

Preface

This consultation document has been produced by the Battery Energy and Storage System (BESS) and Solar Working Group on behalf of the Institute of Acoustics (IOA), and the Association of Noise Consultants (ANC) under the supervision of the IOA Renewable Energy Advisory Group (REAG). This proposed good practice guide is the output of a process to capture and report good practice in the assessment of sound from BESS & Solar PV developments. Any comments on this document should be sent using the form on a link available on the IOA website by Friday 20th November 2026. The document is expected to be of use to all parties involved in the planning process of these schemes, ensuring that an appropriate level of sound assessment is undertaken, the level of risk identified, and appropriate conditions set.

We would like to take this opportunity to thank all of those individuals who have given their time to assist with the development of this document, especially the core working group members, and those on the peer review group.

It should be noted that the guide represents the consensus of the working group members. It does not necessarily reflect the views of the individual, stakeholders or companies contributing to the guide, and should not be construed as such.

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**THIS IS A DRAFT DOCUMENT FOR
CONSULTATION ONLY**

All images used in this document have been generated using AI and are included as example illustrations only. All data reported in this document is taken from real life operational or in-planning developments; however, numbers have been amended to retain site confidentiality.

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1 Introduction

1.1 Background

1.1.1 This guide has been produced following discussions within the Institute of Acoustics' (IOA) Renewable Energy Advisory Group (REAG). The REAG identified a significant knowledge gap across a range of stakeholders, in respect of sound associated with solar photovoltaic developments and battery energy storage systems. The purpose of this guidance is therefore to provide a reference point for all stakeholders, drawing together technical knowledge from plant suppliers, developers, and acoustic consultants.

- This guide will be of relevance to
- Manufacturers of plant and system integrators
- Developers
- Acoustic consultants
- Planning authorities and statutory bodies
- Environmental health practitioners, and
- The general public.

1.1.2 The guide is designed to be used at the feasibility, planning and implementation stages of a project within the United Kingdom, and should be read with the relevant planning policy guidance that exists separately in England, Wales, Scotland and Northern Ireland.

1.2 Scope of the Document

1.2.1 This guide is intended to be used with reference to utility scale solar photovoltaic (PV) developments and battery energy storage systems (BESS). It is not intended for use in respect of rooftop PV, domestic battery systems and similar.

1.2.2 Whilst certain aspects of this guidance may be applicable to smaller-scale commercial schemes, it has been prepared primarily with reference to developments exceeding a power capacity of 1 MW for PV and 5 MW for BESS. It is particularly relevant for projects ranging from 50 MW to over 1 GW.

Operational Sound

1.2.3 The purpose of this guide is to bring together knowledge in respect of sound generated from the operation of PV and BESS developments. It's aims are to educate stakeholders on the sound generation mechanisms of PV and BESS plant and to provide guidance on how to model, measure and assess operational sound from PV and BESS developments.

1.2.4 For plant manufacturers and systems integrators, the guidance discusses the importance of providing high quality, useful sound level and operational data that can then be used by practitioners, for example, acoustics consultants, to produce robust sound propagation models. Examples are also provided as to how this data could be presented.

1.2.5 The guide also provides advice for acoustic consultants and other practitioners on how to incorporate manufacturer supplied sound level data into a propagation model, what assumptions can be made in respect of plant operations, and how to make realistic predictions.

1.2.6 The guide is not intended to provide a method of assessment of operational sound, as sufficient guidance already exists in the form of British Standards and similar, notably

BS 4142:2014+A1:2019 (BS 4142) (1). The guide is intended, however, to provide detail in respect of how to consider sound character, operational parameters, candidate plant, 'worst-case' and 'realistic worst-case' predictions, and other elements of context that may inform such assessments.

- 1.2.7 The guide uses the terms sound and noise in the same manner as BS 4142. Sound is a physical phenomenon that can be measured using a sound level meter and can therefore be quantified and described objectively. Noise relates to the human response to sound and is generally understood to mean sound that is unwanted or undesirable.
- 1.2.8 By providing guidance on the prediction of sound levels from PV and BESS developments, the guide seeks to give all stakeholders confidence that noise impacts can be appropriately assessed during the planning stages of a project, even though final plant specifications may not be known at this stage.
- 1.2.9 The setting of noise limits falls outside the scope of this guide, as this is a matter of Government policy. However, guidance is provided on the management and control of noise from a development through the use of appropriate planning conditions. Guidance is also included on the monitoring of operational sites for the purpose of quantifying sound levels.

Construction Sound

- 1.2.10 Sound levels arising from the construction of a PV or BESS development is not considered in any detail within this guide.
- 1.2.11 For EIA-scale developments, construction sound should be assessed with due regard to BS 5228-1:2009+A1:2014 (2).
- 1.2.12 For PV schemes, particular consideration should be given to any piling activities associated with the installation of PV panel arrays. Piles for PV arrays can be relatively short in length, so are not comparable to those used for buildings, however, they can number in the tens of thousands for a single site. Accordingly, both the sound level and duration of piling events should be considered.
- 1.2.13 Large PV and BESS developments may introduce a temporary but notable increase in HGV movements on roads surrounding a development site, which may also need to be considered at the planning stage.
- 1.2.14 For smaller, non-EIA developments, construction sound may not need to be specifically assessed, though it is advised to seek the opinion of the relevant planning authority in this regard.

Occupational Sound

- 1.2.15 This guide considers environmental sound only and is not intended to be used in respect of on-site occupational sound levels.

1.3 Relevant Standards & Guidance

- 1.3.1 Rather than comment on relevant standards or guidance documents separately in each section, this is provided as a consolidated list as Appendix 1.

2 What is a BESS?

2.1 Battery Energy Storage Systems (BESS)

- 2.1.1 A Battery Energy Storage System (BESS) captures electrical energy from energy generators and stores it in rechargeable batteries for later use. A BESS stores renewable energy during periods of peak generation, when electricity supply exceeds demand, and discharges it when demand is higher. It also supports continuity of electricity supply by providing backup to the grid during periods of instability, such as peak demand, stress events or outages. In addition, BESS can help reduce renewable energy curtailment and deliver grid balancing services, supporting the stability and efficient operation of the electricity network.
- 2.1.2 The location of BESS depends on the intended use case and determines the services the system can provide. For most BESS, which will be connected into the National Grid, the location is reliant on having sufficient grid capacity available i.e. it will need to be located close to a substation with sufficient connection capacity. 'On-site BESS' on the other hand, can provide 'black start' services, helping to bring large generators back online following the event of a larger system failure, or to provide resilience for large energy users, for example, data centres.
- 2.1.3 Crucially, a BESS site is not always operational i.e. charging or discharging, rather, it is often on standby to respond to specific network requirements.
- 2.1.4 The term BESS generally relates to the entire battery storage development, however, 'BESS,' 'BESS units' and similar terms, can sometimes refer simply to the batteries or battery containers. In this document, BESS means the entire development.
- 2.1.5 There are a number of parameters that characterise a BESS, and some of the most relevant are defined below
- **Rated Power Capacity:** The total discharge capability, measured in megawatts (MW), i.e. the maximum rate of discharge the BESS can achieve.
 - **Rated Energy Capacity:** The total amount of stored energy in megawatt-hours (MWh).
 - **Storage Duration:** The amount of time a BESS can discharge at its Rated Power Capacity before exhausting its Rated Energy Capacity.
 - **C-rate:** The rate at which a battery can be fully charged or discharged in one hour. Charging at a C-rate of 1C means that the battery is charged from 0-100%, or discharged from 100-0%, in one hour. Charging at a C-rate of 0.5C means that the battery is charged from 0-100% or discharged from 100-0% in two hours.
- 2.1.6 As an example, a BESS could be described as 100 MW / 400 MWh, and in this case
- 100 MW means that the BESS can instantly discharge a maximum of 100 MW.
 - 400 MWh means that it can discharge at 100 MW for 4 hours. This is because $400 \text{ MWh} / 100 \text{ MW} = 4 \text{ hours}$
- 2.1.6 Therefore, we can say that
- the Rated Power Capacity is 100 MW
 - the Rated Energy Capacity is 400 MWh and,
 - the Storage Duration is 4 hours

- 2.1.7 Many BESS sites installed in the UK prior to 2026 operate with a two-hour storage duration (C rate = 0.5), which was typically long enough to satisfy peak demand requirements and worked well with existing markets. Future BESS developments, however, may have a much larger storage duration, as technology evolves and energy markets change. For example, the UK's Long Duration Energy Storage (LDES) scheme includes BESS with storage durations of 8 hours and more.

2.2 Components of a BESS Development

- 2.2.1 The design of BESS is continuously evolving, addressing issues such as energy density, efficiency of cooling, sound levels, battery degradation, and storage duration. The standard items of plant, however, consist of batteries, inverters and Medium Voltage (MV) transformers. Initially these were installed as separate items, however, integrated plant is now becoming more commonplace.

Batteries

- 2.2.2 Batteries are stored in banks, either within battery containers or modular 'battery cubes.' Figure 2-1 provides an example of both types of unit.

Figure 2-1: Examples of battery units



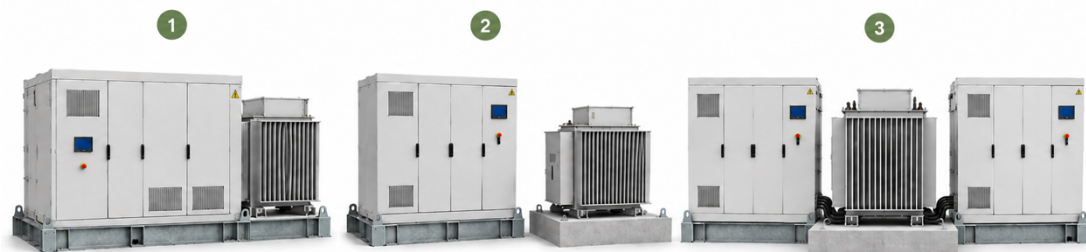
- 2.2.3 The internal environment of early battery containers was often controlled with off-the shelf Heating & Ventilation Air Conditioning (HVAC) units, which provided air flow through the container. The disadvantage with this design however, is that temperature distribution throughout the container is unlikely to be uniform, resulting in excess degradation in some of the batteries depending on where they are located within the container. This results in a lowering of both performance and life expectancy. Developments in battery container design mean that any HVAC requirements are now generally incorporated into the overall design philosophy (alongside chiller units), rather than simply bolting on a third-party HVAC unit to the outside of the container. For this reason, it should not be assumed that standard, commercially available HVAC units are sufficient to include in a propagation model to simulate the sound level output of a battery container.
- 2.2.4 Battery cubes use liquid cooling systems (consisting of a pump and fan) to distribute cooled fluid around the batteries. Maintaining optimal temperatures in this way ensures the batteries work efficiently, leading to prolonged life cycles. A small HVAC system may also be included.

- 2.2.5 Liquid cooling systems are now also incorporated into larger battery containers, alongside purpose designed HVAC systems.
- 2.2.6 Battery cubes and containers can contain hundreds or thousands of individual battery cells. Cells are generally grouped into modules, which are themselves grouped into racks.
- 2.2.7 A battery is a Direct Current (DC) device. Although solar farms can be a DC generator, most other energy generation and electrical networks are Alternating Current (AC). Accordingly, the incoming AC current needs converting to DC when charging the batteries. Similarly, the DC current needs converting back to AC when discharging the batteries. The devices used to convert between these two states are often referred to as Power Conversion Systems (PCS).
- 2.2.8 The level of sound generated by the battery cooling systems can vary considerably between manufacturers, though often the sound output from standalone battery containers and cubes tends to be lower than the sound output of the PCS. Nonetheless, battery cooling always needs to be considered within a noise impact assessment, and the ratio of battery units to PCS units can mean that the cumulative sound emissions associated with the batteries may be comparable or higher than the PCS units, when considering the BESS site as a whole.

Power Conversion Systems

- 2.2.9 Most modern PCS can convert power bidirectionally i.e. AC to DC and DC to AC, so a single unit can be used for both charging (import) and discharging (export).
- 2.2.10 The level of cooling required is defined by both the ambient temperature and the amount of electrical energy flowing through the unit¹. It is not normally appropriate to only consider ambient temperature on its own.
- 2.2.11 A PCS will generally consist of one or several inverters and a MV transformer. Sometimes these are separate elements and sometimes they are combined into a single unit. Figure 2-2 provides some examples of PCS configurations. When the inverter(s) and MV transformer of a PCS is paired up on a single mounting frame or base, this is often referred to as an MV Skid.

Figure 2-2: Examples of PCS configurations



Configuration 1: Inverter and transformer on a single MV skid

Configuration 2: Standalone inverter and transformer

Configuration 3: Two inverters and a single transformer in a T arrangement

¹ The amount of electrical energy flowing through a unit is often referred to as 'the load'.

- 2.2.12 The cooling mechanisms of the PCS are often the noisiest component of a BESS development, and this usually relates to the cooling of the inverters, rather than the cooling of the MV transformers. Although transformers can be mechanically cooled, the MV transformers used in a PCS are usually passively cooled, which generates no sound. This type of transformer is referred to as ONAN (Oil Natural, Air Natural) within its specification documents and site layout drawings.
- 2.2.13 Although both the inverter and the MV transformer will generate electrical sound, this is typically low in level and is often masked by the sound from the cooling systems.
- 2.2.14 When undertaking sound level predictions for a BESS development, care should be taken to consider suitably rated (electrically) PCS and battery equipment, based on compatible and representative equipment specifications. It is not appropriate to mix and match battery plant and PCS units without considering the electrical rating of the units and advice should be sought from a suitably qualified, engineering specialist or BESS plant supplier/manufacturer. Using 'off-the-shelf' sound level data for different battery and PCS unit combinations could risk not being representative.
- 2.2.15 The acoustics practitioner can provide guidance on acoustic requirements and likely noise-control measures; however, they are unlikely to have the specialist electrical knowledge needed to confirm the proposed plant layout, equipment ratings, quantities, or system compatibility. Responsibility for these aspects should therefore rest with the developer, system integrator, or electrical designer.
- 2.2.16 Increasing the electrical rating of an inverter may mean higher sound levels for individual units; however, the overall number of units may be able to be reduced. Similarly, selecting a lower rated unit may mean that more units would be required for proper operation, resulting in higher overall sound level output.
- 2.2.17 It should be noted that some developments will install purposely over-rated inverters to allow for future site augmentation, and the potential for this to occur should also be considered when undertaking any sound level propagation modelling.
- 2.2.18 Not all of the inverters on a BESS site may require the same rating. For example, some battery cubes may be arranged in groups of six, whilst others may be arranged in groups of eight. Although each group may be serviced by an identical looking PCS, in this case the PCS for the six-battery cube group would require a lower rated inverter than the PCS for the eight-battery cube group. Accordingly, the sound level output of the two PCS may be different.

High Voltage (HV) Transformers

- 2.2.19 The voltage from a BESS will often need to be stepped up when connecting into the National Grid and this requires the use of a HV transformer.
- 2.2.20 It is not a requirement for a HV transformer to be included in every BESS development, as often there will be one in a nearby substation that the BESS can be connected into. If HV transformers are included as part of the development, there will usually only be one or two units. They should be easy to identify on a site layout, as they will be located within a separate HV Compound.
- 2.2.21 A HV transformer may generate much higher levels of sound than the MV transformers and should always be considered within a noise impact assessment, if present in the development. Whereas a BESS MV transformer is typically naturally cooled, a BESS HV transformer is usually mechanically cooled.

- 2.2.22 Mechanically cooled transformers are referred to as ONAF (Oil Natural, Air Forced) or OFAF (Oil Forced, Air Forced).
- 2.2.23 HV transformers can purposely be over-rated to allow for future site augmentation, so this should also be considered when undertaking any sound level propagation modelling. Similarly, it should be noted that the sound level output from an existing HV transformer may increase after site augmentation, as it would have previously been working with lower loading and, therefore, lower cooling requirements.
- 2.2.24 Although rare, there may be a requirement for additional electrical plant within or alongside the HV Compound, such as a harmonic filter (which consists of capacitor and reactor banks). Advice regarding this type of electrical plant, which is not typically present within a BESS development, is outside the scope of this document. It should, however, be considered in any noise impact assessment, if present.

Auxiliary Plant

- 2.2.25 The battery cooling systems and PCS will usually be the primary sound sources of a BESS. If there is a HV transformer, then this should also be considered as a primary sound source. Although there will be auxiliary plant, the sound output from this is typically negligible in comparison to the primary sound sources, so does not normally need to be considered within a noise impact assessment. Auxiliary plant can include
- **Battery Management System (BMS):** BMS is the brain of the BESS. Its primary function is to safeguard and protect the batteries from damage in various operational scenarios. This is achieved by ensuring that critical parameters, such as state of charge, state of health, voltage, temperature and current, are kept within pre-determined values.
 - **Controller:** The controller monitors, controls, protects, schedules and communicates with the different components of the BESS and with external devices such as electricity meters.
 - **SCADA:** The SCADA (Supervisory Control and Data Acquisition) system focuses on monitoring the components within the BESS. It communicates with the controller and the BMS to monitor and log battery and inverter status.
 - **Switch rooms:** These can hold the medium voltage switching gear, protection panels, control cabinets and metering. They allow operators to safely isolate parts of the BESS for maintenance.
 - **Earthing transformer:** An additional, small transformer may be installed to provide a safe earthing mechanism for the system. These generally have very low levels of sound output.
 - **Auxiliary transformer:** Auxiliary transformers are used to provide power to the development e.g. for site cabins, lighting etc. The sound level output from an auxiliary transformer is usually much lower than other electrical plant on site.

2.3 Typical BESS Layouts

- 2.3.1 A typical BESS layout will arrange battery containers or cubes into groups, and each group will connect into a PCS, such as a MV Skid. Occasionally, however, the batteries and inverters are installed within a single unit, and these combined units then feed into a separate, external MV transformer.

2.3.2 It is important to note that layout configurations can vary significantly between plant manufacturers. It is not possible, therefore, to model the sound level output of a proposed development for different makes and models of plant, simply by swapping out the source sound level data i.e. producing multiple propagation models using a single site layout. As an example, for the same Rated Power Capacity site

- Manufacturer A may require 40 battery cubes, 20 inverters and 10 MV transformers
- Manufacturer B may require 50 battery cubes, 10 inverters and 5 MV transformers
- Manufacturer C may combine the batteries and inverters into 30 individual units that are then connected into 30 individual MV transformers

Accordingly, modelled layouts should always be attributed to a particular plant specification i.e. make, model and rating of specific plant items.

2.3.3 It is not possible to use a generic layout and apply this to multiple plant manufacturers to compare like for like sound level output. It will always be necessary to understand the relationship between the numbers and arrangements of individual items and specifications of plant.

2.3.4 Similarly, for planning applications where a fixed layout is unlikely to be available, candidate plant can be used but this must be within a technically feasible layout (see Section 4.3 for more details on how a generic layout can be incorporated within a planning application).

- 2.3.5 Figure 2-3 through to Figure 2-8 present example BESS layouts for the batteries, PCS and HV transformers. These layouts are provided to illustrate how the combination of individual items of plant can vary within a BESS site, and are indicative only. They should not be used as the basis of a propagation model, nor are they intended to indicate the likely numbers of plant for any given Rated Power Capacity.

Figure 2-3: Example BESS layout A

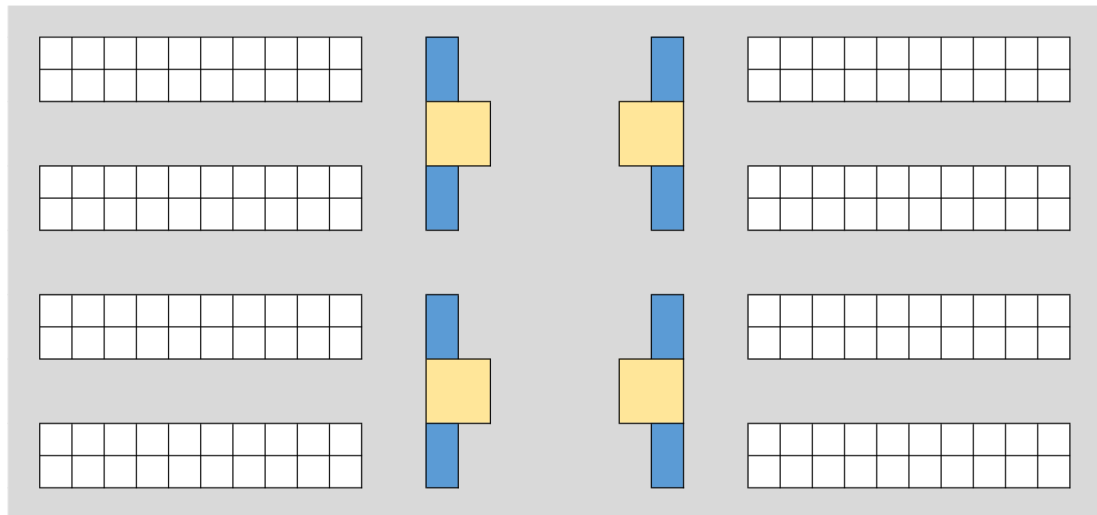
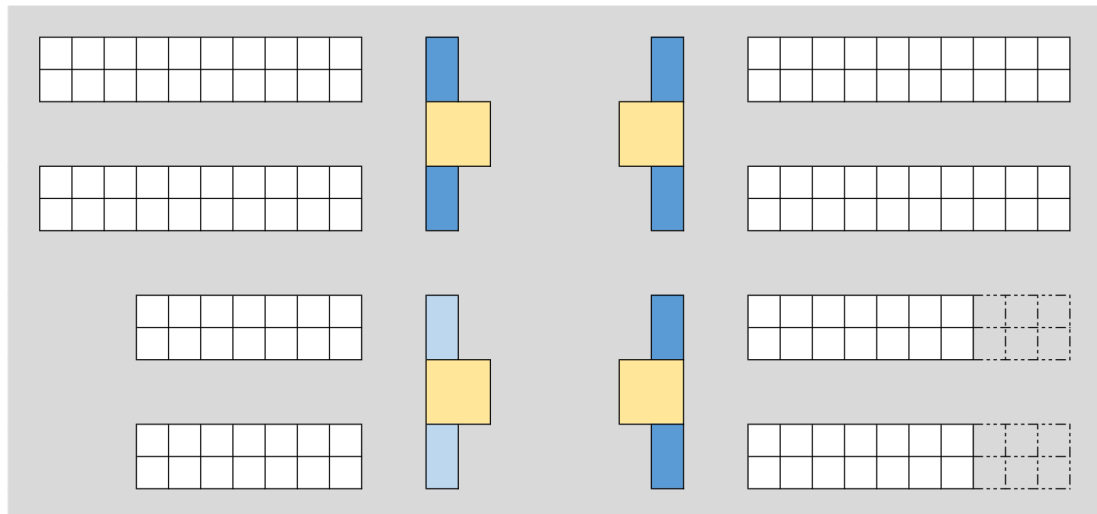


Figure 2-4: Example BESS layout B



In Figure 2-3, groups of 2 x 10 battery cubes (white) are connected into an inverter (blue). Pairs of inverters are then connected into a MV transformer (yellow).

Figure 2-4 presents a similar layout, however, in this example, some of the battery cubes are in smaller banks of 2 x 7. Lower rated inverters are used for the 2 x 7 banks to the left, (light blue), however, the higher rated inverters will still be installed for the 2x7 cube banks to the right, to allow for future augmentation. It is not uncommon for layout drawings to include space for future augmentation, so associated inverters and transformers may need to be over-specified to accommodate this.

Figure 2-5: Example BESS layout C

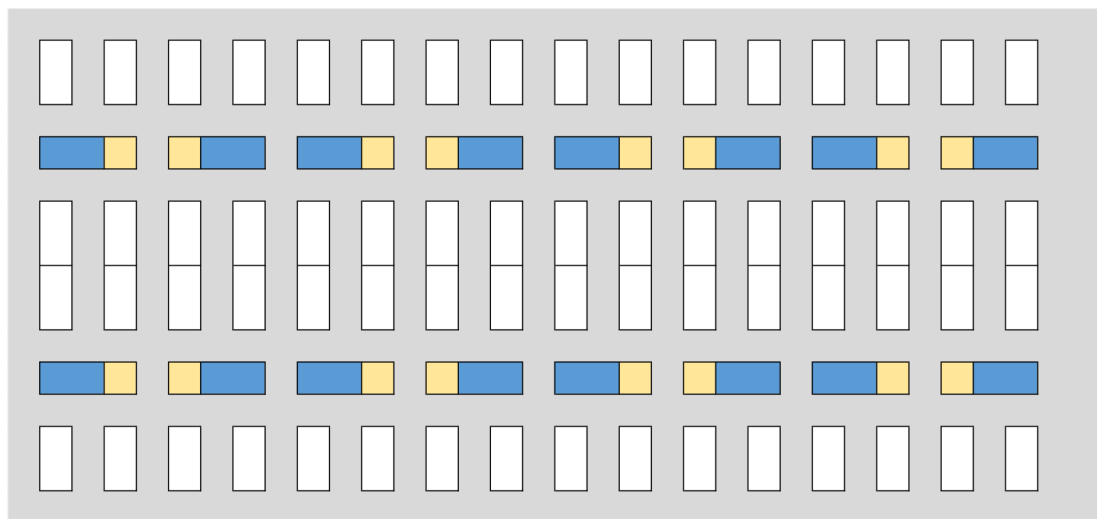
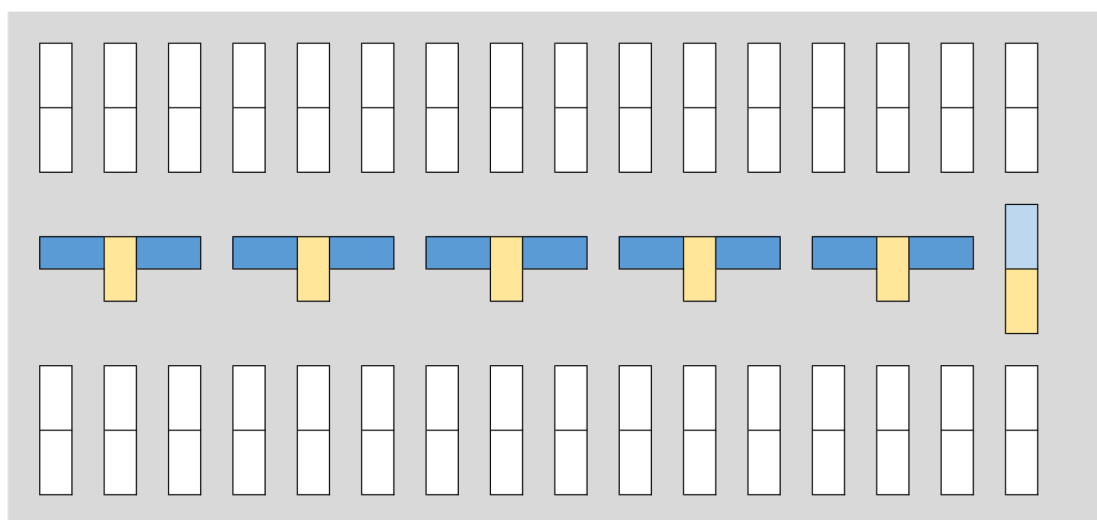


Figure 2-6: Example BESS layout D



In Figure 2-5 four battery containers (white) are connected into a single inverter (blue) and MV transformer (yellow).

