letterkenny 110kV OHL (2)

Dataset	**Averaged Noise Levels dB(A)**							
	L_{A5}		**L_{A50}**		**L_{A90}**		**L_{Aeq}**	
	On	**Off**	**On**	**Off**	**On**	**Off**	**On**	**Off**
All Noise Data	58.1	52.0	50.4	42.0	45.9	36.5	62.2	54.0
- Rain Data	55.8	50.6	48.1	40.6	43.9	35.3	59.5	41.2
< 3mph wind speed	55.8	41.7	48.1	30.0	43.9	27.0	59.5	41.2
0mph	55.8	42.1	48.1	29.6	43.9	27.3	59.5	41.2
Weekday	61.4	52.8	52.9	42.04	47.7	36.1	63.6	50.1
- Rain Data	58.4	51.9	49.5	41.7	44.6	35.8	60.1	43.7
< 3mph wind speed	58.4	47.9	49.5	32.7	44.6	27.8	60.1	43.7
0mph	58.4	49.9*	49.5	32.9*	44.6	30.1*	60.1	46.5*
Night	56.6	48.6	50.3	40.4	46.3	30.1	61.5	56.0
- Rain Data	54.9	45.2	48.8	37.1	45.1	35.6	59.3	35.2
< 3mph wind speed	54.9	35.3	48.8	28.1	45.1	32.9	59.3	35.2
0mph	54.9	35.1	48.8	28.3	45.1	25.9	59.3	35.8
Quiet Day	55.7	55.0	46.8	44.2	43.0	38.4	59.9	54.4
- Rain Data	54.4	54.8	45.6	44.0	43.0	38.2	57.2	41.7
< 3mph wind speed	54.4	44.8	45.6	30.3	43.0	27.1	57.2	41.7
0mph	54.4	45.3*	45.6	28.8*	43.0	25.6*	57.2	41.8*

* Small dataset, i.e. less than 2.5 hours of data

The comparison of the averaged noise levels for all parameters included in the table above demonstrate that measured noise levels during the 'On' survey are significantly more than those measured for the 'Off' survey for all analysis scenarios investigated.

In the course of collecting the noise monitoring equipment after the 'On' survey, it became apparent that the field in which the noise monitoring equipment was placed in was occupied by sheep (no livestock were in the field when the monitoring equipment was initially placed there). The presence of the sheep in close vicinity to the noise meter would indicate that the sheep were a source of significant contamination to the noise readings recorded during the 'On' survey. The fact that none of the other noise monitoring surveys on 110kV lines produced results where the 'On' survey results were significantly greater than the 'Off' survey results would indicate that this survey may have been subject of contamination from a noise source other than the electrical overhead line.

A review of this data in the context of all 110kV survey data is included in Section 6.1 of this study.

4.1.3 Cathleen's Fall (C'Fall) - Srananagh 110kV OHL

Table 4.3 below includes a summary of all averaged data from the analysis of the synchronised noise and weather data at C'Fall - Srananagh 110kV OHL. For each noise parameter, the averaged noise levels for the survey with the infrastructure live (i.e. 'On' in the table) has been placed beside the averaged noise levels for the survey complete during the period of outage (i.e. 'Off' in the table). This enables direct comparison to be made between 'On' and 'Off' surveys for each of the time periods and weather conditions.

The 'On' survey produced a dataset of approximately 166 hours for the purposes of analysis, while the 'Off' survey produced a dataset of approximately 164 hours.

Table 4.3: Comparison of Averaged Data from 'On' and 'Off' Surveys at C'Fall - Srananagh 110kV OHL

Dataset	**Averaged Noise Levels dB(A)**							
	L_{A5}		**L_{A50}**		**L_{A90}**		**L_{Aeq}**	
	On	**Off**	**On**	**Off**	**On**	**Off**	**On**	**Off**
All Noise Data	44.1	37.8	35.1	29.7	31.8	27.2	49.0	38.0
- Rain Data	43.9	37.1	35.0	28.8	31.7	26.5	48.8	36.8
< 3mph wind speed	40.6	37.1	31.5	28.6	28.7	26.3	41.2	36.3
Outliers	40.4	37.0	31.5	28.6	28.7	26.3	39.4	35.9
0mph	36.8	34.2	28.0	27.2	25.8	25.3	35.8	34.3
Weekday	49.5	42.4	39.1	32.6	35.0	29.5	52.7	39.8
- Rain Data	49.5	42.4	38.8	31.8	34.7	28.7	52.5	39.0
< 3mph wind speed	45.1	41.5	33.6	31.2	30.0	28.1	43.5	38.0
Outliers	44.6	41.5	33.6	31.2	30.0	28.1	42.3	37.8
0mph	41.7	41.9	29.4	32.0	25.3	28.7	39.3	38.2
Night	38.7	31.7	31.6	26.7	29.2	25.2	42.1	35.0
- Rain Data	38.7	31.7	31.6	25.7	29.2	24.3	42.1	29.6
< 3mph wind speed	37.3	30.5	30.0	25.7	27.9	24.3	40.5	29.6
Outliers	36.9	30.5	29.7	25.7	27.9	24.3	37.2	29.6
0mph	33.8	29.6	26.9	25.1	25.4	23.9	32.8	28.5
Quiet Day	44.5	39.6	35.3	29.6	31.9	26.6	46.7	38.2
- Rain Data	44.5	39.6	35.3	29.0	31.9	26.2	46.7	37.8
< 3mph wind speed	41.0	39.1	31.1	29.0	28.7	26.2	38.0	37.8
Outliers	40.9	38.8	31.1	29.0	28.7	26.2	38.0	37.5
0mph	37.6	37.1	28.1	27.4	26.1	24.8	34.9	35.5

The comparison of the averaged noise levels for all parameters included in the table above demonstrate that measured noise levels during the 'On' survey are more than those measured for the 'Off' survey prior to considering wind and rain affected data.

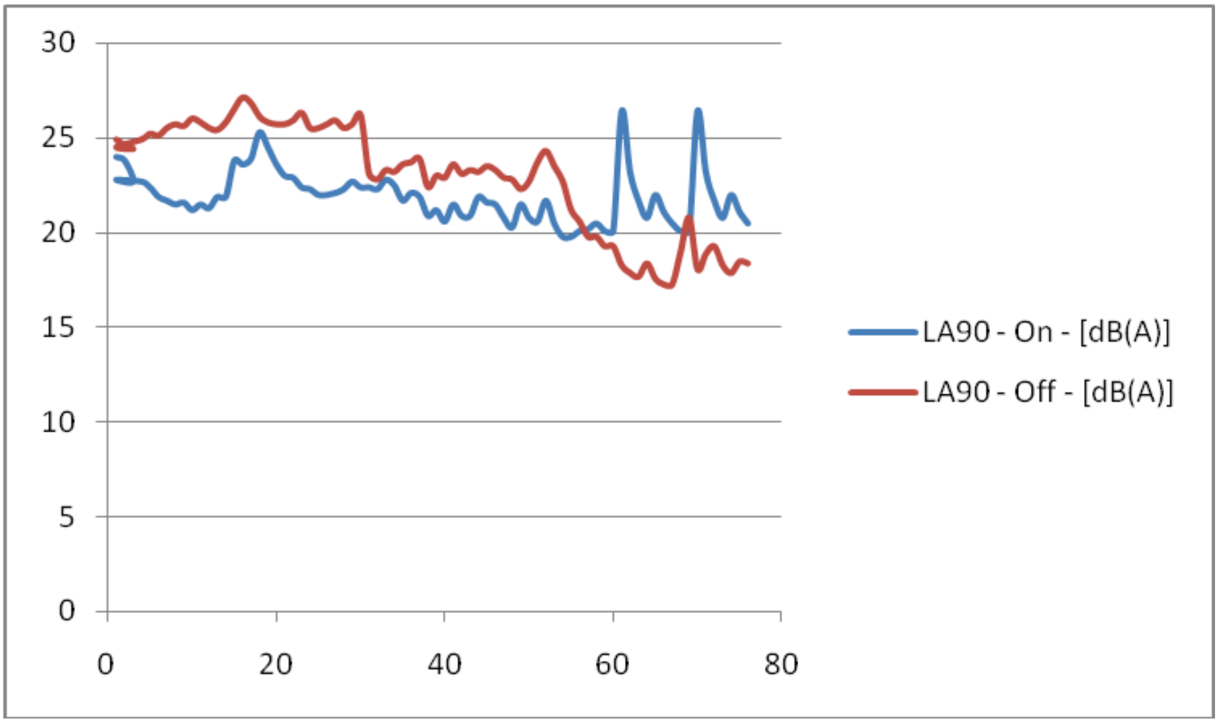
After considering rain and wind affected data, there are only small differences in the recorded data when comparing the datasets for 'On' and 'Off' survey periods.

The data in Table 4.3 provides strong evidence that live 110kV OHL do not produce significant noise levels that contribute to increasing the background (i.e. L_{A90}) or ambient (L_{Aeq}) noise level in the vicinity of the lines. There are marginal differences between the measured noise parameters (i.e. $L_{Aeq,}$ L_{A90}, L_{A5}, L_{A50}) for 'On' and 'Off' surveys but these differences are small and fall within the range of natural variation that would be expected in a low noise environment.

Figure 4.2 below includes a typical cross-section of data points for the background noise level (i.e. L_{A90}) for both 'On' and 'Off' surveys during the night-time period only. This dataset has been refined to exclude all rain and wind affected measurements. The y axis has been altered to give a simple numerical value to represent the passage of time as opposed to having a date and time. This has been done for ease of reference and because two datasets are being represented which have different measurement dates and times.

In the figure below, the background noise levels are quite similar. As in the case of the illustration included in section 4.1.1, if the live infrastructure was producing any significant noise, it would be most noticeable as an elevated background noise level during the 'On' survey at night. The figure below clearly illustrates that there is no elevated background noise levels at night for the 'On' survey.

Figure 4.2: Comparison of Background Noise Levels (L_{A90}) for 'On' and 'Off' Surveys at Night (C’Fall - Srananagh 110kV OHL)



The L_{A5} parameter records the top 5% of noisy activity within a given measurement period. One would expect that significant increases in corona activity when comparing the 'On' survey with the 'Off' survey would result in a significant increase in the L_{A5} parameter for the 'On' survey as compared with the off survey. Table 4.3 illustrates that for all weather conditions and during all time periods, the L_{A5} parameter is higher during the 'On' survey as compared with the 'Off' survey.

This may initially indicate that the difference in L_{A5} measurements may be linked to higher corona discharge events during the 'On' survey. However, upon viewing all of the data in Table 4.3, it is clear that all of the datasets for all of the parameters are higher during the 'On' survey when compared with the 'Off' survey before any of the data is refined to exclude rain or wind affected data. When the wind data is removed, all of the parameters, including the L_{A5}, show closer correlation between the 'On' and 'Off' surveys. This would indicate that it was the higher wind speeds during the 'On' survey that was giving higher noise levels for all parameters (including L_{A5}) and not corona discharge.

As corona noise is commonly linked with wet weather conditions, an analysis exercise was undertaken to isolate all of the rain affected L_{A5} measurement data and compare the 'On' and 'Off' surveys for the various times of day. Unfortunately, there wasn't enough rain affected data in each daytime period for each survey (i.e. 'On' and 'Off') to make a viable comparison.

The weather-adjusted noise levels included in Table 4.3 are below the daytime WHO threshold limits for serious annoyance (55dB L_{Aeq}) and moderate annoyance (50dB L_{Aeq}) for outdoor living areas and the night-time free-field threshold limit of 42dB (L_{Aeq}) for preventing negative effects on sleep.

A review of this data in the context of all 110kV survey data is included in Section 6.1 of this study.

4.1.4 Golagh Tee - Letterkenny 110kV OHL

Damage was caused to the weather station during the 'Off' survey for this location, and therefore it was not possible to analyse the effect of weather conditions on noise levels during this survey. As three full 'On' and 'Off' surveys had been completed at other locations adjacent to existing 110kV overhead lines (as discussed above), and on account of the difficulty in analysing this data without the weather records, a decision was made not to analyse the datasets for this location.

4.2 SURVEY RESULTS FOR 220KV OVERHEAD LINES

4.2.1 Dunstown-Maynooth 220kV OHL - Location 1 Betaghstown

Table 4.4 below includes a summary of all averaged data from the analysis of the synchronised noise and weather data at Location 1 (Betaghstown) on the Dunstown-Maynooth 220kV OHL.

For each noise parameter, the averaged noise levels for the survey with the infrastructure live (i.e. 'On' in the table) has been placed beside the averaged noise levels for the survey complete during the period of outage (i.e. 'Off' in the table). This enables direct comparison to be made between 'On' and 'Off' surveys for each of the time periods and weather conditions.

The 'On' survey produced a dataset of approximately 143 hours for the purposes of analysis, while the 'Off' survey produced a dataset of approximately 102 hours.

Table 4.4: Comparison of Averaged Data from 'On' and 'Off' Surveys at Location 1 (Betaghstown) on the Dunstown-Maynooth 220kV OHL

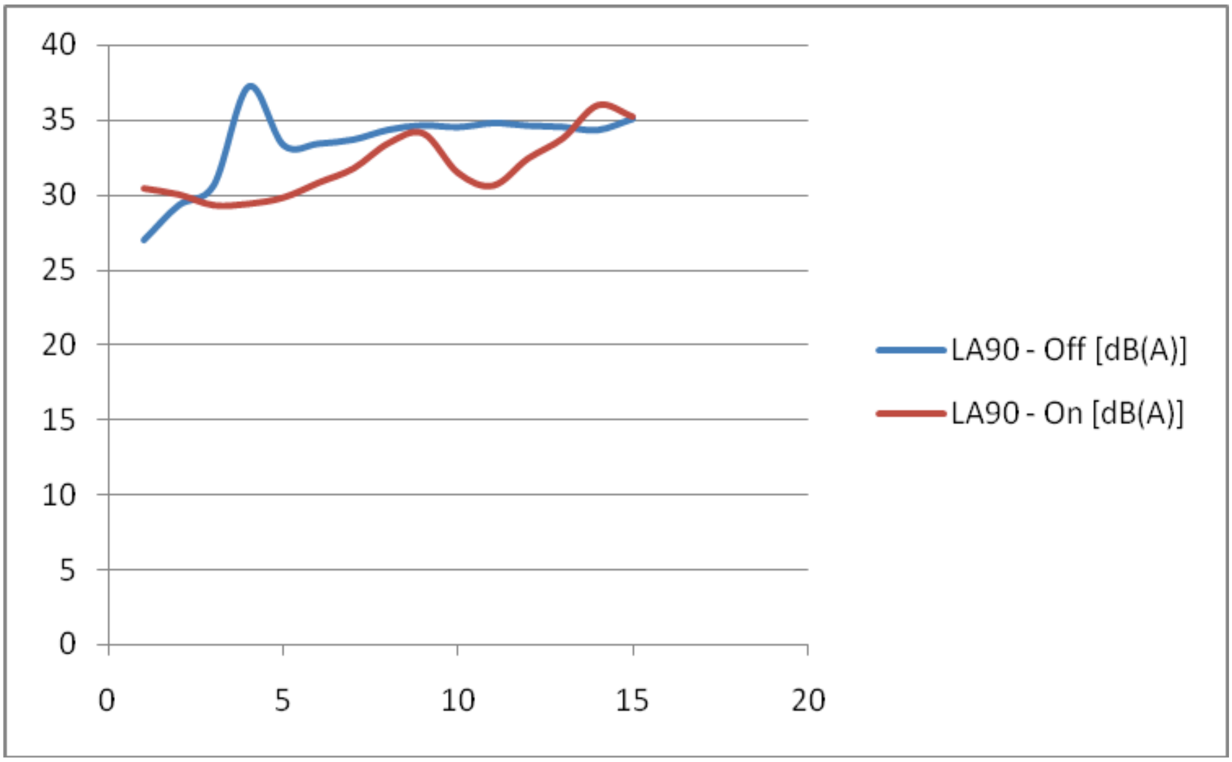
Dataset	**Averaged Noise Levels dB(A)**							
	L_{A5}		**L_{A50}**		**L_{A90}**		**L_{Aeq}**	
	On	**Off**	**On**	**Off**	**On**	**Off**	**On**	**Off**
All Noise Data	46.5	44.2	41.3	39.7	38.3	37.6	45.3	46.0
- Rain Data	46.5	44.2	41.0	39.7	38.0	37.7	45.0	46.0
< 10mph wind speed	45.2	43.9	38.7	39.0	36.7	37.5	44.5	46.0
< 5mph wind speed	44.4	48.5	38.7	39.0	36.0	37.0	44.0	46.0
Weekday	49.6	45.1	44.5	41.0	41.3	38.0	47.1	46.0
- Rain Data	49.5	45.8	44.3	41.0	41.3	38.0	47.0	46.0
< 10mph wind speed	49.1	45.9	44.0	41.0	40.6	38.0	46.9	46.0
< 5mph wind speed	50.4	45.8	45.7	41.0	42.4	38.0	47.5	46.0
Night	42.2	41.4	36.5	38.0	34.6	36.7	41.3	46.0
- Rain Data	41.9	41.3	36.2	37.9	34.6	36.7	40.8	46.0
< 10mph wind speed	40.2	41.2	34.2	37.6	32.3	36.4	38.6	46.0
< 5mph wind speed	39.6	41.0	33.5	37.0	31.8	35.6	37.8	46.0
Quiet Day	47.7	45.4	42.3	40.5	38.6	38.0	44.9	46.0
- Rain Data	47.8	45.3	42.4	40.5	38.6	38.0	44.9	46.0
< 10mph wind speed	46.2	44.5	40.5	40.0	36.7	37.8	42.8	46.0
< 5mph wind speed	46.3	42.6	40.7	38.2	36.9	36.2	41.9	46.0

The comparison of the averaged noise levels for all parameters included in the table above demonstrate that measured noise levels during the 'On' survey are generally similar to those for the 'Off' survey. In the critical time periods where overall noise levels are reduced (i.e. night-time), recorded noise levels were no greater during that 'On' survey than for the 'Off' survey.

Figure 4.3 below includes a typical cross-section of data points for the background noise level (i.e. L_{A90}) for both 'On' and 'Off' surveys during the night-time period only. This dataset has been refined to exclude all rain and wind affected measurements. The y axis has been altered to give a simple numerical value to represent the passage of time as opposed to having a date and time. This has been done for ease of reference and because two datasets are being represented which have different measurement dates and times.

In the figure below, the background noise levels are quite similar. As in the case of the previous illustrations on the measured background noise levels, if the live infrastructure was producing any significant noise, it would be most noticeable as an elevated background noise level during the 'On' survey at night. The figure below clearly illustrates that there is no elevated background noise levels at night for the 'On' survey.

Figure 4.3: Comparison of Background Noise Levels (L_{A90}) for 'On' and 'Off' Surveys at Night at Location 1 (Betaghstown) on the Dunstown-Maynooth 220kV OHL



The L_{A5} parameter records the top 5% of noisy activity within a given measurement period. One would expect that significant increases in corona activity when comparing the 'On' survey with the 'Off' survey would result in a significant increase in the L_{A5} parameter for the 'On' survey as compared with the off survey. Table 4.1 illustrates that for all weather conditions and during all time periods, the L_{A5} parameter is generally similar during the 'On' survey as compared with the 'Off' survey (in some instances it is higher for the 'On' survey and in other instances it is higher for the 'Off survey). This indicates that either random corona discharges were not frequent enough throughout the 'On' survey to register a noticeable change in the recorded noise level or that if they were relatively frequent, they were not of sufficient noise energy as to register a change in the overall L_{A5} measurements.

Either way, the data does not give any evidence that random corona discharge is a significant noise impact from 220kV overhead lines.

As corona noise is commonly linked with wet weather conditions, an analysis exercise was undertaken to isolate all of the rain affected L_{A5} measurement data and compare the 'On' and 'Off' surveys for the various times of day. However, there wasn't enough rain affected data in each daytime period for each survey (i.e. 'On' and 'Off') to make a viable comparison.

The dataset for this location provides strong evidence that the 220kV line in this location does not produce any significant noise emissions at a location immediately adjacent to the OHL. The weather-adjusted noise levels included in Table 4.4 for the 'On' survey are below the daytime WHO threshold limits for serious annoyance (55dB L_{Aeq}) and moderate annoyance (50dB L_{Aeq}) for outdoor living areas and the night-time free-field threshold limit of 42dB (L_{Aeq}) for preventing negative effects on sleep.

A review of this data in the context of all 220kV survey data is included in Section 6.2 of this study.

4.2.2 Dunstown-Maynooth 220kV OHL - Location 2 Currabell

Table 4.5 below includes a summary of all averaged data from the analysis of the synchronised noise and weather data at Location 2 (Currabell) on the Dunstown-Maynooth 220kV OHL.

For each noise parameter, the averaged noise levels for the survey with the infrastructure live (i.e. 'On' in the table) has been placed beside the averaged noise levels for the survey complete during the period of outage (i.e. 'Off' in the table). This enables direct comparison to be made between 'On' and 'Off' surveys for each of the time periods and weather conditions.

The 'On' survey produced a dataset of approximately 141 hours for the purposes of analysis, while the 'Off' survey produced a dataset of approximately 188 hours.

Table 4.5: Comparison of Averaged Data from 'On' and 'Off' Surveys at Location 2 (Currabell) on the Dunstown-Maynooth 220kV OHL

Dataset	Averaged Noise Levels dB(A)							
	L_{A5}		L_{A50}		L_{A90}		L_{Aeq}	
	On	**Off**	**On**	**Off**	**On**	**Off**	**On**	**Off**
All Noise Data	43.0	46.1	39.5	41.3	37.7	39.0	44.6	49.0
- Rain Data	42.1	45.1	38.2	39.8	36.3	37.3	41.0	46.8
< 10mph wind speed	41.7	43.3	37.8	38.0	36.0	35.7	40.5	42.8
< 5mph wind speed	41.5	41.6	37.8	36.3	36.0	33.9	40.5	40.5
Wind speed = 0mph	39.9	39.9	35.7	34.2	33.8	31.9	38.5	37.4
Weekday	46.8	49.6	42.5	44.5	40.6	42.1	47.9	52.1
- Rain Data	45.8	49.6	41.4	43.9	33.4	41.1	43.6	49.9
< 10mph wind speed	45.2	47.3	40.8	41.7	39.1	39.2	42.9	44.3
< 5mph wind speed	45.6	46.8	41.7	41.1	40.1	38.4	43.7	45.8
Wind speed = 0mph	45.8*	49.7	42.3*	42.6	40.7*	39.2	43.1*	42.8*
Night	39.3	43.2	35.8	39.0	34.0	37.0	40.7	46.7
- Rain Data	37.9	40.2	34.2	35.8	32.3	33.7	35.9	41.7
< 10mph wind speed	37.0	38.7	33.3	34.3	32.3	33.7	35.9	35.9
< 5mph wind speed	38.1	37.5	34.5	32.9	32.7	31.7	36.2	35.6
Wind speed = 0mph	37.4	37.2	33.5	31.9	31.7	30.0	36.0	36.8
Rain (Wind <6m/s)	46	47	44	43	41	39	46	45
Quiet Day	43.4	44.9	39.9	39.6	38.2	37.0	42.3	43.7
- Rain Data	42.5	44.6	39.0	39.0	37.1	36.3	40.4	43.1
< 10mph wind speed	42.2	42.0	38.7	38.2	36.9	35.6	40.1	41.9
< 5mph wind speed	41.9	43.0	38.4	37.5	36.6	40.7	40.1	41.2
Wind speed = 0mph	40.0	41.7	36.2	35.8	34.2	33.3	38.3	38.5
Rain (Wind <6m/s)	46	47	43	45	42	44	45	45

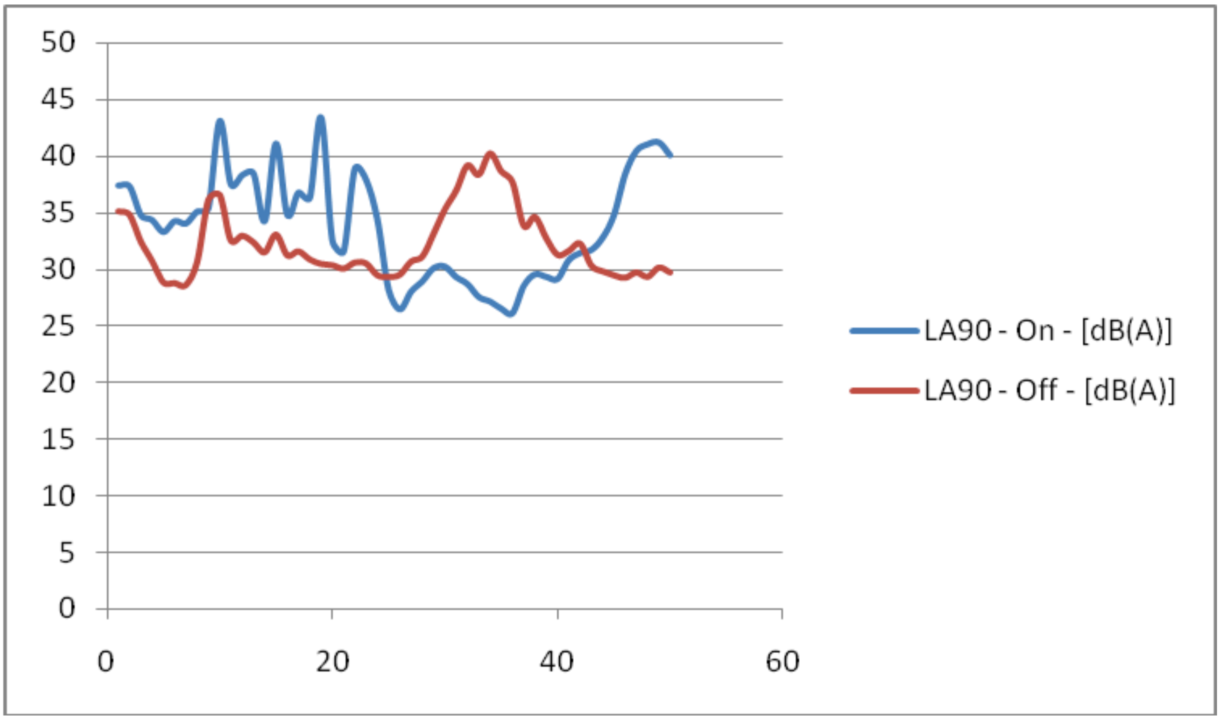
* Small dataset, i.e. less than 2.5 hours of data

The comparison of the averaged noise levels for all parameters included in the table above demonstrate that measured noise levels during the 'On' and 'Off' surveys show very little difference.

The data included in Table 4.5 provides strong evidence that 220kV overhead lines do not produce significant noise emission that contribute to increasing the background (i.e. L_{A90}) or ambient (i.e. L_{Aeq}) noise levels in the vicinity of them. There are marginal differences between all of the measured noise parameters (i.e. L_{Aeq}, L_{A5}, L_{A50}, L_{A90}) for 'On' and 'Off' surveys but these differences are small and fall within the range of natural variation that would be expected in a low noise environment.

To further illustrate the similarity in the recorded background noise levels for the 'On' and 'Off' surveys, Figure 4.4 gives a typical snapshot of the background noise data for both surveys at night with rain and wind affected data removed. This figure follows the same format as explained for Figure 4.3.

Figure 4.4: Comparison of Background Noise Levels (L_{A90}) for 'On' and 'Off' Surveys at Night at Location 2 (Currabell) on the Dunstown-Maynooth 220kV OHL



If the 220kV OHL was producing any significant noise emissions at this location, one would expect an obvious effect on the graph for the 'On' survey demonstrating a consistently elevated noise level. Figure 4.4 demonstrates a similar pattern for the background noise level at night for both surveys.

As in the case of the Betaghstown dataset (i.e. Table 4.4), an analysis of the L_{A5} data in Table 4.5 indicates that the measurements are very similar for the 'On' and 'Off' surveys (actually, marginally lower for the 'On' survey). Any significant random corona discharge activity would be expected to result in an increased L_{A5} noise level during the 'On' survey, therefore there is no evidence to indicate that random corona discharge presents a significant noise impact on 220kV OHL.

As corona noise is commonly linked with wet weather conditions, an analysis exercise was undertaken to isolate all of the rain affected L_{A5} measurement data and compare the 'On' and 'Off' surveys for the various times of day. Comparison of L_{A5} data during the quietest periods of the day (i.e. night and quiet day) during rainfall gave a difference of 1dB between the datasets. A similar difference of 1-2dB was observed between the other parameters (i.e. L_{Aeq}, L_{A50}, L_{A90}) with the 'On' survey being greater in some instances and the 'Off' survey being greater in other instances.

This data does not give any evidence that there is any significant noisy corona activity on 220kV lines during wet weather conditions.

The weather-adjusted noise levels included in Table 4.5 are below the daytime WHO threshold limits for serious annoyance (55dB L_{Aeq}) and moderate annoyance (50dB L_{Aeq}) for outdoor living areas and the night-time free-field threshold limit of 42dB (L_{Aeq}) for preventing negative effects on sleep.

A review of this data in the context of all 220kV survey data is included in Section 6.2 of this study.

4.2.3 Dunstown-Maynooth 220kV OHL - Location 3 Thomastown

Table 4.6 below includes a summary of all averaged data from the analysis of the synchronised noise and weather data at Location 3 (Thomastown) on the Dunstown-Maynooth 220kV OHL.

For each noise parameter, the averaged noise levels for the survey with the infrastructure live (i.e. 'On' in the table) has been placed beside the averaged noise levels for the survey complete during the period of outage (i.e. 'Off' in the table). This enables direct comparison to be made between 'On' and 'Off' surveys for each of the time periods and weather conditions.

The 'On' survey produced a dataset of approximately 44 hours for the purposes of analysis, while the 'Off' survey produced a dataset of approximately 48 hours.