In Figure 2-6 six battery containers are connected into a single inverter and pairs of inverters are connected into a single MV transformer. To the right of the layout, four battery containers are connected into a lower rated inverter (light blue) and a single MV transformer.

Figure 2-7: Example BESS layout E

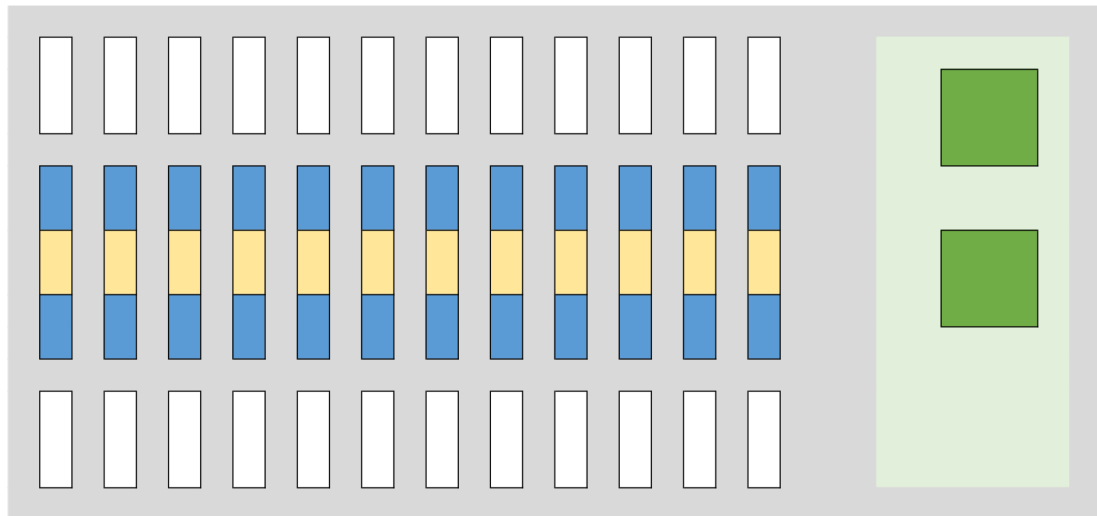
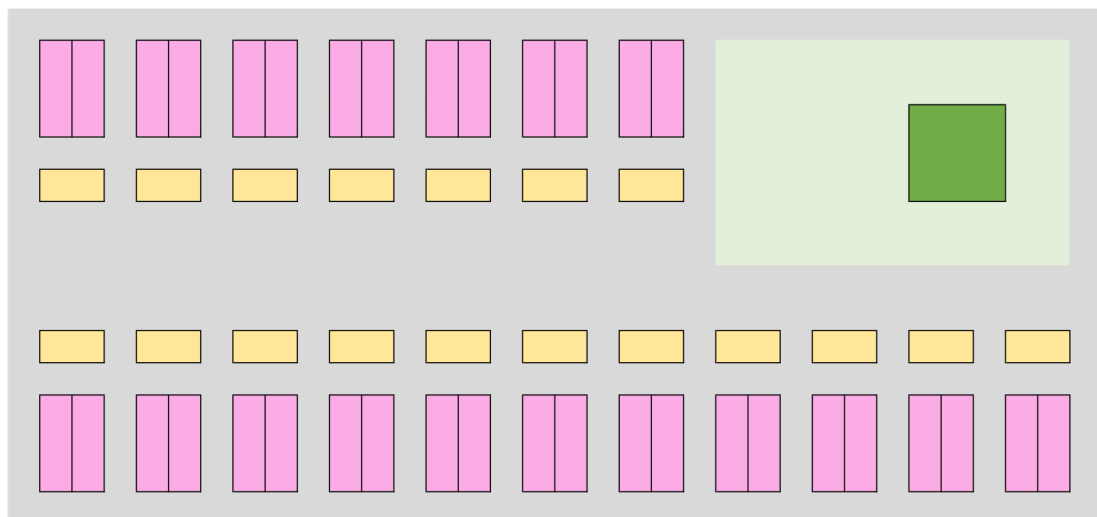


Figure 2-8: Example BESS layout F



In Figure 2-7, each battery container (white) is connected into its own inverter (blue). Pairs of inverters share a single MV transformer (yellow). An HV compound to the right houses two HV transformers.

Figure 2-8 illustrates a layout that uses combined battery and inverter units (pink). Each pair of units is connected into a MV transformer. The layout also includes a single HV transformer.

3 What is a Solar Farm?

3.1 Solar Photovoltaic Developments (PV)

- 3.1.1 A solar photovoltaic (PV) development, commonly referred to as a Solar Farm, generates electricity from the sun through the use of PV panels. The exposure of the panel to sunlight (which is a stream of photons) releases electrons and produces an electric charge. This charge creates an electric current that can be fed into the National Grid or used locally.
- 3.1.2 Along with associated infrastructure, a solar farm typically requires between 2 to 4 acres for each MW of Rated Power Capacity. A typical 50 MW solar farm will consist of around 100,000 to 150,000 panels and cover between 125 to 200 acres² (3). Utility scale solar farms are often located in rural areas due to the requirement for large areas of open land.

3.2 Components of a PV Development

- 3.2.1 A PV development consists of the PV panels, as well as inverters, MV transformers and switch gear. They can also include a BESS within the same development to maximise the usage of the grid connection. PV developments are usually located close to a HV substation to minimise the costs and environmental disturbance associated with connecting underground cables or overhead lines.

PV Panels

- 3.2.2 PV panels are mounted on a frame to elevate them off the ground and fix them at an optimum angle. The panels are arranged in rows that are termed an 'array'.
- 3.2.3 PV panels do not generate any sound, unless they are 'tracking panels' that can follow the movement of the sun across the sky. Tracking panels have slow moving components, however the sound associated with this movement is minimal and this technology is not often found in the UK. Tracking panels are utilised more in countries with clearer skies to follow the direct sunlight, whereas in the UK, the sky is often overcast, so PV developments are designed assuming more diffuse light conditions.

Inverters and PCS

- 3.2.4 PV panels generate DC electricity that usually needs to be converted into AC before use, for example, to export to the National Grid. Therefore, like BESS, PV developments need a PCS and will utilise inverters. Solar inverters come in two distinct forms, as illustrated in Figure 3-1.
- String inverters are small units that are typically attached to the end of each array. String inverters typically range from 50 kW to 500 kW and hundreds of these units may be required for a single PV development.
 - Central inverters are much larger units, which look and operate very similar to the inverters used in a BESS development. Only a small number of central inverters are required for an entire PV development.

² Taken from, *Research Briefing: Planning and solar farms*, House of Commons: Library.

Figure 3-1: Example of a PV central inverter and a string inverter



3.2.5 The sound level output from a string inverter is relatively low in comparison to a central inverter, however, due to the large number of units required for a site, they should always be considered within any noise impact assessment. The following points in respect of string inverters should be noted

- Inverters generate electrical sound, which typically contains a high frequency tonal component (usually between 3000 Hz and 6000 Hz). The level of this sound is generally low (between 35 dBA and 55 dBA at 1 m) and will drop off quickly with distance due to the energy being concentrated in the higher frequency range. However, unlike larger BESS inverters and solar central inverters, many small sized string inverters will not require mechanical cooling, therefore, there is no fan sound present to mask the tonal electrical sound. Sound output from a small string inverter is likely to be low level but tonal.
- As technology improves the available electrical rating level of string inverters continues to increase. Higher rated string inverters are larger and do require mechanical cooling, so are also louder. This does mean, however, that fan sound is likely to mask any high frequency tonal sound.
- It is important to consider what the likely electrical rating of string inverters may be on a site when predicting sound levels. Smaller, lower rated string inverters will be required in much greater numbers than larger, higher rated string inverters i.e. potentially hundreds of units versus tens of units.
- Fan speeds can be fixed on some units and variable on others. Accordingly, some units do not vary in sound output, whereas others are variable.

3.2.6 Central inverters are generally combined into a PCS that is very similar to that used within BESS developments. See paragraphs 2.2.11 to 2.2.18 for relevant information.

Collector Stations

3.2.7 Collector stations are used to combine the outputs from many string inverters, or a smaller number of central inverters. They look very similar to central inverters but the sound level output of these units is generally low and they do not normally need to be considered within a noise impact assessment.

- 3.2.8 Care should be taken to differentiate between central inverters / PCS units and collector stations when reviewing layout drawings for propagation modelling, as they will often look very similar.

3.3 Typical PV Layouts

- 3.3.1 PV layouts tend to be either centralised or decentralised, as illustrated in Figure 3-2 and Figure 3-3.
- 3.3.2 A centralised layout uses a small number of central inverters / PCS, which are often scattered across the site, for example, one unit per field. A decentralised layout uses many string inverters (sometimes in the hundreds), and these are scattered across the entire site.
- 3.3.3 Figure 3-2 illustrates a field of PV panels, all connected into a single, central inverter and MV transformer. Where several central inverters are used on a large site, these may be connected into one or more Collector Stations.

Figure 3-2: Example of Centralised Layout

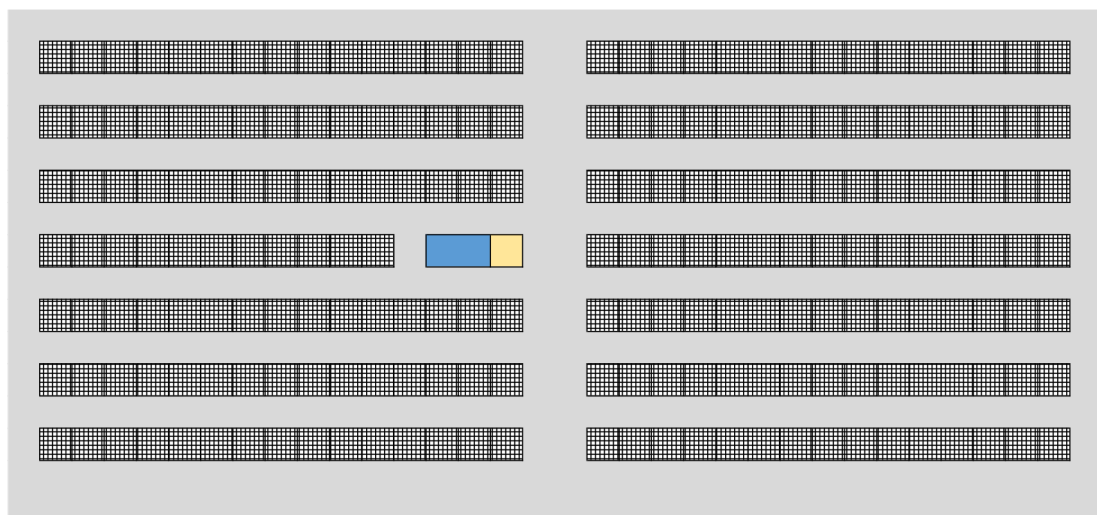
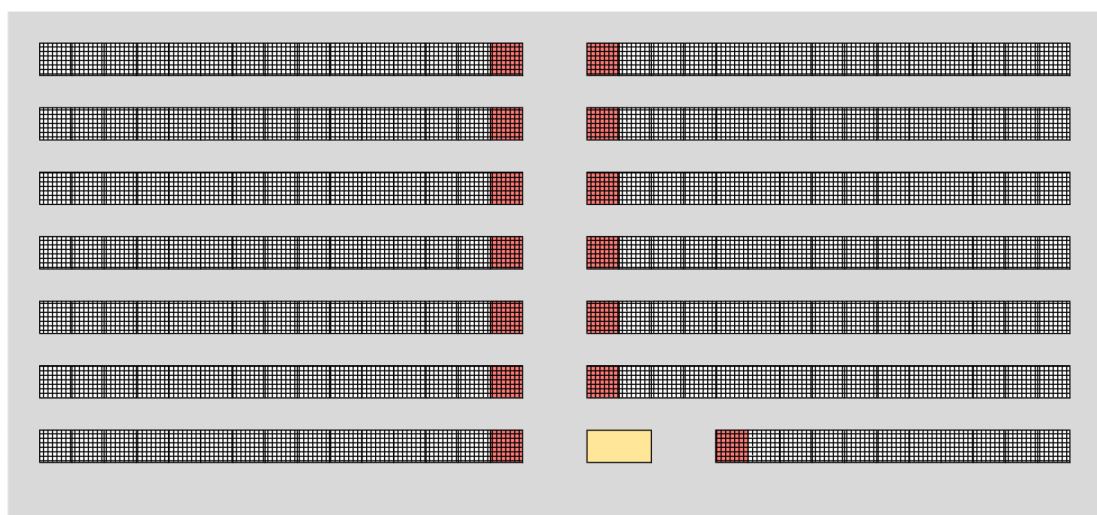


Figure 3-3 illustrates a field of PV panels with a string inverter located at the end of each PV row. All of the string inverters are connected into a single MV transformer (yellow).

Figure 3-3: Example of Decentralised Layout



4 The Approach to Noise Impact Assessments

4.1 Assessment Standards for Proposed Developments

- 4.1.1 Noise impact assessments for proposed developments should be undertaken in accordance with BS 4142:2014+A1:2019 Methods for Rating and Assessing Industrial and Commercial Sound (BS 4142). This standard provides comprehensive guidance to address all of the necessary elements of a noise impact assessment for a PV or BESS development. It enables the likelihood of an adverse impact on residential receptors to be determined, with due consideration of both the level and characteristic of received sound, and the context of the development and the environment that it sits within.
- 4.1.2 Additional guidance in respect of using BS 4142 is provided in the Association of Noise Consultants (ANC) BS 4142:2014+A1:2019 Technical Note (4).
- 4.1.3 BS 4142 is for the assessment of operational sound on residential receptors only. For the assessment of operational sound on non-residential receptors, it is recommended that consultation is undertaken with the Planning Authority or other relevant stakeholders to agree on an appropriate assessment methodology. This will vary depending on receptor type and sensitivity. Reference to ‘receptors’ for the remainder of this Good Practice Guide is in respect of residential receptors only.
- 4.1.4 The BS 4142 assessment uses “outdoor sound levels to assess the likely effects of sound on people who might be inside or outside a dwelling or premises used for residential purposes upon which sound is incident”. The first stage of the assessment is to undertake an estimate of the impact by subtracting a measured Background Sound Level from the Rating Level. The Rating Level is the level of sound received at the receptor location with character corrections added to that level to account for particular characteristics, which may be present in the sound.
- 4.1.5 The second part of the assessment is to then consider the context in which the sound occurs, which may modify the findings of the initial estimate. It is extremely important that this second stage of the assessment is undertaken. Simply comparing the Rating Level to the Background Sound Level is only half of the assessment.
- 4.1.6 Similarly, setting noise level limits purely based on the difference between the Rating Level and Background Sound Level should not be undertaken without due consideration of the context of the development.
- 4.1.7 BS 4142 refers to the following contextual elements that should be considered for every assessment
- the absolute level of sound;
 - the character and level of the residual sound compared to the character and level of the specific sound;
 - whether specific sound insulation and noise control measures have already been incorporated into a receptor (which would lower the sensitivity of the receptor).
- 4.1.8 There may be other contextual elements that are relevant to include in a noise impact assessment, though this will vary between developments and is site specific. Some examples are given in the ANC BS 4142 Technical Note and in the Method Implementation Document (MID) for BS 4142, (5).

- 4.1.9 It is noted that some Planning Authorities have requested assessments of PV and BESS sound for residential receptors to be undertaken in accordance with alternative guidance or standards. In general, this is not recommended and may not provide an appropriate assessment method, though it may provide some additional context to the BS 4142 assessment in certain circumstances. In particular, the following documents have been identified as likely to be inappropriate to include within a noise impact assessment for a planning application.

NANR45 Proposed criteria for the assessment of low frequency noise disturbance

- 4.1.10 The NANR45 document, Procedure for the Assessment of Low Frequency Noise Complaints, (6) states *“The procedure is intended to assist in the evaluation of existing problems. It is not intended as a means of predicting when disturbance might occur, for example in a planning situation, and would not be reliable to use as such”*. Accordingly, it is emphasised that this document is not appropriate for use at the planning stage, nor is it suitable for the prediction or assessment of low-frequency noise impacts.

BS 8233:2014 Guidance on sound insulation and noise reduction for buildings

- 4.1.11 BS 8233:2014 Guidance on sound insulation and noise reduction for buildings (7), is a standard that provides advice on how to design buildings with regards to internal acoustics – it is not a standard for the assessment of external environmental noise.
- 4.1.12 BS 8233 does not provide guidance on acceptable sound levels from industrial sound and does not provide any recommendations on the selection of industrial noise limit values for residential receptors. Rather, it states *“Where industrial noise affects residential or mixed residential areas, the methods for rating the noise in BS 4142 should be applied.”*

WHO Documentation

- 4.1.13 WHO noise publications provide health-based exposure guidance; they do not provide a methodology equivalent to BS 4142 for assessing industrial sound at residential receptors. In particular, they do not provide a framework for rating a specific industrial sound in the context of the prevailing sound environment and its acoustic character.
- 4.1.14 *Environmental Noise Guidelines for the European Region* (8) states that it did not develop specific recommendations for occupational or industrial noise. It explains that industrial sound is heterogeneous, has specific acoustic features and produces relatively localised exposure. Its source-specific recommendations address road traffic, railway, aircraft, wind-turbine and leisure noise, based on long-term average exposure response evidence. The document notes that the 1999 Community Noise Guidelines’ indoor values, and values not covered by the 2018 recommendations, including industrial noise and shopping areas, should remain valid. This does not provide a new industrial noise assessment method or a substitute for BS 4142.
- 4.1.15 *Night Noise Guidelines for Europe* (9) provides generic health-based night-noise exposure values, rather than source-specific industrial noise criteria. It identifies an almost complete lack of information for deriving exposure response relationships between industrial noise and night-time sleep disturbance. It should therefore not be used as an industrial noise assessment methodology or adopted as a fixed criterion for PV or BESS developments.
- 4.1.16 *Guidelines for Community Noise* (10) includes guideline values for specified environments. This includes a value for “industrial, commercial shopping and traffic areas”, for which the stated critical health effect is hearing impairment. It does not provide a criterion for industrial sound affecting residential receptors or a method for assessing such sound.

4.2 Study Areas

- 4.2.1 Historically there has been no consistent approach at what distance noise impacts from BESS or PV developments should be scoped out. The Working Group has seen that in some circumstances, the assessment of sound from BESS developments has been scoped out where the distance to the nearest noise sensitive receptors is as little as 500 m, while other assessments are seen to scope out noise impacts at much larger separation distances, such as 1 km, 1.5 km or 2 km.
- 4.2.2 Where nearest noise sensitive receptors are located 2 km or more from a BESS or PV development, this is sufficient to comfortably scope out noise impacts.
- 4.2.3 Where the separation distance is between 1 km to 2 km it may also be appropriate for a noise impact assessment to be scoped out, however, this will depend on the size of the development, consideration of local context, and with professional judgement from an acoustics practitioner. Use of the Simplified Propagation Model (see Section 7.3) may be helpful here. The simplified calculation results can then inform whether a full noise impact assessment may or may not be required, depending on the indicative operational sound levels, (with due consideration of potential sound characteristics) and the anticipated existing acoustic environment. If the practitioner determines that no further assessment is necessary i.e. a full noise impact assessment can be scoped out, then this should be agreed with the Planning Authority.
- 4.2.4 Where the development is less than 1 km distance from nearest receptors then it is recommended that a noise assessment is undertaken.

4.3 Use of Candidate Plant and Indicative Layouts

Candidate Plant in Planning Applications

- 4.3.1 There is significant variation between different suppliers in sound power level and spectra for comparable items of plant. For example, one manufacturer might offer a louder battery unit and quieter inverter, while another manufacturer might provide the opposite. Likewise, the physical dimensions of comparable items of plant vary, with a resultant impact on the propagation of sound. Attenuators that are available are manufacturer-specific, and the performance of one unit cannot necessarily be applied to another.
- 4.3.2 Although a noise impact assessment is likely to be submitted at the planning stage, the equipment supplier is unlikely to be fixed, and as a result the exact layout and actual source levels are unlikely to be final.
- 4.3.3 A project can be at different stages of development for different forms of planning applications e.g. planning permission in principle, outline planning, detailed planning, development consent order etc. Irrespective of the type of planning permission being sought it is unlikely that the equipment manufacturer will be confirmed prior to planning consent being granted. As a result, the exact layout and actual source levels are unlikely to be final. The primary focus of the noise impact assessment at the planning application stage should therefore be to propose appropriate operational noise limits based on the prevailing acoustic environment, and demonstrate that those limits can be met, through the modelling of a realistic, worst case assessment.
- 4.3.4 After planning consent has been granted, and once the equipment manufacturer and plant has been selected and a detailed layout been finalised, modelling should be carried out again to determine whether the proposed layout and plant complies with the consented noise

limits. This exercise may also determine the final mitigation campaign. The results of this exercise might need to be submitted to the planning authority, either to discharge a planning condition, or as part of a standalone application e.g. matters specified in conditions application.

Selection of Candidate Plant for Propagation Modelling

- 4.3.5 The purpose of propagation modelling at the planning stage is to determine that the proposed site can be developed within an appropriate set of limits considering the prevailing acoustic environment. Modelling should usually be based on a Rochdale Envelope approach, i.e. the maximum design scenario should be assessed.
- 4.3.6 The Rochdale Envelope principal is summarised in online Government guidance 'Nationally Significant Infrastructure Projects: Pre-Application Advice on Environmental Impact Assessment' (11), which states
- *the assessment should be based on a cautious 'worst case' approach and the mitigation measures proposed should adequately address the worst case*
 - *information should be sufficient to enable the main, or the likely significant effects on the environment to be assessed and the mitigation measures should be described, and*
 - *the need for flexibility should not be abused and does not give applicants an excuse to provide inadequate project descriptions.*
- 4.3.7 In respect of operational sound, the Rochdale Envelope 'worst case' approach would require a noise impact assessment to consider the largest anticipated Rated Power Capacity and/or Rated Energy Capacity, rather than selecting individual items of equipment with the highest possible noise output. It would also need to consider the most sensitive time periods and duration of operation. Notwithstanding the requirements of the Rochdale Envelope, care must be taken when reporting on mitigation measures at the planning stage, as these will often be manufacturer and layout specific, so cannot be committed to at the planning stage when candidate plant is being assessed (see Section 8).
- 4.3.8 The selection of candidate plant is important to ensure that any presented results accurately reflect a reasonable design scenario of sound levels that might be expected from the proposed development. The following considerations should be made:
- **Different manufacturers or system integrators** might have a different balance of sound levels between different items of plant. It is likely to be unrealistically conservative to mix and match source levels from different suppliers or system integrators³.
 - **Attenuators** are available for certain items of plant, but these are manufacturer, and possibly model, specific. One manufacturer might represent a maximum design scenario for unattenuated levels, while another might represent a maximum design scenario for attenuated levels.
 - **Physical dimensions.** Manufacturers may have different physical dimensions for plant or attenuators. One manufacturer might represent the maximum design scenario considering barrier attenuation, while another might

³ Note that system integrators may not be bound to specific plant manufacturers, so can legitimately supply equipment from a range of manufacturers on a single site.

represent a reduced maximum design scenario due to increased source height and a subsequent reduction in barrier attenuation.

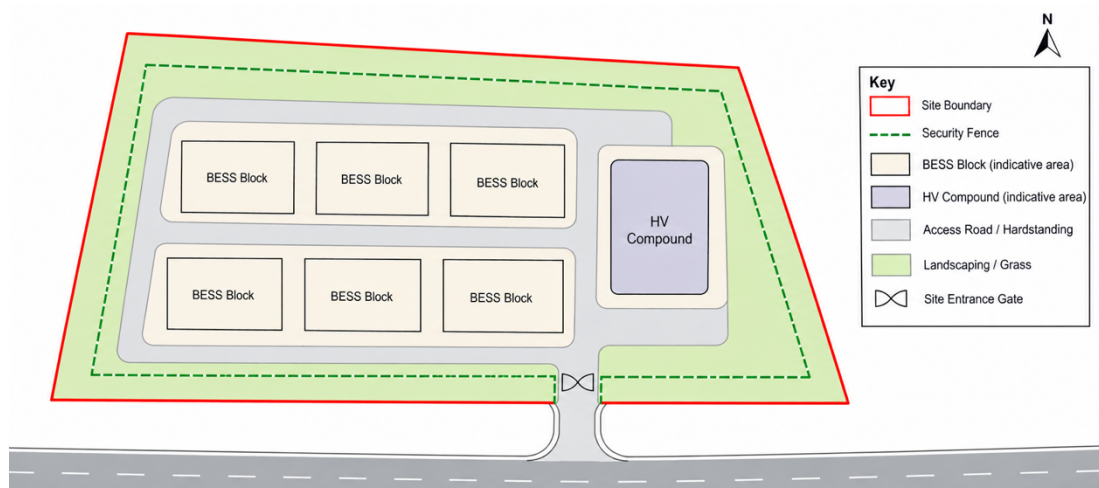
- **Ambient temperature.** The relationship between operational sound power levels and ambient temperature might be important in the determination of candidate plant.
- **Spectral data** and the likelihood of character corrections should also be considered alongside broadband levels in determining the candidate plant.
- **Operation.** The business model or technology of the BESS might affect how different systems are operated, which might impact the determination of candidate plant. For example, sites that may be used for 'grid-forming' should not use candidate plant that cannot operate in this scenario.
- **PV Inverter Types.** In relation to PV developments, the decision between string or central inverters will impact the determination of candidate plant.

- 4.3.9 It would not be appropriate to present modelling based on the quietest available plant unless the proposed development is committed to installing equipment with comparable sound power levels.

Site Layouts for Planning Applications

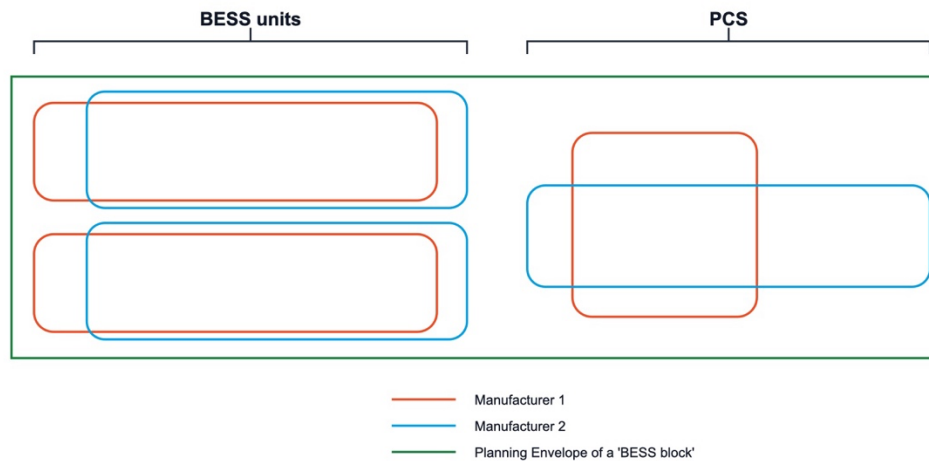
- 4.3.10 It is likely that a generic, manufacturer and technology agnostic layout will be required from a multi-disciplinary perspective at the planning stage. In the case of a BESS development, this is typically determined by representing multiple 'BESS Blocks' within a site layout drawing, rather than by detailing individual items of plant, containers and similar.
- 4.3.11 Use of BESS Blocks on the approved site plans allows for maximum flexibility at the procurement stage. An example of how a planning application drawing may appear is shown as Figure 4-1.

Figure 4-1: Example of a typical planning application site layout



- 4.3.12 A BESS Block will generally contain a number of PCS and its associated BESS units, noting that different manufacturers will have different combinations of components, or different dimensions. Use of Bess Blocks in layout drawings can encompass all likely manufacturers, as illustrated in plan view in Figure 4-2. This provides the application with sufficient layout flexibility to determine the plant manufacturer at a later stage, without having to seek planning consent for a variation.

Figure 4-2: Example of a single BESS Block for use in a Planning Application Layout Drawing



- 4.3.13 Propagation modelling based on a BESS block site layout or similar, should consider the physical dimensions of the selected candidate plant, as well as it's required equipment combinations, to ensure it can be fitted within individual blocks.
- 4.3.14 Noise impact assessment reports submitted in support of planning applications based on a BESS block (or similar) principal, should include both the approved drawings forming part of the application and a separate drawing showing the specific candidate plant layout that has been assessed in the noise model.

5 Operational Parameters

5.1 Operational Considerations

- 5.1.1 The operational sound levels from BESS and PV developments are affected by a wide range of parameters. These include product design, control systems, ambient conditions, and market participation, all of which must be considered over the full life of the asset.
- 5.1.2 As a dispatchable source of energy, BESS may be operated at any time of day. Energy may be exported during periods of high demand, or batteries may be charged when there is a surplus of energy from renewables on the National Grid. This can include night-time hours, when background sound is typically at its lowest level. As such, adverse impacts are more likely with BESS operations during the night.
- 5.1.3 PV developments typically operate during daylight hours with maximum sound level output occurring during the daytime, and so night-time conditions are often of less relevance to solar than to BESS. Nonetheless, it should be recognised that some PV developments may include plant that operates during the night-time, albeit at lower levels.
- 5.1.4 Due to their flexibility and ability to take energy off the grid, as well as put energy onto the grid, BESS operate in a wide range of markets, typically participating in multiple markets simultaneously to maximise revenues. This is known as “revenue stacking”.
- 5.1.5 Conversely, PV developments typically participate in fewer markets, and operators have much less control over their operation due to their inherent dependence upon cloud coverage.

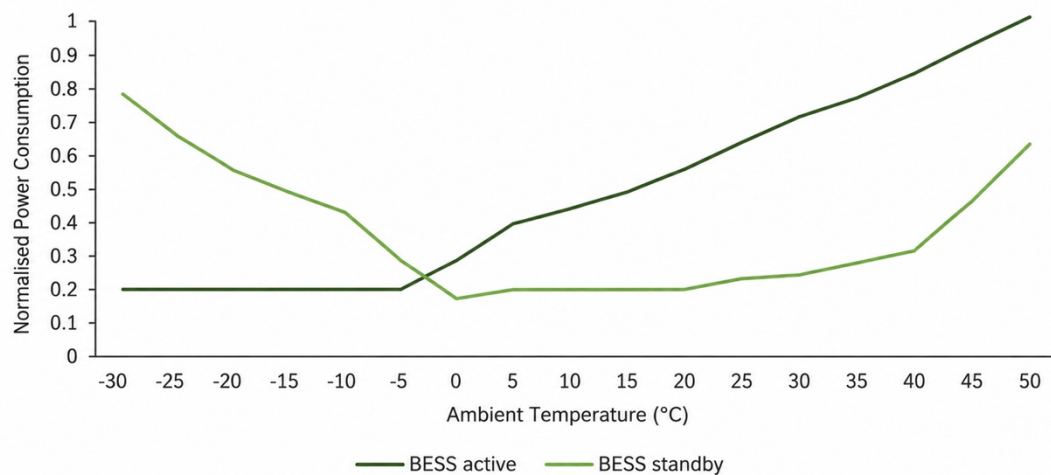
5.2 Heating and Cooling Requirements

- 5.2.1 When considering the heating and cooling requirements of plant it is helpful to think separately of the DC elements of plant i.e. the batteries, and the AC elements of plant i.e. the PCS.

DC Units (Batteries)

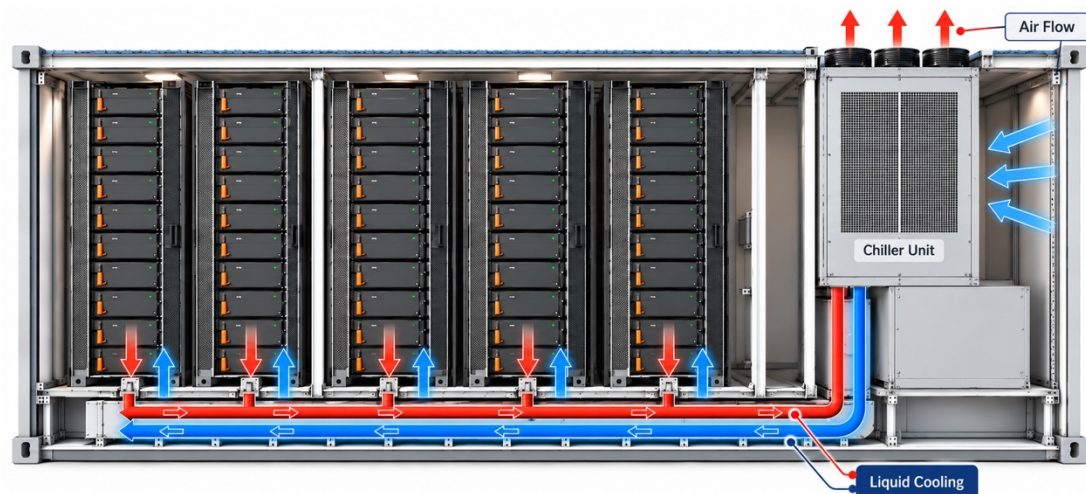
- 5.2.2 Battery cells generate heat when they are operated, during both charging and discharging modes. The rate of heat generation largely depends upon the charging and discharging power, but cooling requirements will also depend upon ambient temperature, system operation, and cell design. Keeping the battery packs within a limited temperature range is required to limit permanent loss of capacity, also known as degradation.
- 5.2.3 DC units will typically contain a HVAC unit and a chiller. The HVAC is used to control the ambient temperature within the battery cube or container, and the chiller is required to control the temperature of the batteries.
- 5.2.4 Figure 5-3. Shows the power consumption data for an HVAC system mounted in a battery container, for periods when the BESS is active and when it is on standby. Reviewing this power consumption data provides an insight into when the HVAC units operate and their workload.

Figure 5-1: Example battery container HVAC activity



- 5.2.5 When the BESS is in standby mode the HVAC will operate increasingly as the ambient temperature drops below 0°C. It will also gradually increase in operation as temperatures increase from approximately 25°C to 40°C, at which point load on the HVAC becomes more substantial. For the majority of the time, however, during ambient temperatures such as may occur in the UK, the HVAC will only draw a small amount of power i.e. be idling, when the BESS is in standby mode and operational sound levels from the HVAC are expected to remain low.
- 5.2.6 When the BESS is active the HVAC will remain idle at temperatures below freezing but will gradually increase in operation as ambient temperature increases.
- 5.2.7 The chillers installed in DC battery units circulate a coolant (such as water), or a refrigerant (such as glycol) to cooling plates located on the battery packs. This keeps cell temperatures within a relatively narrow range, the requirement of which is heavily dependent on cell chemistry, but will typically be in the region of 25-30°C for lithium-ion batteries.
- 5.2.8 The chillers comprise compressors, pumps, and fans. Each chiller unit will require an air inlet (for cool air) and an exhaust (for warm air). A typical chiller configuration is shown in Figure 5-2.
- 5.2.9 The cooling demand of DC components, including battery cells, is determined primarily by the active power, rather than ambient temperature, therefore, it can be expected that the chiller will operate for much of the time when the BESS is active.
- 5.2.10 In cold conditions, heating systems are required to maintain battery cell temperatures within their preferred operating range, and for this electric resistance heaters are typically used, including positive temperature coefficient (PTC) heaters. PTC heaters are inherently self-regulating: as the heater temperature increases, its electrical resistance increases, limiting the current and stabilising the heat output when supplied at a fixed voltage. As resistance heaters are effectively silent, the principal sound level consideration for battery containers generally arises when cooling is required, rather than for heating.

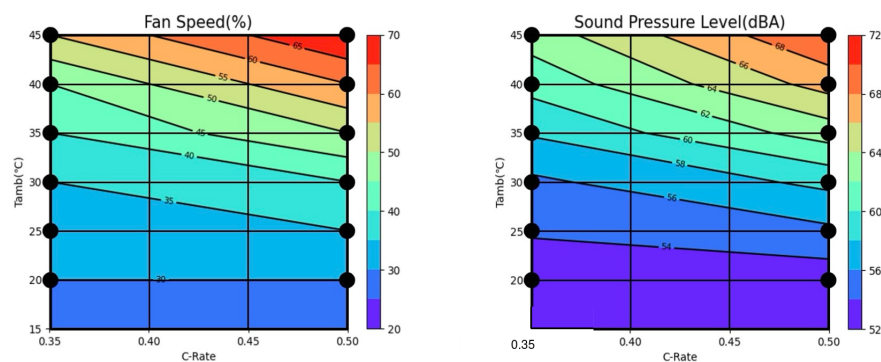
Figure 5-2: Example Liquid Cooling System



5.2.11 Figure 5-3 illustrates the influence of ambient temperature and C-rate on chiller fan speed and the average sound pressure level at a distance of 1 m for a DC battery container.

5.2.12 The chart on the left illustrates how fan speed rises as ambient temperature increases and as C-rate increases. The highest fan speeds occur under the hottest, highest-load conditions. The sound levels shown in the right hand chart follow the same general pattern, increasing as cooling demand rises. This indicates that the higher fan speeds required at elevated temperature and C-rate lead directly to higher operational sound levels.

Figure 5-3: Ambient temperature, C-rate, fan speed and SPL at 1m for a BESS container



AC Units (PCS)

5.2.13 Inverters contain insulated-gate bipolar transistors (IGBTs) or MOSFETs for current conversion, which switch at high frequency (typically between 1 kHz and 20 kHz for IGBTs and above 20 kHz for MOSFETs). The current conversion process generates heat and so cooling is achieved using inbuilt chillers, again including compressors, pumps, and fans. The fans are typically the main source of sound and are often roof-mounted. Again, the cooling system will require an air inlet and an exhaust. These may appear as two distinct sound sources on a larger unit.

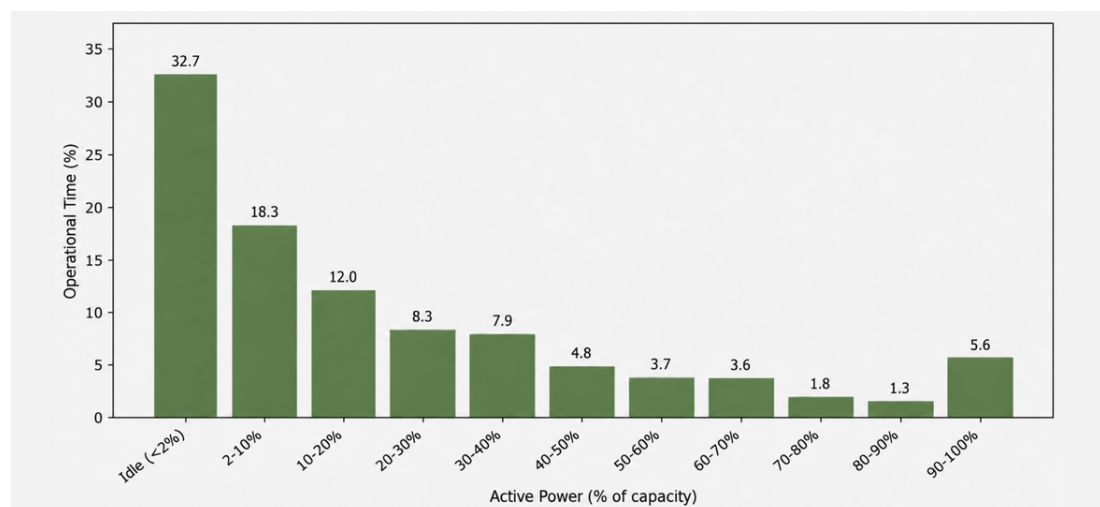
5.2.14 As the operation of the IGBTs or MOSFETs is the primary heat generating mechanism in an inverter, the electrical load on the inverter unit is likely to be the determining factor in regards to the cooling requirements. Accordingly, ambient temperature may play less of a role with many AC inverters than it would with DC battery units.

- 5.2.15 AC power systems involve both active power and reactive power. Active power transfers usable energy, whereas reactive power represents energy that is alternately stored and returned by electric and magnetic fields. Although reactive power produces no net energy transfer over a complete AC cycle, it is required for voltage control and for the operation of equipment such as motors and transformers. BESS plant must therefore be designed to satisfy the reactive-power obligations applicable at its connection point.
- 5.2.16 At a constant system voltage, the current carried by AC equipment is proportional to apparent power. Consequently, the cooling demand of AC components, such as power conversion systems and transformers, generally increases with apparent power.

5.3 Operating Times

- 5.3.1 BESS can charge or discharge over the full spectrum of powers from idle up to rated power. Systems can spend long periods of time in an idle/standby mode, until called upon for trading or to provide contracted services. Figure 5-4 presents an example of Active Power (export only) from a BESS development operating over the period of a year, which illustrates this. Note this is an example only and some BESS developments can operate very differently to the illustrated example, especially with revenue stacking.
- 5.3.2 During standby (idle), a small amount of power may be drawn from the grid to meet auxiliary loads, such as for cell heating/cooling, lighting, security systems, etc.

Figure 5-4: Example of distribution of metered power (export) for an operational BESS



- 5.3.3 Figure 5-5 illustrates the average hourly power output of an operational solar farm, expressed as a percentage of its installed capacity, for each month of the year. The profile demonstrates the strong seasonal relationship between solar generation and the availability of daylight. Note that this example is specific to a particular development, rather than presenting typical levels for all PV developments in the UK.

Figure 5-5: Average power output by hour of day and calendar month

Average Power (%)	Month											
Hour of Day	1	2	3	4	5	6	7	8	9	10	11	12
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	2	5	2	0	0	0	0	0
5	0	0	0	2	7	10	7	4	0	0	0	0
6	0	0	1	11	25	24	24	13	5	0	0	0
7	0	0	13	27	41	35	36	24	18	8	0	0
8	0	8	25	45	55	46	50	41	31	19	9	0
9	9	15	35	57	68	55	60	55	42	27	12	8
10	13	25	48	65	75	58	70	60	49	34	22	18
11	13	33	49	62	65	61	62	61	52	35	23	15
12	13	33	49	62	64	56	60	60	53	31	19	13
13	19	33	50	55	59	57	59	57	52	21	14	8
14	13	26	33	46	50	55	55	47	40	11	4	0
15	6	16	22	39	42	42	44	38	30	8	0	0
16	0	8	18	23	35	39	33	25	8	0	0	0
17	0	0	5	13	16	26	25	14	0	0	0	0
18	0	0	0	4	10	13	13	4	0	0	0	0
19	0	0	0	0	2	5	4	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

- 5.3.4 During the winter months, the shorter daylight period restricts generation to a relatively narrow part of the day. In December and January, generation is predominantly concentrated between approximately 08:00–16:00, with comparatively low peak outputs reflecting the lower solar elevation and reduced available solar irradiance.
- 5.3.5 As daylight hours increase through the spring, generation begins progressively earlier in the morning and continues later into the evening. The broadest generation profile occurs during the late spring and summer months, particularly between May and July, when output can occur from approximately 04:00–20:00. During these months, the highest average output generally occurs around the middle of the day, when the sun is at its greatest elevation and incident solar radiation is typically highest.
- 5.3.6 Peak output occurs in May rather than around the June summer solstice, with the highest value shown in the dataset being approximately 75% of installed capacity at 10:00 in May, compared with approximately 70% in July and 61% in June. Although available daylight and clear-sky solar irradiance are greatest around the summer solstice, actual PV output is also influenced by prevailing weather conditions and module temperature. UK climate averages show that May can experience greater sunshine duration than June or July; for example, the Met Office 1991–2020 UK averages record approximately 192 hours of sunshine in May, compared with 171 hours in June and 173 hours in July. (Met Office) In addition, photovoltaic module efficiency decreases as cell temperature increases, meaning that cooler conditions can allow a PV array to convert incident solar radiation slightly more efficiently than during hotter summer conditions. These effects provide a plausible explanation for the May maximum observed in the dataset.
- 5.3.7 Overall, Figure 5-5 indicates a broad period of elevated daytime generation from approximately May to August, with typical midday output in the region of 55–70% of installed capacity and occasional values approaching 75%, rather than a single sharply defined annual peak. The pattern then reverses through autumn, with the period of generation becoming progressively shorter as sunrise becomes later and sunset earlier.
- 5.3.8 Duration is only part of the seasonal variation; the intensity of generation within the daylight window varies in the same direction. Solar elevation in the UK at noon increases from roughly 13° in midwinter to around 60° in midsummer, reducing atmospheric path length and increasing the incident irradiance on the array plane. The combined effect is evident in the midday values, which rise from 13 - 18% of capacity in December and January to 55 - 75% in May to July, a factor of approximately four.

- 5.3.9 The variation in output is not determined by daylight duration and solar elevation alone. Factors including location, cloud cover, atmospheric conditions, panel orientation and system efficiency also influence the percentage of installed capacity achieved at any particular time. The values shown therefore represent an average operational profile for the example site, rather than the maximum output that could occur under ideal clear-sky conditions.
- 5.3.10 Output is zero in all months between 20:00 and 03:00, indicating that the inverters and associated plant may not be operational overnight. From April to September, however, low-level generation of between 2% and 25% of capacity occurs from around 04:00 to 07:00, i.e. within the night-time period as defined in BS 4142:2014+A1:2019. Plant operation during part of the night-time period therefore cannot be discounted on the basis of daylight alone.

5.4 Battery Ageing

- 5.4.1 Battery cells lose energy capacity as they age, due to both calendar ageing and cyclic ageing.
- Calendar ageing is largely dependent on time, temperature and state of charge; elevated temperatures and states of charge generally cause increased ageing over time.
 - Cyclic ageing is dependent on energy throughput, temperature, state of charge and power; elevated values of any of these parameters cause increased cyclic ageing.
- 5.4.2 Battery cell ageing causes an increase in internal resistance, and hence increased heat generation and cooling requirements. Consequently, sound level data should be handled on the understanding that cooling loads may increase over time, which may either increase sound levels or lead to longer running of cooling systems.

5.5 Augmentation

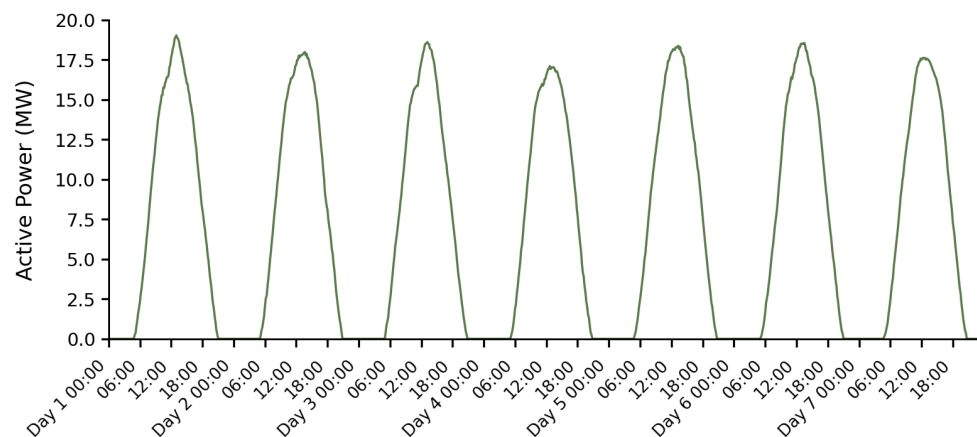
- 5.5.1 As battery ageing reduces the usable energy capacity of a BESS over time, some asset owners are opting to add additional units in a process known as augmentation. This may be planned during the initial design phase of the project (with an augmentation schedule known in advance) or decided during the project's life, for example due to changing market conditions.
- 5.5.2 The addition of only DC units is known as 'DC augmentation'. This has the effect of increasing the total ratio of energy capacity to power capacity, and hence reducing the C rate. To ensure degradation across all units remains roughly constant, both the existing and the new DC units are typically operated at the same C rate, which will be lower than the C rate of the overall site.
- 5.5.3 DC augmentation may be used to convert existing sites to longer duration systems and potentially enable access to additional revenue streams, for example, the UK cap-and-floor scheme, which is only open to BESS with durations of 8+ hours). DC augmentation will tend to reduce the sound level from an individual DC unit as the units will operate at a lower C rate than before augmentation (meaning lower cooling load), but this must be balanced against the increased number of DC units on the site.
- 5.5.4 The addition of both DC and AC units to an existing site (such that the new DC units can be operated at the same C rate as the existing units) is known as 'AC augmentation'. This will tend to add sound uniformly across both DC and AC units as units are added with the same ratio as on the existing site (e.g. 4 DC units per AC unit).

5.6 Electricity Markets

- 5.6.1 BESS operate in a wide range of markets covering balancing services, frequency response services, and backup capacity. Dispatch scheduling is achieved using optimisation techniques fed by forecasts of weather and electricity prices. As such, BESS operating profiles may vary over time and are not known with certainty far in advance. However, peak activation is driven by human activity, such as the peaks in electricity consumption in the morning and evening, which cause imbalances in supply and demand, leading to market price fluctuations targeted by BESS.
- 5.6.2 Full power operation of BESS is to be expected for energy trading but is much less common for grid services such as virtual inertia and reactive power provision. 24/7 full power operation is unrealistic as this would typically imply violation of warranty restrictions for maximum daily throughput or resting times. Such operation is also not supported by current or predicted future market patterns.
- 5.6.3 Thermal power plant, such as coal or gas fired plant, feature large rotating masses in their turbines and generators along with large quantities of high-temperature materials. Consequently, these provide high levels of mechanical and thermal inertia, which help resist rapid changes in system frequency following changes in generation or demand. As power systems decarbonise and synchronous thermal generation is displaced by inverter-based resources, such as wind, solar and batteries, system operators increasingly need alternative sources of stability, frequency support, and voltage control.
- 5.6.4 BESS are well placed to mitigate these issues through the provision of “virtual inertia” (also known as “synthetic inertia”). This involves rapidly providing or absorbing high levels of power for short periods. BESS that are capable of this will typically allow short bursts of high overloads, such as 150% overload for up to 10 seconds. This type of operation forms part of what is known as “grid forming” control of inverters, which allows the creation of grid “islands” and supports black start of a network following a power outage. It is unlikely that such short periods of high load will have meaningful impacts on site sound levels.
- 5.6.5 Figure 5-6 through to Figure 5-8 provide examples of active power for a typical 20 MW PV development and for two 100 MW BESS developments that are operating in distinctly different markets. All charts represent a one week period. Positive values of active power represent the BESS exporting, whereas negative values represent periods where the batteries are charging (importing).