Table 4.6: Comparison of Averaged Data from 'On' and 'Off' Surveys at Location 3 (Thomastown) on the Dunstown-Maynooth 220kV OHL

Dataset	Averaged Noise Levels dB(A)							
	L_{A5}		L_{A50}		L_{A90}		L_{Aeq}	
	On	**Off**	**On**	**Off**	**On**	**Off**	**On**	**Off**
All Noise Data	40.2	40.5	34.9	35.7	32.2	33.4	39.1	39.6
- Rain Data	40.2	39.6	34.8	34.8	32.0	33.4	39.1	38.1
< 10mph wind speed	40.2	39.4	34.8	32.3	32.1	32.2	39.1	37.9
< 5mph wind speed	39.5	38.2	34.0	33.4	31.3	31.1	37.9	36.7
Wind speed = 0mph	37.9	37.7	31.9	32.6	29.0	30.1	36.4	34.7
Weekday	43.2	44.6	38.4	39.9	35.9	37.6	41.4	42.3
- Rain Data	42.0	43.9	38.3	39.1	35.9	37.6	41.4	41.1
< 10mph wind speed	42.0	44.3	38.3	39.4	34.8	37.1	41.4	41.4
< 5mph wind speed	42.4	43.0	37.4	38.4	35.1	36.4	40.0	40.7
Wind speed = 0mph	43.3*	ND	39.3*	ND	37.5*	ND	40.3*	ND
Night	35.8	35.9	30.1	30.5	27.0	28.0	34.5	33.3
- Rain Data	35.8	35.8	30.1	30.4	27.0	28.0	34.5	33.3
< 10mph wind speed	35.8	35.8	30.1	30.4	27.0	27.9	34.5	33.3
< 5mph wind speed	35.3	35.8	30.0	30.4	27.0	27.9	34.5	33.3
Wind speed = 0mph	36.1	36.5	29.4	31.3	26.4	28.8	34.3	33.9
Quiet Day	40.2	39.0	35.5	35.1	32.8	33.0	37.5	36.6
- Rain Data	40.2	39.0	35.5	35.1	32.8	33.0	37.5	36.6
< 10mph wind speed	40.2	39.0	35.5	35.1	32.8	33.0	37.5	36.6
< 5mph wind speed	40.2	38.3	35.5	34.6	32.8	32.4	37.5	36.2
Wind speed = 0mph	39.5	37.5*	34.7	33.1*	31.9	30.0*	37.1	34.0*

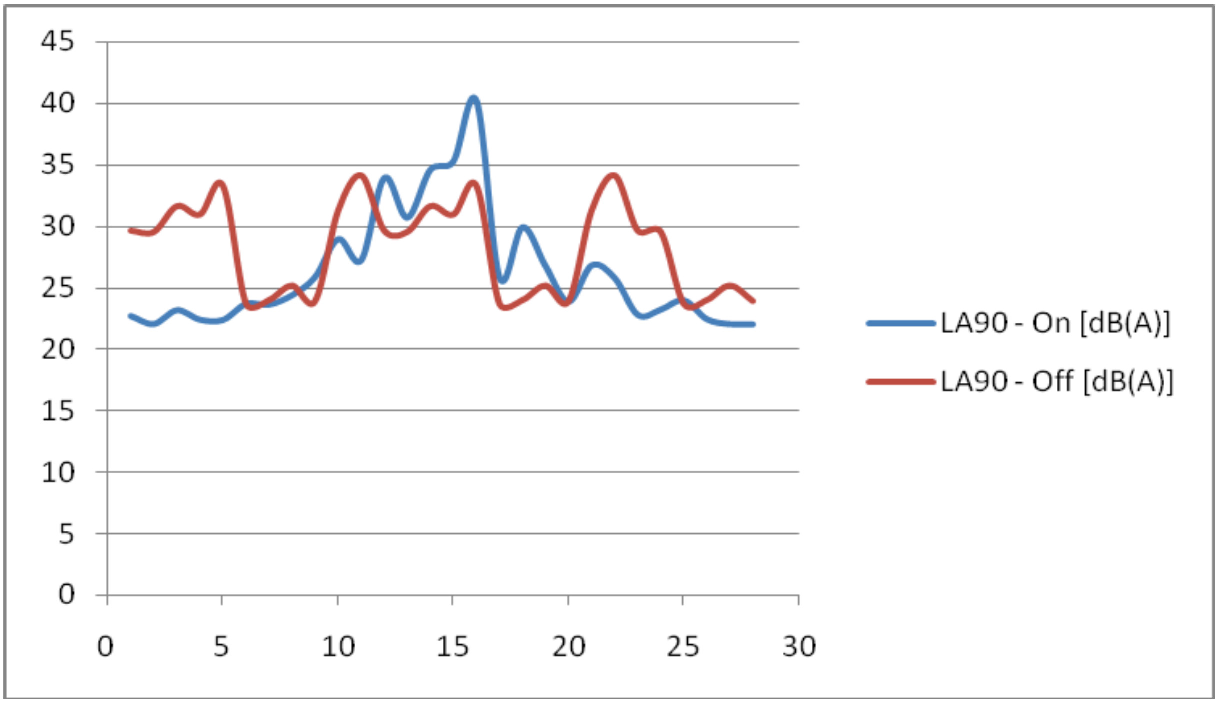
* Small dataset, i.e. less than 2.5 hours of data, ND = No Data

The comparison of the averaged noise levels for all parameters included in the table above demonstrate that measured noise levels during the 'On' and 'Off' surveys show very little difference.

The data included in Table 4.6 provides strong evidence that 220kV OHL do not produce significant noise emission that contribute to increasing the background (i.e. L_{A90}) or ambient (i.e. L_{Aeq}) noise levels in the vicinity of them. There are marginal differences between the measured noise parameters (i.e. L_{A90}, L_{Aeq}, L_{A5}, L_{A50}) for 'On' and 'Off' surveys (the measured noise levels for the 'Off' surveys are marginally greater in this instance) but these differences are small and fall within the range of natural variation that would be expected in a low noise environment.

Figure 4.5 provides a snapshot of the background noise data during 'On' and 'Off' surveys at night with rain and wind affected data removed. As with the previous sites as Betaghstown and Currabell, the pattern is similar for 'On' and 'Off' surveys and illustrates that there is no significant noise being emitted from the 220kV overhead line.

Figure 4.5: Comparison of Background Noise Levels (L_{A90}) for 'On' and 'Off' Surveys at Night at Location 3 (Thomastown) on the Dunstown-Maynooth 220kV OHL



An analysis of the L_{A5} data in Table 4.6 indicates that the measurements are very similar for the 'On' and 'Off' surveys. Any significant random corona discharge activity would be expected to result in an increased L_{A5} noise level during the 'On' survey, therefore as with the Betaghstown and Currabell survey results, there is no evidence to indicate that random corona discharge presents a significant noise impact on 220kV OHL.

As corona noise is commonly linked with wet weather conditions, an analysis exercise was undertaken to isolate all of the rain affected L_{A5} measurement data and compare the 'On' and 'Off' surveys for the various times of day. However, there wasn't enough rain affected data in each daytime period for each survey (i.e. 'On' and 'Off') to make a viable comparison.

The weather-adjusted noise levels included in Table 4.6 are below the daytime WHO threshold limits for serious annoyance (55dB L_{Aeq}) and moderate annoyance (50dB L_{Aeq}) for outdoor living areas and the night-time free-field threshold limit of 42dB (L_{Aeq}) for preventing negative effects on sleep.

A review of this data in the context of all 220kV survey data is included in Section 6.2 of this study.

4.3 SURVEY RESULTS FOR 400KV OVERHEAD LINES

4.3.1 Oldstreet-Woodland 400kV OHL - Ardrums Great

Table 4.7 below includes a summary of all averaged data from the analysis of the synchronised noise and weather data at Ardrums Great on the Oldstreet-Woodland 400kV line.

For each noise parameter, the averaged noise levels for the survey with the infrastructure live (i.e. 'On' in the table) has been placed beside the averaged noise levels for the survey complete during the period of outage (i.e. 'Off' in the table). This enables direct comparison to be made between 'On' and 'Off' surveys for each of the time periods and weather conditions.

The 'On' survey produced a dataset of approximately 240 hours for the purposes of analysis, while the 'Off' survey produced a dataset of approximately 139 hours.

Table 4.7: Comparison of Averaged Data from 'On' and 'Off' Surveys at Ardrums Great on the Oldstreet-Woodland 400kV OHL

Dataset	Averaged Noise Levels dB(A)							
	L_{A5}		L_{A50}		L_{A90}		L_{Aeq}	
	On	Off	On	Off	On	Off	On	Off
All Noise Data	48.0	44.8	44.0	40.7	42.0	38.5	52.2	44.9
- Rain Data	47.8	44.8*	43.9	40.7*	42.1	38.6*	52.0	45.0*
< 10mph wind speed	44.2	44.0*	41.3	40.1*	39.9	38.5*	43.7	44.9*
< 5mph wind speed	43.4	41.9*	40.8	39.4*	39.5	36.9*	42.7	44.9*
Weekday	49.4	49.5	45.0	44.2	43.1	41.4	50.1	47.6
- Rain Data	49.4	49.6*	45.0	44.2*	43.1	41.0*	50.1	47.7*
< 10mph wind speed	47.0	49.5*	43.4	43.6*	41.8	41.3*	45.8	47.8*
< 5mph wind speed	45.8	46.5*	43.0	41.6*	41.7	41.1*	44.6	47.7*
Night	46.3	41.0	42.6	38.2	40.6	36.3	54.3	42.1
- Rain Data	44.8	41.0*	42.3	38.2*	39.4	36.3*	54.0	42.1*
< 10mph wind speed	42.0	41.0*	39.4	37.5*	37.9	35.7*	41.4	42.1*
< 5mph wind speed	42.6	38.6*	39.4	36.7*	38.0	34.9*	40.2	41.8*
Quiet Day	47.9	44.1	44.3	39.8	42.7	37.9	50.6	43.8
- Rain Data	47.0	43.7*	44.2	39.9*	42.0	37.6*	50.6	43.8*
< 10mph wind speed	44.4	44.2*	42.3	39.1*	40.4	37.2*	43.5	43.9*
< 5mph wind speed	44.2	43.6*	41.8	39.2*	40.5	37.3*	44.1	44.1*

* Portions of weather data missing, therefore refinement to dataset only completed where weather data available.

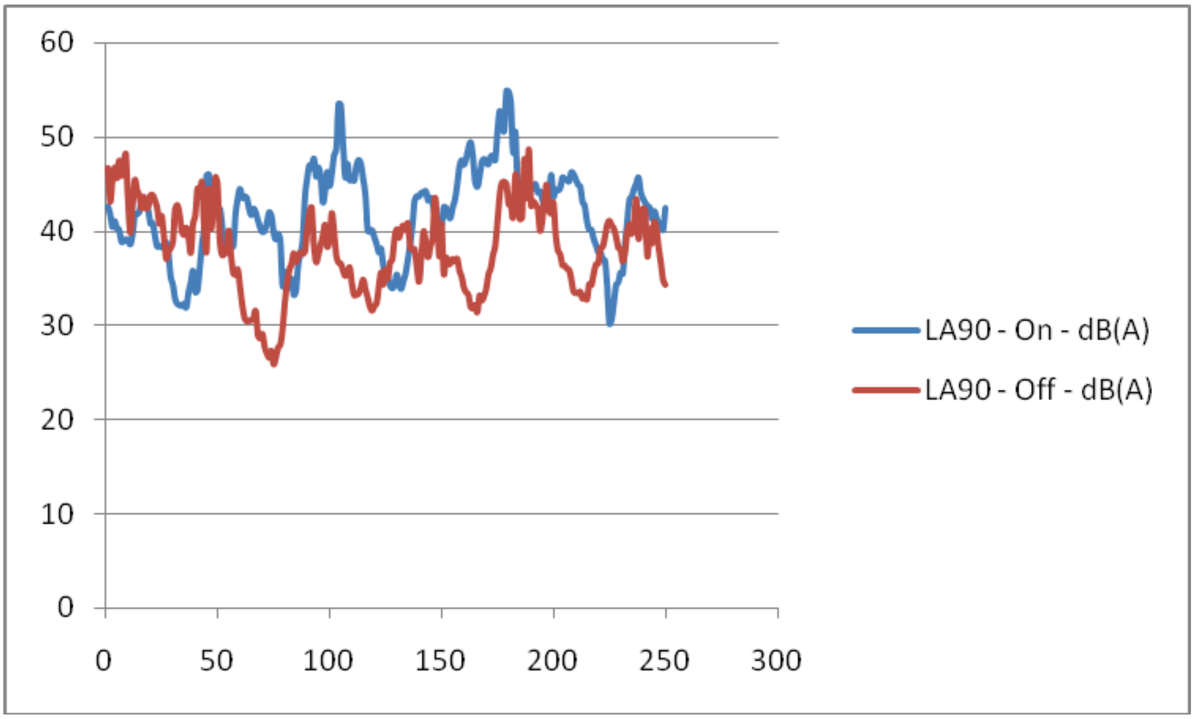
The portion of the weather data was not recorded during the 'Off' survey on account of an error in the functioning of the weather station; therefore the approach to the analysis of these datasets was a little different to the strategy outlined for the 110kV and 220kV surveys. As some of the weather data was missing for the 'Off' survey, it was not possible to refine this dataset to make a direct equivalent comparison with the 'On' survey. For this reason, the entire dataset for all time periods and including all rain and wind affected data was used for the purposes of comparison between 'On' and 'Off' surveys.

By presenting graphical representations of both surveys for all time periods, elevated noise levels as a result of wind/rain affected periods will be clearly visible on the graph. However, of more use to this study, quiet periods can be directly observed on the graph.

Figure 4.6 illustrates all of the L_{A90} noise data for all of the time periods without any refinement to remove rain and wind affected data. There are sections of the data that show clear signs of been heavily influenced by weather conditions, most notably the significant peaks in the blue graph (i.e. the 'On' Survey. A large portion of the data for both graphs is centred around the 40dB(A) line, indicating a relative similarity between the core section of the datasets for both surveys. Also, the regular troughs in the both surveys approaching the 30dB(A) line (which represent the night time L_{A90} during this surveys) show a relatively similar drop for both 'On' and 'Off' surveys.

If there was significant steady state noise emissions from the 400kV OHL, one would expect the low noise troughs in the graph for the 'On' survey to be higher than those for the 'Off' survey as this steady state noise from the OHL would result in a higher base noise level for the background noise during quiet periods. This figure provides a good indication that the 400kV OHL is not emitting any significant detectable steady state noise level which is above the background noise level for the 'Off' survey.

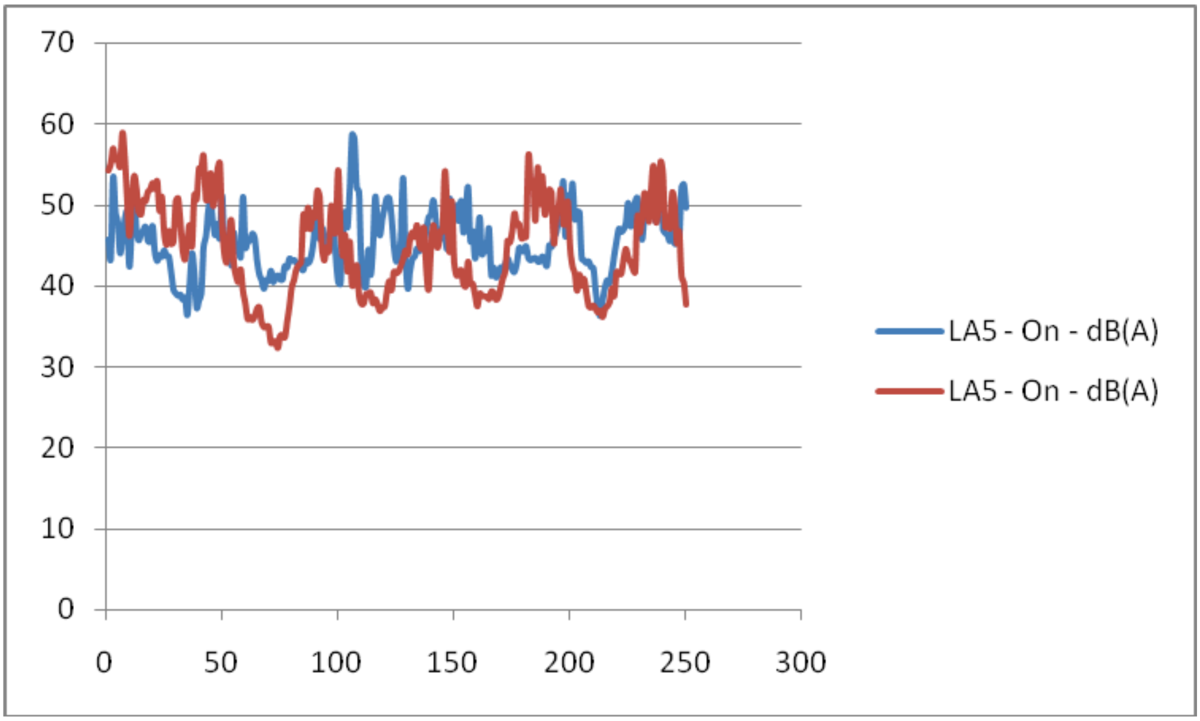
Figure 4.6: Comparison of All Background Noise Levels (L_{A90}) for 'On' and 'Off' Surveys on the Oldstreet-Woodland 400kV OHL (Rain & Wind Affected Data Included)



The L_{A5} parameter records the top 5% of noisy activity within a given measurement period. One would expect that significant increases in corona activity when comparing the 'On' survey with the 'Off' survey would result in a significant increase in the L_{A5} parameter for the 'On' survey as compared with the off survey. Figure 4.7 illustrates that for all weather conditions and during all time periods, the L_{A5} parameter is generally similar during the 'On' survey as compared with the 'Off' survey.

It must be noted that there was no significant period of rainfall during the 'On' survey (i.e. two 15-minute measurements only) and therefore, it would not have been possible (even if some of the weather data had not been lost during the 'Off' survey) to make any analysis of possible corona noise effects during rain affected conditions from this survey. The fact that no measurements were undertaken on live infrastructure during periods of rain means that no conclusion can be drawn from this survey in relation to potential corona effects from 400kV overhead lines during rainy conditions.

Figure 4.7: Comparison of All L_{A5} Noise Levels for 'On' and 'Off' Surveys on the Oldstreet-Woodland 400kV OHL (Rain & Wind Affected Data Included)



The weather-adjusted noise levels included in Table 4.7 for the 'On' survey are below the daytime WHO threshold limits for serious annoyance (55dB L_{Aeq}) and moderate annoyance (50dB L_{Aeq}) for outdoor living areas and the night-time free-field threshold limit of 42dB (L_{Aeq}) for preventing negative effects on sleep.

A detailed discussion of this data is included in Section 6.3 of this study.

4.4 SURVEY RESULTS FOR SUBSTATIONS

4.4.1 Dunfirth 110kV Substation

Noise monitoring was completed at four different locations in the vicinity of the Dunfirth 110kV Substation, two at alternative distances (i.e. 5m and 10m) from the southern boundary of the substation and two at alternative distances from (i.e. 5m and 10m) from the western boundary of the substation site. No measurements were taken at the northern boundary of the substation as the road would be the dominant noise source at this location. It was not possible to access the eastern boundary on account of the excessive amounts of vegetation.

Five minute measurements were completed at each location as a steady state noise was being emitted from the substation. The noise meter was paused to exclude any other noise sources (e.g. passing traffic on road etc.) during the measurement periods. For the measurements completed at the southern boundary, subjective observations were recorded that pylon corona noise was audible at low levels. On the western boundary, the subjective observations were that substation noise, pylon corona noise and noise from the T210 converter/transformer were audible.

Table 4.8 presents the noise monitoring data from the survey at the Dunfirth 110kV substation on 19th March 2013.

Table 4.8: Noise Monitoring Data for Dunfirth 110kV Substation

Boundary	Distance from Boundary (m)	Date/ Time	L_{Aeq} [dB(A)]	L_{Amax} [dB(A)]	L_{Amin} [dB(A)]	L_{A5} [dB(A)]	L_{A50} [dB(A)]	L_{A90} [dB(A)]
Southern	5	14:59	39	54	32	43	36	34
Southern	10	15:07	39	52	32	43	36	34
Western	5	15:16	37	53	31	40	35	34
Western	10	15:27	38	49	35	41	38	36

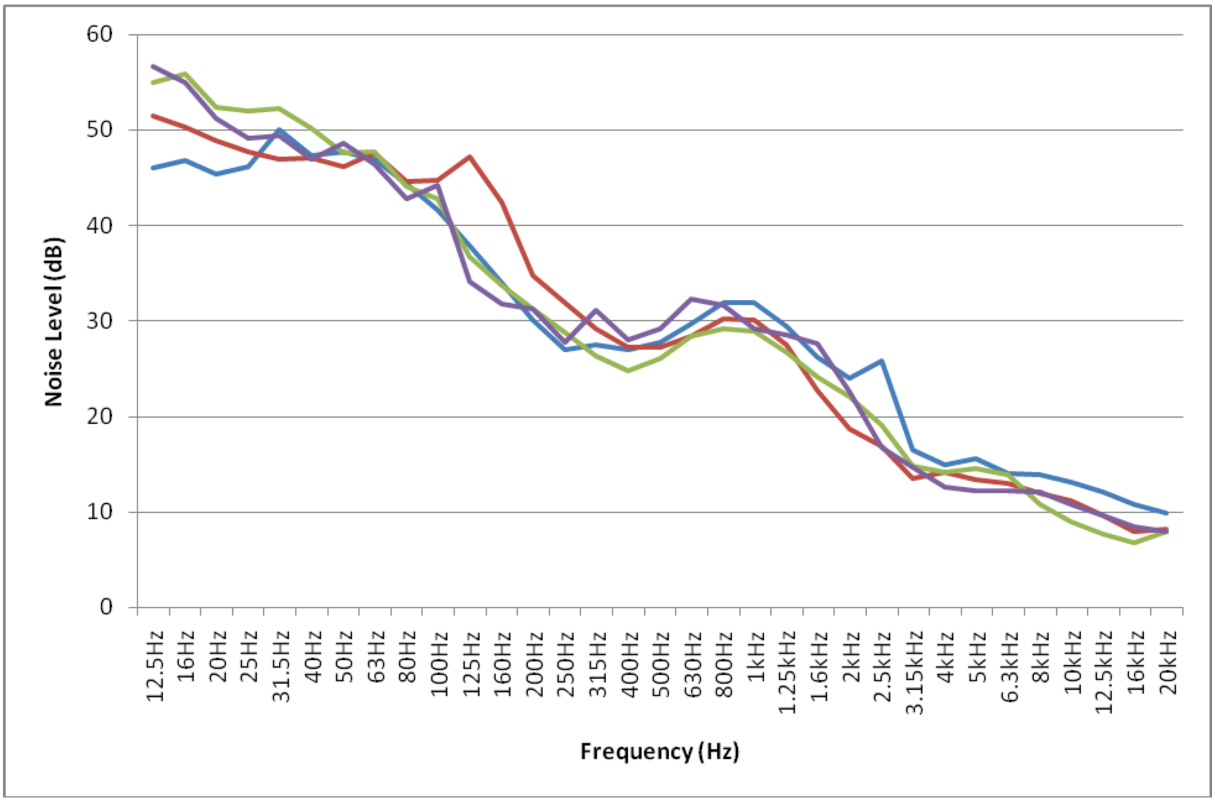
As noise propagates from a noise source, the noise energy dissipates at a constant rate as the distance from the source increases. Therefore, if a particular noise source is dominant, successive noise measurements at a greater distance from the source should show a progressive reduction in the measured noise levels as you travel away from the source.

In this instance, most parameters (i.e. L_{A50}, L_{A5}, L_{A90}) including the average noise level (i.e. L_{Aeq}) do not demonstrate any drop in the noise level at measurement locations 5m and 10m from the respective boundaries. This data indicates that the substation noise stops being the dominant noise source within a short distance of exiting the substation boundary (i.e. within the first 10m). This does not mean that the substation noise is not contributing to the ambient noise level in the vicinity of the boundary, as the subjective observations confirm that corona/substation/ transformer noise is audible. Nevertheless, it provides valuable information that noise from the 110kV substation is quite low in close proximity to the substation boundary (i.e. <40dB L_{Aeq}).

The measured noise levels at the boundary of this substation are below the daytime WHO threshold limits for serious annoyance (55dB L_{Aeq}) and moderate annoyance (50dB L_{Aeq}) for outdoor living areas. They are also below the night-time free-field threshold limit of 42dB (L_{Aeq}) for preventing negative effects on sleep.

Spectral data was recorded throughout each of the measurements completed at Dunfirth 110kV substation to determine if there were any tonal features in the recorded noise levels. Figure 4.8 illustrates the typical spectral profile recorded during all measurements at the site. The low frequency range (i.e. 12-315Hz) is dominant in all measurements, while there is very little representation in the high frequency range. Most importantly in terms of this study, there are no distinct peaks in the data that would represent a distinct tone. On the basis of this data, it can be concluded that there are no distinct tonal elements to the noise from a 110kV substation.

Figure 4.8: Typical Spectral Profile of Noise Levels at Dunfirth 110kV Substation



4.4.2 Gorman 220kV Substation

Noise monitoring was completed at eight different locations in the vicinity of the Gorman 220kV Substation, two at alternative distances (i.e. 5m and 10m) from each boundary of the substation. Five minute measurements were completed at each location as a steady state noise was being emitted from the substation. The noise meter was paused to exclude any other noise sources (e.g. passing traffic on road etc.) during the measurement periods.

Subjective observations taken during the measurement survey recorded that substation noise, pylon corona noise and T210 converter/transformer noise was audible along all four boundaries of the substation. Table 4.9 includes the noise monitoring data recorded during the survey at the Gorman 220kV substation.

Table 4.9: Noise Monitoring Data for Gorman 220kV Substation

Boundary	Distance from Boundary (m)	Date/ Time	L_{Aeq} [dB(A)]	L_{Amax} [dB(A)]	L_{Amin} [dB(A)]	L_{A5} [dB(A)]	L_{A50} [dB(A)]	L_{A90} [dB(A)]
Southern	5	10:13	43	48	40	44	43	42
Southern	10	10:20	41	48	38	42	41	40
Western	5	10:28	39	55	37	40	39	38
Western	10	10:34	38	51	35	40	37	36
Northern	5	10:45	37	51	33	40	36	34
Northern	10	10:54	37	54	32	41	35	33
Eastern	5	11:04	40	51	36	42	39	38
Eastern	10	11:10	41	50	35	45	39	37

As noise propagates from a noise source, the noise energy dissipates at a constant rate as the distance from the source increases. Therefore, if a particular noise source is dominant, successive noise measurements at a greater distance from the source should show a progressive reduction in the measured noise levels as you travel away from the source.

On two of the boundaries (i.e. northern & eastern), most parameters (i.e. L_{A50}, L_{A5}, L_{A90}, L_{Aeq}) do not show any significant drop between boundary measurement locations at 5m and 10m. The data at these boundaries indicates that the substation noise stops being the dominant noise source within a short distance of exiting the substation boundary (i.e. within the first 10m).

On the western boundary, there are marginal reductions of 1-2dB(A) between the 5m and 10m measurements for a number of the parameters (i.e. L_{A50}, L_{A90}, L_{Aeq}) and this is marginally more pronounced on the southern boundary with a different of 2dB(A) between the average noise levels recorded (i.e. L_{Aeq}). This data indicates that substation noise remains more dominant on the western and southern boundaries (probably on account of the layout of the plant within the site), but on account of the relatively small decrease in the measured noise levels between 5m and 10m at these boundaries, substation noise would not remain dominant far beyond the 10m distance from the substation boundary.

As with the discussion on the 110kV substation, the substation noise will still contribute to the ambient noise level beyond the point where the substation noise is dominant, however this contribution will diminish quickly with distance from the substation boundary. Nevertheless, it provides valuable information that steady state substation noise from the 220kV substation is quite low in close proximity to the substation boundary (i.e. 43dB L_{Aeq} at 5m).

The measured data from the Gorman substation survey illustrates that noise levels from a 220kV substation are well within the daytime WHO threshold limits for serious annoyance (55dB L_{Aeq}) and moderate annoyance (50dB L_{Aeq}) for outdoor living areas and the night-time free-field threshold limit of 42dB (L_{Aeq}) for preventing negative effects on sleep.

Spectral data was recorded throughout each of the measurements completed at Gorman 220kV substation to determine if there were any tonal features in the recorded noise levels. Figure 4.9 illustrates the typical spectral profile recorded during all measurements at the site. As in the case with the 110kV substation measurements, the noise levels from the substation are dominated by noise levels in the low frequency range. However, unlike the 110kV substation measurements there are a number of significant peaks in the mid-frequency range (i.e. 300-600Hz) and one at the lower frequency range (i.e. approximately 80Hz) which fulfil the description of being tonal.