- 5.6.7 Figure 5-6 illustrates a regular daily generation profile on clear sky days. Power output rises after sunrise, peaks around midday and falls back to zero by sunset. No generation occurs during the night-time. Given that a similar sequence occurs every day there is no evidence of grid curtailment during the week or any power outages.

Figure 5-6: Example active power exports. PV Development



- 5.6.8 Figure 5-7 shows a BESS operating between approximately +98 MW when exporting and -75 MW when importing, so charging times will take slightly longer than discharge times. The regularity of exports and imports, limited number of reversals (from + to -), and relatively smooth profile, suggests scheduled charging and discharging. Rather than responding rapidly, the BESS is likely to be storing energy during low price periods and exporting energy during higher price periods. This suggests it is working in an energy arbitrage market.

- 5.6.9 In contrast, Figure 5-8 shows a BESS that is operating with numerous, rapid reversals between near maximum power values. Active power oscillates around 0 MW and sustained activity for either exporting or importing is minimal. This suggests it is working to provide fast frequency response services i.e. virtual inertia.

Figure 5-7: Example active power variations. BESS Development #01

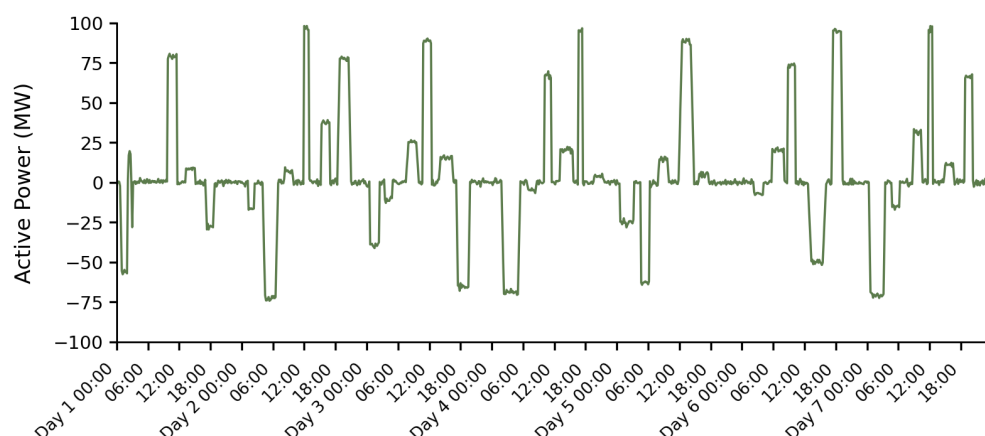
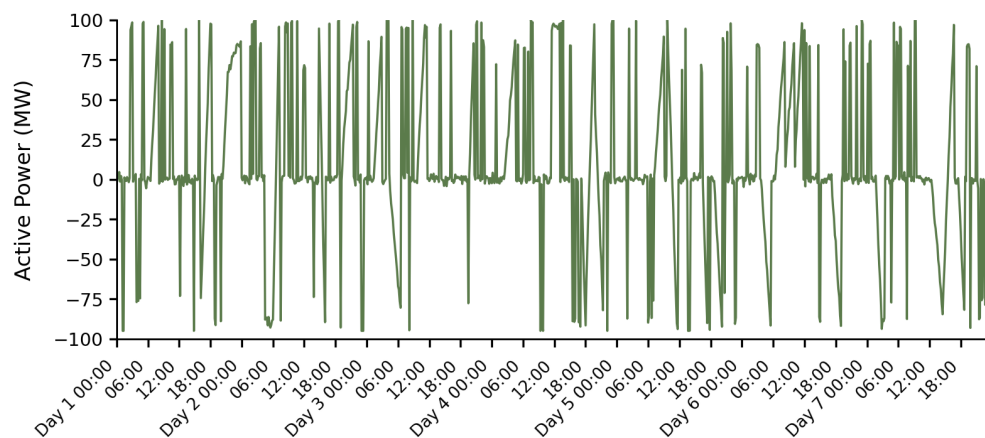


Figure 5-8: Example active power variations. BESS Development #02



- 5.6.10 In summary, whilst PV developments are likely to have a fairly predictable operating profile, albeit subject to weather conditions and grid curtailment or similar, BESS operation is not always limited to simple charge, discharge, and standby states.
- 5.6.11 How a BESS may operate is unlikely to be known at the planning application stage, and so it is also unlikely that that a particular operating profile can be considered within a planning application noise impact assessment. If undertaking sound level monitoring of an active site, however, it will be important to consider the operating profile of the development both for the survey planning and subsequent data analysis (see Section 11).

Long Duration Energy Storage (LDES)

- 5.6.12 UK BESS deployments in the early 2020s were strongly motivated by ancillary service revenues, whereby systems make money by tracking electricity grid frequency and rapidly responding to maintain grid frequency within allowable limits. However, in some advanced markets such as in the UK, these services have started to become saturated (12). Along with continued improvements in BESS technologies, this has led to an increased interest in electricity storage as a means of bridging longer duration gaps in renewable energy supply, taking the role traditionally filled by fossil fuel power plant.
- 5.6.13 Some electricity system operators have consequently launched schemes to incentivise deployment of long duration energy storage (LDES), such as the cap-and-floor scheme in UK. This provides stable revenues for electricity storage systems with durations of 8 hours or more.

5.7 Sodium-Ion batteries

- 5.7.1 Lithium-ion batteries, specifically lithium iron phosphate (LiFePO_4 , or LFP) batteries, have dominated the BESS market in the early 2020s. However, it is expected that sodium-ion (Na-ion) batteries will gain market share in the future.
- 5.7.2 Na-ion batteries have a lower energy density than LFP batteries, which is an operational disadvantage; the volumetric energy density of Na-ion is expected to be around half that of Li-ion, therefore, one could imagine that the area required to develop a Na-ion development would be significantly larger than LFP. However, due to reduced fire safety risks, it is possible that spacing between Na-ion units could be lower than that required between Li-ion units.

- 5.7.3 Sodium is, however, significantly more abundant than lithium: sodium comprises around 2.6 % of Earth's crust by mass, whereas lithium comprises only around 0.002 % of Earth's crust. Sodium-containing raw materials are therefore generally more widely available, and this is expected to support lower raw material costs.
- 5.7.4 When compared with Li-ion, Na-ion batteries also benefit from higher round-trip efficiencies and lower degradation when operated at higher powers. As such, some manufacturers are targeting early deployment of Na-ion BESS at AI data centres (AIDC), which can have spikes in load.
- 5.7.5 Na-ion batteries can also be operated safely over a wider range of temperatures. As such, cooling requirements can be significantly reduced, and some manufacturers have designed Na-ion BESS with only passive cooling. Consequently, Na-ion battery units could be effectively silent, with the only site sound coming from the AC units and similar.
- 5.7.6 The lower cooling requirements of Na-ion BESS could be particularly important for LDES systems, which have higher ratios of energy capacity to power capacity than shorter-duration systems.

6 Source Sound Data

6.1 The Importance of Comprehensive Data

- 6.1.1 This section provides guidance for acoustic practitioners on how to incorporate manufacturer supplied data into a propagation model.
- 6.1.2 Guidance is also presented in respect of how sound level data should be provided by manufacturers for individual items of plant, and explains what additional non-acoustic data should be provided alongside the sound data. It is necessary to provide both acoustic (sound) and non-acoustic (operational) data to enable a robust propagation model to be built.
- 6.1.3 The provision of high-quality, comprehensive data is extremely important to determine the likely emission levels of a development.
- 6.1.4 Low quality acoustics data, or a lack of supporting non-acoustic data, will lead to incorrect predictions of immission levels, i.e. the sound levels received at a receptor. This could be in the form of an underestimation of the immission levels, or, as a result of having to include a number of operational assumptions in the model, an over-estimate.
- 6.1.5 An under-estimate of the immission levels at the planning application stage can lead to significant difficulties at the procurement stage, as noise level limits may have been set with regard to under-estimated, operational sound levels. This can significantly limit the range of plant available for the Developer to select from, and specifying equipment that can meet the conditioned noise level limits can be extremely difficult, or require significant extra investment in noise control measures.
- 6.1.6 An under-estimation of the sound levels at the procurement stage may lead to noise disturbance and complaints, or non-compliance with the conditioned limits.
- 6.1.7 Conversely, an over-estimate of the immission levels can lead to a requirement for needless but expensive mitigation measures to be put in place. These can include limiting operations of the development (therefore reducing energy yield/energy output), the fitting of unnecessary noise control equipment, or the construction of unnecessary barriers or bunds.
- 6.1.8 It should also be noted that a lack of detailed acoustic and non-acoustic data may mean that contractual or planning obligations cannot be met.
- 6.1.9 For a manufacturer publishing sound level data, or for an acoustics practitioner relying on manufacturer provided data for modelling, the following elements must be considered
- The use of sound power levels (SWL) or sound pressure levels (SPL)
 - The provision of spectral data
 - Any variation in sound levels for each element or façade, and any resultant directivity
 - Any variation of sound levels with fan speed or other cooling plant, ambient temperatures, and operating temperatures
 - Any variation of sound levels for the same items of plant with different electrical ratings or C-rates.

6.2 Product Literature

- 6.2.1 Acoustic consultants depend heavily on manufacturer-supplied sound data to predict operational sound levels and to design mitigation measures, yet the quality of that data varies considerably between manufacturers. While some provide comprehensive, standards-based acoustic test reports, including sound power levels, frequency spectra, operating conditions and measurement uncertainty, others supply only a single A-weighted decibel figure, with little supporting information. The level of detail varies not only in the acoustic data provided, but also in how the operating conditions are described. Sound level output can change significantly with electrical load, fan speed and thermal operating conditions, and without a clear description of these conditions, it can be difficult to determine whether reported sound levels are representative of the conditions that will occur during plant operation. This can lead to overly conservative assumptions in propagation models.
- 6.2.2 It is recommended that sound level literature published by plant manufacturers should be produced in two parts.
- Part 1 should be a detailed Sound Level Measurement Report explaining how, and to what standard, the measurements were taken, any subsequent data analysis, and the measured and/or calculated sound levels.
 - Part 2 should be a brief Sound Level Data Sheet, that includes enough information for the plant to be modelled. It is envisaged that the Sound Level Data Sheets could be issued as a standalone document, as well as being appended to the Sound Level Measurement Report.
- 6.2.3 In some cases it may be necessary to produce several Sound Level Data Sheets for a single product, for example, one for each operational mode.
- 6.2.4 Sound Level Measurement Reports may vary considerably depending on the complexity of the survey that has been undertaken, therefore, a prescriptive description of these is not included. Sound Level Data Sheets, however, are expected to be brief (2 pages per reported dataset/measured operating mode) and relatively uniform, and a completed example plus blank Sound Level Data Sheet templates are included as Appendix 2. Plant manufacturers are encouraged to adopt these templates or develop similar data sheets for sound level reporting.
- 6.2.5 It is necessary for sound level measurements to be undertaken in accordance with recognised international standards. Similarly, any subsequent data analysis and calculation of sound levels should also be undertaken in accordance with recognised standards.
- 6.2.6 The standards to be used will be dependent on the measurement equipment available and the setting that the measurements will be taken in. A number of appropriate standards are included in Appendix 1 that cover the use of both sound pressure level meters and sound intensity probes, and consider measurements undertaken in laboratory conditions, other internal settings, for example, at the place of manufacturing, and in external locations.
- 6.2.7 Although relatively common, it is not good practice to report informally measured sound pressure levels at a given distance i.e. reporting sound levels not measured in accordance with a recognised international standard. Use of the recommended standards for measurements will consider many aspects that are often neglected through informal measurement and reporting. These can include, but are not limited to
- Influence of background sound

- Influence of reflecting surfaces and other nearby obstacles
- Directivity, consideration of particularly noisy elements, and consideration of noisier and quieter facades
- Spectral content

6.2.8 For acoustics practitioners preparing a noise impact assessment report or similar, all data used in the propagation model should be traceable, for example, to documentation provided by a plant manufacturer or system integrator, or to measurements of operational plant.

6.3 Use of Sound and Operational Data

6.3.1 Table 6-1 sets out the key acoustic and operational information that should be provided by manufacturers and understood by the acoustician, noting that not all of this information may be available within a single report.

6.3.2 The recommendations in this table are to promote greater consistency in the quality and presentation of manufacturer-supplied data, while ensuring that the operating conditions to which the reported sound levels relate are clearly understood and can be adopted with minimal uncertainty in any propagation model.

Table 6-1: Reporting and use of Sound and Operational Data

Item	Guidance for manufacturer	Guidance for acoustician
Sound power levels & sound pressure levels	Sound power level (SWL) data should be provided in preference to sound pressure levels (SPL). Regardless, all SWL and SPL should be measured in accordance with an appropriate recognised international standard, with the standard and measurement methodology clearly identified. Any decibel (dB) weightings should be clearly stated as dBA for A-weighted levels and dBZ for unweighted levels. Where SPLs are provided, the measurement distance, microphone positions, acoustic environment and other relevant test conditions should be reported.	SWL should be used as the preferred input to the propagation model. Where only SPL data are available, assess whether the data can reliably be converted to SWL and document any assumptions or limitations.
Spectral data	Provide spectral data, preferably in one-third-octave bands, wherever possible. Any frequency weighting should be clearly identified, dBA or dBZ. Where multiple single figure sound levels are being provided, for example, a different SWL for each façade, corresponding spectral data should also be provided. It is incorrect to assume the same spectral data can be used for each element or façade of most plant.	Use spectral data as model inputs wherever available, rather than relying on single figure levels. Where only single figure levels are available, consider which frequency band to use within the model. ISO 9613 suggests to use 500 Hz in this situation but it may be appropriate to consider alternative frequency bands, for example, 100 Hz, for the modelling of a large transformer.

Item	Guidance for manufacturer	Guidance for acoustician
Facades of units and noisy elements	Where emissions from a unit, for example a container or enclosure, are non-uniform, provide separate data for individual facades, the roof and/or other significant emitting surfaces. Higher-emitting areas such as vents, fans, exhausts or grilles should be identified separately where practicable.	Model each façade and roof separately, where possible. Represent significant individual sources separately within the propagation model where appropriate. Avoid assuming uniform radiation from a container/enclosure where the manufacturer's data indicate that emissions are non-uniform.
Variation of fan speed with temperature, electrical load or C-rate	Describe how fan speed is controlled and how it varies with operating conditions, including temperature, electrical load and, where appropriate, C-rate. Clearly state whether fan control is based on internal temperature within the container/unit, external ambient temperature, electrical loading, or a combination of these factors. This relationship should be presented graphically and/or in tabular form, including relevant control set points and operating ranges.	Use the manufacturer's operating information to establish which fan speeds are likely to occur under the conditions being assessed. Ensure that the operational data selected for the model correspond to the relevant operating conditions. For example, a unit that is designed to operate reliably in very high temperature locations is unlikely to require fans to operate at 100%, if installed in the Scottish Highlands. Consider whether multiple operating scenarios are required, for example day/night, summer/winter etc.
Variation of sound output with fan speed	Provide acoustic data showing how sound output varies with fan speed. Where different fan operating modes exist, provide acoustic data for each significant mode or fan speed range. Graphical presentation of sound level against fan speed, supported by tabulated data where possible, is preferred.	Use the relationship between fan speed and sound output to select appropriate acoustic inputs for each operating scenario. Consider representative and, where appropriate, worst-case operating conditions rather than assuming that the maximum fan speed applies continuously.
Operating mode	Clearly identify the operating modes relevant to the equipment, such as charging, discharging, standby, night-modes etc. State the acoustic output associated with each significant mode where these differ.	Determine which operating modes are relevant to the assessment and ensure that the corresponding acoustic data are used.
Measurement uncertainty	Report measurement uncertainty associated with the acoustic data, where available, and identify the measurement standard and methodology used to determine it.	Consider the stated measurement uncertainty when assessing the reliability and robustness of the manufacturer's data. Where uncertainty is significant or unavailable, this should be reflected in the assumptions and limitations of the assessment.
Equipment configuration	Clearly identify the equipment configuration to which the acoustic data apply, including the equipment model, electrical rating, type of cooling systems, enclosure/container configuration and any other features that may affect sound emissions.	Consider whether the tested configuration is representative of the equipment proposed for the project. Where the proposed configuration differs from the tested configuration, identify and account for any potential differences in sound emissions.

7 Sound Level Propagation Modelling

7.1 Overview

- 7.1.1 Two approaches for propagation modelling are presented. The first approach is a simplified model intended for use at the site selection and screening stage only i.e. prior to any planning application. The second approach is for a detailed model that should be used at the planning application stage (for both EIA and non-EIA developments), and for detailed design, such as may occur during procurement.

7.2 Propagation Modelling Standards

- 7.2.1 There are several nationally and internationally recognised sound level propagation models that are used for the prediction of sound pressure levels at receptor locations. These propagation methods vary in terms of their complexity and the level of detail required for each modelling parameter.
- 7.2.2 This Good Practice Guide considers a UK context, and the recommended propagation model for the prediction of BESS and PV sound levels in the UK is ISO 9613-2 (13), alongside the recommendations in the accompanying ISO 17534-3 (14).
- 7.2.3 Whilst no guidance on what propagation model to use is explicitly given in the Overarching National Policy Statement for Energy (EN-1) (15) or the National Policy Statement for Renewable Energy Infrastructure (EN-3) (16), it is noted that ISO 9613-2 is mentioned in National Policy Statement for Electricity Networks Infrastructure (EN-5) (17), which considers the use of overhead lines.
- 7.2.4 The use of commercial or inhouse software for sound level predictions can be used, but with care, and the practitioner should be familiar with any nuances, options and peculiarities of the chosen software. All software users should be confident that the results are accurate, consistent, and comply with test cases, such as those in ISO TR 17534-3.

7.3 Simplified Propagation Model

- 7.3.1 A simplified A-weighted broadband propagation model can aid in site selection and screening prior to a planning application or EIA scoping.
- 7.3.2 Use of the simplified model can also be helpful to determine the requirement for a noise impact assessment, where the separation distance between a proposed development and nearest noise sensitive receptor is between 1 km to 2 km (see 4.2.3). It should never be used, however, where the requirement for a full noise impact assessment has been scoped in.
- 7.3.3 The simplified model is presented in Equation 1, which is based upon ISO 9613-2 and modified on the Working Group's experience. The SPL, $L_{p,i}$, at the receptor point, i , is calculated from the logarithmic sum of the SWL of all sources within a distinct area, $L_{W,Tot}$, minus the attenuation for spherical geometric divergence for a point source (-11 dB), atmospheric attenuation at 10°C at a relative humidity of 70 per cent at 500 Hz⁴ (1.93 dB per km), and hard ground (+3 dB), as follows

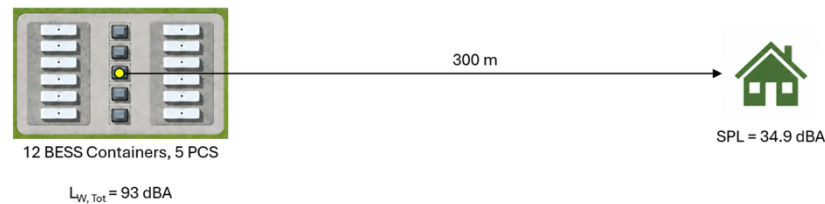
⁴ Value taken from the 1/3 octave preferred frequency of 500 Hz Table 1(g) and applied to the whole 1/1 octave band, as per the ISO 9613-2 recommendation.

Equation 1

$$L_{p,i} = L_{W,Tot} - 20 \log_{10} \left(\frac{d_i}{d_0} \right) - 8 - \frac{1.93d_i}{1000}$$

where, d_i , is the distance between the source and the receptor in metres and the reference distance, d_0 , is 1 m. The sound source position for the distinct area should be the centre point of that area, as shown in Figure 7-1.

Figure 7-1: Simplified model example. One BESS compound



7.3.4 The total SWL used in Equation 1 $L_{W,Tot}$, is calculated by logarithmic summation of the SWL of each source with the distinct area, $L_{W,i}$, for the total number, N_{Tot} , of each source, N_i , and is given by

$$L_{W,Tot} = 10 \log_{10} \left[\sum_{i=1}^{N_{Tot}} N_i 10^{(0.1L_{W,i})} \right]$$

7.3.6 If the result needs to be rounded, then rounding to the nearest integer shall be done on the final SPL result only. Rounding shall not be performed during any of the preceding and intermediate calculation steps. Note that Equation 1 should not be used for the calculation of SWL from 1 m SPL and vice versa.

7.3.7 If the development consists of several distinct areas, such as multiple fields for a PV site where string inverters may be installed across many locations, then the calculation should be completed for each distinct area, based upon the professional judgement of the practitioner. Examples are provided in Figure 7-2 and Figure 7-3. The result shall be combined by logarithmically summing the calculated SPLs.

Figure 7-2 Simplified model example. One HV compound and two PV fields

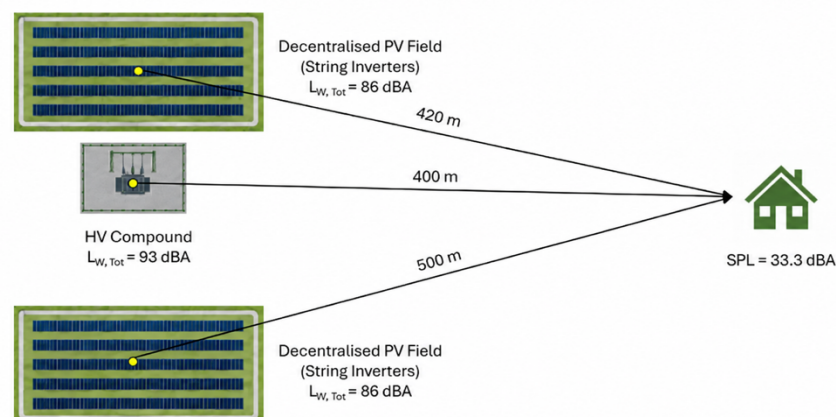
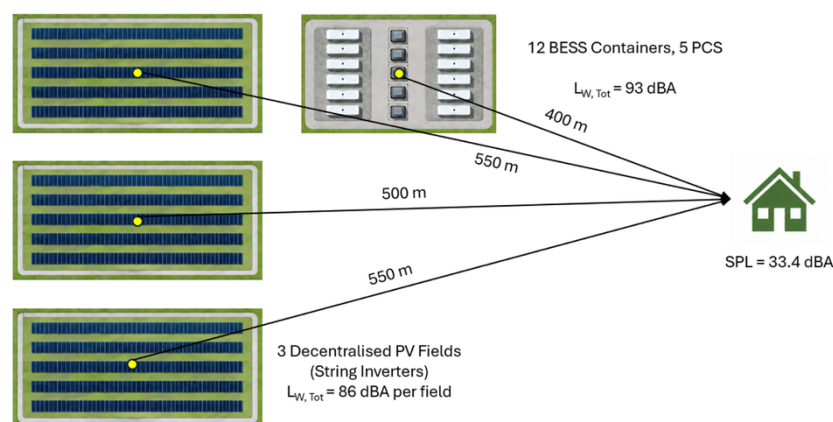


Figure 7-3: Simplified model example. One BESS compound and three PV fields



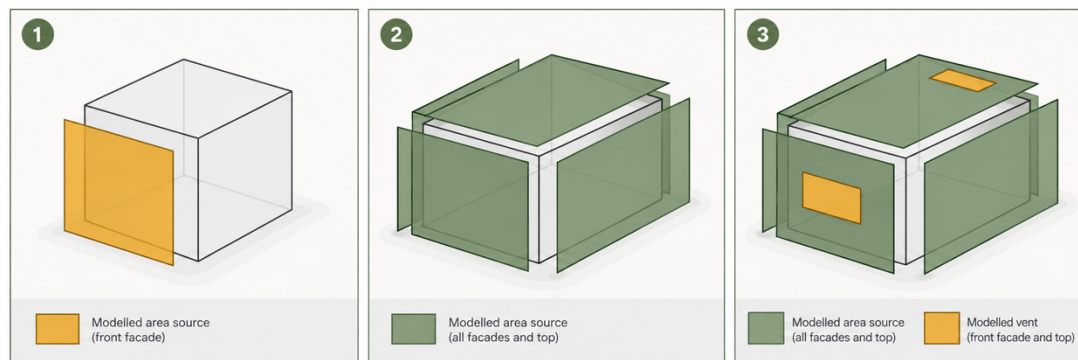
7.4 Standard Propagation Model

- 7.4.1 The standard method for propagation modelling shall follow ISO 9613-2, alongside the recommendations in the accompanying ISO 17534-3.
- 7.4.2 Detailed guidance on the use of source sound level data within the propagation model is provided in Section 6 and additional guidance in respect of operational parameters that may be useful to inform the modelling assumptions is given in Section 5. The information provided below, however, is a summary of the general specifications recommended for modelling and is not just specific to source sound level data.
- 7.4.3 Some developments may already have a preferred plant selection, however, the majority of schemes will not have this detail during the planning stage; therefore, it will be necessary to consider representative candidate plant that could be installed at the site. It is good practice to agree the choice of plant between the developer and the practitioner, and care should be taken to ensure the selected candidate plant is appropriately specified (electrically) and the numbers, layout and specification of plant defined to inform a realistic worst-case assessment (see 2.2.15 and Sections 2 and 3 more generally).
- 7.4.4 It is recommended that the source sound level data used are SWL data, as opposed to SPL data. The use of SPL data can be susceptible to increased uncertainty owing to limited knowledge of the method of measurement, though it is acknowledged that some SPL data may be appropriate for use, if SWL data is not available. Regardless, the reference for the source data should be stated when reporting.
- 7.4.5 Source data should be provided in either 1/1 octave data ranging from 63 Hz to 8,000 Hz, or 1/3 octave frequency bands ranging from 50 Hz to 10,000 Hz. For detailed modelling requirements, the attenuation terms for 1/1 or 1/3 octave frequency bands are required.
- 7.4.6 The resolution of the source and attenuation bands should be consistent throughout the calculation, such as 1/1 or 1/3 octave bands. Source data from 1/3 octave bands can be combined to 1/1 octave bands, prior to model input; however, 1/1 octave band data shall not be converted to 1/3 octave band data.
- 7.4.7 The use of broadband source data should generally be avoided, although this may be appropriate for use within the simplified modelling approach described above. If, however, only broadband data are available, then it will be necessary to consider (and report) which

frequency band has been used for the propagation parameters. ISO 9613 advises that the 500 Hz (1/1 octave band) should be used, however, it may be appropriate to use an alternative frequency depending on the sound source being modelled, for example, a transformer whose sound energy is expected to be concentrated around 100 Hz. Any deviation from the 500 Hz band should always be justified in any report.