Figure 4.9: Typical Spectral Profile of Noise Levels at Gorman 220kV Substation

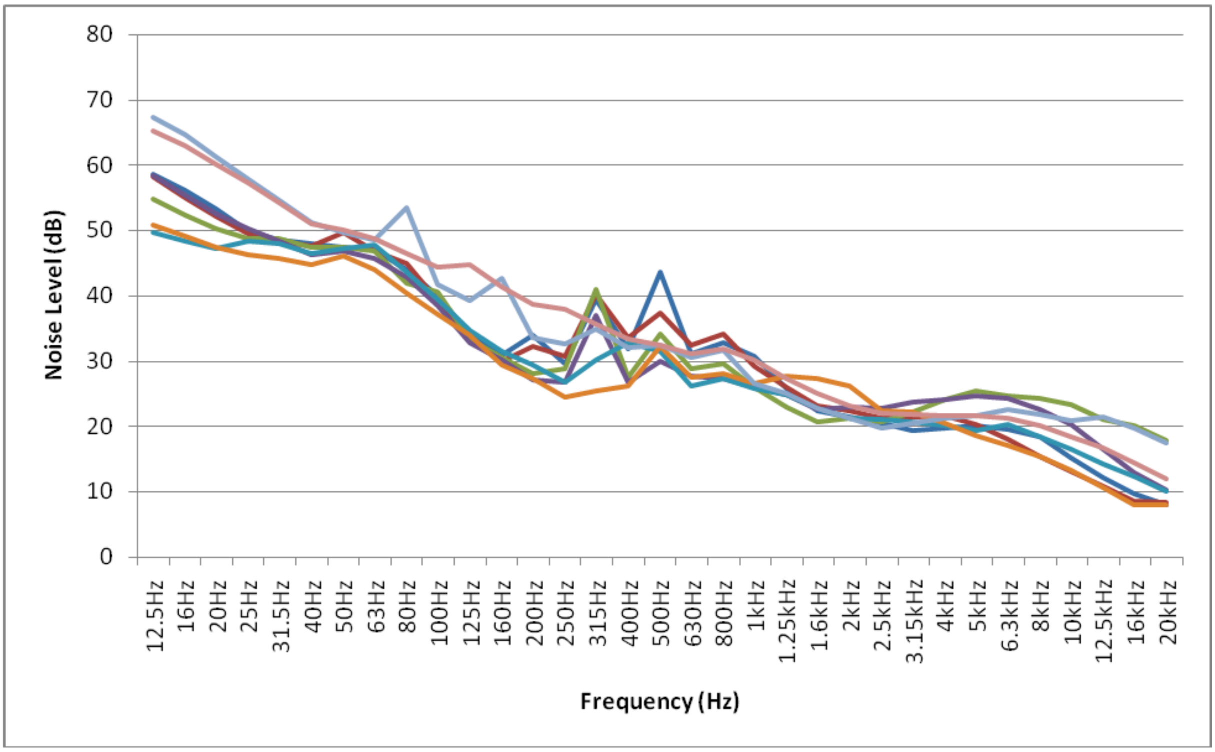


Figure 4.9 illustrates that there are tonal qualities to the noise from 220kV substations. This is discussed further in Sections 6 and 7 of this study.

4.4.3 Woodland 400kV Substation

Noise monitoring was completed at nine different locations in the vicinity of the Woodland 400kV Substation, two at alternative distances (i.e. 5m and 10m) from the southern, western and eastern boundaries of the substation and three at alternative distances from the transformer (i.e. 11m, 22 & 47m). Five minute measurements were completed at each location as a steady state noise was being emitted from the substation. The noise meter was paused to exclude any other noise sources (e.g. passing traffic on road etc.) during the measurement periods.

Subjective observations taken during the measurement survey recorded that substation noise, pylon corona noise and transformer noise was audible along all four boundaries of the substation. Table 4.10 includes the noise monitoring data recorded during the survey at the Woodland 400kV substation.

Table 4.10: Noise Monitoring Data for Woodland 400kV Substation

Boundary	**Distance from Boundary (m)**	**Date/ Time**	**L_{Aeq} [dB(A)]**	**L_{Amax} [dB(A)]**	**L_{Amin} [dB(A)]**	**L_{A5} [dB(A)]**	**L_{A50} [dB(A)]**	**L_{A90} [dB(A)]**
Southern	5	14:23	41	53	36	43	40	39
Southern	10	14:38	42	48	37	43	41	40
Western	5	14:52	51	56	49	52	50	50
Western	10	15:00	50	60	48	51	50	49
Transformer	11	15:08	53	55	51	55	53	52
Transformer	22	15:15	52	54	50	53	52	51
Transformer	47	15:24	48	50	46	49	48	47
Eastern	5	15:45	46	57	43	48	46	44
Eastern	10	15:53	49	56	45	51	49	47

As described in Sections 4.4.1 and 4.4.2, if a particular noise source is dominant, successive noise measurements at a greater distance from the source should show a progressive reduction in the measured noise levels as one travels away from the source.

The measurement data included in Table 4.10 shows no progressive reduction in the noise levels for all relevant noise parameters as distance increases from the southern, western and eastern boundaries. The data for the transformer measurements show a clear progressive reduction in the noise levels for all parameters with distance from the transformer. The measurement strongly indicates that the transformer is the dominant noise source throughout the substation and that it remains the dominant noise source up to distances of at least 50m away from it.

The noise survey at Woodland 400kV substation illustrates how the higher voltage substations are significantly louder than the 110kV and 220kV substations, producing average noise levels of greater than 50dB(A) beyond a 20m distance from the boundary of the substation.

Spectral data was recorded throughout each of the measurements completed at Woodlands 400kV substation to determine if there were any tonal features in the recorded noise levels. Figure 4.10 illustrates the typical spectral profile recorded during all measurements at the site. This figure demonstrates how the overall noise level from the substation is dominated by noise levels in the low and mid frequency ranges. The data shows clear tonal peaks at approximately 100Hz, 200Hz and 300Hz, which follow the spectral profile discussed in Section 2.3 of this report.

Figure 4.10: Typical Spectral Profile of Noise Levels at Woodland 400kV Substation

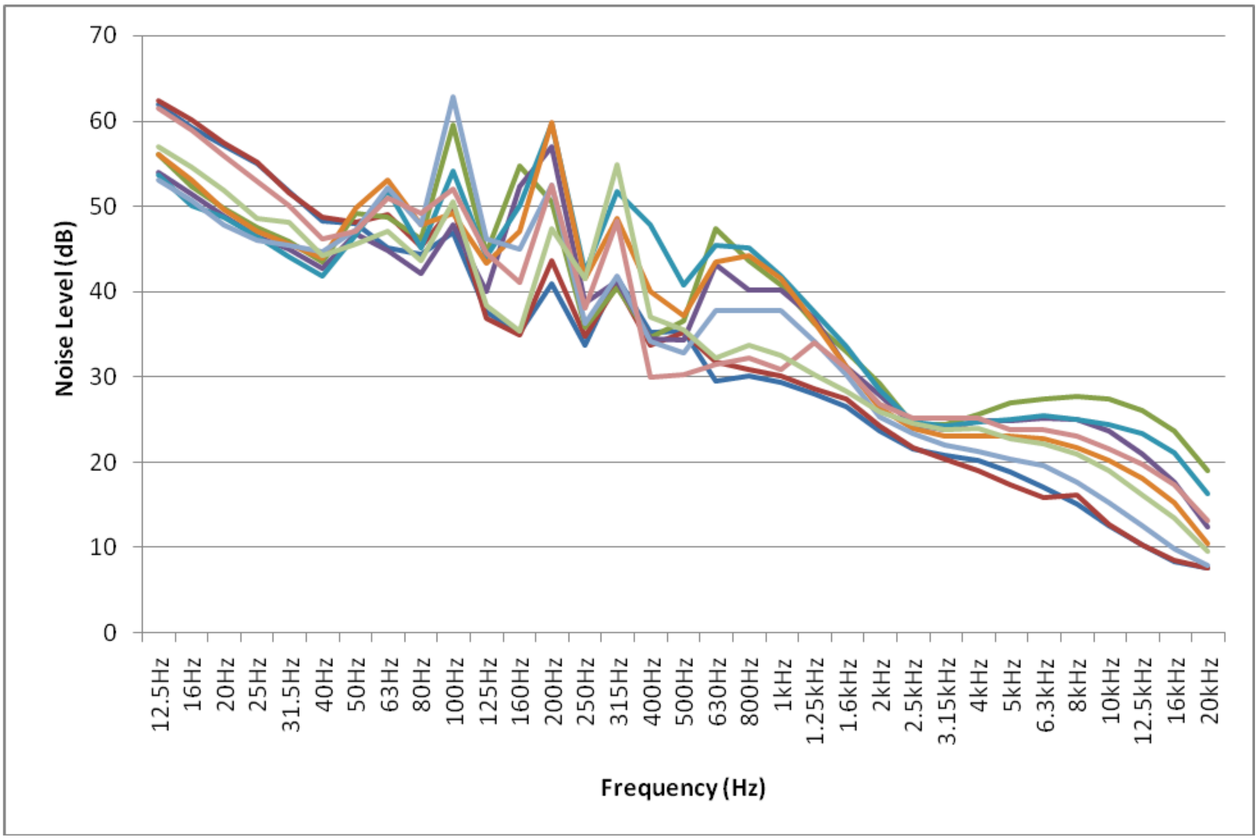


Figure 4.10 illustrates that there are significant tonal qualities to the noise from 400kV substations. This is discussed further in Sections 6 and 7 of this report.

5 AECOM SURVEY ON 400KV OVERHEAD LINE

5.1 INTRODUCTION

AECOM were separately commissioned by EirGrid to undertake a long term noise survey in the vicinity of the Dunstown-Moneypoint 400kV OHL in Cloney, Co Kildare. The report produced by AECOM is included in its entirety in **Appendix B** and summarised in the sections below. The conclusions and recommendations from the AECOM report are included in the sections that follow and help to supplement the overall conclusions and recommendations from this Evidence Based Study.

5.2 METHODOLOGY

Noise monitoring was undertaken at three locations in the vicinity of the existing 400kV OHL: directly beneath a tower; at a mid-span location between two towers; and a distance of approximately 200m from the line as a control location. The control location is intended to capture the general background noise under the same weather conditions, but excluding noise from the OHL.

All noise measurements were made using Rion NL-52 integrating sound level meters and Rion NC-74 acoustic calibrators. The meters were set to log in 10 minute contiguous periods. Monitoring stations were set up in each location comprising an all-weather equipped sound level meter mounted between 1.2m and 1.5m off the ground in free-field conditions. At the control site, a weather station was also erected to record rainfall, temperature, ambient air pressure, wind speed and wind direction. All of these parameters were logged over one minute and ten minute intervals.

The noise meters were set to automatically log the following parameters: L_{Aeq}, L_{AMax}, L_{Amin}, L_{A05}, L_{A10}, L_{A50} and L_{A90}. Each parameter was logged at 1-minute intervals, allowing more detailed correlation with the 1-minute rainfall data.

5.3 MEASURED DATA

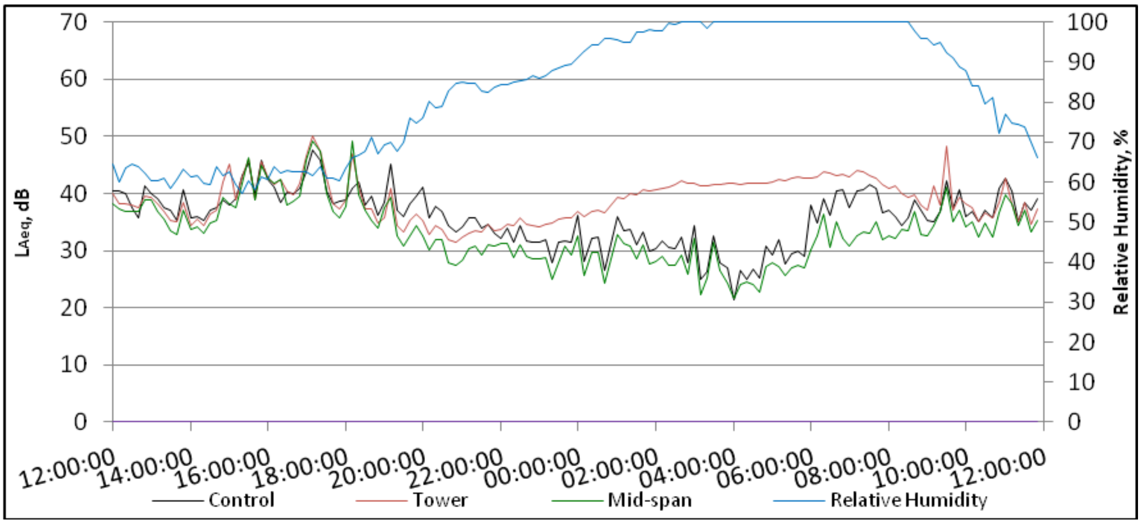
Table 5.1 presents that average and absolute measurements for the 10-week survey period. During the 10-week measurement period, a wide variety of weather conditions were recorded. For the first 4 weeks, conditions were predominantly dry with a total of 10.5mm of rain recorded, while the following 6 weeks had a total of 165mm of rainfall. Wind speeds were variable with individual maximum gust speeds of up to 15m/s recorded, although 10-minute average wind speeds remained below 5m/s for over 99.5% of the monitoring period. Temperatures remained between 3.5ºC and 18.5ºC for 90% of the measurement period. Humidity remained above 70% for 90% of the measurement period.

Table 5.1: Summary of Measured Noise Levels Over 10-Week Period

Location	Noise Level dB(A)							
	Average from 1-minute Values					Absolute over Entire Monitoring Period		
	L_{Aeq}	L_{AMax}	L_{Amin}	L_{A10}	L_{A90}	Total L_{Aeq}	Maximum L_{AMax}	Minimum L_{AMin}
Control	37.8	52.8	27.3	40.6	30.3	42.1	91.7	15.6
Tower	41.4	52.8	35.2	43.2	37.7	45.6	97.8	21.1
Mid-span	36.4	50.2	28.1	38.9	30.7	42.2	99.8	15.8

In analysing the data from the 10-week survey, AECOM concluded that while control and mid-span noise levels generally decreased at night in dry conditions, this was not the case with the tower locations. Figure 5.1 is a graphical demonstration of this from the AECOM report (see **Appendix B**).

Figure 5.1: Typical Dry 24-hour Variation in $L_{Aeq, 10min}$ Level for All Locations



Figures 5.2 - 5.4 are also taken from AECOM report and show the distribution of noise levels for the control, mid-span and tower monitoring locations during dry conditions. These figures illustrate the relative similar distribution between control and mid span locations but illustrate an increase in the distributed noise levels for the tower location, which is attributable to corona noise.

The report makes the connection between the increase in humidity levels (especially at night) and the increase in corona noise levels at the tower and postulates that this may contribute to corona noise being the dominant noise source at night near the tower structure.

Figure 5.2: Distribution of $L_{Aeq,\ 1min}$ Levels at the Control Location (Dry Conditions)

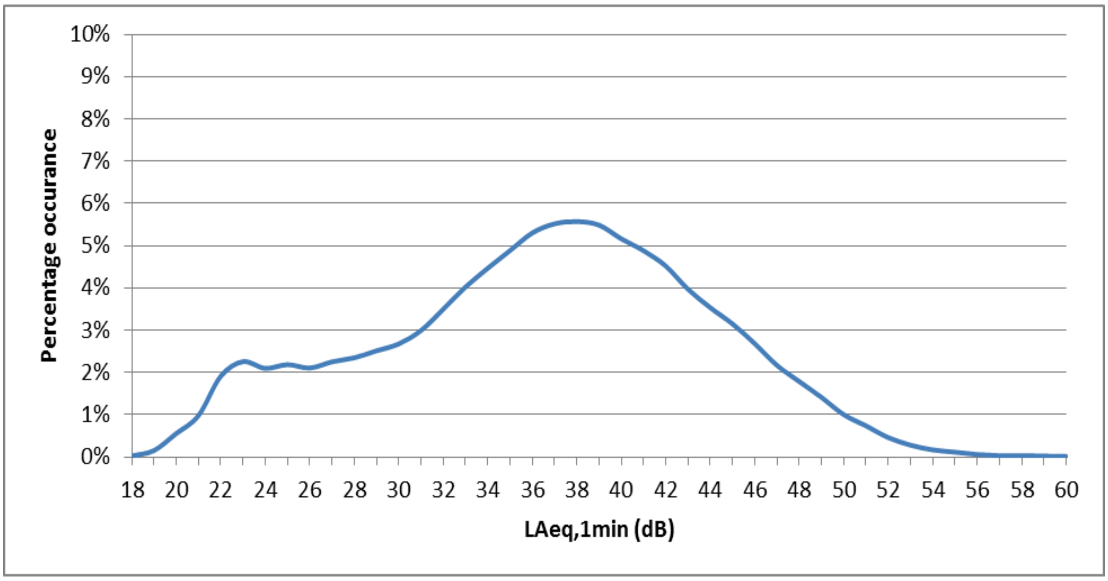


Figure 5.3: Distribution of $L_{Aeq,\ 1min}$ Levels at the Mid-Span Location (Dry Conditions)

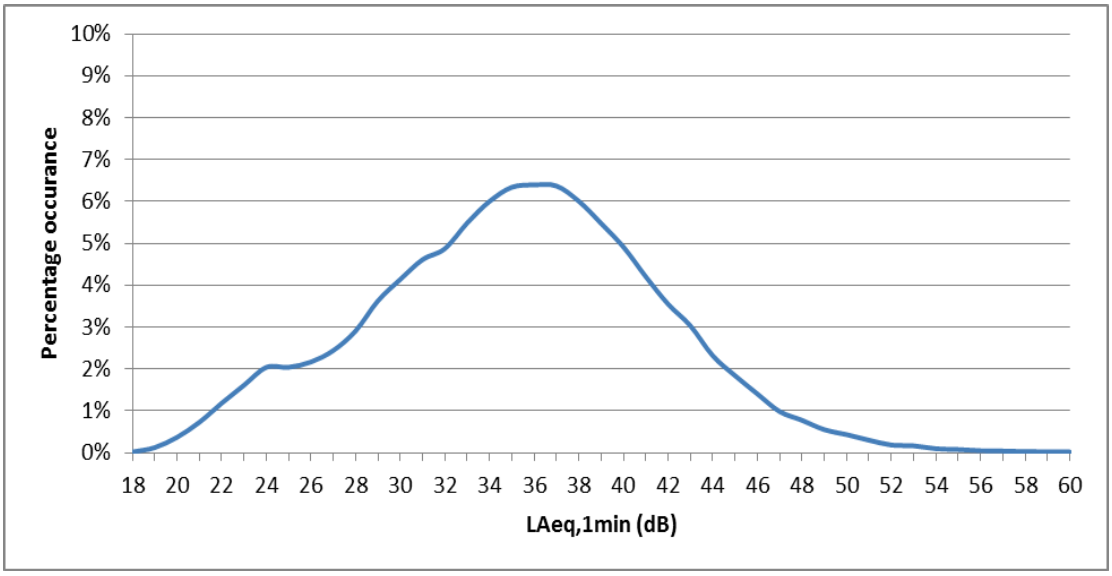
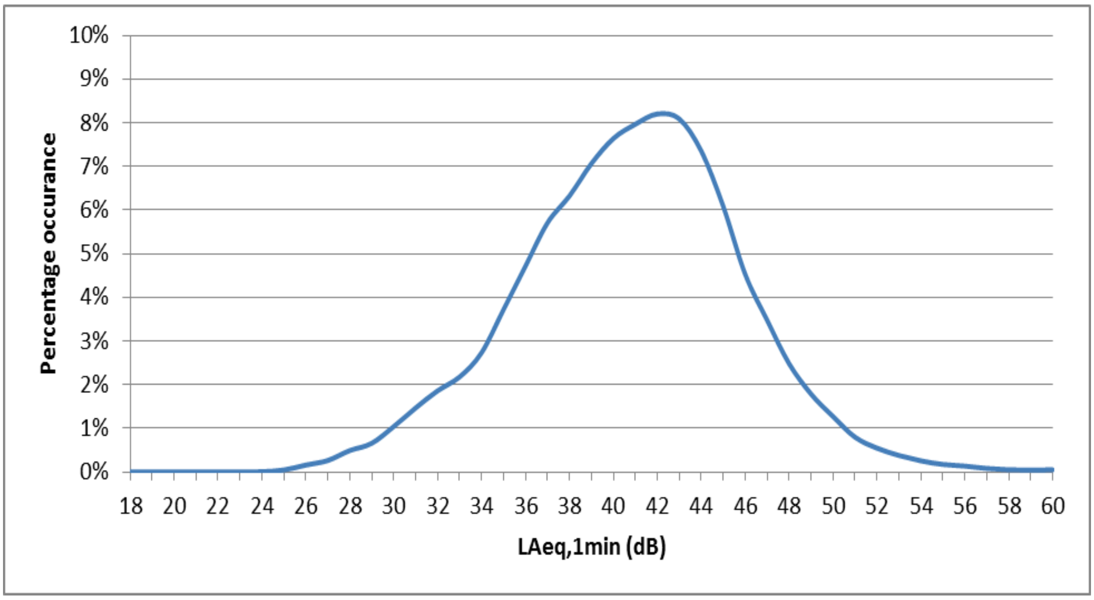


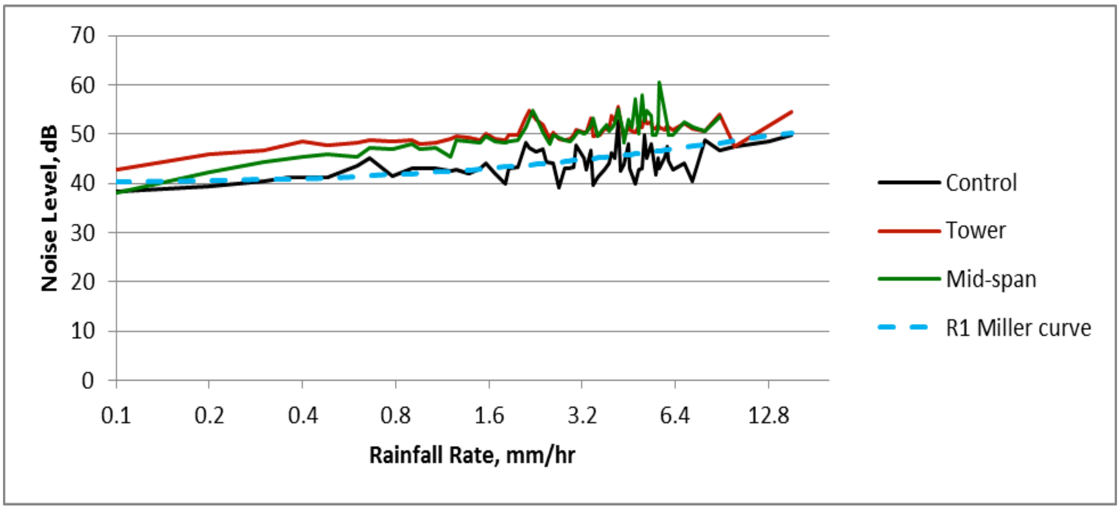
Figure 5.4: Distribution of $L_{Aeq,\ 1min}$ Levels at the Tower Location (Dry Conditions)



The AECOM Report provides separate analysis of rainfall affected data to determine the potential corona effects that may be prevalent during periods of rain. Figure 5.5 presents a graphical illustration of average noise levels plotted against rainfall rate. The greater number of recorded noise levels at lower rainfall rates allow for the smoother line observed at the lower rainfall rates. The greater variation at higher rates is a consequence of fewer instances of very high rates of rainfall.

The graph illustrates the increased noise level attributed to corona noise between the control site and the mid-span and especially tower locations, with reported increase of approximately 6dB observed when comparing the tower and control locations.

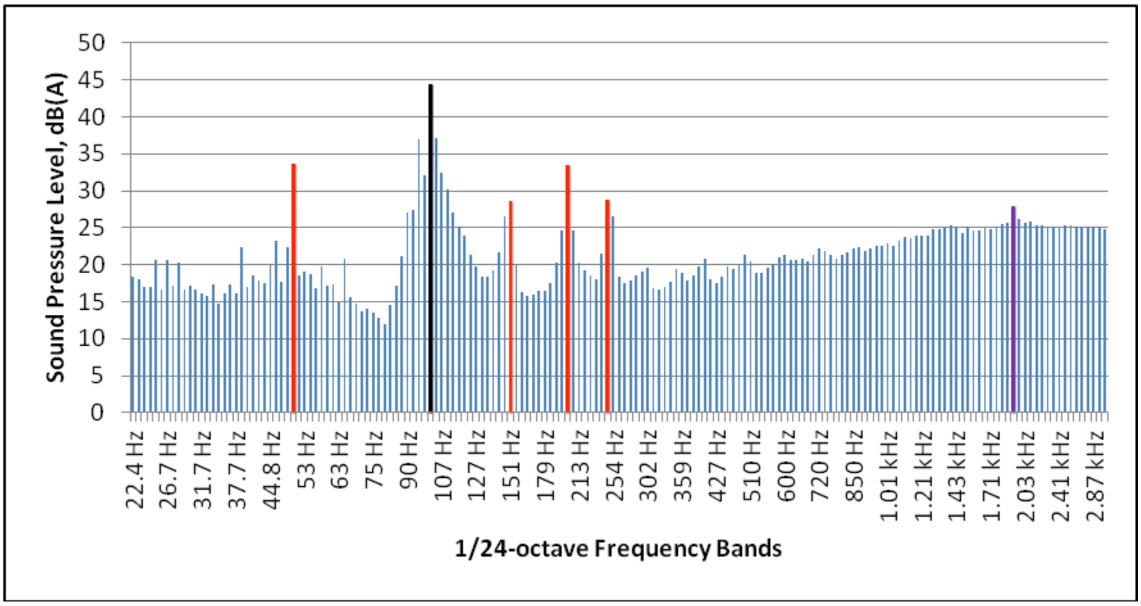
Figure 5.5: Measured Noise Levels Against Rainfall Rate for All Sites



Spectral analysis of selected audio recordings identified a tonal component to the corona noise at 100Hz, which tallied with the expected tonal frequency based on an expected tonal component at twice the electrical frequency of the system (which is 50Hz in Ireland).

Figure 5.6 from the report illustrates a sample 1/24-octave band analysis demonstrating the principal tones and associated harmonic frequencies.

Figure 5.6: 1/24-Octave Band Analysis of Corona Noise at Mid-Span Locations



6 DISCUSSION AND CONCLUSION

6.1 DISCUSSION ON SURVEY RESULTS FROM 110KV OVERHEAD LINES

Section 4.1 of the report includes the survey results and analysis of survey data for the survey locations adjacent to 110kV OHL. As discussed in Section 4.1.4, no weather data was retrieved for the 'Off' survey at Golagh Tee - Letterkenny 110kV OHL, and therefore no detailed analysis of the data for this site was undertaken.

Section 4.1.2 highlighted the large difference between the datasets recorded at C'Fall Golagh Tee - Letterkenny 110kV OHL and how this may have related to the fact that sheep were placed in the field subsequent to the meter being placed there. On account of what appears to be significant contamination to the dataset for the 'On' survey from this noise source, this location has not figured significantly in terms of drawing conclusions from the surveys.

The discussion of the noise associated with 110kV lines is therefore based predominantly on the survey results and subsequent analysis of the data from C'Fall Golagh Tee - Letterkenny 110kV OHL and C'Fall - Srananagh 110kV OHL. For both locations, a full dataset of noise and weather synchronised data was retrieved for both 'On' and 'Off' surveys and no known source of noise contamination that could have potentially skewed any of the datasets is suspected.

Tables 4.1 and 4.3 indicate that when rain and wind affected data are removed from each of the noise parameter datasets (i.e. L_{A5}, L_{A50}, L_{A90}, L_{Aeq}), the measured noise levels are similar for 'On' and 'Off' surveys. Particular attention was paid to the background noise level (i.e. L_{A90}) during the quietest periods of the day (i.e. night). If the 110kV OHL was producing a constant detectable noise emission, one would expect that this would be most clearly observed during the night when background noise levels were at their lowest. The background noise levels were observed to be similar for 'On' and 'Off' surveys at both locations, with no clear sign of elevated noise levels during the 'On' survey. Figures 4.1 and 4.2 were included in Section 4.1 to illustrate a comparable trend to the measured background noise levels for 'On' and 'Off' surveys at both locations.

While the comparison of the background noise levels during the quietest periods of the day demonstrates that there is no clear constant noise source from the infrastructure during the 'On' survey, this parameter does not account for short random events such as corona discharge which may occur only occasionally (the L_{A90} represents the noise level exceeded for 90% of the measured time during a defined measurement period). The L_{A5} parameter represents the noise level exceeded for 5% of the measured time during a measurement period and would be expected to capture noisy corona discharge events subject to them being sufficiently common and noisy.

The L_{A5} measurements summarised in Tables 4.1 and 4.3 do not provide any evidence that corona discharge events are sufficiently regular or loud as to result in an increase in the measured L_{A5} noise levels.

Approximately 717 hours of noise data synchronised with weather data was retrieved from C'Fall Golagh Tee - Letterkenny 110kV and C'Fall - Srananagh 110kV OHL. The analysis of this data for each of the noise parameters relevant to this study (i.e. L_{A5}, L_{A50}, L_{A90}, L_{Aeq}), demonstrates that there was no increase in the measured noise levels during the 'On' survey when compared with the 'Off' survey. The analysis of data from the studies on the 110kV OHL provides strong evidence that there is no significant noise emissions from 110kV OHL.

The results from the 110kV surveys support the findings of the literature review which indicate that corona noise only starts to become a significant noise issue at voltages of 350-500kV and above.

6.2 DISCUSSION ON SURVEY RESULTS FROM 220KV OVERHEAD LINES

Section 4.2 of the report includes the survey results and analysis of survey data for the survey locations adjacent to 220kV OHL. Noise surveys were completed at three different locations along the Dunstown-Maynooth 220kV line - Betaghstown, Currabell and Thomastown. In all, 666 hours of noise and weather synchronised data was collected for 'On' and 'Off' surveys at all three locations.

Analysis of the datasets at all three locations (see Tables 4.4, 4.5 & 4.6) demonstrate that when rain and wind affected data was removed, there is no significant difference between the measured noise levels for all relevant parameters (i.e. L_{A5}, L_{A50}, L_{A90}, L_{Aeq}), for 'On' and 'Off' surveys. The data for quieter periods of the day (i.e. night) do not show elevated noise levels during the 'On' surveys as illustrated in Figures 4.3, 4.4 and 4.5.

The L_{A5} parameter records the top 5% of noisy activities during a measurement period and would be expected to capture noisy corona discharge events subject to them being sufficiently regular and noisy. The L_{A5} measurements summarised in Tables 4.4, 4.5 and 4.6 do not provide any evidence that corona discharge events are sufficiently regular or loud as to modify the measured noise level or present any significant noise impact.

Significant periods of rain affected data was recorded during the 'On' and 'Off' surveys at the Dunstown Maynooth 220kV Currabell site. The data for quiet periods of the day (i.e. night and quiet day) show no significant difference between 'On' and 'Off' survey for all parameters recorded (i.e. L_{Aeq}, L_{A90}, L_{A50}, L_{A05}). This provides strong evidence that significant rain induced corona discharge is not evident for 220kV OHL.

The results of the analysis of what is a large dataset for all three locations, provides a strong evidence base for stating that there are no significant noise emissions associated with 220kV OHL.

The results from the 220kV surveys support the findings of the literature review which indicate that corona noise only starts to become a significant noise issue at voltages of 350-500kV and above.

6.3 DISCUSSION ON SURVEY RESULTS FROM 400KV OVERHEAD LINES

Section 4.3 provides an outline of survey data and analysis for one location (Ardrums Great) along the Oldstreet-Woodland 400kV OHL. It was only possible to complete surveys around the outage schedule at one location on the 400kV network on account of the shortage of programmed works on the 400kV network during the survey period for this project.

As discussed in Section 4.3, a portion of the weather data for the 'Off' survey was not recorded on account of a fault with the weather station. On account of this, the analysis of the Oldstreet - Woodland 400kV OHL data concentrated on the entire datasets and the use of graphical representation to view noise level trends in the quieter periods for both 'On' and 'Off' surveys.

Figures 4.6 illustrates that L_{A90} noise levels in the quietest (night-time) periods are similar for 'On' and 'Off' surveys, indicating that the 400kV OHL was not producing a steady state noise level that was increasing the background noise level at the monitoring location. Figure 4.7 illustrated that the trends for the L_{A5} data were similar for both 'On' and 'Off' surveys. Because there was no significant period of rainfall during the 'On' survey at this location, it was not possible to make any analysis of potential corona noise effects from 400kV OHL during rain affected conditions. However, the literature review indicated that corona noise only starts to become a significant issue at voltages of 350-500kV.

On account of the fact that no rain affected data was recorded during the 'On' survey, no conclusions can be drawn from the survey at Oldstreet Woodland 400kV OHL (Ardrums Great) in relation to the potential for corona noise effects from 400kV OHL during rainy conditions. For this reason, more survey work over a longer period of time (to ensure a significant dataset was recorded during rainy conditions) was required for 400kV OHL. It is in this context that EirGrid commissioned AECOM to undertake a 10-week survey adjacent to the existing Dunstown-Moneypoint 400kV OHL at Cloney, Co Kildare (see Section 5). A discussion of the findings of this survey is included in Section 6.4.

6.4 DISCUSSION ON AECOM 400KV SURVEY

Section 5 provides a description of the methodology and measurements from a 10-week noise survey at locations adjacent to the 400kV OHL at Cloney, Co Kildare. The significant duration of the survey ensured that a substantial dataset was recorded, including noise measurements under all weather conditions. In particular, the survey enabled a significant dataset to be recorded during rain affected conditions to determine if corona effects were a significant noise source associated with 400kV OHL.

The AECOM report shows the distribution of noise levels for the control, mid-span and tower monitoring locations during dry conditions, illustrating an increase in the distributed noise levels for the tower location, which the report has attributed to corona noise. The report makes the connection between the increase in humidity levels (especially at night) and the increase in corona noise levels at the tower and postulates that this may contribute to corona noise being the dominant noise source at night near the tower structure.

The AECOM report provides separate analysis of rainfall affected data to determine the potential corona effects that may be prevalent during periods of rain. The graphical output of this analysis illustrates the increased noise level attributed to corona noise between the control site and the mid-span and especially tower locations, with reported increase of approximately 6dB observed when comparing the tower and control locations. Spectral analysis of selected audio recordings identified a tonal component to the corona noise at 100Hz, which tallied with the expected tonal frequency based on an expected tonal component at twice the electrical frequency of the system (50Hz in Ireland).

The more limited dataset gathered as part of the Oldstreet - Woodland 400kV OHL (Ardrums Great) survey meant that definitive conclusions could not be drawn in relation to the potential for significant corona effects from 400kV OHL. The more extensive 10-week survey completed by AECOM gave the substantial dataset that enabled more definitive analysis and conclusions to be drawn in relation to potential corona effects from 400kV OHL. On the basis of this analysis, more definitive recommendations can be made in relation to the acceptable proximity of residential receptors to 400kV OHL and this is presented in Section 7 of the report.

6.5 DISCUSSION ON SURVEY RESULTS FROM SUBSTATIONS

Section 4.4 includes details on noise surveys completed at different types of substations (i.e. 110kV, 220kV & 400kV) on the Irish network. Short-term noise measurements were taken at various locations recording the steady state noise level at different boundaries and at different distances from standard 110kV, 220kV and 400kV substations.

The results of the measurement surveys demonstrate that in the case of 110kV and 220kV substations, the substation noise (including low level corona and transformer noise) stop being the dominant noise source at a distance of 10-15m from the boundary of the substation. The noise will still be subjectively audible and contribute to the ambient noise level beyond this distance; however the extent of this contribution will reduce significantly with distance.

The spectral analysis of the 110kV and 220kV substations demonstrated that there was no distinct tonal aspects to the 110kV substation noise; however clear tonal elements could be discerned at up to three locations on the 220kv frequency spectrum. Any recommendations for 220kV substations should include consideration of the tonal elements to the noise from these substations.

The noise measurements included in the surveys were conducted on the basis of recording steady state noise from the substation sites. This does not reflect any potential random corona effects that may arise under certain weather conditions and which may result in short-term increases in the recorded noise levels from the substation. The survey data from the 110kV and 220kV OHL and the findings of the literature review indicate that significant noise impacts from corona effects are not common at these voltages (i.e. 110kV & 220kV). The survey methodology for substations did not provide an opportunity to confirm this, as outlined in Section 3.2.5.

For both 110kV and 220kV substations, the measured noise levels at 10m are well within the daytime WHO threshold limits for serious annoyance (55dB L_{Aeq}) and moderate annoyance (50dB L_{Aeq}) for outdoor living areas and the night-time free-field threshold limit of 42dB (L_{Aeq}) for preventing negative effects on sleep.

In the case of the noise measurement survey for the 400kV substation, the effect of a higher voltage transformer can be clearly observed in the noise monitoring results associated with the transformer. The measurement strategy at various distances demonstrated that the transformer was still the dominant noise source at distances of greater than 50m. The measured average noise levels (L_{Aeq}) were greater than 50dB(A) at a distance of greater than 20m from the substation boundary, which is above the daytime WHO threshold limit for moderate annoyance in an outdoor living area.

The measured noise levels from the 400kV transformer are above the WHO night-time free-field threshold for preventing disturbance to sleep (i.e. 42dB) for measurement distances up to 50m. In addition to this, the spectral analysis of the 400kV substation data demonstrates that there are clear tonal elements to the substation noise with clear tonal peaks being identified in a number of low to mid frequencies. On account of the higher measured noise levels from 440kV substations and the more discrete tonal elements to the noise from these substations, there is a significantly higher potential for noise impacts from 400kV substations as compared with 110kV and 220kV substations. This is reflected in the recommendations included in Section 7 of this report.

As in the case of the 110kV and 220kV discussion, the measurement survey for the 400kV substation did not reflect any potential random corona effects that may arise under certain weather conditions and which may result in short-term increases in the noise levels from the substation.

The data from the substation surveys provides valuable information on the steady state noise levels from substations of various types and gives a good profile of the tonal characteristics associated with the different types of substations. This data provides a valuable tool to enable recommendations to be presented in Section 7 of this report.

6.6 CONCLUSION

Based on the survey results and analysis included in Section 4 of this report, it is possible to make robust statements on the noise emissions from electricity infrastructure, which are strongly supported by the evidence from the surveys and analysis.

Based on the survey results and analysis completed for the 110kV OHL, there is strong evidence indicating that there are no significant detectable steady state noise emissions from 110kV OHL. The survey results and analysis completed for the 220kV OHL also indicate that there is strong evidence in support of there being no significant detectable steady state noise emissions from 220kV OHL.

Corona discharge is a well recognised phenomenon associated with electrical infrastructure under certain weather conditions. The large datasets collected as part of 110kV and 220kV OHL surveys provide a strong evidence base that random corona discharge is not sufficiently regular or loud enough to significantly alter measured noise levels from these types of infrastructure. This finding corroborates the findings from the literature review which indicated that corona noise is not a significant noise issue below 350kV.

The survey results and analysis completed for the one 400kV OHL, combined with the additional 10-week survey completed by AECOM at a separate 400kV OHL location, indicate that significant corona noise effects are observed from 400kV OHL. Under dry conditions, this is limited to immediately adjacent to tower locations, while under wet conditions this observed for mid span but most notably tower locations. A maximum difference of 6dB was observed under wet conditions between tower and control locations. A tonal component to this noise was also recorded. These observations align with the literature review which indicated that corona noise starts to become an issue at voltages of 350-500kV and above.

Noise measurement surveys completed at 110kV, 220kV and 400kV substations recorded the steady state noise levels in the vicinity of the boundaries of these substations. In the vicinity of the 110kV substation, average noise levels (i.e. L_{Aeq}) of less than 40dB(A) were recorded. The measured L_{Aeq} noise levels at the noisiest boundaries were in the range of 40-45dB(A) for the 220kV substation and 50-55dB(A) for the 400kV substation. Spectral analysis of all substation types demonstrated that there are distinct tonal elements to the noise from 220kV and 400kV substations

7 RECOMMENDATIONS

On the basis of the results of this study, a number of recommendations have been included in this section for the purpose of protecting the amenity of noise sensitive receptors in the vicinity of any proposed transmission infrastructure development. The recommendations are presented in the context of being of use as part of the design and siting process for such future projects.

The noise studies on 110kV and 220kV OHL present a strong database of evidence that indicates that these lines do not produce steady state noise levels that are likely to result in a significant noise impacts at receptors in the vicinity of them. There is no evidence that random corona discharge events are sufficiently regular or loud as to result in significant noise impacts to noise sensitive receptors in their vicinity. On this basis, the planning of 110kV and 220kV OHL should not be significantly constrained on the basis of potential noise issues associated with these types of infrastructure.

The noise study on the 400 kV OHL provided a strong database of evidence to indicate that these lines do produce significant corona noise effects under certain conditions, which are immediately adjacent to the tower under dry humid conditions and at tower and mid span locations under wet conditions. The literature review indicates that corona effects start to become significant in noise impact terms at voltages in the range of 350-500kV, and the evidence presented in this study would appear to verify this.

While Section 5 does illustrate the potential for significant corona noise under certain conditions immediately adjacent to 400kV towers and to a lesser extent mid span OHL, the noise levels from these corona effects are relatively low (i.e. low 40s dB) in the context of other typical environmental noise sources such as road traffic noise. However, there is potential for noise impacts from such corona effects under certain conditions such as properties located very close to such infrastructure in quiet rural locations (especially at night under humid or wet conditions). The potential for noise impacts is further exacerbated by the tonal characteristics associated from this corona noise.

The standard Irish reference document for undertaking noise assessments is the Environmental Protection Agency (EPA) Office of Environmental Enforcement (OEE) *Guidance Note for Noise: Licence Applications, Surveys and Assessments in Relation to Scheduled Activities (NG4).* NG4 would recommend the use of a tonal correction of +5dB(A) to account for the tonal characteristics of a noise source such as that from corona noise. Any assessment of noise impacts from 400kV lines should be undertaken on the basis of the worst-case corona noise levels as included in Section 5 of this report, but including an additional 5dB(A) penalty to account for the tonal characteristics of the noise as outlined in the EPA NG4 document.

Setting an absolute recommended minimum distance between a 400kV tower or OHL and a sensitive property is difficult as it is very much dependent on the background noise levels at that particular property. As outlined in the previous paragraph, the best approach is to determine an appropriate distance based on worst-case corona noise levels (including tonal correction) assessed against the background noise level (i.e. L_{A90}) at the particular property in question.

As a practical example, the AECOM report used a control at 200m distance, at which location no noise impacts from the 400kV OHL were observed. Similarly, the potential noise effects from the tower were observed to be significantly greater than the mid span OHL. As a rule of thumb for undertaking high level assessments prior to undertaking more detailed assessment on a property by property basis, it may be appropriate to use a recommended reference separation distance of 200m between any property and a 400kV tower and 100m between any property and an OHL.

The survey on the 110kv substation at Dunfirth indicated that measured noise levels (L_{Aeq}) were less than 40dB(A) at 5m from each of the boundaries of the substation. This is below the WHO night-time free-field threshold limit of 42dB for preventing effects on sleep and well below the WHO daytime threshold limits for serious and moderate annoyance in outdoor living areas (i.e. 55dB & 50dB respectively). Spectral analysis of the data recorded at this site demonstrated that there were no distinct tonal elements to the recorded noise level. To avoid any noise impacts from 110kV substations at sensitive receptors, it is recommended that a minimum distance of 5m is maintained between a 110kV substation and the land boundary of any noise sensitive property.

The survey on the 220kv substation at Gorman indicated that measured noise levels (L_{Aeq}) were approximately 43dB(A) at 5m from the most affected boundary of the substation. This is marginally above the WHO night-time threshold limit for preventing disturbance to sleep (i.e. 42dB). Spectral analysis of the noise from the Gorman substation demonstrated that there are a number of distinct tonal elements to noise in the low to mid frequency range. To avoid any noise impacts from 220kV substations at sensitive receptors, it is recommended that a distance of 20m is maintained between the nearest site boundary and the nearest sensitive receptor.

The survey on the 400kv substation at Woodland indicated that measured noise levels (L_{Aeq}) were approximately 53dB(A) at 11m from the main transformer in the substation. The measured noise levels also indicated that the substation/transformer noise remained the dominant noise source at distances of 50m and greater from the boundary of the substation.

The measured noise data from the 400kV substation is above the WHO daytime threshold limit for moderate annoyance in outdoor living areas (50dB) at 11m and significantly above the WHO night-time free-field threshold limit for preventing disturbance to sleep (42dB) at 47m distance from the substation boundary. Spectral analysis also demonstrated that there was a number of distinct tonal elements to the measured noise level in the low frequency range.

On account of the significant broadband noise levels and tonal noise elements associated with 400kV substations, it is recommended that a minimum distance of 150m is maintained between the nearest substation boundary and the nearest sensitive receptor.

8 REFERENCES

Akagi, Y., Sato, K., Iwama, N., Kubota, K., (1998), *Low-noise Conductor for Harmonizing 1,000 kV Transmission Lines with the Environment*. U. D. C. 621.315.14.027.89 : 534.11 : [551.556+537.525.3]

Al-Faraj, M. A., Shwehdi, M. H., Farag, A. S., (1997), *Environmental Effect on High Voltage AC Transmission Lines Audible Noise*. Energy Conversion Engineering Conference, 1997. IECEC-97. Proceedings of the 32nd Intersociety, Vol. 3, p. 2082-2087.

Belardo, C. A., Fujimoto, F. T., Jardini, J. A., Bistafa, S. R., Kayano, P., Masiero, B. S., Nascimento, V. H., Ribeiro, F., Mercato, E., Lima, R. G., Chavez, L., Tamai, E., (2006), *Dynamic Absorption of Transformer Tank Vibrations and Active Canceling of the Resulting Noise*. 1st Congress on Operational Excellence and innovation of AES Businesses in Latin America, 2006.

Bhatti, S. A., Shan, Q., Glover, I. A., Atkinson, R., Portugues, I. E., Moore, P. J., Rutherford, R., (2009), Impulsive Noise Modelling and Prediction of Its Impact on the Performance of WLAN Receiver. 17th European Signal Processing Conference (EUSIPCO 2009), Glasgow, Scotland. Aug 24-28, 2009. pp 1680-1684.

British Standard BS4142: 1997 – *Method for rating industrial noise affecting mixed residential and industrial areas.* British Standard Institution.

Chang, Y-H., Hsu, C-H., Lin, H-W., (2009), *Design of Low-Noise Power Transformer with the Noise Effect Survey on the Resident*. IMCAS'09 Proceedings of the 8th WSEAS International Conference on Instrumentation, Measurement, Circuits and Systems, p. 223-227.

Chartier, V. L., Blair, D. E., Easley, M. D., Raczkowski, R. T., (1995), *Corona Performance of a Compact 230-kV Line*. USA: IEEE Transactions on Power Delivery, Vol. 10, No. 1, January 1995.

Cigre (1999) *High Voltage Overhead Lines - Environmental Concerns, Procedures, Impacts and Mitigations,* Cigre Working Group 22.14.

Department of Energy and Climate Change (2011) *National Policy Statement for Electricity Networks Infrastructure (EN-5),* UK Department of Energy and Climate Change.

Environment Agency (2004) *Integrated Pollution Prevention and Control (IPPC) Horizontal Guidance for Noise Part 2 - Noise Assessment and Control*, UK Environmental Agency.

Environment Protection Agency (2012) *Guidance Note for Noise: Licence Applications, Surveys and Assessments in Relation to Scheduled Activities (NG4),* Ireland: Environmental Protection Agency Office of Environmental Enforcement (OEE).

Gela, G., LaForest, J. J., Zaffanella, L. E. (1993) *HVDC Transmission Line Reference Book*. Electric Power REsearch Institute, 3412 Hillview Avenue, Palo Alto, Califormia, 1993, Section 3, pages 1-188.

Leventhall, G., (2003), *A Review of Published Research on Low Frequency Noise and its Effects*. UK: Department for Environment, Food and Rural Affairs.

Medeiros, E. B., Borges, E. N. M., (2005) Evaluation of the Global Attenuation Noise Coefficient of an Active Control System in an Open Space. Forum Acusticum Budapest 2005: 4th European Congress on Acustics, 2005, PP. 893-897.

Medeiros, E. B., Kroeff, G., (1998), *Acoustic Modeling and Simulation of an Urban Substation*. Journal of the Acoustic Society of America, Vol. 103, Issue 5, pp. 2838-2838.

Meyer, R. E., Aldrich, T. E., Easterly, C. E., (1989), *Effects of Noise and Electromagnetic Fields on Reproductive Outcomes*. USA: Environmental Health Perspectives, Vol. 81, pp. 193-200.

Masti, R. S., Desmet, W., Heylen, W., (2004), *On the Influence of Core Laminations Upon Power Transformer Noise*. Proceedings of the 2004 International Conference on Noise and Vibration Engineering, Leuven, Belgium. 3851-3862, Sept. 20-22, 2004.

Muhr, M., Pack, S., Schwarz, R., Kornhuber, S., Koerbler, B., (2004), *Sound Analysis and PD Measurement of HV Transmission Lines*. ACEDTsinghua University Press, p. 191-194.

Scottish Government (2011) *Planning Advice Note PAN 1/2011 - Planning and Noise*, UK: Scottish Government.

Shan, Q., Bhatti, S. A., Glover, I. A., Atkinson, R. C., Portugues, I., Moore, P. J., Rutherford, R., (2009a), *Characteristics of Impulsive Noise in Electricity Substations*. 17th European Signal Processing Conference (EUSIPCO 2009), Glasgow, Scotland. Aug 24-28, 2009. pp 2136-2140.

Shan, Q., Bhatti, S. A., Glover, I. A., Atkinson, R. C., Portugues, I., Moore, P. J., Rutherford, R., (2009b), R., (2009b), *Extraction of Impulsive Noise from Measurements in a 400kV Electricity Substation.* International Conference on Energy and Environment, 2009-03-19 - 2009-03-21, India.

Shan, Q., Glover, I. A., Moore, P. J., Portugues, I., Judd, M. D., Rutherford, R., Watson, R. J., (2009c), Impulsive Noise Environment of High Voltage Electricity Transmission Substations and Its Impact on the Performance of Zigbee. Paper Presented at XXIX General Assembly of the International Union of Radio Science, Chicago, Illinois, USA.

Straumann, U., Fan, J., (2009), *Audible Noise from AC-UHV Transmission Lines - Theoretical Comparison of Broadband and Tonal Components*.

Straumann, U., Weber, H. J., (2010), *Potential Reduction of Audible Noise from New and Aged Overhead Transmission Line Conductors by Increasing Their Hydrophilicity*. Cigre 2010, B2-113.

Task Force of the Corona and Field Effects Subcommittee of the Transmission and Distribution Committee (1982), *A Comparison of Methods for Calculating Audible Noise of High Voltage*

Transmission Lines, USA: IEEE Transaction on Power Apparatus and Systems, Vol. PAS-101, No. 10 October 1982

Task Force of the Radio Noise and Corona Subcommittee of the Transmission and Distribution Committee (1975) *Audible Noise from Power Lines - Measurement, Legislative Control and Human Response*. USA: IEEE Transaction on Power Apparatus and Systems, Vol. PAS-94, No. 6, November/December 1975.

Zhang, Z., Zeng, R., Yu, Z., (2009), *Measurement of Corona Characteristics and Electromagnetic Environment of +/-800kV HVDC Transmission Lines under High Altitude Condition.* Progress in Electromagnetics Research Symposium Proceedings, Moscow, Russia, August 18-21 2009, 61-65.

Wordpress (2011), 'What is Corona Effect', Overview [online], available at: http://electricalnotes.wordpress.com/2011/03/23/what-is-corona-effect/ [accessed 20 Feb 2013].

World Health Organisation (WHO) (1999), *Guidelines for Community Noise*

World Health Organisation (WHO) (2009), *Night Noise Guidelines for Europe*

World Health Organisation (WHO) (2011), *Burden of Disease from Environmental Noise - Quantification of Healthy Life Years Lost in Europe.*

GLOSSARY OF ACOUSTIC TERMINOLOGY

Additive White Gaussian Noise	A channel model in which the only impairment to communication is a linear addition of wideband (see below) or white noise (see below) with a constant spectral density (expressed as watts per hertz of bandwidth) and a Gaussian distribution of amplitude (see below).
Ambient noise	The totally encompassing sound in a given situation at a given time, usually composed of sound from many sources, near and far.
Amplitude	The amplitude of a periodic variable is a measure of its change over a single period (such as time or spatial period).
Attenuation	The reduction in level of a sound between the source and a receiver due to any combination of effects including: distance, atmospheric absorption, acoustic screening, the presence of a building façade, etc.
Attenuation coefficient	A quantity that characterises how easily a material or medium can be penetrated by a beam of sound.
A- weighting	Normal hearing covers the frequency (pitch) range from about 20Hz to 20,000 Hz but sensitivity is greatest between about 500Hz and 5,000Hz. The “A-weighting” is an electrical circuit built into noise meters to approximate this characteristic of human hearing.
Background noise	The steady existing noise level present without contribution from any intermittent sources. The A-weighted sound pressure level of the residual noise at the assessment position that is exceeded for 90 per cent of a given time interval, T($L_{AF90,T}$)
Broadband	Sounds that contain energy distributed across a wide range of frequencies.
Coherence bandwidth	The statistical measurement of a range of frequencies over which the channel can be considered flat.
Decibel (dB)	The logarithmic measure of sound level. 0dB is the threshold of normal hearing. 140 dB(A) is the level at which instantaneous damage to hearing is caused. A change of 1 dB is detectable only under laboratory conditions.
dB (A)	Decibels measured on a sound level meter incorporating frequency weighting (A weighting) which differentiates between sounds of different frequency (pitch) in a similar way to the human ear. Measurements in dB(A) broadly agree with an individual's assessment of loudness. A change of 3 dB(A) is the minimum perceptible under normal conditions and a change of 10 dB(A) corresponds roughly to doubling or halving the loudness of a sound.
Façade level	The noise level at a Golagh Tee - Letterkenny 110kV m from the façade of a building is described by the term façade level , and is subject to a higher noise level than one in an open area (free-field conditions) due to reflection effects.
Free-field	These are conditions in which the radiation from sound sources is unaffected by the presence of any reflecting boundaries or the source itself. In practice, it is a field in which the effects of the boundaries are negligible over the frequency range of interest. In environmental noise, true free-field measurement conditions are seldom achieved and generally the microphone will be positioned at a height between 1.2 and 1.5 metres above ground level. To minimise the influence of reflections, measurements are generally made at least 3.5 metres from any reflecting surface other than the ground.
Hertz (Hz)	The unit of sound frequency in cycles per second.
Impulsive	A noise that is of short duration (typically less than one second), the sound pressure level of which is significantly higher than the background.
L_{A90}	A noise level exceeded for 90% of the time during a measurement period, often used for the measurement of background noise.
$L_{Aeq,T}$	This is the equivalent continuous sound level. It is a type of average and is used to describe a fluctuating noise in terms of a single noise level over the same period (T). The closer the L_{Aeq} value is to either the L_{AF10} or L_{AF90} value indicates the relative impact of the intermittent sources and their contribution. The relative spread between the values determines the impact of intermittent sources, such as traffic, on the background.
Narrowband	Sounds that contain energy distributed across a small range of frequencies.
Noise	Sound that evokes a feeling of displeasure in the environment in which it is heard, and is therefore unwelcomed by the receiver.
Noise emission	The noise emitted by a source of sound.

Noise immission	The noise to which a receiver is exposed.
Residual noise	The ambient noise that remains in the absence of the specific noise whose effects are being assessed.
Sound	Physically: a regular and ordered oscillation of air molecules due to a source of vibrations which creates fluctuating positive and negative acoustic pressure above and below atmospheric pressure. Subjectively: the sensation of hearing caused by the ear being excited by the acoustic oscillations described above.
Sound power level	The logarithmic measure of sound power in comparison to a reference sound intensity level of one picowatt (1pW) per m^2 where: $L_W = 10 \log_{10}\left(\frac{W}{W_0}\right)$ dB Where W is the rms value of sound power in pascals; and W_0 is 1 pW
Sound pressure level	Sound pressure refers to the fluctuations in air pressure caused by the passage of a sound wave. It may be expressed in terms of sound pressure level at a point, which is defined as: $Lp = 20Log P/P_0$ dB Where: P is the sound pressure; P_0 is a reference pressure for propagation of sound in air and has a value of $2x10^{-5}$Pa.
Threshold hearing	The lowest amplitude sound capable of evoking the sensation of hearing in the average healthy human ear (0.00002 Pa, equivalent to 0dB)
Tonal	Sounds which cover a range of only a few Hz which contains a clearly audible tone, i.e. distinguishable, discrete or continuous noise (whine, hiss, screech, or hum etc.) are referred to as being 'tonal'
Wideband	In communications, a system is wideband when the message bandwidth significantly exceeds the coherence bandwidth (See above) of the channel.
White Noise	A random signal with a flat (constant) power spectral density.

APPENDIX A

OVERVIEW OF ELECTRICITY TRANSMISSION INFRASTRUCTURE, INCLUDING TYPICAL CONSTRUCTION METHODOLOGY

A1 Description of Typical Electricity Transmission Project Designs

The transmission network in Ireland comprises structures and overhead lines, underground cables and substations. When the need for a new circuit is identified in Ireland, EirGrid will consider all available solutions for the new circuit. This will include overhead line and underground cable solutions, considering both High Voltage Alternating Current (HVAC) and High Voltage Direct Current (HVDC) technology, as appropriate.

Factors which will influence the solution decision include technical, economic and environmental considerations. It is important to note that each project is different and EirGrid will determine potential technology solutions on a project-by-project basis. EirGrid will continue to keep technology developments under review and will consider new technologies as appropriate.

A1.1 Overhead Lines (OHL)

Transmission lines are generally supported on either wooden pole sets or steel lattice towers. Towers along a straight of the alignment are known as intermediate towers. Angle towers are used where a line changes direction and conductors are held under tension.

The type and height of structures required will vary according to the voltage of the overhead line, and the location and type of environment and terrain in which they are placed.

A1.2 Structure Design

For all new electricity transmission projects, efficient, appropriately placed and optimally designed structures are carefully considered and proposed. The design employed depends on the local environment, topography and technologies involved, and will vary from 110 kV, 220 kV or 400 kV, depending on the specific transmission need identified.

The spacing between structures depends on technical limitations and on the topography, particularly to ensure that conductors maintain a specific minimum clearance above the ground at all times.

Steel Lattice Tower Structures
The weight of conductors and characteristics of 220 kV and 400 kV lines require that they be supported exclusively on lattice steel structures (this also applies to angle towers along a 110 kV line). The three phases (conductors) of a circuit are carried in a horizontal plane.

Table A1: Key Design Features: Single Circuit 220 kV and 400 kV overhead line structures

Key Design Features	220 kV Indicative Range	400 kV Indicative Range
Height range	Depends on technical details of individual projects but generally between 20-40m	Depends on technical details of individual projects but generally between 20m -52m
Maximum range of width at ground level	6m to 12m	7m to 12m
Number of foundations per structure	4	4
Average span between towers	Approx. 320m (dependent on local topography)	Approx. 350 (dependent on local topography)

Example of a 400 kV intermediate tower design along the Dunstown-Moneypoint overhead line, Co Clare

Example of a 220 kV intermediate tower design along the Cashla – Flagford overhead line, Co Roscommon

Single Circuit 110 kV Overhead Lines

A 110 kV single circuit overhead line requires that conductors (and earth wires[1]) are supported on a combination of steel lattice angle towers and double wood intermediate polesets.

The average span between polesets for a 110 kV single circuit alignment is approximately 180m; however, the actual span achievable depends on local topography. Again, the three phases of the circuit are carried in a horizontal plane.

Table A2: Key Design Features of Single Circuit 110 kV overhead line support structures

Key Design Features	110 kV Indicative Range
Height range (double wood polesets)	16m to 23m (incl. buried depth normally 2.3m)
Pole centres	5m
Number of foundations	2
Height range (steel angle towers)	18m to 24m
Maximum width at ground level	4m to 9.8m
Average span	180m

Example of a typical 110kV single-circuit double wood polesets with earthwire (Co Sligo)

On an alignment there may arise a very slight change in direction, and this may necessitate, in the case of a 110 kV single-circuit line, the use of a braced wood poleset, wherein the space between the polesets is reinforced with steel members.

---

[1] Lines running above the conductors which protect the conductors from lightning strike.