- 7.4.8 If the practitioner is only provided with broadband data for a given item of plant, it may be appropriate to use a spectrum for a known typical or similar item of plant. The spectrum should be adjusted to equal the broadband level. If this approach is adopted, it shall be clearly stated and referenced in any report.
- 7.4.9 It is recommended that most sound sources are modelled as a box to differentiate the positions of sound sources, such as air intakes and outlets (see Figure 7-4). This will help to identify areas requiring noise mitigation.

Figure 7-4: Differing approaches to modelling of a 'box' sound source



- 7.4.10 Image 1 illustrates how a sound source could be modelled where one side is dominant in terms of sound output. This could be the case for a BESS cube, where the entire front of the unit is an open vent and all cooling plant is located in this area, and is particularly relevant when they are located in blocks, side by side and back to back.
- 7.4.11 Image 2 illustrates how a sound source could be modelled when either
- i) a single SWL is provided for the entire unit (a relatively common approach, although generally less appropriate for detailed noise modelling), or
 - ii) separate SWLs are provided for each façade (the preferred approach).
- 7.4.12 Where a single SWL is given for an entire item of plant (i), the practitioner should ensure that the combined SWL of all modelled sides of the box, is equivalent to the given SWL for the whole unit.
- 7.4.13 In some cases, as illustrated in Image 3, manufacturer supplied data or on-site measurements may identify specific areas with higher sound level outputs, typically air inlets and exhausts. These should be modelled independently where the available information allows.
- 7.4.14 For small sound sources such as string inverters, the use of point sources can be considered adequate, however, for most items of BESS and PV plant, this will not be appropriate and the box approach is considered more suitable unless the manufacturers data sheet recommends otherwise.

- 7.4.15 Ground within BESS compounds and HV compounds should be modelled as acoustically hard, unless a different ground factor can be justified. Although BESS and PV developments are often located in rural areas, BESS and HV equipment is commonly installed on concrete slabs, compacted gravel or other relatively hard surfaces. Applying a generic soft-ground assumption across the whole site may therefore, overstate ground attenuation. Softer ground assumptions may remain appropriate for Solar PV, subject to the actual site conditions.
- 7.4.16 Topographical data should be incorporated within the propagation model. Free open-source Ordnance Survey (OS) topographical data such as Terrain 50 and national LiDAR campaigns can be appropriate for use, but there may be instances where more detailed data is required.
- 7.4.17 Topographical data is typically included within the model in the form of contour line files (often provided in a polygon format such as .shp or DXF) or raster datasets such as ASCII/TIF grid data. For avoidance of doubt, digital terrain model (DTM) data should be used, and not digital surface model (DSM) data, as the latter includes elevation data of surface features such as trees and buildings, which can cause unwarranted barrier effects.
- 7.4.18 In instances where final ground elevation levels are to be altered to accommodate the BESS or PV development (i.e. cut/fill of land or flattening of the site area), then this should be incorporated within the model. Sometimes this data can be provided by the developer as part of wider topographical surveying works, however, it can also be incorporated by the practitioner manually. For BESS developments, it is recommended that if the final site level varies, then an averaged Above Ordnance Datum (AOD) level is assigned to a single contour line that encapsulates the site area, or separate contour lines added for each terraced area.
- 7.4.19 Where manual contour lines have been added in, it will then be necessary to remove any residual topographical data within the manually flattened area that may have been imported with the original topographical data set. Having height fluctuations across the site can result in inaccuracies in modelling, such as over estimation of screening and/or tilted sound sources, causing some sound sources to be incorrectly positioned.
- 7.4.20 The Practitioner should be cautious when applying mitigation, such as including enclosures, as this may change the source emission height and directionality of the source. For example, a sound enclosure may move the source of the cooling from the vertical side of the plant to the horizontal roof of the plant, which may reduce the effectiveness of other mitigation measures, such as barriers.

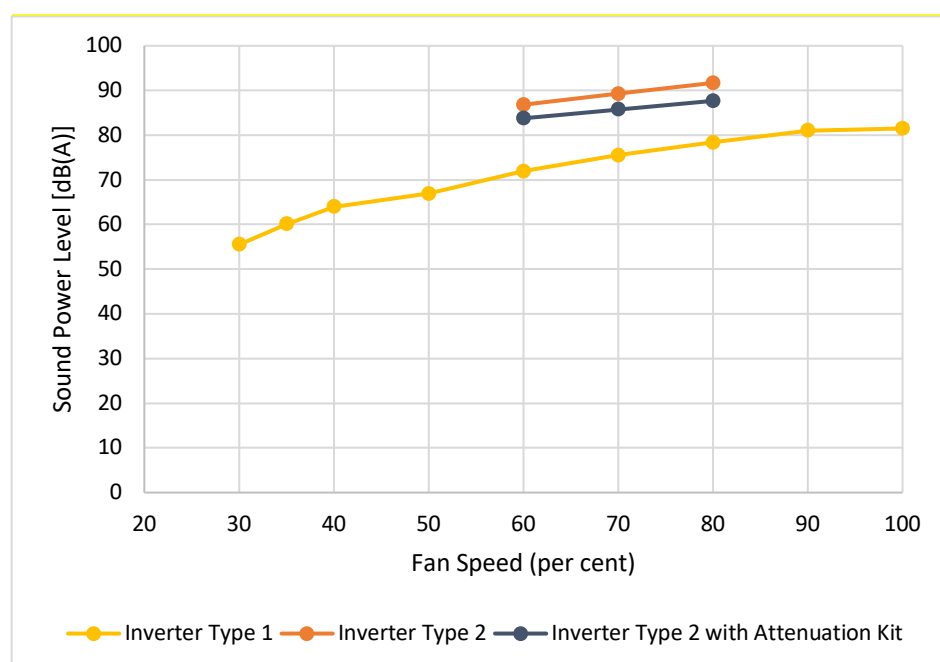
7.5 Modelled Scenarios

- 7.5.1 When predicting the SPL at receptor locations, it is prudent to consider either the typical-case or the realistic worst-case. The typical case would be the normal day to day operation of the plant, whilst the realistic worst-case may be when the plant is operating at its expected maximum. This does not mean that all plant is operating at its theoretical maximum, which may be a 'worst-case scenario' but is unlikely to be a realistic worst case. The assumptions for operational parameters of PV and BESS used in any model should be declared, with supporting information, in any associated reports.
- 7.5.2 The operation of PV developments tend to be much more regular than that of BESS, which can vary significantly depending on the markets they are operating within. As such it may be appropriate to consider a typical case scenario for PV. For BESS, however, a realistic worst-case scenario should be considered, as 'typical' is likely to be very hard to define.
- 7.5.3 Whereas PV developments are likely to operate in line with available daylight, BESS developments rarely operate with such regularity. It would not normally be appropriate to

declare in any BESS assessment that the BESS will only operate for n number of hours a day, or charge/discharge n number of times per day. As an example, for a BESS with a storage duration of two hours, it would be reasonable to think that it may discharge for two hours in the morning, charge for two hours during the afternoon, discharge again for two hours in the evening and then charge for another two hours ready for the next day. In reality, this is unlikely to be the case. Export times may last as long as two hours but could also be much less depending on the energy requirements of the grid, whilst import times may last longer than two hours, as charging may occur slowly.

- 7.5.4 A realistic worst-case model for BESS would predict the greatest SPLs expected over reference times of 15 minutes at night and 1 hour during the day-time and it should be assumed that these levels could be reached at any time. This is in contrast to a typical-case model for a PV development, which could consider the normal cycles of export that are likely to be dictated by sunlight conditions, time of year etc.
- 7.5.5 The SWL for some plant items will vary by fan speed, therefore assessing the typical-case and realistic worst-case may need to be adjusted for the reference time, for example, maximum fan speeds may vary between daytime and night-time periods. A daytime and night-time prediction should, however, be conducted regardless of technology.
- 7.5.6 Plant manufacturers may provide information that can give detailed SWLs as a function of fan speed and/or temperature. An example of the variation of SWL with fan speed is given in Figure 7-5. A single value may be appropriate to characterise the realistic worst-case or typical-case SWL, such as choosing the 80 per cent fan speed for the worst-case and 60 per cent for the typical-case.
- 7.5.7 It should not be assumed that 100% fan speed represents a worst-case scenario as many units are designed to operate in environments with far greater ambient temperatures than typically occur in the UK. Accordingly, fan operations may never exceed a particular speed for a given site and confirmation of maximum anticipated fan speeds should be sought from the plant manufacturer or system integrator on a project by project basis.

Figure 7-5: Comparing SWLs for different inverters and fan speeds



8 Noise Control and Mitigation

8.1 Overview

- 8.1.1 This section of the guide considers the control of environmental airborne sound from BESS and PV developments at noise-sensitive receptors. It does not apply to controlling sound in the workplace (occupational noise).
- 8.1.2 Although some aspects will be applicable to operational developments, this section is intended to address the control of sound during the development of a new site only. The guidance given is intended to be followed at the design and procurement stages, with the aim of reducing the risk of adverse noise impacts on nearby sensitive receptors.
- 8.1.3 Guidance on how to design an individual item of BESS or PV plant to meet a specific acoustic performance criterion is not provided, as this requires specialist expertise and is dependent on the equipment manufacturer. Similarly, mitigation of tonal characteristics at source requires specialist expertise and is dependent on the equipment manufacturer.
- 8.1.4 For the purpose of this guide, “*Noise control*” means the general concept of limiting the impacts of environmental airborne sound. “*Mitigation measures*” means the specific measures that may be applied in order to control sound to meet relevant criteria.

8.2 When to consider mitigation and noise control

- 8.2.1 Noise control should primarily be achieved by avoiding adverse sound immissions at sensitive receptors through appropriate site selection, layout and design. Where this is not practicable, mitigation measures may be required to reduce immission levels and achieve the relevant noise criteria.
- 8.2.2 Table 8-1 provides an overview of when it is appropriate to consider the specification and implementation of mitigation measures.
- 8.2.3 Noise impact assessments supporting planning applications are typically based on candidate equipment and indicative layouts. However, the exact mitigation requirements will depend on the final plant selection, plant locations and site layout determined during procurement and detailed design. Mitigation measures identified at the planning stage should therefore be treated as indicative and should not be relied upon as the final design solution.
- 8.2.4 It is good practice to identify and implement any required mitigation measures before a development becomes operational. Where necessary, mitigation measures should therefore be specified as part of the procurement and detailed-design stages of the development.
- 8.2.5 A wider range of mitigation measures is generally available, and is usually simpler and more cost-effective to implement, while a new site remains in development. Retrofitting measures after a site becomes operational can be more complex, disruptive and constrained.
- 8.2.6 Once a site is operational, logistical, physical and safety constraints may limit the options available for implementing mitigation measures. Examples include:
- the inability to de-energise all or part of the site;
 - insufficient space for specific noise-control elements;
 - restrictions on the use of available space arising from fire safety, access or similar requirements;

- contractual obligations, responsibilities and liabilities; and
- difficulty isolating and measuring individual items of plant, or assessing mitigation performance, owing to extraneous sound from elsewhere on the site.

Table 8-1: Mitigation Through Project Development Stages

Development Stage	Approach to Noise Control
1 Feasibility Studies	Consideration of mitigation measures are not normally required, however, site selection and early layout design should seek to avoid adverse noise impacts at sensitive receptors.
2. Planning Application	Assess likely noise impacts using candidate equipment and indicative layouts. Any mitigation identified should be treated as indicative only and should not be relied upon as the final design solution.
3. Procurement & Detailed Design	Optimum stage for specifying noise control. Confirm requirements against the final equipment and layout, and incorporate measures into the detailed design, specifications and procurement process.
4. Construction & Commissioning	Provide for fine-tuning and optimisation of installed equipment and operational parameters to reduce sound levels, where practicable.
5. Operation	Retrofitting mitigation may be complex and constrained by operational, safety, physical and contractual factors; available options are often limited and more costly.

8.3 Identifying sound sources that require mitigation

- 8.3.1 Effective noise control requires the identification of sound sources and quantifying them in terms of their contribution to the total specific sound level at a receptor. Mitigation measures are generally most effective when applied to the sources that contribute greatest to the total sound level at a receptor.
- 8.3.2 It is normally necessary to undertake detailed propagation modelling in order to quantify the contribution from each item of plant to the total specific sound level at each receptor. Once the receptors where noise control is required have been identified, a list of each item of plant contributing to the sound level at that receptor should be produced, ordered by greatest contribution first. Where the contribution of a specific item of plant (or group of similar items of plant) is at least 10 dB below the total specific sound level, it is not necessary to consider this sound source for mitigation measures (noting that when the more dominant sound sources are mitigated, this may bring previously disregarded sound sources back into consideration).
- 8.3.3 In some instances, it may be beneficial to reduce the sound output from a particular unit type across the entire development site, for example, lowering the sound output of all of the inverters. However, due to the large scale of some BESS and PV developments, in many cases wholesale changes will not be required, and individual items of plant (for centralised PV developments) or smaller groups of plant should be considered, for example, all inverters within 'field A'.

8.4 Constraints on Noise Control

8.4.1 Noise control for a BESS or PV development should not be considered in isolation but as one of many factors in the design and operation of the development. Mitigation measures introduced to control sound may affect other design factors or may be unfeasible due to other relevant constraints. Examples of other factors and relevant constraints include

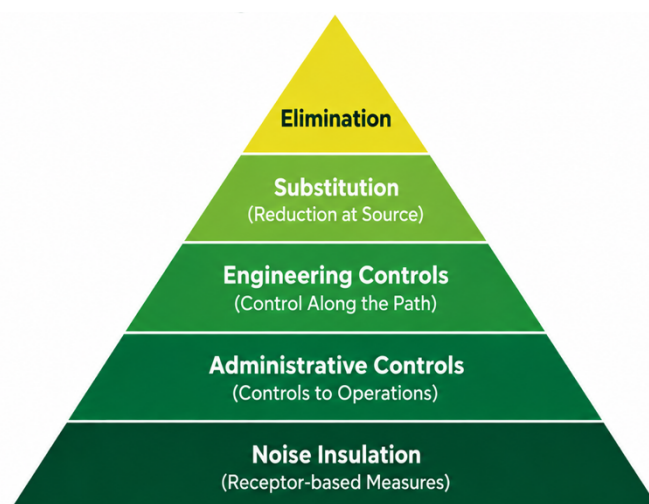
- cost
- planning requirements: mitigation measures that are fixed structures could require additional planning permission, for example acoustic barriers
- practicality of implementing the mitigation measure(s)
- the correct functioning of the equipment and warranty limitations, for example warranties may be void if fan speeds are lowered beyond a certain set point
- the layout of the site
- rated electrical capacity of the development, including export capacity obligations
- environmental and technical constraints, such as visual and landscape, hydrology, ecology, etc.
- equipment supply chain
- timescales for design, construction and operation; and
- wider sustainability objectives

8.4.2 With due regard to 8.2 and 8.4.1 above, it is beneficial for acoustic practitioners to collaborate with other disciplines early on in the design process to consider noise control and to apply mitigation measures into the design of the development if required. This will assist in ensuring that mitigation measures are site-specific, coordinated, proportionate and do not result in unintended adverse consequences in other areas.

8.5 Hierarchy of Noise Control

8.5.1 If noise control is required, it is recommended that sound should be managed in accordance with the recognised hierarchy of noise control, as shown in Figure 8-1, which prioritises mitigation measures based on effectiveness, efficiency, and sustainability. The hierarchy emphasises the importance of eliminating or reducing sound at source and through design, rather than relying on transmission path or receptor-based mitigation. The former measures are considered to be the most effective means of mitigation.

Figure 8-1: Hierarchy of Noise Control



Elimination

- 8.5.2 Elimination represents the most effective form of noise control and involves the complete removal of a sound source. Total elimination may be achieved due to the initial siting of a development so that sound emitting equipment is located sufficiently far away from sensitive receptors, such that sufficient noise control of the development is inherent due to its siting and/or design. While total elimination of operational sound is not always achievable for solar and PV developments, opportunities for partial elimination should be explored at the design stage. This may include avoiding unnecessary or duplicated plant, rationalising the number of inverters, PCS units or transformers, and selecting system configurations that minimise the quantity of sound emitting equipment. Early collaboration between acousticians, electrical engineers and equipment suppliers is essential to identify such opportunities without compromising the functionality of the development.

Substitution (Reduction at Source)

- 8.5.3 Where elimination is not practicable, substitution should be pursued through the selection of inherently quieter equipment. This may include specifying plant with lower sound power levels or selecting equipment with low-sound or variable-speed cooling systems. Where possible, detailed manufacturer data or verified operational data should be used in place of overly conservative assumptions to accurately determine the mitigation measure(s) required in practice.
- 8.5.4 As described in Section 2.3, the combination of plant can vary significantly between manufacturers, and plant combinations and layouts should be considered very carefully. When looking for quieter layout alternatives, it is not as simple as comparing the source sound levels of similar items of plant. For example, Supplier A may provide an inverter with a sound power level of 75 dBA and require 20 of those inverters to be installed, whereas Supplier B has an inverter with a sound power level of 80 dB, but only requires 4 units to be installed.
- 8.5.5 In the above example the total sound power level would be 88 dB for Supplier A and 86 dB for Supplier B. Substituting one item of plant with another of a slightly higher sound level output may reduce overall sound levels, depending on the required number of plant and its location(s) within the site. This could sometimes be achieved by specifying a higher electrical rating, which would reduce the overall number of plant items.

Engineering Controls (Control Along the Path)

- 8.5.6 Engineering controls are intended to disrupt the sound propagation between source and receptor. Measures may include site layout design to maximise separation distances to sensitive receptors, use of buildings, containers or landform to provide screening, acoustic enclosures for plant items, and acoustic barriers or bunds to interrupt direct sound paths.

Administrative Controls (Controls to Operations)

- 8.5.7 Administrative controls can manage the timing of sound generation and can provide effective supplementary mitigation. Potential mitigation measures include restricting or optimising operations during certain time periods where feasible, implementing seasonal or temperature-dependent operational strategies and minimising the number of sound emitting items of equipment operating at the same time.
- 8.5.8 For BESS and PV, potential administrative controls will be specific to the equipment operating at that development. In many cases potential administrative controls may be unfeasible due to other relevant constraints and/or may compromise the functionality of the development. In particular it is noted that because a development may operate in many markets, limiting the times of operations is likely to be impractical or impossible. For these reasons, specific examples of administrative controls for BESS and solar facilities are not provided in this guide.

Sound Insulation (Receptor based Measures)

- 8.5.9 Sound insulation or other receptor-based mitigation measures represent the least preferred option within the hierarchy of noise control. Such measures do not address sound at source and may be inappropriate or inconsistent with planning guidance. Receptor-based mitigation measures should therefore only be considered where all other reasonable mitigation measures have been exhausted and where their use can be robustly justified on a site-specific basis. Receptor-based mitigation measures will involve the consideration of building acoustics, which are specific to an individual property, and are outside the scope of this document. For these reasons mitigation measures at the receptor are not considered further in this guide.

8.6 Example Mitigation Measures for BESS and PV Developments

- 8.6.1 Example mitigation measures for BESS and PV developments are provided below and ordered according to the hierarchy of noise control (tier 1 down to tier 5). If mitigation measures are required, those at the top of the hierarchy are to be prioritised first and those at the end of the list are to be considered last, taking into account all other constraints on mitigation, as detailed in 8.4.1.
- 8.6.2 Where possible, detailed manufacturer data or verified operational data should be used in place of overly conservative assumptions to accurately determine the mitigation measure(s) required. For example, propagation models that assume plant is operating with maximum sound level emissions corresponding to very high ambient temperatures are not realistic for developments in the UK, and in that case, any mitigation measures determined would be overly conservative and not necessarily required in practice.

Tier 1 Mitigation Measures: Elimination

- 8.6.3 Eliminate (remove) the sound source if possible. The primary mitigation measure to achieve this is to locate the development so that it is sufficiently far away from sensitive receptors,

noting that, for most developments, site location is principally determined by proximity to the electricity user or National Grid substation.

- 8.6.4 Mitigation measures also include reducing the number of sound sources where possible by removing some items of equipment. This may include avoiding unnecessary or duplicated plant, rationalising the number of inverters or transformers, and selecting system configurations that minimise the quantity of sound emitting equipment.

Tier 2 Mitigation Measures: Substitution

- 8.6.5 Where elimination is not possible, substitution should be pursued by reducing the sound level emissions of the source. Mitigation measures include substitute an item of equipment with an equivalent item of equipment that has a lower sound power level.
- 8.6.6 For PV developments, consider swapping string or central inverter options. Consider swapping between centralised and decentralised layouts.
- 8.6.7 Specifically for PCS and battery cubes or containers
- Where the equipment has a 'low-noise' mode, operate the unit in this low-noise mode where possible. Note that this can have an impact on the electrical and thermal performance of the equipment.
 - Where the equipment has a variable-speed cooling system, operate the cooling system at a lower speed through the operational parameters of the unit. Note that this can have an impact on the electrical and thermal performance of the equipment.
 - Where the equipment has a fixed-speed cooling system, reduce the set point fan speed to operate the cooling system at as low a speed as is possible for the site – this would need to be determined by the plant supplier, considering the electrical rating and anticipated loading of equipment, as well as local ambient temperatures. Note that reducing the set point fan speed can affect warranties.
 - Where the equipment manufacturer offers an optional sound attenuation kit (such as is applied to the air inlets/outlets of the unit), apply the attenuation kit. Note that this can have an impact on the electrical and thermal performance of the equipment and also increase the size of the unit.

Tier 3 Mitigation Measures: Engineering Controls

- 8.6.8 **Positioning of equipment:** Position equipment as far away from receptors as possible through site layout design. Many sites have a limited area available for equipment and a specific item of equipment, for example, a grid transformer, may require to be in specific location. Therefore, there are often significant constraints on how far the equipment can be positioned away from receptors.
- 8.6.9 Some equipment, such as PV inverters (string or centralised) have flexibility in their location and consideration should be given to position those within the PV arrays as far as reasonably possible from receptors. For example, the selection of a substation location and/or BESS compound in a hybrid/co-located development, could maximise the distance to receptors as an embedded design consideration at an early stage. It should be noted that in order to reduce the specific sound level from a single item of equipment by 6 dB at a receptor, the distance from that item of equipment to the receptor would need to be doubled (based on

- a simple calculation), therefore, it is typically more practical to consider other mitigation measures to achieve such a reduction.
- 8.6.10 **Orientation of equipment:** Orientate equipment that does not emit sound omnidirectionally, so that sound is directed away from the receptor. For example, where HVAC systems, inlet vents or exhaust vents are attached to one side of a unit, orient these away from the most relevant receptor direction. When considering orientation, always consider sound that may be leaving the top of a unit – roof mounted fans, for example, may render orientation of plant ineffective.
- 8.6.11 **Consideration of buildings and structures:** Locate equipment such that existing or buildings provide acoustic screening between the equipment and receptors. Similarly, locate proposed site buildings, such as switch rooms, control buildings or personnel welfare buildings, to provide some acoustic screening between equipment and receptors.
- 8.6.12 Where possible position equipment within the development, such that an item of equipment provides acoustic screening between other items of equipment and receptors. For example, by locating inverters between battery storage containers. For PV developments, use solar panels to provide acoustic screening from string inverters.
- 8.6.13 **Natural barriers & landscaping.** Make use of natural barriers, bunds and landform to provide acoustic screening between the equipment and receptors. If there are low lying areas that are suitable for locating noisier items of equipment, which may offer some partial reduction in sound level, then consider using these areas.
- 8.6.14 Where there is existing earth-work material that has been excavated during construction of a development, a bund can be constructed using that material in a suitable location to provide acoustic screening between equipment and receptors.
- 8.6.15 In respect of the use of trees around a development, it should be noted that attenuation from forestry (foliage) applies only where the foliage is sufficiently dense to completely block visibility through the propagation path. It is not a suitable basis for assuming meaningful attenuation from ordinary landscaping or scattered trees.
- 8.6.16 Foliage needs to be sufficiently dense for a considerable extent (>50 m) to benefit from a small amount of attenuation,⁵ however, a sparse tree line or tree belt as part of landscaping plantation will not offer a significant reduction in sound propagation and should not be taken into account.
- 8.6.17 Propagation modelling should only consider dense foliage assuming the forestry area will not be felled/removed in future. Similarly, any dense planting around a site may need many years to achieve any meaningful attenuation, so should not normally be considered.
- 8.6.18 **Acoustic barriers:** Barriers should be placed close to the equipment for maximum acoustic effect, notwithstanding ventilation, access, or other design requirements. It should be noted that the attenuation at the receptor provided by the barrier is typically modest and is unlikely to be as great as 10 dB(A) unless the barrier is very tall or is very close to the source (or receptor). It should also be noted that the performance of a barrier is highly dependent on the dimensions, materials, density, presence of air gaps, design of the barrier, and quality of installation, and performance must be adequately maintained over the lifetime of the development.

⁵ ISO 9613-2:2024 suggests attenuation at 500 Hz is equal to 0.05dB/m where foliage is sufficiently dense. Note: level of attenuation varies by frequency.