Braced double wood poleset

Double Circuit Overhead Lines

Overhead alignments can be configured as single circuit or double circuit (two separate circuits supported on a single structure). This generally only occurs where two single circuit lines are in close proximity (for example on approach to a substation), or where space is at a premium.

Double circuit alignments, including 110 kV overhead lines, always require to be supported by lattice steel towers. The average number of structures on a line is 3-4 per km depending on topography. In addition, the structures are higher, as each circuit must be carried in a vertical plane.

Typical 110 kV double circuit structures

A1.3 Construction of Overhead Lines

Overhead line construction typically follows a standard sequence of events comprising:

- Prepare access;
- Install tower foundations/Excavation;
- Erect towers or wood poles;
- Stringing of conductors;
- Reinstate tower sites and remove temporary accesses.

Prepare Access

It is preferable to have vehicular access to every tower site for foundation excavation, concrete delivery and a crane to erect towers. With wood pole construction, (on 110 kV single circuits) a crane is not usually required, as these are normally erected with a digger using a lifting arm.

Access can take various forms and is dependent on ground conditions. In poorer conditions, more complex access works are required which can vary from the laying of bog mats, or laying temporary wooden matting, to installing crushed stone roads. Some of this work may entail removal of topsoil.

Access routes may require to be constructed for both the construction and maintenance of the transmission line, and may be temporary or permanent.

Every effort is made to cause least disturbance to landowners and local residents, and to cause the least potential environmental impact during construction. As a result, the most direct access route to a tower installation may not always be the most appropriate.

Example of a newly built access route for a transmission project, Co. Donegal

Install Tower Foundations/Excavation

Tower foundations are typically 2–4m deep with excavation carried out by mechanical excavator. Excavations are set out specifically for the type of tower and the type of foundation required for each specific site.

A larger footing may be required in the case of weak soils. Pile foundations may be required in the case of deep bog. In the case of rock being encountered at shallow depths, reduced footing size foundations may be required.

Prior to excavation, the foundations for each tower site will be securely fenced off to ensure the safety of members of the public and livestock. Tower stubs (the lower part of the tower leg) are concreted into the ground. Once the concrete has been poured and cured, the excavation is back-filled using the original material in layers. Surplus material is removed from site.

The excavation required for a wooden poleset is typically 1.5m-2m x 3m x 2.3m deep; no concrete foundations are required for polesets in normal ground conditions. Installation time is approximately two per day. The average foundation size for a braced poleset is 9.3m x 3.1m x 3.2m deep.

In addition to the excavation required for the poleset itself, where ground conditions dictate, stay lines may be required. This generally involves excavation of four trenches (approximately 2m x 2m x 1.8–2m deep) at a distance from the poleset. The installation of stay wires expands the area of disturbance associated with the erecting a poleset.

Stay lines in place, Donegal 110 kV Project

Concrete foundations are required for all steel towers. Foundation size and type is dependent on ground conditions and tower type, but is typically 4m x 4m x 3.1m for each foundation pad. The base installation time is approximately one week.

110kV angle towers at Sranangh Station with exposed substructures

For all transmission lines with earth wires, there is a requirement to install an earth ring or mat at the base of the structure to ground the structure for safety reasons. The ground around the base of structures is excavated after conductors and earthwires are in place and the earth ring is installed.

Earth ring on Donegal 110kV Project

Erect Towers or Wood Poles

Materials required for construction are transported around the site by general purpose cross country vehicles with a lifting device. Excavators are generally of the tracked type to reduce likely damage to and compaction of the ground. In addition a temporary hard standing may be required for machinery and this may require the removal of topsoil. Materials are delivered to site storage/assembly areas by conventional road transport and then transferred to sites.

Tower erection can generally commence two weeks after the foundations have been cast. Tower steelwork is usually delivered to site and assembled on site.

Installation of tower using a derrick pole at the base

Construction of wooden poleset support structure for Donegal 110 kV Project (Binbane – Letterkenny)

Stringing of conductors

Once angle towers are erected, conductor stringing can commence, installing conductors from angle tower to angle tower via the line intermediate structures. Conductor drums are set up at one end of the straight with special conductor stringing machinery, and pulled from one end to the other.

Stringing Machine

Conductor stringing equipment

Reinstate tower sites and remove temporary accesses

The disturbed ground around a tower or poleset location is made good, and all temporary access materials generally removed.

A1.4 Line Uprating and Refurbishment

In general a transmission line requires little maintenance. It is periodically inspected to identify any unacceptable deterioration of components so that they can be replaced as necessary. A more detailed condition assessment on a line is usually carried out when it is approximately 35 years old.

The majority of the existing transmission grid was constructed after 1960; the majority of those lines constructed prior to 1960 have already been refurbished. There is an on-going programme of line refurbishment concentrating on older lines.

Refurbishment projects are condition based, and once a line has been identified for refurbishment, consideration is given to the potential opportunity to upgrade its carrying capacity or thermal rating. This might involve replacing existing conductors with modern conductors which, while having effectively the same diameter, can carry significantly greater amounts of electricity.

Often the additional weight of these replacement conductors means associated replacement of support structures with stronger structures. Where structures require replacement during a line upgrade or refurbishment, additional excavation may be required particularly where angle towers or structures require replacement. In general they are replaced within the footprint of the original structure.

Insulators and conductors are normally replaced after about 40 years, and towers are painted every 15-20 years or as necessary.

A1.5 Underground Cabling (UGC)

High voltage (HV) circuits can only be laid underground using special HV cables designed specifically for underground use. The conductors in underground HV cables must be heavily insulated to avoid a short circuit between the conductor and the ground around the cable.

Table A3: Key Design Features: Underground Cabling

Key Design Features	HV Cable (typical dimensions)
Cable Trenches	c.0.6m wide-1.25m deep for a 110 kV trench, c. 1.1m wide x 1.25m deep for 220 kV and 400 kV for a single cable
Joint Bays	6m long, 2.5m wide and 1.8m deep
Excavation trench for Joint Bay	7m long, 3m wide and 2m deep
Average span between joint bays	500m–700m
Directional Drill entry and exit pits	1m x 1m x 2m

The cable is installed directly into the ground in an excavated trench. The majority of high voltage cable routes are located along public roads and open spaces. It is very unusual for a cable route to cross private open ground but this may be the case on occasion. The civil contractor will scan the ground using a cable avoidance tool (CAT), carry out a visual inspection of existing services and compare the information with the utility service records which they will have obtained from the various service providers in advance. If any previously unidentified services are discovered the site engineer will adjust the cable route accordingly.

Typical 110kV Trench Excavation (Ducts in Trefoil Formation)

The overall installation of a cable route over a large distance is broken down into sections of cable that are connected using a cable joint. Cable joints are installed in joint bays which are typically concrete structures buried underground, occurring generally every 500–700m along an alignment, and ranging in size up to 6m long, 2.5m wide and 1.8m deep.

Typical Joint Bay Construction Adjacent to Public Road

If the cable was installed directly in the ground the entire trench from joint bay to joint bay must be fully excavated. The advantage with installing cable in pre-laid ducts is that only a short section of cable trench, up to 100m is open at any time. This helps to minimise the impact on the local residents and minimise traffic impact at any given time.

Typical HV Cable Installation

Once installed, the road surface is reinstated. Where a cable route is in an open area, it is returned to agricultural/grassland use. Where a cable passes through forested land the route is not replanted with trees to prevent any damage to the cable by tree root growth.

Re-growth following underground cable construction on agricultural land

A1.6 Substations

Substations connect two or more transmission lines; they take the electricity from the transmission lines and transform high to low voltage, or vice versa. They contain various electrical equipment, including voltage switches, transformers, protection equipment, and associated lines and cabling.

The siting of a substation depends on topography; the ground must be suitable to meet technical standards. With regard to earthing requirements and soil stability, substations are usually constructed on reasonably level ground, in areas that are not liable to flooding or crossed by significant watercourses.

A substation site is normally future proofed with the capability to be extended if the need arises.

Substations can take two forms:

An Air Insulated Switchgear (AIS) substation is where the electrical equipment infrastructure is primarily installed outdoors, with the use of natural air as an insulation between circuits. This option requires a relatively large compound footprint.

Sranangh 220kV/110kV substation, Co Sligo, example of a typical outdoor AIS substation

A Gas Insulated Switchgear (GIS) substation, is where gas (Sulphur Hexafluoride – SF6) is used as the insulation between circuits. This requires the electrical equipment to be contained internally, in buildings of some 11–13m over ground. This allows for a significantly smaller substation footprint.

Both options require the associated provision of access roads off and onto the public road network and the provision of associated electrical equipment and infrastructure (including underground cables), as well as ancillary waste water treatment facilities and other site development and landscaping works. Both are therefore significant civil engineering projects.

Example of a typical indoor GIS substation, Co Limerick

APPENDIX B

400KV TRANSMISSION LINE MONITORING

NOISE REPORT PREPARED BY AECOM CONSULTANTS

APRIL 2015

400kV Transmission Line Monitoring

Noise Report

April 2015

47071393.NOISE

Prepared for:
EirGrid

UNITED
KINGDOM &
IRELAND

REVISION SCHEDULE

Rev	Date	Details	Prepared by	Reviewed by	Approved by
1	December 2014	Draft Report	Conor Tickner Graduate Acoustic Consultant	Chris Skinner Associate - Acoustics	Paul Shields Head of Acoustics
2	April 2015	Draft Report after client comments	Conor Tickner Graduate Acoustic Consultant	Chris Skinner Associate - Acoustics	Paul Shields Head of Acoustics

AECOM
12 Regan Way
Chetwynd Business Park
Chilwell
Nottingham
Nottinghamshire
NG9 6RZ

Limitations

AECOM Infrastructure & Environment UK Limited (“AECOM”) has prepared this Report for the sole use of EirGrid Plc (“Client”) in accordance with the Agreement under which our services were performed. No other warranty, expressed or implied, is made as to the professional advice included in this Report or any other services provided by AECOM.

The conclusions and recommendations contained in this Report are based upon information provided by others and upon the assumption that all relevant information has been provided by those parties from whom it has been requested and that such information is accurate. Information obtained by AECOM has not been independently verified by AECOM, unless otherwise stated in the Report.

The methodology adopted and the sources of information used by AECOM in providing its services are outlined in this Report. The work described in this Report was undertaken between 2nd September and 13th November and is based on the conditions encountered and the information available during the said period of time. The scope of this Report and the services are accordingly factually limited by these circumstances.

Where assessments of works or costs identified in this Report are made, such assessments are based upon the information available at the time and where appropriate are subject to further investigations or information which may become available.

AECOM disclaim any undertaking or obligation to advise any person of any change in any matter affecting the Report, which may come or be brought to AECOM’s attention after the date of the Report.

Certain statements made in the Report that are not historical facts may constitute estimates, projections or other forward-looking statements and even though they are based on reasonable assumptions as of the date of the Report, such forward-looking statements by their nature involve risks and uncertainties that could cause actual results to differ materially from the results predicted. AECOM specifically does not guarantee or warrant any estimate or projections contained in this Report.

Unless otherwise stated in this Report, the assessments made assume that the sites and facilities will continue to be used for their current purpose without significant changes.

Where field investigations are carried out, these have been restricted to a level of detail required to meet the stated objectives of the services. The results of any measurements taken may vary spatially or with time and further confirmatory measurements should be made after any significant delay in issuing this Report.

Copyright

TABLE OF CONTENTS

EXECUTIVE SUMMARY

In this report, noise emissions from the 400kV overhead power transmission line in Cloney, Co. Kildare has been quantified based on data from more than 10 weeks of measurements. Noise measurements were made simultaneously at three locations relative to the line: directly beneath a tower, at the mid-span position half way between towers, and at a distance of approximately 200m from the line as a control location.

Measurements showed noise level increases with increasing rainfall at all sites. At the control location, the increases in noise level closely match standardised predictions of the noise level increases from rainfall alone (i.e. the sound of rainfall hitting the ground and objects). At the tower and mid-span locations however, there were significantly greater increases in noise level than would be expected from the rainfall alone.

It was determined that; at the control location the contribution to the overall noise levels by the transmission line is low in all weather conditions. At the mid-span location close to the line, the contribution to the overall noise levels by the transmission line is low in dry conditions but increases rapidly with rainfall. In high rainfall conditions, the noise from the line at the mid-span increases significantly and is the dominant noise source.

During dry conditions, noise levels recorded at the tower location were significantly greater than those recorded at other locations. Noise from the transmission line was particularly dominant at night. Noise levels are usually expected to decrease at night, and whilst decreases were observed at night at both control and mid-span locations, levels increased at night at the tower location. It was noted that at night, humidity levels were often greater and temperatures were lower, increasing condensation effects which may contribute to noise generation from the line at the tower location. During a wide range of weather conditions, noise from the line is the dominant noise source at the tower location. For periods of higher rainfall rates, the noise from the line at the tower increases significantly.

It has been determined that; the primary sources of noise from the line during dry conditions are located at the tower. The primary sources of noise from the line in wet conditions are the conductors along the length of the line, and hence similar levels are experienced at tower and mid-span locations during high rainfall rates.

Several noise prediction methodologies have been evaluated and comparisons made between the predicted noise emissions from the line and measured noise levels. Two primary prediction methodologies, from the Electronic Power Research Institute (EPRI) and the Bonneville Power Administration (BPA) respectively, were obtained for comparison. An additional set of four *Evolutionarily Formed* prediction methodologies outlined in a research paper have also been included for analysis.

Output parameters of the prediction methodologies are the median noise level during rainfall, the L_{50}, and the 95th percentile noise level during rainfall, the L_5. EPRI and BPA methods were found to be most consistent with each other in their predictions. The Evolutionarily Formed methods cover a greater range of values and are considered to be less reliable and less consistent than either of the EPRI or BPA methods.

With the exception of one of the Evolutionarily Formed methods, all predicted noise levels are greater than those measured. The extent to which the methodologies tend to over-predict the noise levels depends on the noise indicator and the measurement location.

The most accurate predictions for both parameters occurred for the control location, although there remains a significant error between predicted and measured levels. Predictions suggested clearly audible and marginally significant noise impacts from the line at this location. Conversely, measurements at this location suggested that generally the noise from the line is not clearly audible and contributes very little to the overall noise levels, suggesting little noise impact from the line at this location. Predictions for the L_{50} were generally found to be more accurate than predictions for the L_5.

Noise levels at both the tower and mid-span locations were over-predicted to an even greater extent. Predictions for the L_{50} were again generally more accurate than predictions for the L_5 at both these locations. The L_{50} was predicted slightly more accurately at the tower location whereas the L_5 predictions were slightly more accurate at the mid-span. The accuracy of noise level predictions at the tower and mid-span locations were generally low.

Discrepancies between measured and predicted noise levels from this line could be due to variations in line load, ageing effects, or other variables. The prediction methodologies may be best suited for worst-case or new-line noise impact predictions. The BPA and EPRI methods are considered to be more consistent and therefore more suitable for use in the predictions of future noise emissions from overhead lines.

1 INTRODUCTION

AECOM has been commissioned by EirGrid to perform long term noise monitoring of a 400kV overhead power transmission line with the intention of capturing noise from corona discharge over a range of weather conditions. Of particular interest is the variation of noise at different positions along the line.

Acoustic measurements were undertaken for a period of approximately 10 weeks under and in the vicinity of the transmission line. In addition, short measurements were taken at the site to provide further detail of the sound at various distances from the line. The monitoring took place between 2nd September 2014 and 13th November 2014.

An explanation of acoustics terminology is provided in Appendix A.

2 NOISE SOURCES AND STANDARDS

When examining overhead transmission lines from a noise perspective, there are a number of potential noise sources to consider; each depending on the parameters of the line in question. The primary noise sources are: Aeolian, gap discharge and corona discharge noise. These are described below.

2.1 Aeolian Noise

Aeolian noise is caused by the movement of air over an obstacle, creating trailing vortices in the air flow. These vortices have oscillatory periodic components which can cause periodic fluctuations in pressure, generating steady tones. The frequency of these tones is proportional to the velocity of the air and inversely proportional to the size of the obstacle.[1] A laminar wind must blow steadily and perpendicular to the lines to set up an Aeolian vibration, which can produce resonance if the frequency of the vibration matches the natural frequency of the line.

This type of noise is usually infrequent and low-level. No Aeolian noise has been observed by AECOM staff on site at any time during monitoring, although it is recognised that Aeolian noise is often difficult to identify and the presence of this noise on cannot be excluded definitively.

2.2 Gap Discharge

Gap discharge is caused by sparking between hardware components. This effect is usually infrequent and most often removed by the selective design of the overhead line. Gap discharge is usually a sign of hardware failure or damage and can usually be easily located for repair[2]. Gap discharge is a much more significant phenomenon for radio interference (RI) than for audible noise and was not observed as a source of audible noise by AECOM staff on site.

2.3 Corona Noise

Corona noise is the most commonly observed noise source from overhead lines. It is most often observed as a frying, hissing or crackling sound and is a function of various parameters including the line voltage, relative air density, the electric field on the surface of the conductor, the line geometry and the condition of the line. It is rarely observed for low voltage overhead lines but is known to be a significant parameter for lines operating above 345 kV[2].

Corona is induced by the electric field in localised areas where the gradient is greatest (at the surface of the conductor, usually where an irregularity causes an increased electric field), and

---

1 Lilien, J-L, 'Power Line Aeolian Vibrations', Université de Liege, 2013
2 Electric Power Research Institute, Transmission Line Reference Book 345kV and Above, Second Edition, EPRI, 1982

consists of an electric discharge which makes the surrounding air molecules ionise, or undergo a change of electric charge. This phenomenon gives rise to pressure fluctuations in the air surrounding the conductor, generating noise which is generally broadband in character. As the corona effect increases, such as during high levels of rainfall, the pressure fluctuations align with the electrical frequency, oscillating at twice the electrical frequency of the system. This causes tonal components at twice the electrical frequency (and subsequent harmonics) to be present in the acoustic emissions of the line.

2.4 Guidance and Standards

No specific standard exists for assessing noise from overhead lines. The noise emissions are categorised under ‘industrial sound’ and the relevant assessment standard is therefore BS 4142[3]. This standard is used to assess and quantify the significance of the impact from industrial sound sources on sensitive receptors.

BS 4142 makes no explicit reference to overhead line noise and does not give specific instructions for assessment of noise sources generated during rainfall. A separate guidance document exists; TR(T)94[4], which gives an applicable method for assessment of overhead lines and takes account of the varying background noise levels with varying rainfall rates, but remains in-line with the fundamental methods and principles of BS 4142. TR(T)94 describes separate methods for assessing noise levels during both wet and dry weather conditions, and is better suited to the assessment of sound emissions from overhead lines.

3 MEASUREMENT SITE

The measurement site, in Cloney in rural County Kildare, was selected for the monitoring by the client, based on the requirements set out in the agreement with AECOM. The site is enclosed to the east by countryside, with the R417 approximately 500 meters from the measurement locations. Immediately to the south is a mixture of woodland and fields, with the R427 approximately 400 meters south of the tower and 200 meters south of the closest measurement location to the road. Both of the closest roads are relatively minor single carriageway roads. There is open rural countryside to the north and a mixture of trees and open countryside to the west. The transmission line runs between the north-east and south-west through the area, and the area immediately surrounding the line is predominantly flat.

The soundscape at the measurement site is dominated by a low level of distant road traffic noise during busy periods and by wind and the movement of foliage at other times. Occasional animal sounds such as from birds, dogs and a horse, were observed at times by AECOM staff on site.

The plan in Appendix B shows the location of the site and the long term acoustic monitoring locations.

4 SCOPE AND METHODOLOGY

4.1 Monitoring Procedures

Noise monitoring was undertaken in three locations relative to the power line; directly beneath a tower, at the mid-span position half way between towers, and at a distance of approximately 200m from the line as a control location. The control location is intended to capture the general background noise under the same weather conditions, but largely excluding noise from the line.

---

[3] BS 4142:2014, *Methods for rating and assessing industrial and commercial sound*

[4] National Grid Company PLC, Technical Report TR(T)94, 1993. ‘A Method for Assessing the Community Response to Overhead Line Noise’,

These monitoring locations recorded noise data for a total period of 10 weeks from 02/09/2014 to 13/11/2014, split into five approximately two-week periods listed below:

- Period 1 – 02/09 to 19/09
- Period 2 – 19/09 to 30/09
- Period 3 – 30/09 to 13/10
- Period 4 – 13/10 to 29/10
- Period 5 – 29/10 to 13/11

This breakdown has been used due to the timing of site visits to download data and change equipment batteries, and does not relate to any characteristics of sound from the transmission line.

Measurements were undertaken using the following instrumentation:

- Rion NL-52 integrating sound level meters; and
- Rion NC-74 acoustic calibrator.

The meters were set to log in 10 minute contiguous periods, with regular 15-second audio recordings taken at each period start. In addition, a full time history of 100ms L_{pA} sound pressure level measurements was logged at each location to allow calculation of noise indicators over other periods.

The calibration level of each meter was checked using a field calibrator before and after the measurements, and during each visit for equipment maintenance, with no significant changes in calibration level detected (with the exception of damaged equipment as noted below). Calibration certificates are included in Appendix F.

Monitoring stations were set up in each location comprising an all-weather equipped sound level meter mounted between 1.2m and 1.5m off the ground in free-field conditions. At the control site, a weather station was also erected to record rainfall, temperature, ambient air pressure, wind speed, and wind direction. All these parameters were logged over one minute and ten minute intervals.

At the end of each period, batteries were replaced, data were downloaded and equipment checks were made. Short-term attended sound measurements in the wider area were taken during the set-up and at the first maintenance visit.

Due to flooding at the site, one of the meters recorded no data for the last few days of the monitoring period. A short period of data was also not recorded at the end of Period 1 as instrument batteries ran flat prior to the planned maintenance visit. Details of lost data are included in Appendix E

4.2 Data Processing Procedures

The meters were set to automatically log the parameters L_{Aeq}, L_{Amax}, L_{Amin}, L_{A10}, and L_{A90} (see Appendix A for definitions).

Raw data were processed to return each of those parameters for 1-minute intervals, allowing more detailed correlation with 1-minute rainfall data.

Data deemed unsuitable for analysis were removed from the dataset. Details of removed data are included in Appendix E. Reasons for removal were due to contamination by staff during set-out, collection or maintenance, due to very high wind speeds, or due to the equipment failure noted above.

The remaining data were separated into contiguous 24-hour periods for initial analysis. This allowed an overview of the levels with respect to weather conditions and time of day. More detailed analysis required the data to be separated by time of day and by weather conditions (wet and dry). This allowed the variation with time of day to be more closely examined, and the effects of rainfall on the noise levels to be quantified.

5 CORONA NOISE PREDICTION

There are a number of methodologies for predicting corona discharge noise from power lines. There are two main methods that have been selected for analysis; the BPA[5] and EPRI[6] methods. An additional set of prediction methodologies have been obtained for comparison. These additional methods were Evolutionarily Formed using iterative algorithms to determine the dependence of the noise on a variety of parameters[7].

A number of parameters are used in all methods to predict noise levels, such as: conductor surface gradient[8], conductor diameter, the number of subconductors, and the geometric arrangement of the conductors, i.e. heights, widths and separation distances. The BPA method also takes altitude into account, resulting in higher predicted noise levels at high altitudes. Since the altitude at the monitoring site is low (approx. 55m above sea level[9]), this has no significant effect on the calculations for the site under consideration but could be significant elsewhere. All parameters were sourced from the client unless alternate source is given.

Each prediction methodology yields two results; the noise level exceeded for 50% of the time during rain, or the L_{50}, and the noise level exceeded for 5% of the time during rain, or the L_5. These are defined slightly differently depending on methodology chosen.

It is important to note that the L_5 and L_{50} noise levels defined by these methodologies do not directly relate to percentile noise levels as normally reported by sound level meters. The percentile values ($L_{N,T}$) produced by sound level meters present the noise level which is exceeded for N% of a defined time interval, T. However the L_5 and L_{50} levels calculated by the prediction methodologies present the corona noise level which will be exceeded for 5% or 50% of time whilst rain is falling.

5.1 BPA Method

The method established by the Bonneville Power Administration (BPA), calculates the median audible noise levels during measurable rain. The primary output is the L_{50} level during rain at a given measurement point. It was developed from long term measurements on a number of full-scale operating or test lines.

The calculation is different depending on the number of subconductors in each conductor bundle; a different calculation is required when there are three or more conductors. The line examined in this report has only two subconductors for each conductor bundle.

---

[5] Electric Power Research Institute, 'Chapter 7: Corona and Field Effects', Transmission Line Reference Book 115-230 kV Compact Line Design, EPRI, 2007.

[6] Electric Power Research Institute, 'Chapter 6: Audible Noise', Transmission Line Reference Book 345kV and Above, Second Edition, EPRI, 1982, p. 267-318.

[7] K-H Yang, et al, 'New Formulas for Predicting Audible Noise from Overhead HVAC Lines Using Evolutionary Computations', IEEE Transactions on Power Delivery, Vol. 15: Issue 4, IEEE, 2000, p. 1243-1251.

[8] Method obtained IEE Power Series 17, "High Voltage Engineering and Testing", Appendix 3.4, Annexure B

[9] Irish Grid Reference. 2008 Data. Available at: http://www.gridreference.ie/ [2014].

Where there are multiple phases, the noise level from each phase is calculated separately and then summed logarithmically. The line examined in this report has three phases with a lateral separation of 10.5m. A diagram of the tower dimensions is given in Appendix C. The altitude is approximately 55m above sea level, which makes the altitude correction very small (less than 0.2 dB).

For the L_5 level, a fixed correction factor of +3.5 dB is suggested. For fair weather dry conditions a fixed correction factor of -25 dB is suggested. The L_{50} is described as representative of 'steady rain' conditions, whereas the L_5 is described as representative of 'heavy rain' conditions. These conditions are not quantified.

5.2 EPRI Method

The method established by the Electronic Power Research Institute (EPRI) is calculated empirically from test data similar to the BPA method. It is a function of similar parameters, but does not account for altitude. The default calculation for this method is the L_5 level during rain.

Again, this calculation applies to a single phase. Where there are multiple phases, the noise level from each phase is calculated separately and then summed logarithmically.

This method does not offer a dry or fair weather prediction, instead quantifying the variation of empirical data as being 'up to 9 dB lower' in dry conditions. Noise levels are considered to be highly dependent on surface condition parameters such as age, grease, dust, and other particles. A wet correction factor P_{wc} is calculated and applied to output the predicted L_{50} level during rain.

These calculations are based upon data collected in Pittsfield, USA, which experiences a local median rainfall of 0.75 mm/h. A local rainfall climate correction factor is provided which can be manually determined from the median rainfall at any given location.

5.3 Evolutionarily Formed Methods

Evolutionarily Formed methods[10] utilise a genetic algorithm (GA) or genetic programming (GP) process to iteratively modify prediction formulae using empirical data. Calculations are based on a single-phase (1P) or three-phases (3P) and output the L_5 or L_{50} rain noise level. After testing a number of the methods against old and new experimental data, the most accurate prediction formulae were presented. Each method is given a short-code to be identified, for example the genetic algorithm (GA) single-phase (1P) L_{50} level (L50) formula is given the short code GA1PL50. The presented formulae include GA1PL50 as described; along with the genetic programming single-phase L_5 level (GP1PL5), the genetic programming 3-phase L_5 level (GP3PL5) and the genetic programming 3-phase L_{50} levels (GP3PL50).

The outputs of these methods are stated to be representative of stable rain (≤2.7mm/hr) for the L_{50} levels and heavy rain (≥7.7mm/hr) for the L_5 levels. They do not contain conversion factors between methods. However, single phase methods can be calculated individually and logarithmically summed to obtain a three-phase prediction. For comparative purposes, all evolutionarily methods are presented in three-phase form. No dry or fair weather prediction is offered in this method.

---

[10] K-H Yang, et al, 'New Formulas for Predicting Audible Noise from Overhead HVAC Lines Using Evolutionary Computations', IEEE Transactions on Power Delivery, Vol. 15: Issue 4, IEEE, 2000, p. 1243-1251.

5.4 Rainfall Rate Corrections

Only the EPRI methodology explicitly states a rainfall rate correction factor. In the BPA methodology the levels are simply described as ‘steady rain’ and ‘heavy rain’ conditions without quantification. The evolutionary methods state similar descriptions but quantify them to mean ≤2.7mm/hr for steady rain, or ≥7.7mm/hr for heavy rain.

The EPRI methodology indicates a local climate correction factor to account for the variation in rainfall rates for the local area. This correction factor is related to the median and the 95th percentile rainfall rates at the location of their empirical study. These values are 0.75 mm/h and 6.4 mm/hr respectively.

In Cloney, Co. Kildare, the local median rainfall rate was recorded as 0.8 mm/hr, and the local 95th percentile rainfall rate was recorded as 5.1 mm/hr. These result in a correction factor of less than 0.5 dB with respect to either the L_5 or L_{50} calculation. The effect of local climate is therefore considered to be insignificant to any conclusions which may be drawn.

5.5 Predicted Levels

Using each of the prediction methods and the transmission line specification provided by EirGrid (see Table C.1 in Appendix C), predictions of the expected noise levels at lateral distances of 5 and 200 meters from the base of the tower have been made. These locations are representative of the monitoring locations. Results are shown in Table 5.1.

TABLE 5.1: PREDICTED CORONA DISCHARGE NOISE LEVELS

Distance from Transmission Line	Sound Level Indicator	Predicted Noise Level, dB					
		BPA	EPRI	GA1PL50	GP1PL5	GP3PL50	GP3PL5
5m	L_{50}	55.2	56.0	57.4	-	54.3	-
	L_5	58.7	61.2	-	65.3	-	57.3
200m	L_{50}	46.0	44.5	41.6	-	45.8	-
	L_5	49.5	49.7	-	48.7	-	37.8

The 5m L_{50} levels are fairly consistent, with about 3 dB difference between all methodologies. The 5m L_5 predictions are less consistent, with 8 dB between all methodologies.

The 200m L_{50} and L_5 levels are less consistent than 5m levels, with more than 4 dB between L_{50} levels and almost 12 dB between L_5 levels.

It should be noted that the BPA and EPRI methods agree to within 2.5 dB in both locations and for both parameters, possibly suggesting a greater consistency than the evolutionary formed methods.

5.6 Predicted Rain Noise

Predicted levels in Table 5.1 relate to the transmission line as the sole source of noise. In practice, there will be additional noise from the surrounding area. In particular, rainfall is a potentially significant component of the ambient noise, especially in conditions when corona noise is likely to be present.

Prediction methodologies for the noise from rainfall itself can be applied based on a dry baseline noise level and additional predicted rain noise. The rain noise prediction is based on one of series of Miller-curves[11]. An R1 curve has been selected as most suitable for the measurement location, i.e. a rural area with a grassy ground surface. The R1 Miller-curve for a 40 dB dry ambient level is shown in Figure 5.1 below.

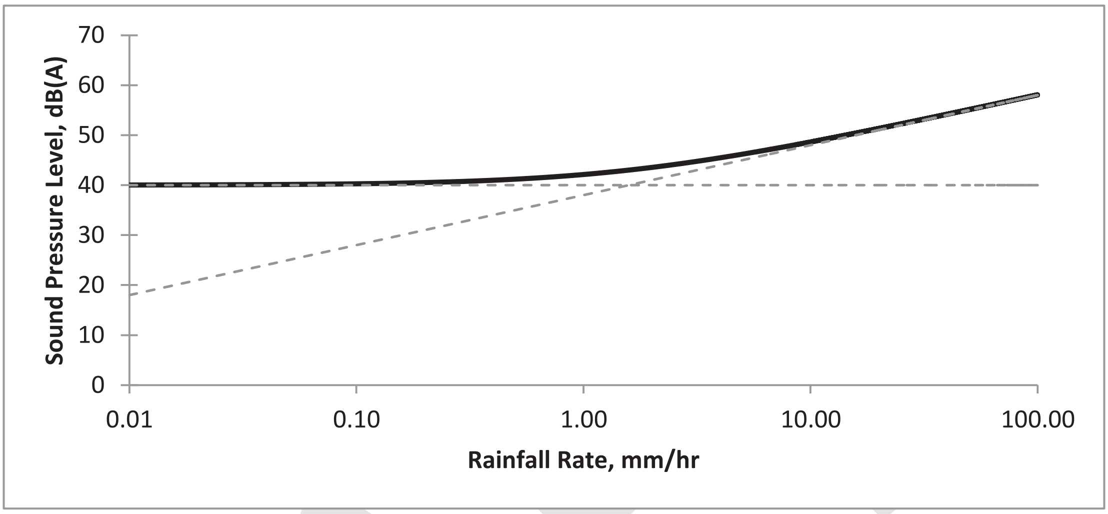


Figure 5.1: R1 Miller Rain Noise Curve

5.7 Noise Levels with Distance

The identified corona noise prediction methodologies discussed above have been calculated at a range of distances to produce graphs of predicted sound level against distance. These levels hence show how the predicted noise levels fall with distance. Figure 5.2 shows the predicted L_5 levels and Figure 5.3 shows the predicted L_{50} levels, for each methodology with distance.

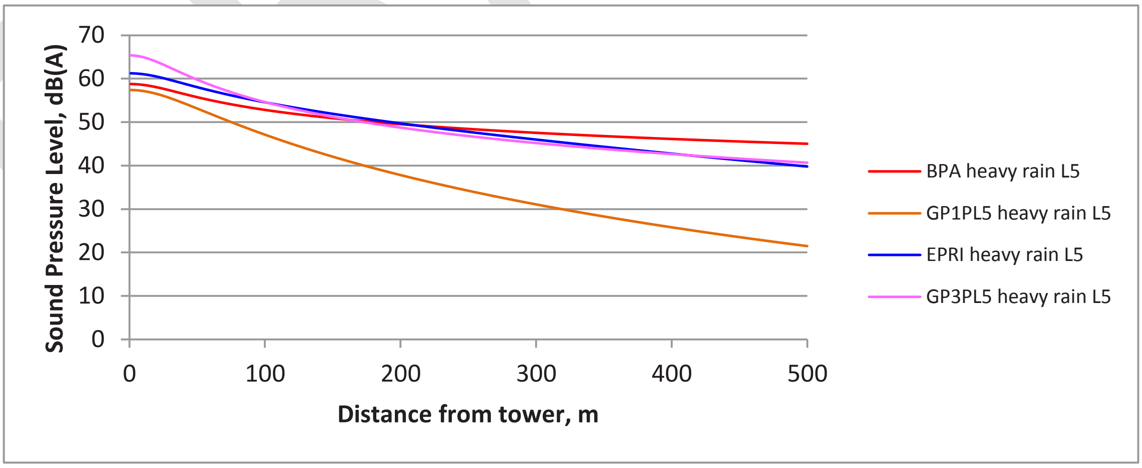


Figure 5.2: Predicted L_5 levels with distance from the line

---

[11] National Grid Company PLC, Technical Report TR(T)94, 1993. 'A Method for Assessing the Community Response to Overhead Line Noise',

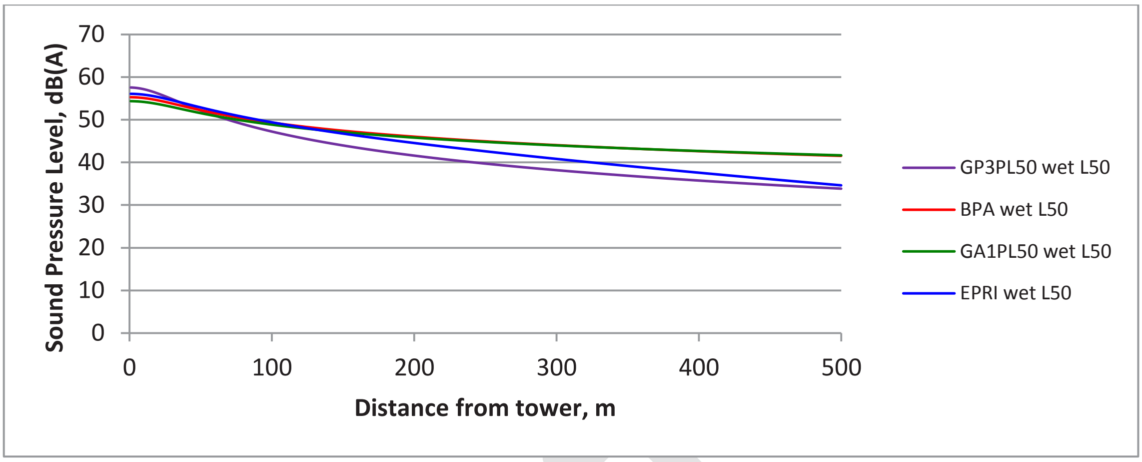


Figure 5.3: Predicted L_{50} levels with distance from the line

The L_{50} predictions are in greater agreement near to the tower, with a greater spread at further distance, particularly from 100m. Excluding the GP1PL5 method, which appears to result in notably different levels to the other methodologies, the L_5 methods have a generally good agreement at greater distances, even to 300m and beyond.

6 MEASURED DATA

During the monitoring, large amounts of data were recorded, including weather conditions and a range of sound level parameters. This section provides an overview and initial analysis of the measured data.

6.1 Overview

Over the monitoring period, several noise parameters were measured, including the L_{Aeq}, L_{Amax}, L_{Amin}, L_{A5}, L_{A10}, L_{A50} and L_{A90}. Given the large quantities of data, these parameters can be presented in a number of ways. As an overview of all 10 weeks of data, the absolute or average level is preferred (see Appendix A for further explanation of the noise metrics used). Absolute values more closely match the methods used in presenting data from previous short term measurements, however as they summarise data over a much longer time period, the amount of information regarding corona noise which can be drawn from these values is limited. The average values presented represent typical values measured over the 1-minute logging periods.

The average and absolute measurements for the whole ten weeks are displayed below in Table 6.1, with the exception of the absolute L_{10} and L_{90} which are unable to be calculated from periodically logged data. While absolute and average parameters provide a method of interpreting large periods of data, the variation of values is lost.

TABLE 6.1: 10-WEEK TOTAL NOISE LEVELS SUMMARY

	Noise Level, dB							
	Average from 1-minute values					Absolute over entire monitoring period		
Location	L_{Aeq}	L_{Amax}	L_{Amin}	L_{A10}	L_{A90}	Total L_{Aeq}	Maximum L_{Amax}*	Minimum L_{Amin}
Control	37.8	52.8	27.3	40.6	30.3	42.1	91.7	15.6
Tower	41.4	52.8	35.2	43.2	37.7	45.6	97.8	21.1
Mid-span	36.4	50.2	28.1	38.9	30.7	42.2	99.8	15.8

* Whilst it is generally not possible to identify the cause of the measured maximum noise levels, it is considered likely that these are due to other local noise sources, such as animals, birds, or weather conditions. A review of audio recordings collected at the times of some peaks in measured noise levels has been undertaken to provide further information on potential causes of maximum noise levels. This has identified, that, whilst noise from the power lines is audible at times, the maximum noise levels in all cases reviewed were due to other sources, such as birdsong, dogs barking, other animals, local human activity, overflying aircraft, or weather conditions (heavy rainfall/thunder storms).

As there was a wide range of variation in noise levels and weather conditions over the monitoring period, this report has focussed on presentation of the 5th and 95th percentiles for 1-minute or 10-minute values. This provides the range of values within which the data lie for 90% of the time.

Another more detailed representation of the data considers the hourly variations over a 24-hour day. Tables of average hour-by-hour levels for each measurement location are shown in Appendix D.

6.2 Weather conditions

During the monitoring period, a wide variety of weather conditions were recorded. The weather was predominantly dry for the first 4 weeks where a total of 10.5 mm of rain was recorded. The following six weeks recorded almost 165 mm of rainfall.

Wind speeds were variable with individual maximum gust speeds of up to 15 m/s recorded. Despite this, the maximum gust speed was less than 5m/s for over 80% of all 10-minute periods and the 10-minute average wind speeds remained below 5 m/s for over 99.5% of the monitoring period and below 2.8 m/s 90% of the time. Where high wind speeds were considered to have compromised noise measurements these periods were excluded from subsequent analysis included in this report. See Appendix E for details of excluded data.

Temperatures varied between -2˚C and 23˚C, remaining between 3.5˚C and 18.5˚C for 90% of the monitoring period. The mean temperature was 11.4˚C.

Relative Humidity was generally high, with a minimum of 49% recorded over the complete period. Humidity remained above 70% for 90% of the monitoring period and often reached 100%, particularly at night when temperatures dropped.

Ambient air pressure was generally slightly low, with the median air pressure at 1006 mbar, compared to a standard atmospheric pressure of 1013 mbar. The ambient air pressure exceeded 1013 mbar only for approximately 25% of the monitoring period.

6.3 Dry Noise Levels

During the dry periods of monitoring, noise levels at the control and mid-span sites varied as would be expected, with lower levels during the night and higher levels during the day. Level distribution graphs for the control and mid-span locations are shown in Figures 6.1 and 6.2 below.

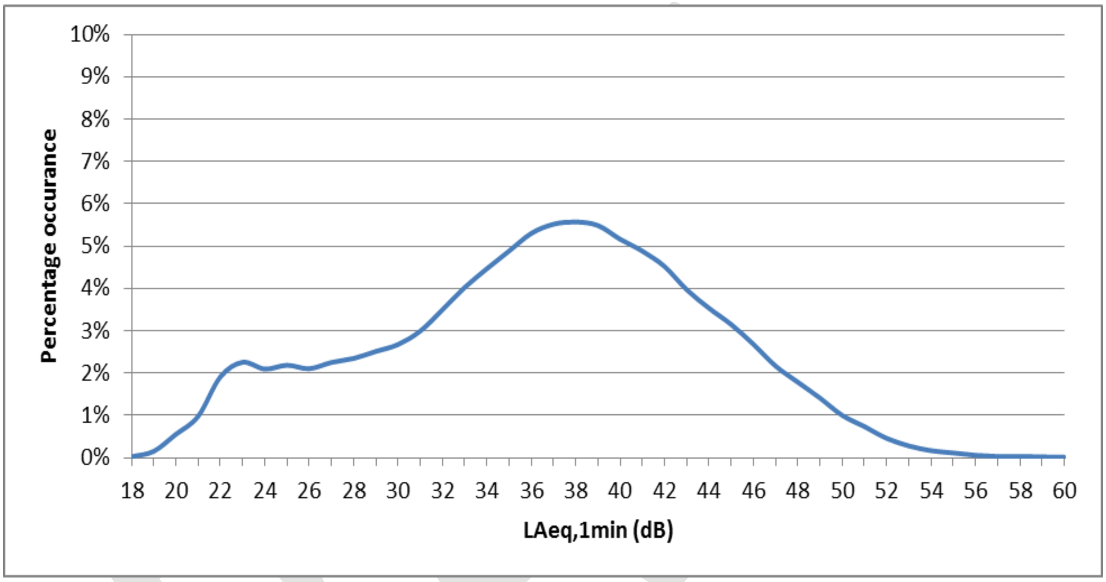


Figure 6.1: Distribution of $L_{Aeq,1min}$ Levels at the Control location

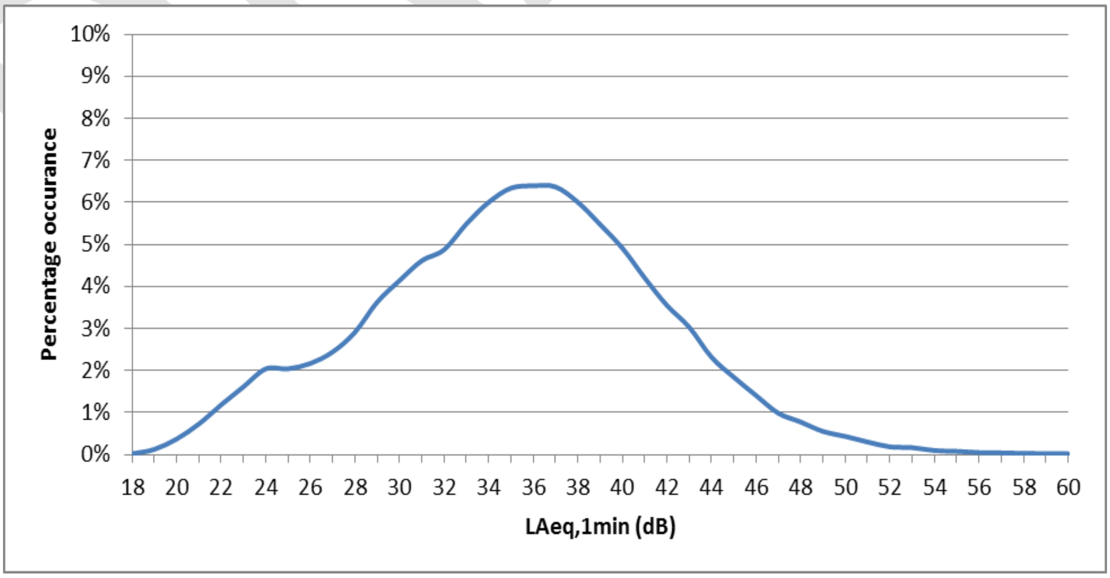


Figure 6.2: Distribution of $L_{Aeq,1min}$ Levels at the Mid-span location

The tower location experienced a quite different set of noise levels. While the control and mid-span levels generally decreased at night, levels at the tower often did not decrease, and sometimes increased. This phenomenon (shown in a typical dry 24-hour noise level plot for all sites in Figure 6.3) has the effect of significantly increasing the distribution of noise levels upwards, and resulting in a far narrower range of observed levels. The level distribution graph for the tower is shown in Figure 6.4 below. The tower experiences a greater and narrower band of noise levels, indicating a relatively constant and dominant source of noise.

It has been noted that when air is cooled, such as at night time, the relative humidity increases significantly. The rise in noise levels at the tower location corresponds with the increase in humidity. This is an indication that corona noise is dependent on humidity and could be the dominant noise source at night near to the tower. Analysis of the recorded audio from this location confirms the presence of corona noise during these times.

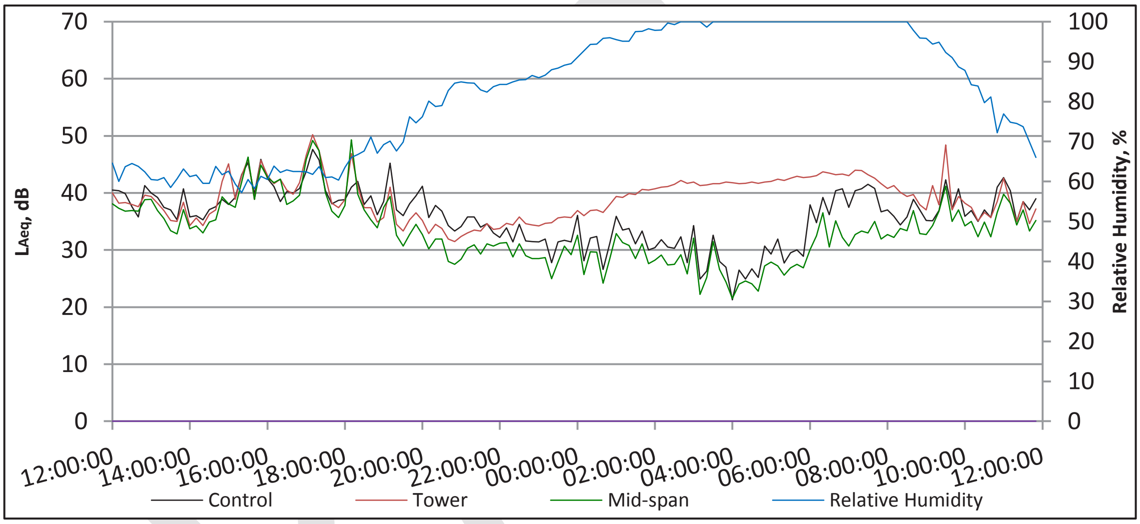


Figure 6.3: Typical dry 24-hour variation in $L_{Aeq,10min}$ level for all locations

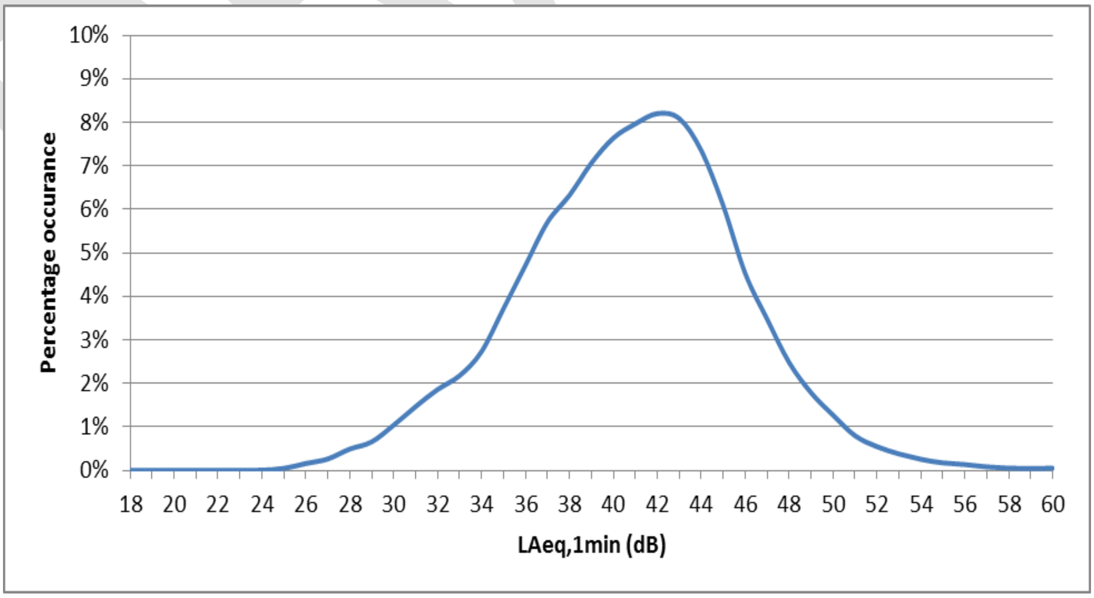


Figure 6.4: Distribution of $L_{Aeq,1min}$ Levels at the Tower location

At the tower location, 90% of dry 1-minute L_{Aeq} levels are between 38.2 dB and 55.6 dB, a range of 17.4 dB. At the mid-span location however, 90% of dry 1-minute L_{Aeq} levels are between 32.0 dB and 53.6 dB, a range of 21.6 dB. At the control location, 90% of dry 1-minute L_{Aeq} levels are between 28.7 dB and 52.0 dB, a range of 23.3 dB. This reduced range at the tower location is consistent with corona noise limiting the lowest noise levels observed at the tower location.

6.4 Noise Levels during Rainfall

Noise levels during rainfall consist primarily of three components; background noise, rain noise and corona noise. The impact of corona noise is expected to be minimal at the control site but significant at the mid-span and tower locations. The average noise level is shown plotted against rainfall rate in Figure 6.5. In addition, this graph shows the general R1 rain noise curve presented previously (based on an assumed background level of 40 dB). A greater number of recorded noise levels at lower rainfall rates allow for a smoother line with fewer peaks and troughs. The greater variation at higher rates is a consequence of fewer instances of very high rates of rainfall during the monitoring period, compared with much longer periods of dry and low rainfall rates. At low rainfall rates, noise levels at the control and mid-span locations are significantly lower than those at the tower, aligning approximately with the expected level from background and rain noise alone (represented by the R1 Miller curve). At all sites there is a general trend towards greater noise levels with greater rainfall rates.

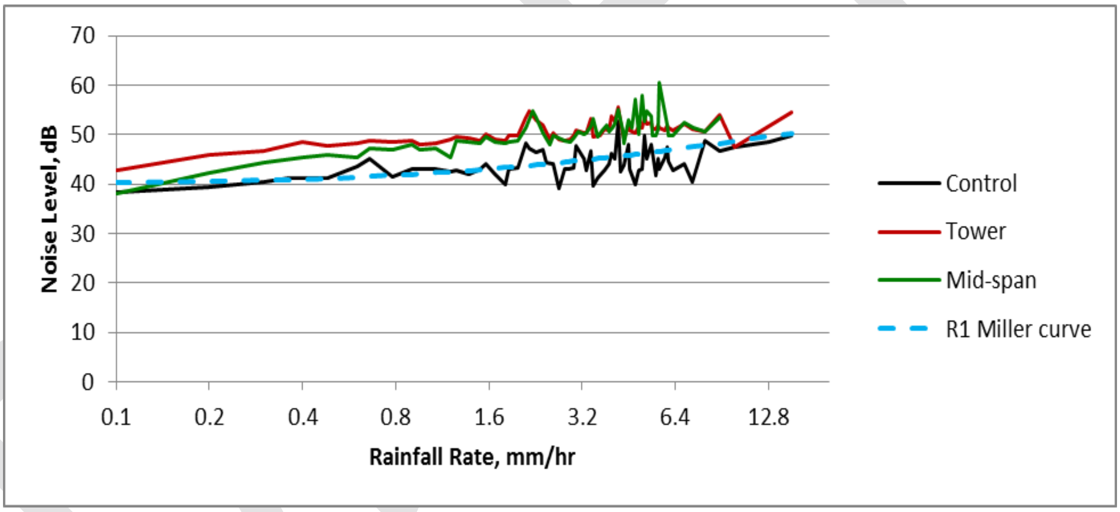


Figure 6.5: Noise level against rainfall rate for all sites.

Control location noise levels can be seen to follow the general Miller curve estimates well, being on average 0.7 dB lower than the Miller curve and within ±4.5 dB for 90% of the time. Tower location noise levels were on average 6.1 dB above the Miller curve, varying between 4 and 10 dB higher for 90% of the time. Mid-span noise levels were on average 5.5 dB above the Miller curve, varying between 3 and 9 dB higher for 90% of the time.

The mid-span location is seen to transition with increasing rainfall. During dry weather, the measured levels are similar to those at the control location, whilst at higher rainfall rates (above approximately 1.3 mm/hr), they match those at the tower location.

6.5 Spectral analysis

Spectral analysis of selected audio recordings identified the characteristic presence of a 100 Hz hum. This is due to a well understood principle of corona effects generating strong tonal components at twice the electrical frequency of the system[12] (electrical frequency is 50 Hz in Ireland). A detailed 1/24-octave band analysis is presented in Figure 6.6 and shows the presence of a tone at 50 Hz, and associated harmonic frequencies in multiples of 50 Hz up to 250 Hz, with 100 Hz being the strongest component. These are seen at both the tower and mid-span location, with an example from the mid-span location shown in Figure 6.6 below.

An increase in level at 1.9 kHz during rainfall was also noted; whilst this is assumed to be associated with corona generation, the precise cause of this increase is unknown.

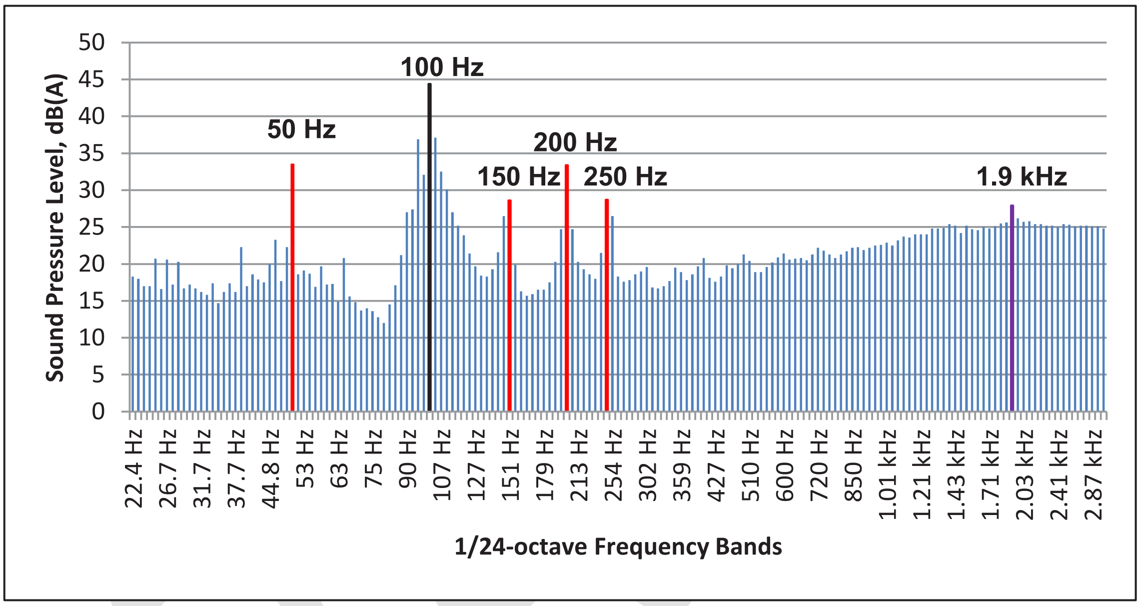


Figure 6.6: 1/24-octave band analysis of corona noise at mid-span location; tones highlighted

7 COMPARATIVE ANALYSIS

7.1 Comparison with predicted wet ambient levels

In order to predict noise levels during rainfall, it is necessary to identify the ambient noise level at each measurement location in the absence of rain. This has been taken as the average $L_{Aeq,1min}$ noise level at the location during dry periods of monitoring. Such dry ambient sound levels for each location are given in the Table 7.1 below, with separate values for daytime and night time.

It should be noted that during these dry conditions, levels at the tower are significantly greater than those at the mid-span and control locations, with electrical noise prominent throughout much of the monitoring period. Typical day and night levels as presented in Table 7.1 differ by less than 1 dB at the tower, compared with 7 and 6 dB differences between daytime and night time levels at the control and mid-span locations respectively.

---

[12] Electric Power Research Institute, ‘Chapter 6: Audible Noise’, Transmission Line Reference Book 345kV and Above, Second Edition, EPRI, 1982, p. 276

TABLE 7.1: DRY AMBIENT SOUND LEVELS (AVERAGE $L_{AEQ,1MIN}$)

Time of Day	Control	Tower	Mid-span
Day (07:00-23:00)	39.9	41.2	37.8
Night (23:00-07:00)	32.9	40.4	31.8

An R1 Miller curve is used to predict the background level during rain. Whereas general assessments can be made on the basis of a general Miller curve, the true curve values depend on time of day and on each location's dry ambient sound level. Correcting for these specific conditions, differences between expected level and measured levels can be quantified. These are summarised in Table 7.2 below.

TABLE 7.2: DIFFERENCE BETWEEN PREDICTED AND MEASURED LEVEL

Weather conditions	Average Predicted Level Above Miller Curve, dB		
	Control	Tower	Mid-span
Light rain (≤0.5 mm/hr)	0.6	2.7	3.1
Medium-Heavy rain (≥0.5 mm/hr)	0.2	5.9	6.9

Measured levels at the control location are within 1 dB of the predicted levels in all conditions considered in this table. The mid-span shows the greatest exceedance of predicted rainfall levels, but the tower levels are the greatest in absolute terms. It should be noted that there are higher dry background levels at the tower, especially at night due to the greater electrical noise present in this location in dry conditions. This has the effect of increasing the predicted rainfall sound levels and hence reducing the noted exceedances.

By logarithmically subtracting the contribution of the ambient noise levels (including predicted contribution from rain) from the total noise, the contribution of other sources, primarily corona noise, can be quantified. This is shown in Table 7.3 below.