- 8.6.19 Attenuation from a barrier should never be assumed and should always be modelled. Barrier performance is often overestimated and can be less effective than expected. Furthermore, introducing a barrier can redirect reflected sound to another receptor, potentially increasing immission levels in certain areas.
- 8.6.20 In general, the use of a perimeter fence or similar as an acoustic barrier is unlikely to provide meaningful attenuation. If properly designed, it may offer some attenuation to plant located alongside the barrier but may be ineffective at attenuating sound from plant located further into the site.
- 8.6.21 **Enclosures:** Enclose an item of equipment in an acoustic enclosure (either fully or partially). Enclosures to fully encase items of equipment are specific to that item and require specialist expertise to design and manufacture, to be both effective at mitigation and to maintain the correct functioning of the equipment. Individual enclosures are typically high in cost, specific to a manufacturer/model of equipment and not necessarily available. Enclosures can also require additional area, so can impact on the layout of a site. Accordingly, unspecified individual enclosures to encase items of equipment should not be relied upon, particularly if the specific item of equipment that will be installed on the development is unknown.
- 8.6.22 **Relocate into buildings:** Relocating items of equipment from outdoors to inside a building should only be considered where all other mitigation measures have been exhausted, as it has a major impact on all aspects of a development. It should also be noted that plant located within a building will often require associated cooling plant, which tends to be located externally (often at roof level), or utilises ducting to the outside of the building, thereby introducing additional sound sources.

Tier 4 Mitigation Measures: Administrative Controls

- 8.6.23 As stated in 8.5.7, specific examples of administrative controls for BESS and PV developments are not provided in this section of the guide.

Tier 5 Mitigation Measures: Sound insulation

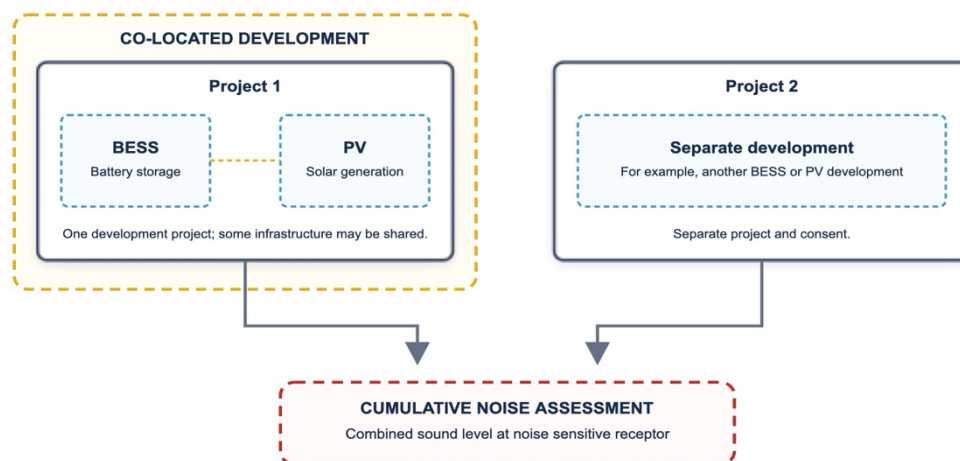
- 8.6.24 As stated in 8.5.9 examples of sound mitigation measures at the receptor are not provided within this section of the guide.

9 Co-located Developments, Cumulative Impacts and Progressive Development

9.1 Overview

- 9.1.1 Co-location (in this document) refers to having two or more forms of technology as part of the same project. This guide primarily considers co-located BESS and PV developed together, as opposed to BESS or PV alongside other technologies, however, the principals will generally apply to all co-located technologies.
- 9.1.2 In a co-located development, two technologies may share some key bits of infrastructure, such as a HV transformer, and will usually form part of the same planning application or consent. Although they may be developed more-or-less in parallel, and by the same entity, they can also be built out in phases. Beyond this, there are a range of ways in which co-located projects may be developed and operated.
- 9.1.3 This section also considers cumulative sound, which refers to instances where sound from multiple projects may influence the ambient sound level at a given assessment location. It also considers progressive development, which is the cumulative sound environment that may develop from the continuous development of an area over time.
- 9.1.4 Figure 9-1 illustrates how noise impact assessments are required to consider both co-located and cumulative developments.

Figure 9-1: Elements of Co-located and Cumulative Assessments



9.2 Assessment of Co-located Developments

- 9.2.1 Two or more technologies forming part of the same project (i.e., sharing grid connections, land, planning consent etc.) may need to be assessed such that noise limits applied to the project need to be met by the two technologies operating together. As both technologies will generally be under the control of the same entity it is reasonable to expect that entity to be able to regulate sound in such a way as to keep levels within a common shared noise limit.
- 9.2.2 In some cases, different technologies, sharing a consent, grid connection etc., may be constructed and / or built under different legal entities or sold post construction. This may

introduce some further complexity but should not change the fundamental principles in this guide.

- 9.2.3 Careful consideration should be given to the potential operational hours of each element of the development and how these may interact. Whilst a BESS may operate at any time of the day or night, the sound level output of the PV element would be directly affected by sunlight hours; so daytime only operations during the winter and encroaching into 'night-time' during the summer. Accordingly, it may be necessary to model and assess multiple operational scenarios outwith the traditional daytime (07:00 – 23:00) and night-time (23:00 – 07:00) periods.

Co-location with a wind farm.

- 9.2.4 It is not possible to quantitatively assess the cumulative sound from wind farms co-located with other technologies as the sound from wind turbines is assessed under different guidance⁶ (ARWTN, 2026). Wind turbine operations and BESS / PV operations must therefore be considered separately in two individual noise impact assessments. It may be appropriate, however, to undertake a qualitative co-located assessment if the wind farm and co-located technology could both reasonably have an adverse noise impact at a given location.
- 9.2.5 If a cumulative operational sound level is to be estimated, a suitable correction should be used to convert between the LA90 metric used in wind farm noise assessments, and the LAeq sound level metric used in BS 4142. This would allow the wind farm sound level to be added logarithmically to the other technology(s)' sound level. It is stressed, however, that this cumulative sound level should neither be assessed following BS 4142 or ARWTN, and cannot be assessed quantitatively. It can only be used to help inform a qualitative assessment.

9.3 Cumulative Assessments for Planning Applications

- 9.3.1 Cumulative sound refers to the sound from multiple projects (which each in themselves may consist of multiple co-located technologies) operating together.
- 9.3.2 A cumulative noise limit applied to different projects should not be used, since such limits are not (normally) enforceable; the meeting of a cumulative limit would be dependent on the behaviour of multiple independent parties, of which the operator would have no control.
- 9.3.3 It is common for BESS and PV developments to be proposed close to substations, however, where substations have a reasonable amount of available connection capacity, this can result in several projects being clustered around them, creating multiple potential scenarios. Early discussions with an Environmental Health Officer or Planning Officer are essential to determine which scenarios warrant a noise impact assessment. It is important to remember that not all proposed developments may be consented and built out, especially when several projects compete for limited grid connection capacity i.e. the substation might not be able to accommodate every proposal.
- 9.3.4 When undertaking cumulative assessments, it may be necessary to include additional receptors beyond those closest to the proposed development. This is particularly relevant if predicted sound levels are low at a specific receptor from the proposed project but high cumulative sound levels could arise when considering neighbouring projects. Cumulative noise levels at receptors located between developments may be higher than at receptors

⁶ Wind turbine noise in the UK is assessed in accordance with 'Assessment and Rating of Wind Turbine Noise'(2026). It cannot and should not be assessed in accordance with BS 4142, even in a cumulative setting.

located closest to one of the developments. Accordingly, a cumulative noise impact assessment may need to consider a larger study area.

- 9.3.5 BESS and solar projects are often located near to grid substations. These may have been operating for many years and as such the sound from the substation can legitimately be regarded as part of the background sound level, though this should be discussed and agreed with the relevant authority.
- 9.3.6 When assessing cumulative scenarios care should be taken to ensure that BS 4142 character corrections are applied appropriately. For example, character corrections would normally only apply to the proposed development being assessed.
- 9.3.7 Notwithstanding, there are occasions when consideration should also be given to the cumulative impact on the character of received sound at a receptor. For example, the introduction of a HV transformer in a new project could increase the existing tonality at a receptor location that is close to an existing HV transformer, changing it from 'just perceptible' to 'clearly perceptible'.

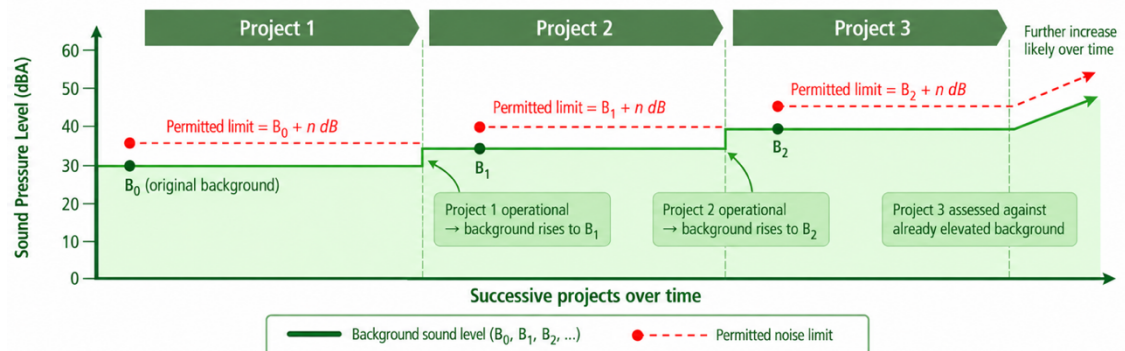
9.4 Considering the Cumulative Sound Environment for Compliance Assessments

- 9.4.1 Pre-construction sound monitoring may be necessary around a consented development site where other developments have been constructed since the original baseline sound level monitoring was completed. This is particularly useful when an existing sound source may be contributing particular characteristics to the sound environment at a location where the new site is expected to demonstrate compliance. Pre-construction monitoring can protect the developer/operator from unnecessary character corrections resulting from pre-existing sound characteristics, which could lead to operational restrictions or the imposition of additional mitigation measures.

9.5 Continuous Progressive Development

- 9.5.1 Where a substation has a large amount of available connection capacity it is not unusual to find several energy generation or electrical infrastructure developments being developed successively over several years. Care must therefore be taken to ensure that any protections put in place at the beginning of the first development are not eroded through subsequent development, for example, as a result of 'background creep'.
- 9.5.2 Background creep describes the progressive upward movement of the measured background sound level as successive developments become operational. If each new proposal is assessed against the background level prevailing at the time of its own survey, earlier consented development may already be contributing to that baseline. If each project is then permitted a noise limit expressed as the newly measured background sound level plus n dB, the permitted sound level can rise with each successive consent.
- 9.5.3 The effect is illustrated in Figure 9-2. Project 1 is assessed against the original background sound level, B_0 . Once operational, it may raise the prevailing sound environment to B_1 . Project 2 is then assessed against B_1 and allowed a correspondingly higher limit. Following operation of Project 2, the background may rise again to B_2 . Repeating the process for Project 3 can erode the protection that the original baseline was intended to provide for nearby residents.

Figure 9-2: Example of background creep



- 9.5.4 One way to avoid this outcome is to retain and use the original, representative baseline data for subsequent noise impact assessments. In this example, Projects 1, 2 and 3 could each be assessed against B_0 , rather than allowing the operational sound from earlier projects to become part of the baseline for later projects. This maintains a consistent reference point for protecting nearby residents and makes the cumulative effect of all projects explicit. The original baseline should be suitably robust, representative of the relevant periods, and appropriate to the assessment location.
- 9.5.5 There can, however, be circumstances in which it is legitimate to consider the operational sound from an existing development as part of the baseline environment. For example, a substation that has operated for several decades may be an intrinsic and established feature of the local sound environment. Whether this is appropriate should be determined case by case, considering the development's history, permanence, operational characteristics and its relationship to the proposed development.

10 Setting of Planning Conditions

10.1 The Six Tests

10.1.1 Whilst the planning systems used to consent developments differ slightly across the UK, consents in all regions can be issued with a series of planning conditions. Separate guidance regarding the use of these conditions is available across the UK, specifically in the 'National Planning Policy Framework' (for England) [1], 'Circular 4/98 The Use of Planning Conditions in Planning Permissions' (for Scotland) [2], 'Circular WGC 016/2014 The Use of Planning Conditions for Development Management' (for Wales) [3], 'Development Management Practice Note 20 Use of Planning Conditions' (for Northern Ireland) [4] and 'OPR Practice Note PN03 Planning Conditions' (for Republic of Ireland) [5]. The guidance documents adopt many of the same principles, including when and why conditions should be used. All four documents also require planning conditions to be:

- Necessary
- Relevant to planning
- Relevant to the development
- Enforceable
- Precise, and
- Reasonable in all other respects

10.1.2 These six requirements are sometimes referred to as 'the tests'. Planning conditions should only be used where they satisfy the six tests.

10.1.3 Whilst it is noted that guidance regarding planning conditions may vary significantly elsewhere in the world, alignment with the six tests may also be desirable in other jurisdictions (for example most stakeholders would want a planning condition to be precise rather than being vague and open to interpretation).

10.1.4 Key considerations with respect to each of the six tests are outlined below.

Necessary

10.1.5 Planning conditions relating to sound (or noise) should normally be expected to protect noise sensitive receptors. If it can be demonstrated that the impacts of sound are negligible (for example due to a significant distance), planning conditions relating to sound might not be necessary.

10.1.6 A planning condition requiring post-completion monitoring, or periodic monitoring, for locations in the absence of complaints is not necessary unless there is reasonable justification that a specific development requires this. In the case of complaints, monitoring can be undertaken to demonstrate compliance with the consented noise limits.

10.1.7 Specific conditions limiting sound pressure levels in certain one-third octave bands or at specific frequencies should be avoided as these are not necessary, provided that noise limits are conditioned through the use of Rating Levels (see 10.1.19).

10.1.8 Noise limits related to low frequency sound or restricting sound character should not be imposed as these are not necessary, provided that noise limits are conditioned through the use of Rating Levels (see 10.1.19).

Relevant to planning

- 10.1.9 Where sound is not a material consideration in the determination of a planning application, a planning condition relating to sound levels should not be included in the consent.
- 10.1.10 Conditions which place requirements on a development regarding nuisance are not relevant to planning as statutory nuisance is not a planning issue. Similarly, conditions which require compliance with other regulatory frameworks (such as building standards, control of noise at work regulations, environmental permitting, etc) are not relevant to planning.
- 10.1.11 Where the content of a proposed condition is not relevant to planning it may be more appropriate to include this content in an advisory note/informative.
- 10.1.12 Conditions which require equipment to be a specific model/manufacturer or to meet a certain accreditation or to meet a specified sound power level are not relevant to planning.

Relevant to the development to be permitted

- 10.1.13 Any conditioned noise limit should relate solely to the proposed development. Conditioned noise limits should not apply cumulatively to multiple sites. In most cases the applicant is unlikely to be in control of the cumulative sound levels. Even in cases where the applicant does control an adjacent site, conditioned cumulative noise limits should still be avoided, as the status of ownership could change over the lifetime of the development.

Enforceable

- 10.1.14 Planning conditions should be defined so that it is straightforward to demonstrate compliance with them and thus provide an effective basis for the control and regulation of sound. Conditions imposed in an unreasonable way, so that it proves impracticable or inexpedient to enforce them, should be avoided.
- 10.1.15 In many cases it would be beneficial for a planning condition to state that in the event of a written request from the relevant authority the methodology for demonstrating compliance is submitted to the relevant authority for agreement before undertaking work.

Precise

- 10.1.16 Noise limits should be defined as specific, measurable values. Any margin for interpretation should be minimised as far as practicable.
- 10.1.17 Noise limits should be determined taking into account the factors relating to context as defined in Clause 11 of BS 4142:2014+A1:2019 and other guidance (such as that provided by the ANC). The condition should not allow for any further adjustment of the noise limits, for example by re-evaluation of context or re-assessment of impact.
- 10.1.18 Noise limits should be defined as separate rating levels for daytime and night-time periods according to BS 4142:2014+A1:2019 methodology and be levels external to a property in free-field conditions (at least 3.5 m from any reflecting surface other than the ground). The reference time interval to which the noise limits apply shall be according to BS 4142:2014+A1:2019 (i.e. 1hr for daytime and 15mins for night-time). There should be no ambiguity in the frequency weighting applicable to the noise limits.
- 10.1.19 Conditioning noise limits through the use of rating levels ensures that any tonality (including low frequency tonal sound) is controlled through the application of character corrections according to clause 9 of BS 4142:2014+A1:2019.

- 10.1.20 Locations to which noise limit(s) relate should be defined in the planning condition with coordinates and the applicable coordinate system as an EPSG code (for example EPSG code 27700 for Great Britain). A suitable spread of noise-sensitive receptors should be specified in the condition to ensure that any other residential properties (i.e. groups of properties or properties further away from the development) are reasonably protected by the proposed planning condition. Noise limit(s) should be defined for noise-sensitive receptors (typically dwellings or other properties used for residential purposes) which exist or have planning permission on the date at which the planning application for the development is validated.

Reasonable in all other respects

- 10.1.21 Noise limits should be defined to offer an appropriate level of protection to residents from sound. Therefore, it is considered preferable to impose noise limits in relation to the acoustic environment, rather than based on the predicted sound levels presented in a noise impact assessment at the planning application stage. This approach balances the need to provide appropriate protection with an appreciation of the fact that the layout or candidate plant might not be fixed at the time of the application.
- 10.1.22 It is not reasonable to assign the same planning condition or noise limits to multiple developments as a standard approach to setting planning condition. Planning conditions should be justified on a case-by-case basis taking into account the specifics of the development and may not be reasonable in all instances.
- 10.1.23 As described in previous sections, sound from BESS and Solar equipment is predominantly due to sound from cooling equipment. At the time of writing, there is no evidence to suggest the impact of sound from BESS or Solar sites is any different to that from other industrial or commercial activities. It is considered unreasonable to set more stringent limits on BESS and Solar sites than other industrial or commercial activities.
- 10.1.24 The Working Group identified a number of conditions that were collectively considered to set unreasonable noise limits. These conditions were considered unreasonable due to:
- Limits being set significantly below background sound levels, with no specific justification. The Working Group also considered the enforceability of these conditions.
 - Sound pressure level limits being set in specific one-third octave bands, in particular at 100 Hz. In some cases these limits were so low with respect to ambient conditions that they were considered unenforceable.
 - The setting of rating level limits at a specified margin above background sound levels in areas of low background sound (for example less than 30 dB LA90,T). The Working Group consider there to be limited evidence that the margin above background is a good indicator of impact in areas of low background sound and consider a fixed level approach to be reasonable.
 - The rating level limit being lower than the existing residual sound level and the condition requiring compliance with the rating level limit to be determined by measurement only.
 - Noise limits in the planning condition being lower than the assessment criteria established at the planning application stage, after the noise impact assessment report at the planning stage has been accepted.
- 10.1.25 Where flexibility in the design of the development and specification of plant is needed at the planning stage, it may not be necessary for specific mitigation measures (for example

acoustic barriers) to be a condition of the planning consent⁷. It should be recognised that mitigation measures detailed in a noise impact assessment at the planning application stage can be based on candidate equipment, however, as it is common practice that when the site is constructed, different equipment may be installed, alternative mitigation measures or no mitigation measures may be required.

- 10.1.26 It may be appropriate for a noise impact assessment at the planning application stage to propose a draft planning condition for the development.
- 10.1.27 In respect of a development that contains wind turbine(s) co-located with BESS/solar, operational sound should be controlled through separate planning conditions for the wind turbine(s) and BESS/solar. It is not appropriate to set noise limits that consider the cumulative operation of the wind turbines alongside the BESS/solar. Refer to section XX of this guide for co-located developments.
- 10.1.28 It is recommended that planning conditions from the planning authority are reviewed by a suitably qualified acoustician on behalf of the applicant.
- 10.1.29 Conditions which place unjustifiable and disproportionate financial burdens on an applicant are unlikely to be considered reasonable.

10.2 Discharging Planning Conditions

- 10.2.1 A suitably qualified acoustician should be involved when discharging planning conditions relating to sound.
- 10.2.2 If there is a pre-commencement condition to submit a detailed noise mitigation plan, the reader should refer to Section 8 for guidance on mitigation measures.
- 10.2.3 The reader should refer to section 11 for details of the operating conditions of the site for demonstrating compliance.

NOTE: IOA Acoustics Bulletin Article

Appended to this document (see the last 2 pages of this doc) is an article from the July/August 2026 issue of the IOA Acoustics Bulletin, which presents example planning conditions for BESS and PV developments. It is the intention to include these example conditions in this guide.

⁷ It is acknowledged that on a Development Consent Order (DCO) application, there may be environmental commitments describing specific noise mitigation measures.

11 Monitoring of Operational Sites

11.1 Overview

- 11.1.1 Sound monitoring of operational developments is a complex process that requires careful consideration prior to any survey. It is reliant on input from the site operators and surveys are unlikely to produce robust results if the acoustician is left to undertake monitoring and draw conclusions without additional operational information being made available. Similarly, in the event of a complaint, it is also essential to have information from the complainant and/or Local Authority on the nature of the complaint, in order to undertake an effective investigation.
- 11.1.2 This section is not intended to provide definitive instructions for sound monitoring, as these are already described in detail in a number of national and international standards. Rather, it discusses the various elements specific to battery and solar developments that need to be considered when planning or carrying out a sound survey and presents a series of steps to be followed for the analysis of measured sound data.
- 11.1.3 It is intended that the information collected in accordance with the following guidelines can be used for the purposes of:
- Compliance monitoring, to determine whether a site is operating within its noise level limits;
 - Complaints investigations; and,
 - Acceptance testing for site handovers, provision of warranties and similar.
- 11.1.4 Appendix 1 provides a list of standards and guidance documents that provide advice on sound monitoring, including for the measurement of sound pressure levels and sound intensity measurements.
- 11.1.5 Note the following terms that are used within this section;
- Noise Monitoring Location (NML) refers to a place where sound level monitoring has been undertaken; and,
 - Noise Assessment Location (NAL) refers to the place where a sound level has been quantified for noise assessment purposes.
- 11.1.6 NML and NAL are not mutually exclusive. Where possible the NML and the NAL should be at the same location, however, this is often not possible. Accordingly, this section goes on to describe how to undertake an assessment at the NAL when monitoring has been undertaken at a different location.

11.2 Planning Acoustic Measurements

- 11.2.1 The careful planning of acoustic measurements is essential to a successful compliance monitoring campaign. A survey and analysis plan should be created (the Measurement Plan), as part of documenting why, how, what, where and when measurements are conducted. The key items to consider are:
- why the measurements are needed, e.g. for compliance, acceptance testing or complaints?
 - how are the measurements to be conducted and analysed?

- what is to be measured to enable an assessment to be made against the appropriate limits or criteria, and what data (including non-acoustic data) needs to be collected to undertake an analysis?
 - where should the measurements be conducted, for example, at a receptor, site boundary, proxy location etc?
 - when is the time to install equipment and measure sound levels and when should you filter the data for analysis?
- 11.2.2 To develop the Measurement Plan it is important to acknowledge that BESS and PV operate differently to many other industrial developments (in terms of sound generation).
- 11.2.3 BESS will operate with periods of discharge and charge during the daytime and night-time. The operation of BESS sites is driven by external market forces, and as such it is often not feasible for sites to be operated in a specific manner for a sound survey.
- 11.2.4 For PV, operation may primarily be during the daytime, however, it is not appropriate to simply ignore night-time periods from any assessment on the assumption that 'solar only works during the daytime', especially during summer periods, where sunrise and sunset can occur very early in the morning and late in the evening. PV sites also have the potential for night-time reactive power operation from the inverters. Additionally, due to the geographic distribution of solar sites and diurnal solar patterns, sites can often be subject to grid curtailment during peak hours of the day.
- 11.2.5 It is preferable not to undertake compliance monitoring for PV developments during winter months during limited periods of daylight.
- 11.2.6 Care should normally be taken not to conduct measurements of operational sound during the commissioning stages of a development, since during this period, operation of plant is often atypical: not all of the plant may be operating, testing of backup generators or emergency equipment may be occurring, some construction activities may still be taking place, and capacity testing of equipment can mean that plant operates for unusual durations or operating capacities.
- 11.2.7 It is noted, however, that there are occasionally opportunities during the commissioning process that would allow for useful measurements. Grid connected BESS, for example, may be required to run one full capacity continuous charge, discharge, charge, discharge cycle¹, as part of the electrical tests required for a site. If sound monitoring could be conducted during such a test, this would allow the maximum operational sound level output of the site to be quantified, however, the scheduling of such tests is likely to be determined by the District Network Operator, National Grid or similar, (rather than the BESS Operator) and can be rescheduled at very short notice.
- 11.2.8 In general, undertaking any sound monitoring during the commissioning stages can be logistically challenging and difficult to rely upon.
- 11.2.9 The Measurement Plan should take account of risk assessments, site induction requirements, access approval, and agreement from the relevant stakeholders, such as the operator, planning officers, environmental health officer and local residents.
- 11.2.10 Safe set-back distances from live plant must be known prior to planning any measurements in its vicinity.
- 11.2.11 For compliance surveys, the planning conditions may contain information on the methodology for measurements and/or applicable noise limits. Information from the

planning application, environmental impact assessment (EIA), planning consent discharge documents, and correspondence between planning authorities and the developer should be provided to the acoustics consultant wherever possible, prior to any survey, as these may be useful in forming the Measurement Plan.

- 11.2.12 For complaints investigations, noise logs from the complainant, and observations from the operator and other stakeholders, can provide guidance on the time, duration, location and character of the sound to be investigated. Correlation between the noise log from the complainant and the operational data should be conducted, for example, by comparing apparent/active/reactive power with a subjective noise rating, prior to undertaking a survey, as this will help inform the Measurement Plan.
- 11.2.13 It is acknowledged that for most developments it is extremely difficult to enable a shutdown. If it is necessary to determine the residual or background sound level in the absence of the development then the operator should be consulted to determine future operational plans to ascertain whether a shutdown is programmed for maintenance or similar, though these events are rare.
- 11.2.14 Although monitoring during an intentional shutdown may be the preferred option, this will often not be possible. However, monitoring could also be undertaken during periods of reduced/minimal operation (which might be common for short-duration BESS sites), a grid outage, or, assuming no construction activities are occurring, during commissioning. Alternatively, appropriate historical sound level data may be available within the documentation produced for the planning application, such as a Noise Impact Assessment or EIAR.
- 11.2.15 Where it is not possible to determine both specific sound level and residual sound level at the same location, carefully selected proxy locations can be used for the determination of the residual sound level; however, the use of any proxy location for this purpose should be fully justified as being in a representative and similar acoustic environment as the NAL. The use of proxy locations should be used if access to the receptor is refused or is unsafe, or to improve the signal to noise ratio, for example, where difference between the specific and residual sound levels are 3 dB or less.
- 11.2.16 It is the Working Group's opinion that measurements at the receptor are preferred over proxy measurements.
- 11.2.17 The practitioner should be familiar with and understand the SCADA and other operational data that is available from the development. Data access and format should be investigated as part of the Measurement Plan and before measurements take place. An example of the available SCADA should be provided to the practitioner before the survey to ensure it will be appropriate for later data analysis.
- 11.2.18 The key parameters that are useful in analysis are active power, reactive power, apparent power, cooling fan operation (if available) and operating temperature. If apparent power data is not available this can be calculated⁸.
- 11.2.19 When producing the Measurement Plan it is important to consider what sound levels need to be quantified, in respect of the operational status of the development. For example, this could be the maximum sound levels that could be produced from the operation of the development, the typical / average sound levels from the operation of the development, the

⁸ $S = \sqrt{P^2 + Q^2}$ where S is Apparent Power (kVA), P is Active Power (kW) and Q is Reactive Power (kVAR)

sound levels when the development is not operating or operating at minimal capacities, or something else.

- 11.2.20 Filtering the survey data with the operational SCADA will allow the sound levels to be determined for these conditions, hereafter referred to as BESS/PV MAX, BESS/PV TYPICAL and BESS/PV OFF.

11.3 Undertaking Acoustic Measurements

- 11.3.1 To determine the specific sound levels for compliance assessments, measurements may be undertaken at or close to the nearest sensitive receptors, at a proxy location, or on the site boundary. For surveys that are to be reported to the Local Authority, NMLs will ideally be agreed with the representative Environmental Health Officer (EHO) prior to the survey.
- 11.3.2 Owing to the variable nature of BESS operations, it is recommended that monitoring is conducted for a minimum period of two weeks. For PV developments, without co-located BESS, the minimum recommended monitoring period is one week. For both development types, however, sound monitoring may need to be extended to ensure an appropriate level of data is captured, for example, due to restricted operational conditions or unfavourable weather conditions.
- 11.3.3 If the survey duration is less than the recommended minimum period then the assessment should be made against the BESS/PV MAX only, as it is unlikely enough data can be collected to determine BESS/PV TYPICAL.
- 11.3.4 Monitoring at or close to the nearest sensitive receptors is the preferred approach. These measurements should be conducted in an external location representative of the NAL. The NML will likely need to be agreed with the landowner, occupier / tenant and the commissioner of the works.
- 11.3.5 While not recommended by this document, where compliance is required to be determined with internal noise level limits, an external measurement location should be used and the internal sound levels estimated by subtracting SRI values in octave bands.
- 11.3.6 Whilst the NML would preferably be within the external amenity area of the nearest sensitive receptor, there are scenarios where this might not be possible or might not be preferred, for example where access is not granted, where the signal to noise ratio needs to be increased (due to the presence of other sound sources), or where the external amenity area is acoustically shielded by the property. In circumstances where the measurement location is not within the external amenity area, measurements should be made as close to the NAL as feasible, or in a location that can be justified as being acoustically representative. Where this is not possible, measurements at a proxy location between the site and the receptor, or on the site boundary, could be used alongside a propagation modelling exercise.
- 11.3.7 Where the Measurement Plan identifies a need for measurements between the NAL and the development, these locations should be justified as having representative residual sound levels as the NAL.
- 11.3.8 Efforts should be made to ensure that any proxy location is sufficiently far from the development that no single source from the site dominates measured sound levels, and that the NML is not subject to specific propagation characteristics that the NAL is not. This is particularly important for measurements made at the site boundary, especially for large developments.

- 11.3.9 Care should be taken to minimise the interference of extraneous sources of sound, which might periodically change in level, for example a boiler flue or a stream in spate. Where possible, the measurement location should be sited away from vegetation that might influence sound levels during breezes or gusts.
- 11.3.10 All SLMs used during unattended surveys should be fitted with a double skinned, over-sized wind shield with a radius of at least 100 mm, or in accordance with the recommendations of the ETSU report on Noise Measurements in Windy Conditions (3).
- 11.3.11 Measurements should be made in conditions approximating free-field, with the influence of reflections minimised by taking measurements at least 3.5 metres from any reflecting surface other than the ground. Special care should be taken in the event that tones are apparent, particularly low frequency tones, to minimise reflections, as local maxima and minima can occur at distances beyond 3.5 metres. In these circumstances it is preferable to site the equipment at a location without a clear reflective path.
- 11.3.12 It is recommended that simultaneous measurements are conducted at or near to the site boundary alongside the primary NMLs. These additional measurements will allow for better determination of fluctuations in sound level at the NALs are owing to the development or to extraneous sources. Care should be taken to avoid areas of local maxima / minima on the site boundary, or to minimise the effects of any features providing barrier attenuation.

11.4 Non-Acoustic Measurements

Meteorological conditions

- 11.4.1 Meteorological conditions need to be monitored throughout the survey to allow for the screening of periods during high windspeeds and rainfall.
- 11.4.2 Ideally, measurements of wind should be undertaken at every NML at a similar height to the microphone, however, it is acknowledged that it is not common practice to install a meteorological station at each NML, and so where fewer meteorological stations are proposed, these should be representative of a greater number of measurement locations. Where a single meteorological measurement location is to be used for multiple NMLs, the meteorological measurement location should be chosen to minimise the influence of local features, for example by not siting it in a sheltered location. Measuring at a height of between 2 m and 5 m may be less likely to be subject to local turbulence than at lower levels.
- 11.4.3 Some meteorological measurement equipment can include moving parts, for example, an anemometer or wind vane. Where this is the case, care should be taken to ensure that any associated sounds generated by the measurement equipment are insignificant at NMLs. Accordingly, it may be necessary to install the meteorological measurement equipment at a different location to the SLMs.
- 11.4.4 All meteorological monitoring equipment should be time-synchronised to the SLMs. Wind and rain data should be set to log in the same logging periods as the SLMs or divisions thereof.

Operational Conditions

- 11.4.5 SCADA needs to be made available to the practitioner for the entire duration of the survey. This should ideally be presented in the same resolution as the SLM logging periods.

- 11.4.6 It may be beneficial to provide SCADA midway through the survey to check on the operational status of the site during the survey. This can be helpful to determine whether survey periods need to be extended, or whether survey equipment can be collected in.

Subjective Observations

- 11.4.7 Subjective observations, particularly in relation to determining any character corrections, whilst still important, should be approached with appropriate caution owing to how BESS and solar sites are operated. It may not be appropriate to simply rely on observations made during equipment installation, maintenance and collection.
- 11.4.8 For example, with respect to BESS sites, it is common for 2-hour sites to complete no more than two charge cycles within a 24-hour period, although the site might be participating in ancillary services markets during the remaining 16 hours of a day. Because BESS site operations are dependent on market conditions, it might not be possible to make subjective observations with any certainty that the site is operating in a particular way. Accordingly, it may be helpful to set sound level meters to undertake periodic audio recordings through the survey period, to allow further observations of the acoustic environment to be made upon completion of the survey.
- 11.4.9 For solar sites, while an assessor might be able to note whether the meteorological conditions are favourable for optimal generation, output is often dependent on grid curtailment. For example, it is common for solar sites to be curtailed during peak generating hours on clear summer days, due to the total national solar generating capacity. Accordingly, assuming that the site is fully operational simply because the sun is shining would be incorrect and would need to be backed up with operational data.
- 11.4.10 Subjective observations can only be noted in a sufficiently robust manner if the assessor has direct contact with the operator of the site or the control room or appropriate SCADA data is provided for the period of observation. Any subjective observations that are recorded in an assessment should be supplemented with operational conditions during the observations.
- 11.4.11 It can be helpful to compare audio recordings made simultaneously at the site boundary and at the receptor locations.

11.5 Reporting

- 11.5.1 With regard to the previous sections, the following should be reported for each survey;
- Equipment used, associated serial numbers and calibration information;
 - Equipment installation height;
 - Equipment installation coordinates;
 - Description of physical installation location and the intervening ground in between NML and development, including a note of whether there is line of sight to the site;
 - Description of acoustic environment at time of installation, servicing and decommissioning of survey equipment;
 - Photos of installed equipment⁹;

⁹ Six photos at each NML are recommended. Looking north, east, south, west, looking from NML to development and looking from NML to NAL.

- Any other considerations of note, for example, the presence of other sound sources, locations of reflective surfaces etc.

11.6 Data Analysis

11.6.1 All measured sound level, meteorological and SCADA data should be aligned prior to the data analysis. Care should be taken when matching timestamps from different data sources. For example, some data is timestamped at the beginning of logging periods, whilst others may be at the end of the logging period (common with some meteorological monitoring equipment). Similarly, some equipment or SCADA may use daylight savings hours, whilst others may not.

11.6.2 The data analysis procedure for a compliance survey or acceptance testing is summarised as follows;

1. Filter all data for periods of high wind speeds and precipitation;
2. Manually filter the data for extraneous sound events;
3. Determine operational values for BESS/PV MAX, TYPICAL, and OFF (or similar, as required);
4. Determine a time period for the hysteresis of cooling equipment;
5. Filter the datasets with due regard to the parameters defined in points three and four and for required assessment periods (day, night etc);
6. Calculate the arithmetic mean of the filtered data sets.

11.6.3 The data analysis procedure for a complaint investigation would likely complement an analysis procedure as described above, with an analysis informed by the complaints log.

Filtering for meteorological conditions

11.6.4 Assuming that secondary wind shields have been used throughout the survey, filtering for wind speeds at or above 5 m/s should be undertaken. If, however, only a standard wind shield has been used, for example, during a short, attended survey, then lower wind speed cut-off values should be adopted.

11.6.5 It may be necessary to filter for different wind conditions. Where the wind speed is low (< 3 m/s), then all wind directions can be used. Between 3 and 5 m/s then downwind wind direction should be used. Downwind is defined as the wind direction from the site to receptor within ± 45 degrees of the bearing from the site to the receptor¹⁰.

11.6.6 When a receptor is in the prevailing upwind or crosswind position, there may not be enough data from the use of downwind sectors only. In addition, when a receptor is downwind of another dominant sound source, filtering to exclude those directions may be of benefit. In these cases, it might be appropriate for the downwind sector to be increased in size, or another representative sector to be defined. Comparison of the different wind sectors may provide additional benefit, such as comparing downwind and upwind sectors.

11.6.7 As a minimum, all data should be filtered 15 minutes either side of a recorded precipitation event. Longer periods may need to be considered depending on local conditions, for example, the presence of water courses.

¹⁰ Care should be taken when averaging wind direction data, since arithmetic average will produce incorrect results. Therefore, wind directions should be converted into vectors, each orthogonal component be averaged and then combined into a single averaged wind direction.

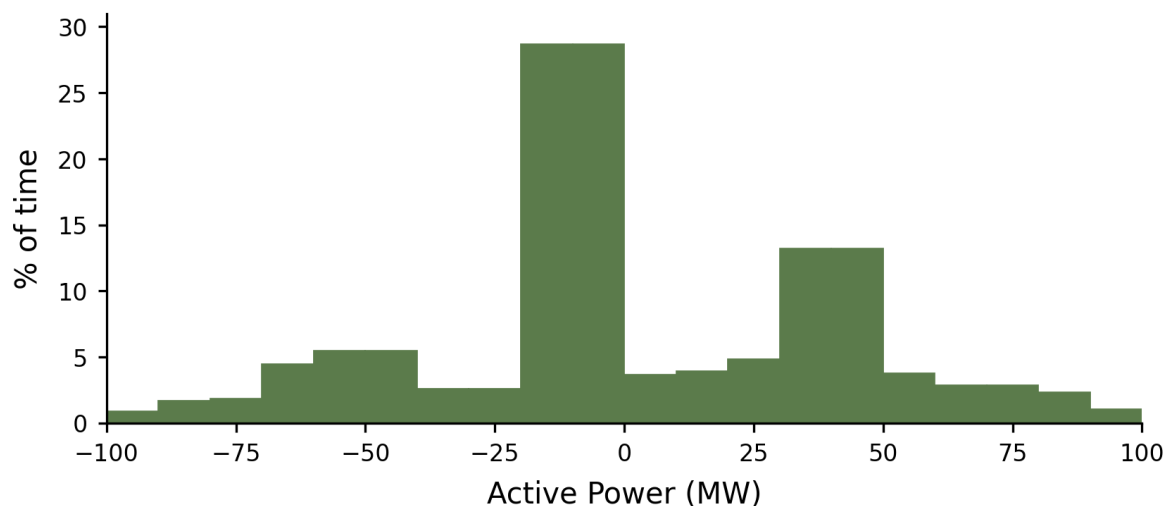
Filtering for sound events

- 11.6.8 Where sound levels increase at an NML but not at the boundary measurement locations, this may indicate extraneous sound events or other local sound sources that can be removed from the dataset.

Filtering for operating conditions

- 11.6.9 The operational parameters referred to for data analysis will vary depending upon the markets that the development is operating in. The examples detailed below refer to Active Power, however, Reactive Power or Apparent Power may be a more appropriate metric to consider, depending on the operation of the site. The operator should be able to advise on the parameters to refer to, and this should ideally have been determined during the production of the Measurement Plan.
- 11.6.10 The following filtering examples are provided for BESS / PV MAX and BESS / PV OFF;
- To determine BESS / PV MAX: Active Power (MW) within 10% of maximum capacity.
 - To determine BESS / PV OFF: Active Power (MW) within 5% of 0, so between - 5 MW and +5 MW for a 100 MW scheme.
- 11.6.11 Due to the varied ways that sites operate, in particular BESS developments, it is not possible to provide definitive guidance as to how to filter the measurement data to determine BESS/PV TYPICAL and this will need to be considered on a case by case basis. The following points should, however, be noted.
- A BESS may discharge and charge its batteries at different rates. Taking a development with a storage duration of 2 hours, as an example; export of electricity may regularly occur for 2 hour periods at a time, but import may often take 4 hours. In this case the BESS would be operating at nearly 100% active power for export but only 50% of active power during import. Filtering of positive and negative active power values would therefore require a different cut off value to be set.
 - The percentage of active power for a PV development will vary with daylight, irradiance etc. If the assessment is to be made over a particular time period, then appropriate values for filtering active power to calculate PV Typical during that period will need to be determined. An assessment of 04:00 – 07:00 in June, for example, would benefit from relatively low active power filtering values, compared to if the assessment was only considering the middle of the day.
 - As previously illustrated in Figure 5-7 and Figure 5-8, the power variations of a BESS will vary considerably depending on the market(s) they are working in. For some operations, trying to quantify BESS TYPICAL may be extremely difficult, as ‘typical’ operations do not occur. However, for some developments, operations may be more regular. In these situations, plotting a histogram of relevant power variations can be useful to identify appropriate filtering criteria. An example is provided as Figure 11-1, which in this case illustrates a BESS development that does not typically operate at maximum capacity. For this particular development it may be more appropriate to determine BESS TYPICAL rather than BESS MAX.

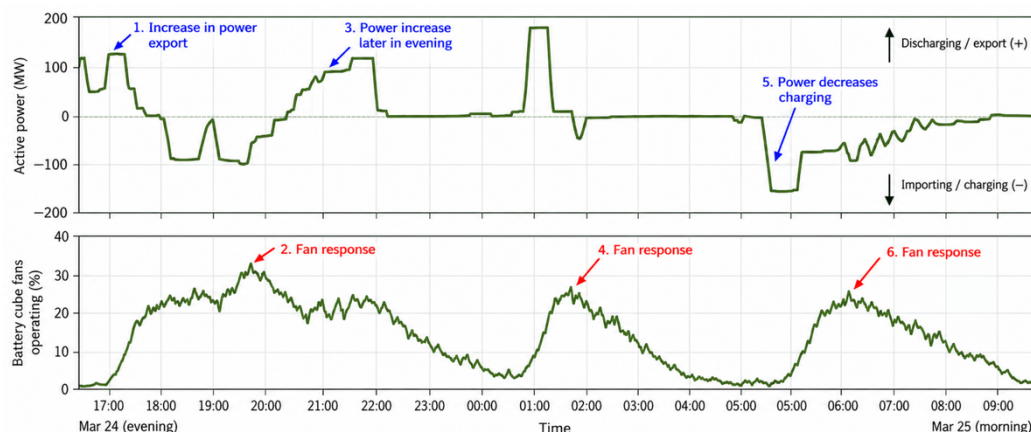
Figure 11-1: Example of active power histogram during sound survey period



Filtering for hysteresis

- 11.6.12 Cooling requirements for plant is variable, and cooling systems may not be operating at maximum simply because the development is operating at maximum capacity. Often there is a time offset between inverter or battery operations and cooling operations. Figure 11-2 shows an example of this, where it can be seen that there is a distinct lag between the percentage of operational fans and active power. Accordingly, it cannot be assumed that the site is at its noisiest for short durations of maximum active power, or similar. The top graph (active power) shows the BESS discharging (positive numbers) and importing (negative numbers), whilst the bottom graph shows the % of battery cube fans operating across the site.
- 11.6.13 It is recommended to plot active power, reactive power and apparent power against fan operations (if available) and / or against measured sound levels to determine a typical time duration for this hysteresis. For this exercise, it may be more useful to compare the operational parameters to sound measurements made at the boundary of the site, rather than at the NMLs representing the nearest sensitive receptors.
- 11.6.14 If this analysis cannot be undertaken, or it is difficult to determine an appropriate value, then a period of 1 hour is advised i.e. data should be filtered to include all sound data for a period of one hour after all relevant active/reactive/apparent power events.

Figure 11-2: Example of battery fan operations against Active Power



Determining the sound level

- 11.6.15 After filtering the data as described, the LAeq values can be arithmetically averaged to determine the Specific Sound Level.

11.7 Verification Through Modelling

- 11.7.1 Monitoring at proxy locations should not be the default position to demonstrate compliance, and attempts should always be made to monitor at the nearest sensitive receptors initially. Nonetheless, it is sometimes necessary to measure at proxy locations, as discussed previously.
- 11.7.2 To enable the use of data collected at a proxy location for compliance assessment purposes, predicted sound levels from the as-built¹¹ development should be used to set noise limits at the proxy location (referred to as the Equivalent Noise Limits).
- 11.7.3 ENLs are calculated by using the development's sound level predictions at the assessment property and then calculating the difference between the predicted level and the noise level limit. This difference can then be added to the predicted level at the proxy NML to determine the ENL. The details of the calculation methods and all propagation modelling should be included in any noise compliance report.
- 11.7.4 If it is deemed that the measured sound levels at the proxy NML meets the Equivalent Noise Limits (ENL), then the sound levels can also be deemed to meet the conditioned noise limits at the assessment property. It should be noted, however, that this relates to absolute sound levels only and care should be taken when considering sound character, for example, in the assessment of a Rating Level, which must consider the character of the sound at the NSR and not at the proxy NML.
- 11.7.5 Care should also be taken to ensure that the background sound levels of any proxy location is taken into account, since it may differ from the receptor location.
- 11.7.6 Propagation models should be updated to account for any changes to the local area, such as change of fields to housing or additional hard areas, changes to topography, new developments or introduced habitats or green spaces.

11.8 Complaints Investigations

- 11.8.1 A complaint for a development is typically made via the planning authority or direct to the site operator. It is important to ascertain the nature of the complaint and to deem if it is valid. A noise log should be issued to the complainant as soon as possible i.e. before the start of any sound survey (see Example noise log in Appendix 2). The use of the noise log should be explained to the complainant. It is recommended that the operator, or the acoustician on behalf of the operator, conducts an interview with the complainant. In addition, if the complaint has come via the planning authority, an interview with the EHO should be conducted.
- 11.8.2 The minimum information to start an investigation is
- where the complaint occurred, for example, garden, bedroom etc.

¹¹ To model the 'as-built' development, care must be taken to ensure that the model considers the operational parameters present at the time of the survey. As-built models should consider the electrical rating of all installed plant and likely loads being placed on that plant. For example, an over-rated unit may be operating at lower noise levels than the manufacturers data suggests.

- when it occurred,
 - the character of sound that caused the complaint,
 - who was affected and
 - how they were affected.
- 11.8.3 The address of the property is required, and where the noise was heard in or around the property. The time when the noise first occurred is useful, since it may be correlated to a particular type of operation, time of day or another event. The character of the sound is helpful to determine if the complaint relates to tone, impulsivity, intermittence or general sound levels.
- 11.8.4 When the interview is conducted, lay-person terms for character or type of sound should be used. It is important to find out who was affected: was it the entire household, several households, a few people or one person. It is useful to interview each person separately, since people may have heard different things based on their hearing response and non-acoustic factors. It should be determined how the noise affects each person, such as if it woke them up, disturbed them in the garden, heard it watching TV or under special conditions.
- For most cases the noise log should be filled in for at least 2 weeks or for enough events to have occurred. If the log is unclear or vague, a follow-up interview with the complainant should be conducted.
 - It may be useful to compare data from any Acceptance Tests or similar, with data provided by the equipment manufacturer prior to the operation of the site. If neither are available, then it may be useful to conduct some measurements according to Section 11.9.
 - The planning conditions for the development may refer to a particular standard or submitted complaints investigation procedure, which should be followed in investigating the complaint. There may be situations where the prior agreed procedure may be deviated from however, owing to the specifics of a complaint. It is important to agree these deviations with the operator and EHO. If there is no prior agreed complaint procedure, then one should be agreed with the planning authority (if appropriate) and the operator.
- 11.8.5 Analysing the noise log with SCADA and meteorological measurements can provide valuable information on the site's operating conditions. The following approaches are suggested:
- Identify the peak times for complaints (such as at night, evening or during the day) from the noise log and compare these to operational parameters and meteorological data.
 - Plot various operating parameters against a subjective 'annoyance' rating, or similar, as an x-y scatter graph. The operating parameters could include active, reactive or apparent power, operating fan speed and temperature.
- 11.8.6 When considering time of complaints, care should be taken to avoid introducing bias, for example, finding that noise complaints only occur during the night and evening when complainants may be at work during the day. In this case, the conditions for the complaint might occur at any time of the day, even though the actual received complaints would not have been during the daytime.
- The complaint can still be valid even if there is no clear correlation between the noise log and other site parameters or time of day. Regardless of the

information from the noise log, a site visit should be conducted with a visit of to the complainant's property.

- Following the installation of a sound level meter and associated equipment, the noise log should be continued to be filled in.
- A complaint could be deemed not to be valid if there is a third-party dominant sound source or third-party development nearby, or the separation between the source and the receptor is sufficiently distant. If an initial survey is conducted, this data should be analysed to determine any relationship between sound levels (and/or character) from the development and the complaint log. Where no relationship exists, further analysis should be conducted to confirm (or otherwise) that the complaint relates to the development.

11.9 On-site Monitoring / Acceptance Testing

11.9.1 Monitoring on site can be used to help investigate complaints, provide useful information in relation to sound characteristics of specific items of plant (for example, to identify a spectral signature), or to undertake site acceptance testing as part of the commissioning/handover process.

11.9.2 For investigative purposes it may not be necessary to follow a specific standard, however, for acceptance testing, one of the standards detailed in Appendix 1 should normally be followed.

Acceptance Testing Requirements

11.9.3 Acceptance testing typically requires the sound level of individual items of plant to be measured, as opposed to the overall site output.

11.9.4 When agreeing requirements for acceptance testing between plant supplier/contractor and the customer, it is important to agree on a set of operating assumptions to be met during any sound level measurements, for example, equipment loading, fan speeds etc. These are referred to herein as Normal Operating Conditions.

11.9.5 It is recommended that any acceptance testing criteria, including a definition of Normal Operating Conditions, is agreed as part of the procurement process.

11.9.6 In order to ensure an appropriate assessment, operational SCADA data should be used to determine that the item of plant under test is functioning under Normal Operating Conditions.

11.9.7 Monitoring should be undertaken for multiple units and assessment cannot be based on the measurements of a single unit type e.g. 1 inverter.

11.10 Other Considerations

11.10.1 It should be acknowledged that any measured sound levels at the receptor can be influenced by other nearby sound sources, which can affect the character of the sound, as well as the overall level. In particular, care should be taken when making any character corrections to determine the BS 4142 Rating Level or similar, in the presence of other nearby developments.

11.10.2 Both BESS and solar farms are often located close to other energy generation projects or electrical infrastructure, such as substations. A situation could arise, therefore, where sound with a particular characteristic is present in the measured sound levels but is not relevant to the development being investigated. An example of this could be where a BESS site is located adjacent to a High Voltage substation that is emitting a 100 Hz tone. In such situations, the following is advised;

- It may be appropriate to undertake baseline monitoring prior to the construction or operation of a consented development, to establish both the existing sound level and sound character at the nearest sensitive receptors. If any particular characteristics in the existing sound environment are identified, these should be noted to ensure the consented development is not unfairly penalised once operational.
- Where existing tonal sound sources may be present prior to the operation of a new BESS or PV development, it may be necessary to undertake tonal analysis before and after first operation, or, if this is not possible for both BESS ON and BESS OFF states or similar. For all tonal analysis the Objective Method presented in Annex D of BS 41425 is recommended. The use of the Objective Method presented in Annex C of BS 41426 should be avoided.
- Consideration should be given to applying additional filtering to measured sound levels to consider the operation of neighbouring operational developments, for example, through directional or temporal filtering.