TABLE 7.3: CONTRIBUTION OF CORONA NOISE SOURCES

Weather conditions	Contribution to total noise level, dB		
	Control	Tower	Mid-span
Light rain (≤0.5 mm/hr)	41.6	47.1	44.8
Medium-Heavy rain (≥0.5 mm/hr)	44.7	52.9	50.7

7.2 Comparison with predicted corona noise

The measured L_{50} and L_5 noise levels as defined in the prediction methodologies are calculated by the average measured noise levels at each location corresponding to the 50th and 95th percentile rainfall rates of 0.8 mm/hr and 5.1 mm/hr respectively. Only one period of rainfall exactly matching 5.1 mm/hr was recorded during the monitoring period, so in this instance, the data for L_5 noise level have been averaged for data relating to rainfall between 4.6 mm/hr and 5.6 mm/hr , with an equal number of measurements above and below 5.1 mm/hr. This approach has been taken to provide a sufficiently large sample of data to allow representative analysis to be carried out. These calculations correspond with the L_{50} and L_5 noise levels, under the assumption that the average noise levels will increase for any increase in rainfall.

These measured L_{50} and L_5 levels have been compared with predicted levels at 200m for the control location and 5m for the tower and mid-span locations. The data for the control location are shown in Table 7.4 below.

TABLE 7.4: MEASURED AND PREDICTED CORONA DISCHARGE NOISE LEVELS: CONTROL LOCATION

	L_{Aeq}, dB						
Noise Indicator	**Measured**	**BPA**	**EPRI**	**GA1PL50**	**GP1PL5**	**GP3PL50**	**GP3PL5**
Wet L_{50}	41.5	46.0	44.5	41.6	-	45.8	-
Heavy Rain L_5	44.6	49.5	49.7	-	48.7	-	37.8

The calculated levels for almost all methods over-predict the result at the control location. The L_{50} predictions are on average 3 dB greater than the measured levels. It should be noted that the BPA, EPRI and GP3PL50 methods predict 3.9 dB greater than measured levels on average. The GA1PL50 methodology predicts to a very high accuracy, with only 0.1 dB difference to the measured level.

The L_5 predictions over-predict to an even greater extent, with the exception of the GP3PL5 method, where calculated levels are more than 7 dB lower levels than measured. The remaining three methodologies agree with each other to within 1 dB but differ from measured levels by 4.7 dB on average.

Equivalent data for the tower location are shown in Table 7.5 below.

TABLE 7.5: MEASURED AND PREDICTED CORONA DISCHARGE NOISE LEVELS: TOWER LOCATION

	L_{Aeq}, dB						
Noise Indicator	**Measured**	**BPA**	**EPRI**	**GA1PL50**	**GP1PL5**	**GP3PL50**	**GP3PL5**
Wet L_{50}	48.4	55.2	56.0	57.4	-	54.3	-
Heavy Rain L_5	51.6	58.7	61.2	-	65.3	-	57.3

The calculated levels for almost all methods over-predict the result at the tower location. The L_{50} predictions are on average 7.3 dB greater than the measured levels.

The L_5 predictions are on average 9 dB greater than measured levels. It is noted that the BPA, EPRI and GP3PL5 methods predict an average of 7.5 dB greater. The GP1PL5 predicts a level 13.7 dB greater that measured.

Equivalent data for the mid-span location measured against predicted levels are shown in Table 7.6 below.

TABLE 7.6: MEASURED AND PREDICTED CORONA DISCHARGE NOISE LEVELS: MID-SPAN LOCATION

	L_{Aeq}, dB						
Noise Indicator	**Measured**	**BPA**	**EPRI**	**GA1PL50**	**GP1PL5**	**GP3PL50**	**GP3PL5**
Wet L_{50}	47.0	55.2	56.0	57.4	-	54.3	-
Heavy Rain L_5	52.8	58.7	61.2	-	65.3	-	57.3

Predicted levels for the mid-span are the same as those for the tower as they are based on the same distance from the line. Predicted levels may increase if line sag is taken into consideration (this will be greatest at the mid-span), however this would further increase the degree to which noise levels are over-predicted. However, the measured sound levels show a lower L_{50} at the mid-span location than that at the tower, but a greater measured L_5 level (although this is still an average of 7.8 dB lower than the predicted values).

8 DISCUSSION OF FINDINGS

8.1 Overall levels

Near to the tower, noise levels are greater in magnitude and consistency than compared to the other sites. Levels typically do not reduce significantly at night and often increase, despite the significant drop in background noise levels (as seen at the control location). Tower levels are typically greater than at the control and mid-span locations during the day and significantly greater at night. Noise levels away from the tower are lower during dry conditions, particularly at night.

It was noted that there was an increase in noise levels during periods of higher humidity. This suggests that humidity is a significant factor in the production of noise in dry conditions. It is likely that this increase is due to higher levels of condensation on the tower insulators and the conductors.

It has been suggested by EirGrid that the use of composite insulators (as opposed to the glass insulators found on the tower under investigation) may influence the noise produced close to the tower, but this has not been quantified as part of this study.

During rain, the control location experienced some increase in levels and rain noise became the dominant noise source above a rainfall rate of approximately 1 mm/hr. Corona noise was determined to contribute to a less than 1 dB increase in average noise levels, but can be audible in the worst-case situations.

Noise levels at the tower rise rapidly with increasing rainfall due to the onset of corona discharge. The prominence of noise from the tower is most significant during low and medium rainfall rates (up to 5 mm/hr), where levels are 6-10 dB greater than background levels at the control location. Higher rainfall rates resulted in increased background noise levels and hence lessened the impact of corona noise. At these high rainfall rates, corona noise was 3-5 dB greater than background levels.

Noise levels at the mid-span monitoring location behaved similarly to the control location in dry conditions and in light rain but experienced a more rapid increase in level with rainfall. Above a rainfall of 1.3 mm/hr, the mid-span noise levels closely match those at the tower. This indicates that in high rainfall, the conductors are the primary source of noise rather than the insulators at the tower.

The noise source levels obtained from this work can be used to predict levels at a variety of distances from power lines for the assessment of new or proposed lines. It is recommended that such calculations be carried out using detailed noise modelling, to account for local geography, ground cover, screening, etc.

8.2 Tonality and Impulsivity

Based on the measured noise levels during rainfall at this location, there is potential for the noise to be considered a significant adverse impact (as described in BS 4142:2014) on potential receptors close to the line. This would depend on the precise distance of receptors from the line and the receptors' sensitivity to noise. The presence of the 100 Hz tonal component increases the audibility of the sound.

The impact of this tonal component has been considered following the methodology set out in BS 4142:2014[13]. According to this method, a noise impact penalty of up to 6 dB can be applied depending on the prominence of the tone under consideration. An additional penalty can also be applied when a sound is found to be impulsive, resulting in a further penalty of up to 9 dB[14].

Detailed sound recordings from a sample audio file have been processed according to the methodologies set out in BS4142. This identified that a tonality penalty of 6 dB and an impulsivity penalty of 4 dB would be applicable under this standard, although these penalties could vary depending on the situation under consideration, such as the distance from the line at which the assessment is being carried out. These can be calculated for other sites and other distances from appropriate measurements or by using suitable acoustic calculation formulae or calculation software.

8.3 Comparison with Predicted levels

Two sets of level predictions were made using a range of prediction methodologies; the prediction of expected levels without the line, i.e. the background noise and rainfall noise, and the prediction of noise levels from the line, i.e. corona noise.

Predictions of noise from rainfall itself apply for all conditions at the control location and can be used as a comparative measure for wet conditions at the tower and mid-span. It was found that in dry conditions and low rainfall rates, the control and mid-span locations closely match the expected levels. The tower experienced much greater levels than expected, typically 1-3 dB greater during the daytime and 7-9 dB during the night time.

During periods of rainfall, measured noise levels at the control location continued to match predicted levels from rainfall alone. The mid-span location experienced expected noise levels for low rainfall rates but levels quickly increased with higher rainfall, similar to those at the tower. Both the mid-span and tower locations experienced noise levels approximately 6 dB greater than expected levels during significant rainfall. This difference is due to the additional corona noise which affects these two measurement locations.

Predictions of corona noise were found to be higher than measured levels. However it is important to consider that the site under investigation is an aged line and it has been

---

[13] BS 4142:2014 Annex D: Objective method for assessing the audibility of tones in sound: Reference method

[14] BS 4142:2014 Annex E: Objective method for measuring the prominence of impulsive sounds and for adjustment of L_{Aeq}

suggested that corona noise levels from a new line can decrease by over 10 dB over the first 3 years of a line's lifetime[15]. This is due to a smoothing effect of weather conditions and pollution on the conductors over time. Excess pollution, dirt, insects and other irregularities can become built up on the line during extended dry weather, increasing noise levels. These are often washed away during heavy rain, restoring previous lower noise levels. Irregularities due to damage to the line, inadequate maintenance or poor design can also increase noise levels. Although prediction methodologies are specified to apply to 'aged conductors', 'aged' is not quantified. This may be a significant factor in the large error of predictions.

Two parameters were predicted, the L_{50} and the L_5, corresponding to the median and 95th percentile noise levels during rainfall respectively. The results from the various prediction methodologies were generally consistent, with strong agreement (within 3 dB) between methodologies at distances under 100m for the L_{50} and between 100-300m for the L_5. Despite some strong agreement between methods, measurements were significantly lower than predicted levels, by over 10 dB in some cases. There was some variation between the individual prediction methodologies, but the BPA and EPRI methods were found to be consistent with each other. It is considered that these methods are more reliable and suitable for future use than evolutionarily formed methods, although the differences between the output from the prediction models and measured levels are of some concern.

This over-prediction of levels may influence any noise assessment of a transmission line, and result in impacts being considered to be more significant than would occur in practice. Despite this, it is also important to consider that initial noise levels from a new line are expected to be significantly greater in the first few years following installation than after some time, making these over-predictions a possible worst-case prediction method.

9 CONCLUSIONS

In this report, noise from the 400kV transmission line in Cloney, Co. Kildare has been quantified based on data from over 10 weeks of measurements. Noise measurements were made simultaneously at three locations relative to the power line; directly beneath a tower, at the mid-span position half way between towers, and at a distance of approximately 200m from the line as a control location during a wide range of weather conditions. A number of methodologies for predicting transmission line noise levels have been evaluated against measured data, and the findings reported.

It has been shown that 200m from the line, at the control location, the contribution to the overall noise levels by the transmission line is low, even in the worst-case weather conditions, when noise emissions from the line are at their greatest difference from ambient levels. Close to the line, near the mid-span point between towers, the contribution to the overall noise levels by the transmission line is low in dry conditions but increases rapidly with rainfall. In high rainfall conditions, the noise from the line at the mid-span increased significantly and was the dominant noise source. Noise levels at the tower were significantly greater than at other locations during dry conditions, particularly at night when humidity levels were often higher. This may be due to condensation effects. During a range of weather conditions, noise from the line at the tower was the dominant noise source, and for periods of higher rainfall rates the noise from the line at the tower increased significantly.

It has been determined that; the primary sources of noise from the line during dry conditions are located at the tower. The primary sources of noise from the line in wet conditions are the conductors along the length of the line.

---

[15] Electric Power Research Institute, 'Chapter 6: Audible Noise', Transmission Line Reference Book 345kV and Above, Second Edition, EPRI, 1982, p. 299.

Prediction methodologies including the BPA method, EPRI method and a number of Evolutionarily Formed methods (GP3PL50, GA1PL50, GP3PL5 and GP1PL5) have been evaluated against measured data. With the exception of the GP3PL5 method which predicted significantly lower levels than measured, all predicted noise levels were greater than those measured.

The significant variation between measured and predicted values could be due to variations in line load, or variations in line ageing effects. The prediction methodologies may be best suited for worst-case initial noise impact predictions. The BPA and EPRI methods are considered to be more consistent and therefore more suitable for use in the predictions of future transmission line noise.

10 RECOMMENDATIONS

It is recommended that more research takes place to further quantify noise from high-voltage transmission lines. Evaluation of the influence of different tower specifications may also allow better identification of the source of dry weather noise at the towers. Long term measurements over several years at a new installation would also allow quantification of variation in sound levels with the aging of conductors.

Assessment of an alternative tower with composite insulators would provide comparative data to determine and quantify any effect of using different insulators, although it has not been confirmed whether insulator selection significantly effects corona noise generation.

Further investigation into the error and accuracy of the BPA and EPRI prediction methodologies would provide useful information for the evaluation of future transmission line developments and quantify or remove a large portion of uncertainty in predicting future noise levels.

The currently adopted method for assessing the impact of transmission line noise, BS 4142, has recently been updated (2014), adopting significantly greater noise impact penalties for tonality and impulsivity than was evident in the previous version of the standard. An investigation into the impact of corona noise on noise sensitive receptors in proximity to transmission line noise would allow further context to be brought to any noise impact assessment for new or modified transmission lines. This may either take the form of the provision of further guidance relating to the implementation of BS4142:2014 or an update to the 21-year old transmission line noise impact guidance given in TR(T)94.

Finally, the development of a new prediction methodology based upon acoustical foundations and noise impact (as opposed to the electrical engineering ‘audible noise phenomenon’ based approach of current prediction methodologies) could be an exceedingly useful tool for future assessments.

APPENDIX A: NOISE PERCEPTION AND TERMINOLOGY

Between the quietest audible sound and the loudest tolerable sound there is a million to one ratio in sound pressure (measured in Pascals, Pa). Because of this wide range, a noise level scale based on logarithms is used in noise measurement called the decibel (dB) scale. Audibility of sound covers a range of approximately 0 to 140 dB. The human ear system does not respond uniformly to sound across the detectable frequency range and consequently instrumentation used to measure noise is weighted to represent the performance of the ear. This is known as the 'A weighting' and annotated as dB(A). Table A.1 lists the sound pressure level in dB(A) for common situations.

TABLE A.1: NOISE LEVELS FOR COMMON SITUATIONS

Typical noise level, dB(A)	Example
0	Threshold of hearing
30	Rural area at night, still air
40	Public library, refrigerator humming at 2m
50	Quiet office, no machinery
60	Normal conversation
70	Telephone ringing at 2m
80	General factory noise level
90	Heavy goods vehicle from pavement
100	Pneumatic Drill at 5m
120	Discotheque – 1m in front of loud speaker
140	Threshold of pain

The noise level at a measurement point is rarely steady, even in rural areas, and varies over a range dependent upon the effects of local noise sources. Close to a busy motorway, the noise level may vary over a range of 5 dB(A), whereas in a suburban area this variation may be up to 40 dB(A) and more due to the multitude of noise sources in such areas (cars, dogs, aircraft etc.) and their variable operation. Furthermore, the range of night-time noise levels will often be smaller and the levels significantly reduced compared to daytime levels. When considering environmental noise, it is necessary to consider how to quantify the existing noise (the ambient noise) to account for these second to second variations.

Statistical Noise Levels

Statistical noise levels can be obtained from measurements, such as L_5, L_{10}, L_{50}, L_{90} etc. Each L_N level represents the level exceeded for N% of the time during the logging period. Typically A-weighted, these can be written in the form L_N dB(A) or L_{AN} dB. The L_{A50} represents the median A-weighted level. The L_{A0} and L_{A100}, usually written L_{Amax} and L_{Amin} respectively, are the maximum and minimum recorded A-weighted levels for each logging period.

Background Noise Levels

A parameter that is widely accepted as reflecting human perception of the ambient noise is the background noise level, $L_{90,}$ which is usually A- weighted and can be written as L_{90} dB(A) or L_{A90} dB. This is the noise level exceeded for 90 % of the measurement period and generally reflects the noise level in the lulls between individual noise events. Over a one hour period, the L_{A90} will be the noise level exceeded for 54 minutes.

Ambient or Activity Noise Levels

The equivalent continuous A-weighted sound pressure level, L_{Aeq} (or L_{eq} dB(A)) is the single number that represents the total sound energy measured over that period. L_{Aeq} is the sound level of a notionally steady sound having the same energy as a fluctuating sound over a specified measurement period. It is commonly used to express the energy level from individual sources that vary in level over their operational cycle.

Noise Changes

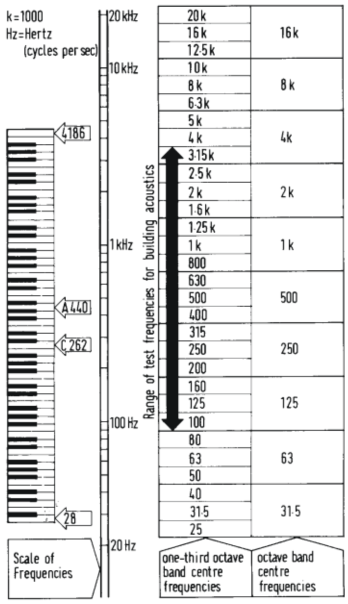
Human subjects are generally only capable of noticing changes in noise levels of no less than 3 dB(A). It is generally accepted that a change of 10 dB(A) in an overall, steady noise level is perceived to the human ear as a doubling (or halving) of the noise level. (These findings do not necessarily apply to transient or non-steady noise sources such as changes in noise due to changes in road traffic flow, or intermittent noise sources).

Frequency Spectrum

Frequency is the rate at which the air particles vibrate. The more rapid the vibrations, the higher the frequency and perceived pitch. Frequency is measured in Hertz (Hz).

A young person with average hearing can generally detect sounds in the range 20 Hz to 20,000 Hz (20 kHz). Figure A.1 below illustrates the range of frequencies, for example, the lowest note on a full scale piano, ‘A’, has a fundamental at 28 Hz, and the highest, ‘G’, a fundamental at 4186 Hz (there will be higher order harmonics). Human speech is predominantly in the range 250 Hz - 3000 Hz.
The musical term ‘octave’ is the interval between the first and eighth note in a scale and represents a doubling of frequency. A series of octave and one-third octave bands have been derived, as shown on Figure A.1 and these are commonly used in noise measurements where it is necessary to describe not only the level of the source noise but also the frequency content. The frequency content of a noise source can be useful for identifying acoustic features such as a whine, hiss or screech. One-third octave bands can be further subdivided into smaller intervals, such as one-sixth octave, one-twelfth octave or one-twenty-fourth octave bands, etc. One-twenty-fourth octave bands are often utilised for spectral analysis to identify tonal components in a signal.

Figure A.1: 1 octave and 1/3 octave frequency bands



APPENDIX B: SITE MAP AND MONITORING LOCATIONS

APPENDIX C: TOWER STYLE AND SPECIFICATIONS

This appendix presents the specification for the power line monitored, as provided by EirGrid.

The transmission line uses Type 401 towers; dimensions of the tower within the measurement site are given below in Figure C.1. The maximum permissible sag on the line at the mid-point between towers is 9 meters.

The line nominally operates at 400kV but is rated for up to 420kV, with the load on the line varying with demand. The specification for the conductor is given in Table C.1.

Figure C.1: Tower style and dimensions

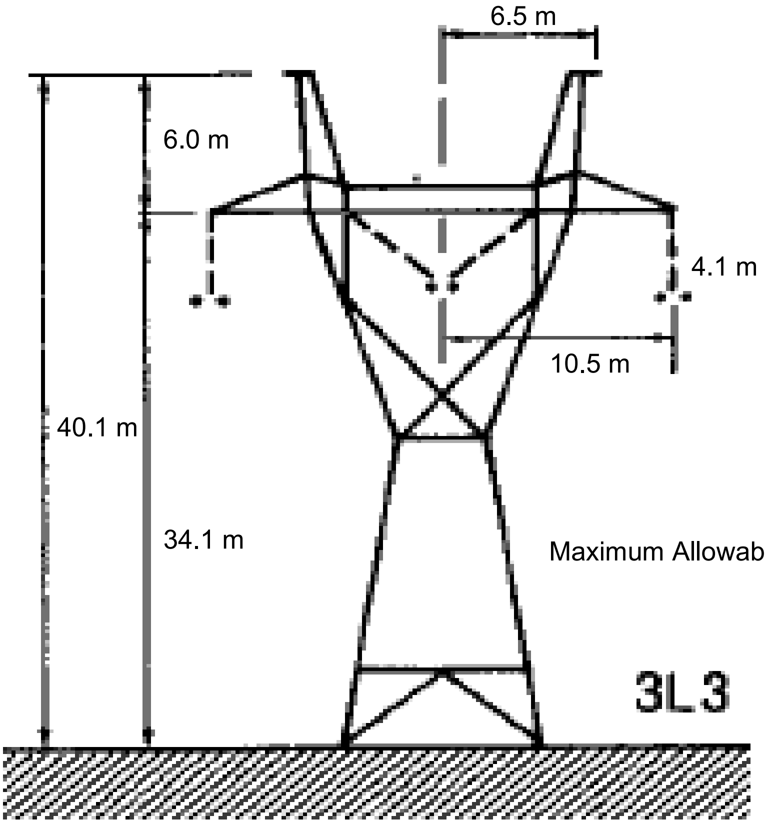


TABLE C.1: CONDUCTOR SPECIFICATION	
Size (approx. mm^2)	600
Actual Area (mm^2)	592
Code Name	Curlew
Conductor diameter, d (cm)	3.168
Mass per unit length, w (kg)	1.98
Young's Modulus, E (kg/m/s^2)	0.65 x 10^6
Coefficient of Linear Expansion, α (˚C^{-1})	19.5 x 10^{-6}
Nominal Breaking Load (kg)	16600

APPENDIX D: MEASURED NOISE LEVELS BY TIME OF DAY

TABLE D.1: 10-WEEK CONTROL NOISE LEVELS BY HOUR

Hour	Average 10-minute Noise Level, dB					Absolute Noise Level, dB		
	L_{Aeq}	L_{Amax}	L_{Amin}	L_{A10}	L_{A90}	L_{Aeq}	L_{Amax}	L_{Amin}
00:00 – 01:00	33.5	46.6	21.5	34.2	23.3	41.1	82.1	16.2
01:00 – 02:00	32.4	45.6	21.0	32.9	22.7	38.5	68.2	15.6
02:00 – 03:00	31.1	44.2	21.0	31.5	22.6	36.5	66	15.6
03:00 – 04:00	30.2	43.1	20.9	30.6	22.4	35.8	64.3	16.1
04:00 – 05:00	31.0	44.0	21.0	31.4	22.5	35.1	62.9	16.8
05:00 – 06:00	34.1	46.6	22.0	34.8	23.9	37.5	71.2	16.8
06:00 – 07:00	38.0	50.4	25.0	38.6	27.9	40.9	77.1	17.3
07:00 – 08:00	41.1	52.5	28.1	41.7	31.6	44.1	82.8	18.5
08:00 – 09:00	42.0	53.6	30.0	42.2	33.3	44.6	89.2	20.0
09:00 – 10:00	40.4	51.5	29.1	40.4	32.0	42.7	78.5	21.2
10:00 – 11:00	39.5	50.0	27.5	38.8	30.2	42.1	88	20.9
11:00 – 12:00	39.6	50.1	27.6	39.2	30.4	42.2	88.9	19.6
12:00 – 13:00	39.9	51.7	27.8	40.0	30.8	42.8	91.7	20.3
13:00 – 14:00	39.8	52.4	28.2	40.6	31.3	42.8	77.9	17.5
14:00 – 15:00	40.3	52.1	28.7	40.9	31.8	43.2	74.9	17.5
15:00 – 16:00	40.7	52.2	28.3	41.0	31.5	43.5	89.4	19.7
16:00 – 17:00	40.8	51.6	28.2	40.7	31.4	44.0	81.3	20.0
17:00 – 18:00	41.1	52.1	28.9	41.5	32.4	44.1	88.9	20.0
18:00 – 19:00	41.4	52.6	28.7	41.9	32.7	44.1	76	19.8
19:00 – 20:00	41.1	52.4	27.9	41.7	31.8	43.5	88.2	19.4
20:00 – 21:00	39.7	50.6	26.2	40.5	30.0	42.1	82.5	18.4
21:00 – 22:00	38.3	50.2	24.1	39.1	27.6	42.0	81.1	17.2
22:00 – 23:00	36.9	49.0	22.7	37.9	25.5	41.6	69.8	16.6
23:00 – 00:00	35.0	47.8	21.8	35.9	24.0	39.9	75.8	16.0

TABLE D.2: 10-WEEK TOWER NOISE LEVELS BY HOUR

Hour	Average Noise Level, dB					Absolute Noise Level, dB		
	L_{Aeq}	L_{Amax}	L_{Amin}	L_{A10}	L_{A90}	L_{Aeq}	L_{Amax}	L_{Amin}
00:00 – 01:00	40.2	48.0	20.9	41.2	37.2	47.0	76.8	16.1
01:00 – 02:00	40.5	47.5	21.0	40.9	37.3	44.8	77.6	16.8
02:00 – 03:00	40.7	47.2	22.0	41.0	37.5	43.8	75.5	16.8
03:00 – 04:00	40.4	46.6	25.0	40.6	37.5	45.9	82.6	17.3
04:00 – 05:00	40.5	47.2	28.1	40.8	37.5	43.0	72.6	18.5
05:00 – 06:00	41.2	48.6	30.0	41.6	37.7	43.4	66.3	20.0
06:00 – 07:00	42.9	51.8	29.1	43.4	38.9	44.7	74.6	21.2
07:00 – 08:00	44.4	54.2	27.5	44.9	39.7	45.8	84.3	20.9
08:00 – 09:00	44.6	55.4	27.6	44.8	39.8	46.3	85.8	19.6
09:00 – 10:00	43.1	53.9	27.8	43.3	38.4	45.7	89.7	20.3
10:00 – 11:00	41.9	53.4	28.2	41.9	36.5	45.2	97.8	17.5
11:00 – 12:00	41.4	52.0	28.7	40.8	35.0	45.9	89.4	17.5
12:00 – 13:00	41.1	52.9	28.3	41.5	35.0	45.1	90.3	19.7
13:00 – 14:00	40.9	54.1	28.2	42.1	35.1	48.0	97.6	20.0
14:00 – 15:00	41.4	54.7	28.9	42.9	35.7	46.2	86.8	20.0
15:00 – 16:00	41.5	54.8	28.7	43.1	35.5	47.0	89.1	19.8
16:00 – 17:00	41.6	55.8	27.9	42.8	35.4	47.3	88	19.4
17:00 – 18:00	41.9	55.1	26.2	43.1	36.2	45.7	93.5	18.4
18:00 – 19:00	41.7	54.0	24.1	43.2	36.3	45.1	83	17.2
19:00 – 20:00	41.4	52.6	22.7	43.0	36.4	44.3	77.4	16.6
20:00 – 21:00	40.6	50.6	21.8	42.4	36.2	43.1	79.3	16.0
21:00 – 22:00	40.3	50.2	33.7	41.7	36.2	44.5	79.9	22.7
22:00 – 23:00	40.3	49.4	34.2	41.9	36.6	46.1	76.8	23.4
23:00 – 00:00	40.1	48.4	34.5	41.3	36.9	45.3	76	21.3

TABLE D.3: 10-WEEK MID-SPAN NOISE LEVELS BY HOUR

Hour	Average Noise Level, dB					Absolute Noise Level, dB		
	L_{Aeq}	L_{Amax}	L_{Amin}	L_{A10}	L_{A90}	L_{Aeq}	L_{Amax}	L_{Amin}
00:00 – 01:00	32.1	43.0	22.9	32.9	24.7	42.9	75.6	16.4
01:00 – 02:00	31.4	43.0	22.5	32.1	24.2	40.5	76.2	16.3
02:00 – 03:00	31.2	42.7	22.6	31.6	24.3	39.3	68.9	15.8
03:00 – 04:00	30.6	41.5	22.7	30.9	24.4	42.4	99.8	16.8
04:00 – 05:00	31.3	42.3	22.7	31.7	24.5	37.7	68.5	17.0
05:00 – 06:00	33.5	44.5	23.5	34.2	25.5	37.1	78.6	17.0
06:00 – 07:00	37.3	47.9	26.0	36.9	28.5	40.2	79.9	17.7
07:00 – 08:00	39.7	50.6	28.3	39.0	31.4	42.8	89.3	19.7
08:00 – 09:00	40.5	51.5	29.7	39.5	32.6	45.6	90.9	22.0
09:00 – 10:00	39.0	49.5	29.2	38.4	31.7	42.4	85.2	21.6
10:00 – 11:00	38.3	49.2	28.2	37.7	30.7	44.2	95.5	20.7
11:00 – 12:00	38.7	48.2	27.7	37.2	30.1	43.4	85.7	19.6
12:00 – 13:00	38.5	48.6	28.3	38.1	30.8	42.3	85.6	19.2
13:00 – 14:00	38.4	47.8	27.6	37.4	30.2	42.8	85.7	17.5
14:00 – 15:00	38.9	48.8	28.6	38.5	31.3	42.9	79.4	16.9
15:00 – 16:00	39.2	49.1	28.4	38.7	31.1	44.7	93.8	19.3
16:00 – 17:00	38.8	48.9	28.3	38.4	31.1	42.3	80.8	20.3
17:00 – 18:00	39.0	49.1	29.0	38.9	31.9	41.9	77.4	20.0
18:00 – 19:00	39.0	49.5	28.6	39.0	31.7	42.1	83.6	19.1
19:00 – 20:00	38.8	49.6	27.9	38.8	31.1	43.3	99.5	19.1
20:00 – 21:00	37.1	46.7	26.5	37.5	29.7	40.5	82.4	18.7
21:00 – 22:00	35.8	46.6	24.7	36.4	27.6	40.3	81.4	16.8
22:00 – 23:00	34.4	44.5	23.5	35.4	26.1	41.4	75.9	16.8
23:00 – 00:00	33.1	44.0	22.9	34.1	25.1	40.6	82.7	16.1

APPENDIX E: DATA LOST OR REMOVED

- Data lost due to battery failure in Period 1:
  - Equipment batteries at the control location failed after 13 days of a 17-day monitoring period. Equipment batteries at the tower location failed approximately 36 hours before collection.
  - Shorter periods between maintenance schedules were implemented. No further data losses due to battery issues were encountered.
  - Incomplete logging periods immediately before failure were also excluded.

- Data lost due to flooding in Period 5:
  - 07/11/14 01:40 onwards was removed from the mid-span location data, it was determined that flooding contaminated the recordings shortly after this time. A total of 52 hours were excluded prior to the equipment failure. A further 106 hours of data were not captured between failure and collection of the equipment. Approximately 8.5 days of data were captured during this period, with a further 6.5 days excluded or not captured.

- Data removed due to high wind speeds:
  - Data corresponding to wind speeds above 5 m/s were excluded from analysis. A total of 5 hours of data were excluded.

- Data removed due to contamination by staff:
  - Initial set-out; the first 30-minutes of data were removed for all locations.
  - Subsequently, the first and last periods of data were removed (usually 10-minutes but were sometimes extended if staff were on site for a greater period of time).
  - Approximately 2.5 hours of data were removed in total.

- Total data removed & remaining:
  - Data lost at control location: Approximately 96 hours
  - Data excluded at control location: Approximately 7.5 hours
  - Good data remaining at control location: Approximately 1728 hours (94%)
  - Data lost at tower location: Approximately 36 hours
  - Data excluded at tower location: Approximately 7.5 hours
  - Good data remaining at tower location: Approximately 1788 hours (98%)
  - Data lost at mid-span location: Approximately 106 hours
  - Data excluded at mid-span location: Approximately 58 hours
  - Good data remaining at mid-span location: Approximately 1667 hours (91%)

APPENDIX F: EQUIPMENT CALIBRATION CERTIFICATES

Equipment calibration certificates are given for the following equipment used:

- Rion NL-52 Sound Level Meter (Tower)
- Rion NL-52 Sound Level Meter (Mid-span)
- Rion NL-52 Sound Level Meter (Control)
- Rion NL-52 Sound Level Meter (Spot measurements)
- Rion NC-74 Acoustic Calibrator
- Weather Station conformance certificates

Certificate of Calibration

Issued by University of Salford (Acoustics Calibration Laboratory)
UKAS ACCREDITED CALIBRATION LABORATORY NO. 0801

UKAS
CALIBRATION
0801

Page 1 of 3

APPROVED SIGNATORIES
Claire Lomax [✓] Andy Moorhouse [ ]
Gary Phillips [ ] Danny McCaul [ ]

acoustic calibration laboratory
The University of Salford, Salford, Greater Manchester, M5 4WT, UK
http://www.acoustics.salford.ac.uk
t 0161 295 3030/0161 295 3319 f 0161 295 4456 e c.lomax1@salford.ac.uk

University of Salford
MANCHESTER

Certificate Number: 01154/4 Date of Issue: 23 January 2013

PERIODIC TEST OF A SOUND LEVEL METER to IEC 61672-3:2006

FOR:	URS Infrastructure & Environment UK Limited 12 Regan Way Chetwynd Business Park Chilwell Notts NG9 6RZ
FOR THE ATTENTION OF:	Heather Billin
PERIODIC TEST DATE:	22nd and 23rd January 2013
TEST PROCEDURE:	CTP12 (Laboratory Manual)

Sound Level Meter Details

Manufacturer	Rion
Model	NL-52
Serial number	01021281
Class	1
Software	Version 1.3

Associated Items	**Microphone**	**Preamplifier**	**Calibrator**
Manu	Rion	Rion	Rion
Model	UC-59	NH-25	NC-74
Serial Number	04337	21323	34425537
Calibrator Adaptor	-	-	NC-74-002

Test Engineer (initial): ______ Name: Gary Phillips

This certificate is issued in accordance with the laboratory accreditation requirements of the United Kingdom Accreditation Service. It provides traceability of measurement to recognised national standards, and to the units of measurement realised at the National Physical Laboratory or other recognised national standards laboratories. This certificate may not be reproduced other than in full except with the prior written approval of the issuing laboratory.

Certificate Number: 01154/4 Date of Issue: 23 January 2013

Procedures from IEC 61672-3: 2006 and TPS 49 Edition 2 June 2009 were used to perform the periodic tests.

Manufacturer's instruction manuals were marked as follows: NL-42/NL-52 Technical Notes (No. 55750 11-03) and NL42/NL-52 Instruction Manual (No. 55530 11-03).

Adjustment data used to adjust the sound levels indicated in response to the application of an electrostatic actuator to sound levels equivalent to those that would be indicated in response to plane, progressive sound waves were obtained from the manufacturer's instruction manuals referred to in this certificate and from information provided by the manufacturer.

The sound level meter calibration check frequency is 1000 Hz, the reference level is 94 dB. As this instrument only has a single range, this range is the reference level range. The instrument was calibrated without a windshield. Consult manufacturer's instructions if using a windshield.

The environmental conditions in the laboratory at the start of the test were:
Static pressure 99.905 kPa, air temperature 22.6 °C, relative humidity 39.1 %.

The initial response of the instrument to application of the associated sound calibrator was 94.0 dB (A). No adjustment of the instrument was required. This indication was obtained from the calibration certificate of the calibrator, 06552 and information in the manufacturer's instruction manuals specified in this certificate, when the instrument is configured as follows, Windscreen Correction: WS None, Diffuse Sound Field Correction: OFF.

With the microphone installed the level of self-generated noise on the most-sensitive level range was:

A:	**14.8 dB***

* Under-range indicated on instrument display

With the microphone replaced by an electrical input device with a capacitance of 14.6 pF, the levels of self-generated noise on the most-sensitive level range were:

A:	**12.1 dB***
C:	**16.6 dB***
Z:	**22.5 dB***

* Under-range indicated on instrument display

The environmental conditions in the laboratory at the end of the test were:
Static pressure 100.500 kPa, air temperature 23.0 °C, relative humidity 33.4 %.

Certificate Number: 01154/4 Date of Issue: 23 January 2013

The sound level meter submitted for testing has successfully completed the class 1 periodic tests of IEC 61672-3:2006, for the environmental conditions under which the tests were performed. However, no general statement or conclusion can be made about conformance of the sound level meter to the full requirements of IEC 61672-1:2002 because evidence was not publicly available, from an independent testing organization responsible for pattern approvals, to demonstrate that the model of sound level meter fully conformed to the requirements in IEC 61672-1:2002, and because the periodic tests of IEC 61672-3:2006 cover only a limited subset of the specifications in IEC 61672-1:2002.

The uncertainty of measurement of the adjustment data given in the instruction manual is the total expanded uncertainty of the instrument, including microphone, instrument case and windscreen. The uncertainty of measurement of the adjustment data for the microphone alone, provided by the manufacturer of the microphone, has been used. No information on the uncertainty of measurement, required by 11.7 of IEC 61672-3:2006, of the adjustment data given in the instruction manual for the instrument case, was published in the instruction manual or made available by the manufacturer or supplier. The uncertainty of measurement of the adjustment data for the instrument case has therefore been assumed to be numerically zero for the purpose of this periodic test. If these uncertainties are not actually zero, there is a possibility that the frequency response of the sound level meter may not meet the requirements of IEC 61672-1:2002.

The microphone corrections applied as specified in 12.6 of IEC 61672-3:2006 were obtained from a frequency response measured by this Laboratory using the electrostatic actuator method. This response in isolation is not covered by our UKAS accreditation.

Instruments used in the verification procedure were traceable to *National Standards*. The electrostatic actuator method was employed in the acoustical tests of a frequency weighting.

The uncertainty evaluation has been carried out in accordance with UKAS requirements. All measurement results are retained at the acoustic calibration laboratory for at least four years.

Certificate of Calibration

Issued by University of Salford (Acoustics Calibration Laboratory)
UKAS ACCREDITED CALIBRATION LABORATORY NO. 0801

UKAS CALIBRATION
0801

Page 1 of 3

APPROVED SIGNATORIES
Claire Lomax [✓] Andy Moorhouse [ ]
Gary Phillips [ ] Danny McCaul [ ]

University of Salford MANCHESTER

acoustic calibration laboratory
The University of Salford, Salford, Greater Manchester, M5 4WT, UK
http://www.acoustics.salford.ac.uk
t 0161 295 3030/0161 295 3319 f 0161 295 4456 e c.lomax1@salford.ac.uk

Certificate Number: 01154/5 Date of Issue: 28 January 2013

PERIODIC TEST OF A SOUND LEVEL METER to IEC 61672-3:2006

FOR:	URS Infrastructure & Environment UK Limited 12 Regan Way Chetwynd Business Park Chilwell Notts NG9 6RZ
FOR THE ATTENTION OF:	Heather Billin
PERIODIC TEST DATE:	28 January 2013
TEST PROCEDURE:	CTP12 (Laboratory Manual)

Sound Level Meter Details

Manufacturer	Rion
Model	NL-52
Serial number	01021282
Class	1
Software	Version 1.3

Associated Items	**Microphone**	**Preamplifier**	**Calibrator**
Manu	Rion	Rion	Rion
Model	UC-59	NH-25	NC-74-002
Serial Number	04338	21324	34425538
Calibrator Adaptor	-	-	NC-74-002

Test Engineer (initial): Name: Gary Phillips

This certificate is issued in accordance with the laboratory accreditation requirements of the United Kingdom Accreditation Service. It provides traceability of measurement to recognised national standards, and to the units of measurement realised at the National Physical Laboratory or other recognised national standards laboratories. This certificate may not be reproduced other than in full except with the prior written approval of the issuing laboratory.

Procedures from IEC 61672-3: 2006 and TPS 49 Edition 2 June 2009 were used to perform the periodic tests.

Manufacturer's instruction manuals were marked as follows: NL-42/NL-52 Technical Notes (No. 55750 11-03) and NL42/NL-52 Instruction Manual (No. 55530 11-03).

Adjustment data used to adjust the sound levels indicated in response to the application of an electrostatic actuator to sound levels equivalent to those that would be indicated in response to plane, progressive sound waves were obtained from the manufacturer's instruction manuals referred to in this certificate and from information provided by the manufacturer.

The sound level meter calibration check frequency is 1000 Hz, the reference level is 94 dB. As this instrument only has a single range, this range is the reference level range. The instrument was calibrated without a windshield. Consult manufacturer's instructions if using a windshield.

The environmental conditions in the laboratory at the start of the test were:
Static pressure 99.732 kPa, air temperature 23.3 °C, relative humidity 35.2 %.

The initial response of the instrument to application of the associated sound calibrator was 94.0 dB (A). The instrument was then adjusted to indicate 94.1 dB (A). This indication was obtained from the calibration certificate of the calibrator, 06553 and information in the manufacturer's instruction manuals specified in this certificate, when the instrument is configured as follows, Windscreen Correction: WS None, Diffuse Sound Field Correction: OFF.

With the microphone installed the level of self-generated noise on the most-sensitive level range was:

A:	**14.6 dB***

* Under-range indicated on instrument display

With the microphone replaced by an electrical input device with a capacitance of 14.6 pF, the levels of self-generated noise on the most-sensitive level range were:

A:	**11.3 dB***
C:	**15.7 dB***
Z:	**21.4 dB***

* Under-range indicated on instrument display

The environmental conditions in the laboratory at the end of the test were:
Static pressure 99.155 kPa, air temperature 23.1 °C, relative humidity 35.8 %.

Certificate Number: 01154/5 Date of Issue: 28 January 2013

The sound level meter submitted for testing has successfully completed the class 1 periodic tests of IEC 61672-3:2006, for the environmental conditions under which the tests were performed. However, no general statement or conclusion can be made about conformance of the sound level meter to the full requirements of IEC 61672-1:2002 because evidence was not publicly available, from an independent testing organization responsible for pattern approvals, to demonstrate that the model of sound level meter fully conformed to the requirements in IEC 61672-1:2002, and because the periodic tests of IEC 61672-3:2006 cover only a limited subset of the specifications in IEC 61672-1:2002.

The uncertainty of measurement of the adjustment data given in the instruction manual is the total expanded uncertainty of the instrument, including microphone, instrument case and windscreen. The uncertainty of measurement of the adjustment data for the microphone alone, provided by the manufacturer of the microphone, has been used. No information on the uncertainty of measurement, required by 11.7 of IEC 61672-3:2006, of the adjustment data given in the instruction manual for the instrument case, was published in the instruction manual or made available by the manufacturer or supplier. The uncertainty of measurement of the adjustment data for the instrument case has therefore been assumed to be numerically zero for the purpose of this periodic test. If these uncertainties are not actually zero, there is a possibility that the frequency response of the sound level meter may not meet the requirements of IEC 61672-1:2002.

The microphone corrections applied as specified in 12.6 of IEC 61672-3:2006 were obtained from a frequency response measured by this Laboratory using the electrostatic actuator method. This response in isolation is not covered by our UKAS accreditation.

Instruments used in the verification procedure were traceable to *National Standards.* The electrostatic actuator method was employed in the acoustical tests of a frequency weighting.

The uncertainty evaluation has been carried out in accordance with UKAS requirements. All measurement results are retained at the acoustic calibration laboratory for at least four years.

Certificate of Calibration

Issued by University of Salford (Acoustics Calibration Laboratory)
UKAS ACCREDITED CALIBRATION LABORATORY NO. 0801

APPROVED SIGNATORIES
Claire Lomax [✓] Andy Moorhouse [ ]
Gary Phillips [ ] Danny McCaul [ ]

UKAS CALIBRATION
0801

acoustic calibration laboratory
The University of Salford, Salford, Greater Manchester, M5 4WT, UK
http://www.acoustics.salford.ac.uk
t 0161 295 3030/0161 295 3319 f 0161 295 4456 e c.lomax1@salford.ac.uk

University of Salford MANCHESTER

Certificate Number: 01154/6 Date of Issue: 29 January 2013

PERIODIC TEST OF A SOUND LEVEL METER to IEC 61672-3:2006

FOR:	URS Infrastructure & Environment UK Limited 12 Regan Way Chetwynd Business Park Chilwell Notts NG9 6RZ
FOR THE ATTENTION OF:	Heather Billin
PERIODIC TEST DATE:	28th and 29th January 2013
TEST PROCEDURE:	CTP12 (Laboratory Manual)

Sound Level Meter Details

Manufacturer	Rion
Model	NL-52
Serial number	01021283
Class	1
Software	Version 1.3

Associated Items	**Microphone**	**Preamplifier**	**Calibrator**
Manu	Rion	Rion	Rion
Model	UC-59	NH-25	NC-74
Serial Number	04339	21325	34425538
Calibrator Adaptor	-	-	NC-74-002

Test Engineer (initial): ______ Name: Gary Phillips

This certificate is issued in accordance with the laboratory accreditation requirements of the United Kingdom Accreditation Service. It provides traceability of measurement to recognised national standards, and to the units of measurement realised at the National Physical Laboratory or other recognised national standards laboratories. This certificate may not be reproduced other than in full except with the prior written approval of the issuing laboratory.

Certificate Number: 01154/6 Date of Issue: 29 January 2013

Procedures from IEC 61672-3: 2006 and TPS 49 Edition 2 June 2009 were used to perform the periodic tests.

Manufacturer's instruction manuals were marked as follows: NL-42/NL-52 Technical Notes (No. 55750 11-03) and NL42/NL-52 Instruction Manual (No. 55530 11-03).

Adjustment data used to adjust the sound levels indicated in response to the application of an electrostatic actuator to sound levels equivalent to those that would be indicated in response to plane, progressive sound waves were obtained from the manufacturer's instruction manuals referred to in this certificate and from information provided by the manufacturer.

The sound level meter calibration check frequency is 1000 Hz, the reference level is 94 dB. As this instrument only has a single range, this range is the reference level range. The instrument was calibrated without a windshield. Consult manufacturer's instructions if using a windshield.

The environmental conditions in the laboratory at the start of the test were:
Static pressure 98.917 kPa, air temperature 23.3 °C, relative humidity 35.2 %.

The initial response of the instrument to application of the associated sound calibrator was 94.0 dB (A). The instrument was then adjusted to indicate 94.1 dB (A). This indication was obtained from the calibration certificate of the calibrator, 06553 and information in the manufacturer's instruction manuals specified in this certificate, when the instrument is configured as follows, Windscreen Correction: WS None, Diffuse Sound Field Correction: OFF.

With the microphone installed the level of self-generated noise on the most-sensitive level range was:

A:	**14.6 dB***

* Under-range indicated on instrument display

With the microphone replaced by an electrical input device with a capacitance of 14.6 pF, the levels of self-generated noise on the most-sensitive level range were:

A:	**11.5 dB***
C:	**16.0 dB***
Z:	**22.1 dB***

* Under-range indicated on instrument display

The environmental conditions in the laboratory at the end of the test were:
Static pressure 99.355 kPa, air temperature 23.3 °C, relative humidity 36.4 %.

Certificate Number: 01154/6 Date of Issue: 29 January 2013

The sound level meter submitted for testing has successfully completed the class 1 periodic tests of IEC 61672-3:2006, for the environmental conditions under which the tests were performed. However, no general statement or conclusion can be made about conformance of the sound level meter to the full requirements of IEC 61672-1:2002 because evidence was not publicly available, from an independent testing organization responsible for pattern approvals, to demonstrate that the model of sound level meter fully conformed to the requirements in IEC 61672-1:2002, and because the periodic tests of IEC 61672-3:2006 cover only a limited subset of the specifications in IEC 61672-1:2002.

The uncertainty of measurement of the adjustment data given in the instruction manual is the total expanded uncertainty of the instrument, including microphone, instrument case and windscreen. The uncertainty of measurement of the adjustment data for the microphone alone, provided by the manufacturer of the microphone, has been used. No information on the uncertainty of measurement, required by 11.7 of IEC 61672-3:2006, of the adjustment data given in the instruction manual for the instrument case, was published in the instruction manual or made available by the manufacturer or supplier. The uncertainty of measurement of the adjustment data for the instrument case has therefore been assumed to be numerically zero for the purpose of this periodic test. If these uncertainties are not actually zero, there is a possibility that the frequency response of the sound level meter may not meet the requirements of IEC 61672-1:2002.

The microphone corrections applied as specified in 12.6 of IEC 61672-3:2006 were obtained from a frequency response measured by this Laboratory using the electrostatic actuator method. This response in isolation is not covered by our UKAS accreditation.

Instruments used in the verification procedure were traceable to *National Standards*. The electrostatic actuator method was employed in the acoustical tests of a frequency weighting.

The uncertainty evaluation has been carried out in accordance with UKAS requirements. All measurement results are retained at the acoustic calibration laboratory for at least four years.

This certificate is issued in accordance with the laboratory accreditation requirements of the United Kingdom Accreditation Service. It provides traceability of measurement to recognised national standards, and to the units of measurement realised at the National Physical Laboratory or other recognised national standards laboratories. This certificate may not be reproduced other than in full except with the prior written approval of the issuing laboratory.

Certificate of Calibration

Issued by University of Salford (Acoustics Calibration Laboratory)
UKAS ACCREDITED CALIBRATION LABORATORY NO. 0801

UKAS CALIBRATION
0801

Page 1 of 3

APPROVED SIGNATORIES
Claire Lomax [✓] Andy Moorhouse [ ]
Gary Phillips [ ] Danny McCaul [ ]

acoustic calibration laboratory
The University of Salford, Salford, Greater Manchester, M5 4WT, UK
http://www.acoustics.salford.ac.uk
t 0161 295 3030/0161 295 3319 f 0161 295 4456 e c.lomax1@salford.ac.uk

University of Salford
MANCHESTER

Certificate Number: 01154/7 Date of Issue: 29 January 2013

PERIODIC TEST OF A SOUND LEVEL METER to IEC 61672-3:2006

FOR:	URS Infrastructure & Environment UK Limited 12 Regan Way Chetwynd Business Park Chilwell Notts NG9 6RZ
FOR THE ATTENTION OF:	Heather Billin
PERIODIC TEST DATE:	29 January 2013
TEST PROCEDURE:	CTP12 (Laboratory Manual)

Sound Level Meter Details

Manufacturer	Rion
Model	NL-52
Serial number	01021284
Class	1
Software	Version 1.3

Associated Items	**Microphone**	**Preamplifier**	**Calibrator**
Manu	Rion	Rion	Rion
Model	UC-59	NH-25	NC-74
Serial Number	04554	21326	34425539
Calibrator Adaptor	-	-	NC-74-002

Test Engineer (initial): GP Name: Gary Phillips

Certificate Number: 01154/7 Date of Issue: 29 January 2013

Procedures from IEC 61672-3: 2006 and TPS 49 Edition 2 June 2009 were used to perform the periodic tests.

Manufacturer's instruction manuals were marked as follows: NL-42/NL-52 Technical Notes (No. 55750 11-03) and NL42/NL-52 Instruction Manual (No. 55530 11-03).

Adjustment data used to adjust the sound levels indicated in response to the application of an electrostatic actuator to sound levels equivalent to those that would be indicated in response to plane, progressive sound waves were obtained from the manufacturer's instruction manuals referred to in this certificate and from information provided by the manufacturer.

The sound level meter calibration check frequency is 1000 Hz, the reference level is 94 dB. As this instrument only has a single range, this range is the reference level range. The instrument was calibrated without a windshield. Consult manufacturer's instructions if using a windshield.

The environmental conditions in the laboratory at the start of the test were:
Static pressure 99.330 kPa, air temperature 23.5 °C, relative humidity 35.7 %.

The initial response of the instrument to application of the associated sound calibrator was 93.9 dB (A). The instrument was then adjusted to indicate 94.0 dB (A). This indication was obtained from the calibration certificate of the calibrator, 06554 and information in the manufacturer's instruction manuals specified in this certificate, when the instrument is configured as follows, Windscreen Correction: WS None, Diffuse Sound Field Correction: OFF.

With the microphone installed the level of self-generated noise on the most-sensitive level range was:

A: 15.3 dB*

* Under-range indicated on instrument display

With the microphone replaced by an electrical input device with a capacitance of 14.6 pF, the levels of self-generated noise on the most-sensitive level range were:

A: 10.6 dB*
C: 15.0 dB*
Z: 20.9 dB*

* Under-range indicated on instrument display

The environmental conditions in the laboratory at the end of the test were:
Static pressure 99.960 kPa, air temperature 24.1 °C, relative humidity 38.5 %.

Certificate Number: 01154/7 Date of Issue: 29 January 2013

The sound level meter submitted for testing has successfully completed the class 1 periodic tests of IEC 61672-3:2006, for the environmental conditions under which the tests were performed. However, no general statement or conclusion can be made about conformance of the sound level meter to the full requirements of IEC 61672-1:2002 because evidence was not publicly available, from an independent testing organization responsible for pattern approvals, to demonstrate that the model of sound level meter fully conformed to the requirements in IEC 61672-1:2002, and because the periodic tests of IEC 61672-3:2006 cover only a limited subset of the specifications in IEC 61672-1:2002.

The uncertainty of measurement of the adjustment data given in the instruction manual is the total expanded uncertainty of the instrument, including microphone, instrument case and windscreen. The uncertainty of measurement of the adjustment data for the microphone alone, provided by the manufacturer of the microphone, has been used. No information on the uncertainty of measurement, required by 11.7 of IEC 61672-3:2006, of the adjustment data given in the instruction manual for the instrument case, was published in the instruction manual or made available by the manufacturer or supplier. The uncertainty of measurement of the adjustment data for the instrument case has therefore been assumed to be numerically zero for the purpose of this periodic test. If these uncertainties are not actually zero, there is a possibility that the frequency response of the sound level meter may not meet the requirements of IEC 61672-1:2002.

The microphone corrections applied as specified in 12.6 of IEC 61672-3:2006 were obtained from a frequency response measured by this Laboratory using the electrostatic actuator method. This response in isolation is not covered by our UKAS accreditation.

Instruments used in the verification procedure were traceable to *National Standards*. The electrostatic actuator method was employed in the acoustical tests of a frequency weighting.

The uncertainty evaluation has been carried out in accordance with UKAS requirements. All measurement results are retained at the acoustic calibration laboratory for at least four years.

CERTIFICATE OF CALIBRATION

ISSUED BY AV CALIBRATION

Date of issue 09 April 2014 Certificate N° 07669

UKAS
CALIBRATION
0653

AV Calibration
2 Warren Court
Chicksands, Shefford
Bedfordshire SG17 5QB
U.K.
Tel: +44 (0)1462 638600
Fax: +44 (0)1462 638601
Email: lab@avcalib.co.uk
www.avcalibration.co.uk
Acoustics Noise and Vibration Ltd trading as AV Calibration

Page 1 of 2 Pages

Approved Signatory

G. Parry [✓] B. Baker [ ]

CLIENT	URS Infrastructure & Environment UK Ltd 12 Regan Way Chetwynd Business Park Chilwell Nottingham NG9 6RZ		
F.A.O.	David Gerard		
ORDER No	-	Job No	UKAS14/03074/01
DATE OF RECEIPT	31 March 2014		
PROCEDURE	AV Calibration Engineer's Handbook section 2		
IDENTIFICATION	Sound Calibrator Rion type NC-74 serial number 34425538 with one-inch housing and adapter type NC-74-002 for half-inch microphone		
CALIBRATED ON	07 April 2014		
PREVIOUS CALIBRATION	Calibrated on 22 March 2013, Certificate No. UCRT13/1035 issued by a UKAS accredited calibration laboratory No. 7623		

This certificate is issued in accordance with the laboratory accreditation requirements of the United Kingdom Accreditation Service. It provides traceability of measurement to the SI system of units and/or to units of measurement realised at the National Physical Laboratory or other recognised national metrology institutes. This certificate may not be reproduced other than in full, except with the prior written approval of the issuing laboratory.

MEASUREMENTS

The sound pressure level generated by the Sound Calibrator in its half-inch configuration was measured five times using a B&K type 4134 microphone with the protective grid in position. The microphone sensitivity was traceable to National Standards.

RESULTS

The mean level of the calibrator output, corrected to the standard atmospheric pressure of 101.3 kPa using manufacturers' data, was

94.01 ± 0.12 dB rel 20 μPa

The fundamental frequency of the sound output was 1002 Hz ± 0.06 %, and its total distortion was (1.30 ± 0.10) %.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor *k* =2, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

During the measurements the laboratory environmental conditions were:

Temperature: 22 to 23 °C
Atmospheric pressure: 99.7 to 99.8 kPa
Relative humidity: 48 to 59 %

GILL

Gill Instruments Limited

Certificate of Conformance

This is to certify that:

Product: **1405-PK-021** **WINDSONIC OPT1 RS232**

Serial Number: **14170043**

Has been manufactured within Gill Instruments Limited Quality Management System, approved to the requirements of BS EN ISO 9001.

The instrument has been tested and calibrated with equipment having full traceability to national standards where applicable and meets the requirements of the Operating Manual Specification and Electrical Conformity (EC Declaration in Manual).

The instrument comes with a **24 Month** warranty against defective materials or workmanship from the date of purchase, providing it has not been tampered with and has been returned through an authorised route to Gill Instruments Limited.

Date created: 24 Apr 2014

Signed by: ....

Les Rann
Quality Engineer

nqa.
ISO 9001
Registered

Gill Instruments Limited
Saltmarsh Park
67 Gosport Street
Lymington
Hampshire
SO41 9EG, UK

Tel: +44 (0)1590 613500
Fax: +44 (0)1590 613501
E-mail: gill@gill.co.uk
Web: www.gill.co.uk

View our current Anemometer range here

CERTIFICATE

rotronic
LEADING IN HUMIDITY MEASUREMENT

Device type	**HC2-S3**
Serialnumber	**0061212050**
RPC-number	**7-0206902313**

ROTRONIC AG certifies that this instrument meets the published specifications. It has been calibrated using standards and instruments as stated below and corresponds to the test requirements of ISO 9001-2008. The reference and service standards are traceable to national standards. The calibrated values are valid under above mentioned conditions only at the time of measurement and are referenced to the indicated references and working standards.

FACTORY CALIBRATION

Adjustment

Temperature	24.61°C
Humidity 1	10.81%rH (@24.60°C)
Humidity 2	34.36%rH (@24.64°C)
Humidity 3	78.16%rH (@24.67°C)

Calibration

	Device	Reference
Temperature	24.61°C	24.63°C
Humidity	49.94%rH	49.96%rH

Date of calibration: 25.09.2013

Reference System

HC2-S (SCS certified)

FUNCTION TEST

Firmware	V2.0
Analog Output	Out1: Humi 0..100%rH (0..1V) Set: 40.00%rH, measured 40.07%rH (0.401V) Out2: Temp -40..60°C (0..1V) Set: 20.00°C, measured 20.09°C (0.601V)
Printnumber	66.0816.07204

Final test passed – 26.09.2013 – quality engineer: S. Cetin

ROTRONIC AG, Grindelstrasse 6, CH - 8303 Bassersdorf
www.rotronic.com

130

setra

Calibration Certificate

Technician: SO SO
Part No: 2781600MA1B2YT1
Model: 278

Serial No: 6015978
Work Order: 24151603
Date: 05/28/2014

Range: 610 to 1100 HPA/MB
Nom. Output: 0.05 to 2.5 VDC
Supply: 24vdc

CALIBRATION DATA

APPLIED PRESSURE (hPa)	TRANSDUCER OUTPUT (VDC)	PRESSURE CONVERSION (hPa)	ERROR (hPa)	EQUIPMENT UNCERTAINTY (hPa)
610.01	0.0492	609.83	-0.18	+/- 0.10
732.50	0.6636	732.72	0.22	+/- 0.10
854.99	1.2762	855.24	0.25	+/- 0.10
977.50	1.8885	977.69	0.19	+/- 0.10
1100.01	2.5009	1100.17	0.16	+/- 0.10

AMBIENT CONDITIONS:
Humidity: 40.0 %RH
Pressure: 1007.6 hPa
Temperature: 27.2 degree C

SPECIFICATIONS:
Accuracy Specification: +/- 0.5 hPa @ +20 degree C (+68 degree F).

NOTES:
1. This calibration was performed in compliance with ANSI/NCSL Z540-1-1994.
2. All errors are expressed in hPa.
3. Consult specification sheet for additional information.
4. This calibration is certified per N.I.S.T. traceable primary standards.
   Reference standard: I/N_00049-SN237-DHI_PPC3-2M_A1.4MS/A160KP.
   Reference standard cal. due date: 8/13/13 - 8/13/14.
5. This certificate may not be reproduced, except in full, without written approval from Setra Systems.
6. This calibration was performed using procedure P2781X.