12 References

1. **British Standards Institute (BSI).** *Methods for rating and assessing industrial and commercial sound.* London : BSI, 2019. BS 4142:2014+A1:2019.
2. —. *Code of practice for noise and vibration control on construction and open sites - Noise.* London : BSI, 2014. BS 5228-1:2009+A1:2014.
3. **Rankl, Felicia.** *Research Briefing: Planning for solar farms.* London : House of Commons Library, 2024.
4. **Association of Noise Consultants (ANC).** *BS 4142:2014+A1:2019 Technical Note.* Northallerton : ANC, 2020.
5. **Environment Agency, Natural Resources Wales & Department of the Environment (Northern Ireland).** Method Implementation Document (MID) for BS 4142. [www.gov.uk](https://www.gov.uk/government/publications/method-implementation-document-mid-for-bs-4142/method-implementation-document-mid-for-bs-4142#contents). [Online] 22 December 2023. <https://www.gov.uk/government/publications/method-implementation-document-mid-for-bs-4142/method-implementation-document-mid-for-bs-4142#contents>.
6. **Moorhose, A.T., Waddington, D.C. and Adams, M.D.** *Procedure for the assessment of low frequency noise complaints.* London : Department for Environment, Food & Rural Affairs (DEFRA), 2011. NANR45 Rev 1.
7. **British Standards Institute (BSI).** *Guidance on sound insulation and noise reduction for buildings.* London : BSI, 2024. BS 8233:2014.
8. **World Health Organization (WHO).** *Environmental Noise Guidelines for the European Region.* Copenhagen : WHO, 2018.
9. **World Health Organization.** *Night noise guidelines for Europe.* Copenhagen : WHO, 2009.
10. —. *Guidelines for Community Noise.* Geneva : WHO, 1999.
11. **Planning Inspectorate.** Guidance Nationally Significant Infrastructure Projects: Pre-Application Advice on Environmental Impact Assessment. [www.gov.uk](https://www.gov.uk/guidance/nationally-significant-infrastructure-projects-pre-application-advice-on-environmental-impact-assessment). [Online] 27 July 2026. <https://www.gov.uk/guidance/nationally-significant-infrastructure-projects-pre-application-advice-on-environmental-impact-assessment>.
12. **Weaver, Neil.** How does a battery energy storage system make money? [Online] 2026. [Cited: 3 July 2026.] <https://modoenergy.com/research/en/how-does-battery-energy-storage-make-money>.
13. **International Organization for Standardization.** *Acoustics — Attenuation of sound during propagation outdoors Part 2: Engineering method for the prediction of sound pressure levels outdoors.* Geneva : ISO, 2024. ISO 9613-2.
14. —. *Acoustics — Software for the calculation of sound outdoors — Part 3: Recommendations for quality assured implementation of ISO 9613-2 in software according to ISO 17534-1.* Geneva : ISO, 2015. SO/TR 17534-3.
15. **Department for Energy Security and Net Zero.** *Overarching National Policy Statement for Energy .* London : The Stationary Office, 2025. EN-1.
16. —. *National Policy Statement for Renewable Energy Infrastructure.* London : The Stationary Office, 2025. EN-3.
17. —. *National Policy Statement for Electricity Networks Infrastructure.* London : The Stationary Office, 2025. EN-5.
18. **A. Hurque, C Magerko, C.Brewster & T. Key.** *Nighttime reactive power support from solar PV inverters.* Copenhagen : 22nd Wind and Solar Integration Workshop (WIW2023), 2023.
19. **Power Systems Consultants UK Ltd.** *Q-Flex project: Reactive power technology catalogue.* Warwick : National Grid Electricity Distribution, 2022.

20. **ETSU.** *Noise measurements in windy conditions ETSU/W13/00386/REP.* London : Department of Trade and Industry, 1996.
21. **Plovsing, B and Kragh, J.** *Comprehensive outdoor sound propagation model. Part 1: Propagation in an atmosphere without significant refraction.* Hørsholm : DELTA Acoustics and Vibration, 2006. Report AV 1849/00.
22. —. *Comprehensive outdoor sound propagation model. Part 2: Propagation in an atmosphere with refraction.* Hørsholm : DELTA Acoustics and Vibration, 2006. Report AV 1851/00.
23. **Kephalopoulos, S., Paviotti, M. and Anfosso-Lédée, F. (2012) Common Noise Assessment Methods in Europe (CNOSSOS-EU). EUR 25379 EN. Luxembourg: Publications Office of the European Union.** *Common Noise Assessment Methods in Europe (CNOSSOS-EU).* Luxembourg : Publications Office of the European Union, 2012. EUR 25379 EN.
24. **International Organization for Standardization.** *1. ISO 9613-1:1993 Acoustics. Attenuation of sound during propagation outdoors. Part 1: Calculation of the absorption of sound by the atmosphere.* Geneva : ISO, 1993. ISO 9613-1.

Appendix 1: Recommended Standards and Guidance

Assessment methodology	
BS 4142:2014+A1:2019 <i>Methods for rating and assessing industrial and commercial sound</i>	It is recommended that BS 4142 provides the basis for all planning application operational noise impact assessments for BESS & PV.
Association of Noise Consultants: BS 4142:2014+A1:2019 <i>Technical Note</i>	Provides practical guidance on interpreting and applying BS 4142, helping practitioners apply the standard consistently where aspects of the methodology require professional judgement. It explains key concepts and procedures within the standard, supporting a more consistent and transparent application of BS 4142 in noise impact assessments.
BS 5228-1:2009+A1:2014 <i>Code of practice for noise and vibration control on construction and open sites - Noise</i>	Provides guidance that can be incorporated into construction noise assessments for BESS or PV.
Sound propagation modelling	
ISO 9613-2:2024 <i>Acoustics — Attenuation of sound during propagation outdoors: Engineering method for the prediction of sound pressure levels outdoors</i>	Specifies an engineering method for calculating the attenuation of sound during outdoor propagation and predicting sound pressure levels at receiver locations from known sound power levels. It covers atmospheric absorption, geometric divergence, ground effect, screening by obstacles, reflections and meteorological conditions
ISO/TR 17534-3 <i>Recommendations for quality assured implementation of ISO 9613-2 in software according to ISO 17534-1.</i>	The 17534 series provide an important mechanism for maintaining consistency and quality in the software implementation of ISO 9613-2. Historically, ISO/TR 17534 has identified and addressed ambiguities in the interpretation and implementation of the ISO 9613-2 methodology, providing agreed recommendations and reference test cases against which noise prediction software can be assessed. Reference to the latest applicable version of ISO/TR 17534, alongside the relevant edition of ISO 9613-2, provides greater confidence that modelling software is applying the methodology consistently, transparently and in accordance with the most up-to-date internationally agreed guidance, particularly where the underlying standard does not fully specify how a calculation should be implemented in software.

Sound level monitoring (baseline and operational surveys)	
<i>BS 7445 Description and measurement of environmental noise</i>	The BS 7445 series provides the UK framework for the description and measurement of environmental noise. BS 7445-1:2003 sets out the principal quantities and general procedures for environmental noise measurement, including the measurement and reporting of sound pressure levels. BS 7445 is principally concerned with how environmental sound is measured and described, rather than providing a specific assessment methodology for individual noise sources. The series provides useful UK-specific guidance on measurement practice and remains relevant to outdoor environmental sound monitoring, although Parts 2 and 3 are relatively old and should be considered alongside the more recent ISO 1996 series.
<i>ISO 1996 Acoustics - Description, measurement and assessment of environmental noise</i>	The ISO 1996 series provides the principal international framework for the description, measurement and assessment of environmental noise. ISO 1996-1:2016 establishes the basic acoustic quantities, assessment procedures and general principles for describing environmental sound, while ISO 1996-2:2017 provides more detailed requirements and guidance for determining environmental sound pressure levels, including direct measurements, measurement locations, measurement durations, meteorological conditions, corrections and uncertainty.
<i>BS EN 61672 Electroacoustics. Sound level meters</i>	BS EN 61672-1:2013 specifies the electroacoustic performance requirements for sound level meters, including Class 1 and Class 2 instruments, while BS EN 61672-2:2013 specifies pattern-evaluation tests used to demonstrate conformity with those requirements and BS EN 61672-3:2013 specifies periodic tests used to verify the continued performance of instruments. For outdoor environmental sound monitoring intended to support planning, regulatory or compliance assessments, Class 1 instrumentation should generally be used and BS EN 61672 equipment calibration certificates should be included in any reporting. The BS EN 61672 series should also be considered alongside BS EN IEC 60942, which covers sound calibrators used to check the performance of sound level meters in the field.

Sound level monitoring (plant measurements)		
For an operational BESS or PV development with multiple items of plant operating simultaneously, sound intensity measurements can have some advantages over conventional sound-pressure measurements using a sound level meter. A sound intensity probe measures the direction and magnitude of acoustic energy flow, which can help identify the source components contributing most to the measured sound, reduce the influence of reflected sound and to some extent, unrelated extraneous sound sources. This can be useful for plant, where fans, vents and cooling systems may produce different sound levels in different areas of the unit, or for operational sites where multiple items of plant are present. Intensity measurements, however, are more technically demanding and time consuming, and require specialised equipment that is often not readily availability to acoustics practitioners. A conventional sound level meter measuring sound pressure levels is generally simpler and more practical for routine environmental monitoring. However, on sites where multiple sources are operating simultaneously, sound pressure measurements can be complicated by contributions from other items of plant, reflections from nearby surfaces and variations in the surrounding acoustic environment, making it difficult to isolate the contribution of an individual source. For measurements of a single item of plant operating in isolation, for example, at a plant manufacturers site, sound pressure measurements should suffice for most practical applications. A sound level meter is simpler, faster and more widely understood, and if the plant is in a suitable acoustic environment and measurements follow appropriate standards, sound pressure measurements can be used to determine reportable sound power levels. Sound intensity measurements are more advantageous where the measurement environment is imperfect. It is less affected by reflected sound and certain forms of background noise, and the directionality of the measurement can help identify which parts of a piece of equipment are emitting higher sound levels. For example, with a BESS container, an intensity scan could help distinguish the contribution from the cooling fans, air inlets and exhausts. The following standards have been separated Grade 1 Precision, Grade 2 Engineering, and Grade 3 Survey, as defined in the ISO 3740 range of standards		
Grade 1 Precision	Requires highly controlled acoustic conditions, such as an anechoic or reverberation test room.	
ISO 3741:2010 Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure. Precision methods for reverberation test rooms	Sound Pressure Level measurements	Determines sound power from measurements in a qualified reverberation room.
ISO 3745:2012 Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure. Precision methods for anechoic rooms and hemi-anechoic rooms	Sound Pressure Level measurements	Requires a highly controlled free-field environment and qualified test room.
ISO 9614-1:1993 Acoustics – Determination of sound power levels of noise sources using sound intensity. Part 1: Measurement at discrete points	Sound Intensity measurements	In-situ or controlled environment method. Measurements are made at discrete points over a defined measurement surface. Can provide 1/1 octave and 1/3 octave band sound power levels.

Grade 2 Engineering	Less stringent environmental requirements; commonly the most appropriate level for practical sound power measurements, including outdoor measurements.	
<i>ISO 3743-1:2010 Acoustics – Determination of sound power levels of noise sources using sound pressure. Engineering methods for small, movable sources in reverberant fields</i>	Sound Pressure Level measurements	Indoor hard walled test room method for relatively small, movable sources, for example a string inverter. Provides octave band sound power levels but 1/3 octave measurements are not provided by the method.
<i>ISO 3743-2:2018 Acoustics – Determination of sound power levels of noise sources using sound pressure. Engineering methods for special reverberation test rooms</i>	Sound Pressure Level measurements	Requires a reverberation test room. Provides octave band sound power levels but 1/3 octave measurements are not provided by the method.
<i>ISO 3744:2025 Acoustics – Determination of sound power levels of noise sources using sound pressure. Engineering methods for an essentially free field over a reflecting plane</i>	Sound Pressure Level measurements	Relevant for outdoor/in situ measurements. Measurements are made over an enveloping surface around the source, normally over a reflecting plane. Provides 1/3 octave band sound power levels. Grade 2 can be achieved outdoors where the required acoustic conditions can be met.
<i>ISO 9614-1:1993 – Part 1: Measurement at discrete points</i>	Sound Intensity measurements	Measurements are taken at a series of discrete positions over the measurement surface. Can provide 1/3 octave band results. Useful where the measurement environment is less than ideal for sound pressure methods.
<i>ISO 9614-2:1996 – Part 2: Measurement by scanning</i>	Sound Intensity measurements	Uses continuous scanning of the measurement surface rather than measurements at individual fixed points. Can provide 1/3 octave band results and can be practical for larger or complex sources. Like Part 1, it can achieve different accuracy grades depending on the measurement conditions.

ISO 3747:2010 Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure. Engineering/survey methods for use in situ in a reverberant environment	Sound Pressure Level measurements	In situ method using a calibrated reference sound source. The source under test must be in a sufficiently reverberant environment and cannot readily be moved. Provides octave band sound power levels only. Cannot provide 1/3 octave band results are not provided by the method.
Grade 3 Survey	Lower accuracy and fewer restrictions on the measurement environment. Useful for less demanding investigations or where higher grade measurements are impractical.	
ISO 3746:2010 Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure. Survey method using an enveloping measurement surface over a reflecting plane	Sound Pressure Level measurements	Simplified outdoor/in situ method using sound pressure measurements around the source. Requires fewer environmental controls than ISO 3744 but provides lower accuracy. Provides octave band sound power levels only. Cannot provide 1/3 octave band results are not provided by the method.
ISO 9614-1:1993 Part 1: Measurement at discrete points	Sound Intensity measurements	As per above but can also be used (subject to certain criteria) where grade 2 criteria cannot be met. Can provide greater flexibility than many sound pressure methods where the acoustic environment is not ideal.
ISO 9614-2:1996 Part 2: Measurement by scanning	Sound Intensity measurements	

Standards for transformer noise only	
BS EN 60076-10:2016 / IEC 60076-10:2016, Power transformers – Part 10: Determination of sound levels.	This standard is specifically intended for determining the sound power level of transformers, reactors and their associated cooling equipment, using either sound pressure or sound intensity measurements. Sound level data for standalone transformers should be measured and reported in accordance with 60076-10.
BS IEC 60076-10-1:2016+A1:2020	An application guide providing practical guidance on applying 60076-10, including measurement procedures, sound fields, background noise, measurement distance, frequency bands and why factory measurements can differ from measurements made on-site.

Appendix 2: Example Forms and Pro-formas

- Example Sound Level Data Sheet (for equipment manufacturers)
- Template Sound Level Data Sheet (for equipment manufacturers)
- Template Noise Complaints Observations Log

Altroniq
123 Electric Avenue
Birmingham
B1 9ZZ

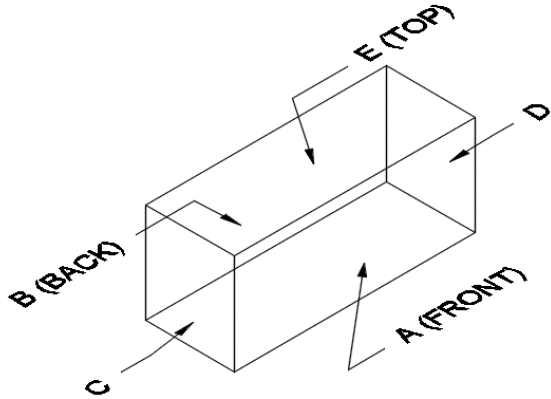
Sound Level Data Sheet



Unit under test		
Unit Manufacturer	Altroniq	
Unit name	AL INV007	
Dimensions	10.5m x 2.5 m x 3.0 m	
Mode of Operation	100% load	
Electrical Rating	2653 kW	
Additional comments re: operation	Unit was fully operational for 30 mins before measurements. All parameters set to run normally. 80% fan speeds. No noise control.	

Survey Information				
Date of survey	01/06/2028			
Measurement Surveyors	The Sound People			
Individual measurement duration	30 seconds			
Measurement setback distance	0.8 m			
Number of valid measurements	Operational	140	Background	70
Meteorological conditions	No rain, wind speed < 1m/s, 21°C			
Location & setting	At Altroniq factory, Birmingham. Test unit located on area of external hardstanding. Approximately 30 m from factory building. All neighbouring building facades and other reflective surfaces located at greater distances.			

Measurement Standard: ISO 3744:2025			Comments
Conformity	Pass	Fail	Apparent Directivity: Noise emitting elements from the chiller created a large disparity in directivity relative to other areas, so initial conformity test was failed. Additional measurements were undertaken to better represent these areas, as per the guidance in ISO3744, to ensure validity with the standard.
Measurement Surface Method	☒	☐	
Background Noise	☒	☐	
Test Environment	☒	☐	
Apparent Directivity	☒	☐	
Range of Sound Pressure Levels	☒	☐	
Calibration	☒	☐	
Test undertaken by	Bob Roden		On behalf of The Sound People Partnership
Test approved by	Claire Riley		C Riley 3/6/28
Test Report	Full test report provided in document number SPP00386-002-R1 dated 3/6/28		

Modelling Recommendations	Sound Sources / Measurement Areas
Sound Power Levels are provided for 100% operational capacity at 80% fan speed. Due to the location of noise-producing elements, noise propagation is directional, and noise models should not assume the overall sound power level is equal across all facades. It is recommended that each surface is modelled separately, using a separate plane source to represent each façade and the top of the unit. The SWL should not be modelled per m² (or an equivalent alternative) as this will result in an over-estimation of the emission level.	 The diagram shows a 3D perspective of a rectangular box. Five arrows point to different surfaces, labeled as follows: 'A (FRONT)' points to the front face, 'B (BACK)' points to the back face, 'C' points to the left side face, 'D' points to the right side face, and 'E (TOP)' points to the top face.

Sound Power Level Data for Modelling, SWL dBA					
1/3 octave band (Hz)	A	B	C	D	E
50	41.9	39.5	27.8	43.3	42.8
63	44.9	41.3	29.8	44.8	46.0
80	47.8	45.8	35.0	48.9	51.0
100	53.6	51.4	39.0	55.0	55.7
125	60.6	57.8	45.0	61.5	63.8
160	67.9	66.3	55.0	71.0	72.5
200	65.2	63.6	52.2	66.9	69.0
250	67.9	64.7	53.7	68.2	71.3
315	73.9	70.4	59.7	73.5	78.7
400	70.5	68.0	56.3	72.2	76.8
500	71.6	69.1	57.3	73.2	77.9
630	76.7	69.3	62.6	72.9	78.2
800	72.8	69.3	57.3	73.1	78.1
1000	73.2	70.4	56.3	74.2	79.1
1250	73.2	70.2	55.9	73.8	78.8
1600	72.1	67.9	55.3	72.0	76.9
2000	70.6	65.4	53.7	70.0	75.2
2500	68.1	63.3	51.0	67.9	73.7
3150	65.9	60.7	48.8	65.3	71.9
4000	62.8	58.5	46.0	62.9	69.1
5000	59.1	54.6	43.0	59.2	65.3
6300	55.1	51.2	39.5	55.9	61.7
8000	54.8	53.5	36.5	57.5	64.4
10000	46.7	42.6	28.0	47.4	53.1
Overall	83.4	79.5	68.2	83.3	88.1

Company name and address	Sound Level Data Sheet	Company logo
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Unit under test		
Unit Manufacturer		Image of unit under test
Unit name		
Dimensions		
Mode of Operation		
Electrical Rating		
Additional comments re: operation		

Survey Information				
Date of survey				
Measurement Surveyors				
Individual measurement duration				
Measurement setback distance				
Number of valid measurements	Operational		Background	
Meteorological conditions				
Location & setting				

Measurement Standard: ISO xxxxx	Comments
<i>Test details go here</i>	<i>Additional details re measurements go here</i>
Test undertaken by	
Test approved by	
Test Report	<i>Refer to related text report here</i>

Modelling Recommendations	Sound Sources / Measurement Areas
<i>Details re: how to use data for noise modelling to go here</i>	<i>Use this space to illustrate the different SWL areas / measurement surfaces</i>

Sound Power Level Data for Modelling, SWL dBA	
1/3 octave band (Hz)	<i>Add 1 column per SWL area / measurement surface</i>
50	<i>Include 1/3 octave SWL data for each SWL area / measurement surface [ensure correct reference to dBZ or dBA]</i>
63	
80	
100	
125	
160	
200	
250	
315	
400	
500	
630	
800	
1000	
1250	
1600	
2000	
2500	
3150	
4000	
5000	
6300	
8000	
10000	
Overall	<i>Single figure SWL levels go here</i>

Development		Project / Document number	
Client		Date issued	

Property name and address	
---------------------------	--

Observations Log										
Date	Start time	End time	What words would you use to describe the observed sound?	Who was affected?	Please circle a value that represents how bothered, disturbed or annoyed you are by the sound.					
			Where was it observed?	How did it disturb you?	Not at all					Extremely
					0	1	2	3	4	5
					0	1	2	3	4	5
					0	1	2	3	4	5

Observations Log											
Date	Start time	End time	What words would you use to describe the observed sound?	Who was affected?	Please circle a value that represents how bothered, disturbed or annoyed you are by the sound.						
			Where was it observed?	How did it disturb you?	Not at all						
					0	1	2	3	4	5	
					0	1	2	3	4	5	
					0	1	2	3	4	5	
					0	1	2	3	4	5	
					0	1	2	3	4	5	
					0	1	2	3	4	5	
					0	1	2	3	4	5	

A proposal for draft planning conditions for solar and BESS developments

A review of planning consents has identified a need for improved planning conditions relating to noise. A trio of conditions is proposed to address this need, and rationale is provided.

By Jim Singleton, Esteban Olmos and Ashley Leiper

A working group has been convened as part of the Institute of Acoustics' Renewable Energy Advisory Group to produce a guidance document for the assessment of sound from solar and Battery Energy Storage System (BESS) developments. A subgroup is responsible for the section of the guidance relating to planning conditions.

As part of this process, the authors of this article have reviewed a number of planning consents for solar and BESS developments, the purpose of which was to identify planning conditions that demonstrated good practice.

However, the authors have identified several common practices that they think could be improved. Those practices include conditions which:

- a) do not meet the six planning condition tests;
- b) set noise limits derived from assessment methodologies that are inappropriate for sound of an industrial nature;
- c) do not consider the reality of planning applications being based on candidate plant and candidate layouts, with the actual plant and layout to be finalised as part of a competitive process once the development has secured consent; and
- d) suggest an unrealistic commonality between the character of specific sound from solar and BESS developments with electrical substations.

A comprehensive discussion following the review of the planning

conditions will be provided in the guidance document, and opinion on these will be sought as part of the IOA consultation to the guidance document.

The authors propose three conditions below, which could be adopted for the majority of solar and/or BESS developments. The authors consider that these conditions provide adequate protection for residents close to proposed developments, while maintaining the need for design flexibility and accounting for the character of specific sound from these developments. A first draft of the conditions was issued to planning and legal professionals for feedback, but it remains the case that legal advice should be sought on a project specific basis where they are being used. The final version of the proposed conditions was prepared by consensus among the authors considering the feedback received.

Rationale

The first condition aims to set operational noise limits that uses precise wording to avoid any ambiguity. The limits are specified in terms of rating levels, as defined in BS 4142:2014+A1:2019. Limits which specify absolute rating levels are preferable to those that limit a margin of rating level over background sound level, as the latter approach could fail the test on precision due to the inherent variability of background sound levels. Two alternative conditions, 1(a) and 1(b), are proposed to reflect different commonly adopted approaches to applying rating

level limits. Both approaches are valid, although certain scenarios may favour one over the other. Where assessment methodologies and criteria have been agreed in consultation with the environmental health officer prior to the completion of a noise impact assessment, it might be appropriate for the noise impact assessment report to include a rating level limit in a draft planning condition for consideration by and discussion with the planning authority.

The second condition requires the submission and approval of an updated noise assessment once the plant layout and specification are finalised. The second condition is provided with cognisance to the typical use of candidate plant at the planning application stage. It should be recognised that the final plant layout and specifications of a development are rarely known at the point of planning submission, as this will be determined through a competitive tendering process at the procurement stage. The second condition is therefore intended to provide comfort to planning authorities that the limits in condition one can be met, while allowing developers the flexibility needed to select the most appropriate equipment for a site. In particular, where the assessment made at planning application stage requires mitigation, the inclusion of this second condition is intended to provide sufficient protection for the residents while removing the need to condition the mitigation measures presented in the candidate plant assessment. This should be seen

favourably by both the local authority and developer. The scope of the updated noise assessment could vary from a simple letter, in scenarios where no changes that alter the outcome of the original assessment are proposed, to a full update to the noise assessment report.

The third condition requires the operator to investigate noise complaints. It is provided partly as a response to reviewing numerous onerous conditions requiring mandatory operational noise monitoring. It is the opinion of the authors that mandatory compliance monitoring is unnecessary for the majority of developments. Instead,

planning condition three is provided to include a robust mechanism for the investigation of operational noise complaints, should they occur. The inclusion of a mechanism to require investigations in the event of a complaint is sufficient such that a condition requiring automatic compliance monitoring is not necessary.

Proposed Conditions

1. (a) The level of sound associated with the operation of the development, when determined externally under free-field conditions, shall not exceed the Rating Levels (as defined in British Standard 4142:2014+A1:2019) at the curtilage of the residential properties detailed in Table 1 below:

Table 1				
Receptor	Eastings	Northings	Daytime (07:00 – 23:00) Rating Level dB L _{Ar,1 hour}	Night-time (23:00 – 07:00) Rating Level dB L _{Ar,15 mins}
Property A	...	...	X ₁	Y ₂
Property B	...	...	X ₂	Y ₂
...	...	...	...	...

Or

1. (b) The level of sound associated with the operation of the development, when determined externally under free-field conditions, shall not exceed a Rating Level (as defined in British Standard 4142:2014+A1:2019) of X dB L_{Ar,1 hour} during the daytime (07:00 – 23:00) and Y dB L_{Ar,15 mins} during the night-time (23:00 – 07:00) at the curtilage of any residential receptor as existing or consented at the time of this consent.
2. Prior to the installation of any noise generating plant, an updated noise assessment based on the final detailed design shall be submitted to and approved in writing by the planning authority. The assessment shall demonstrate that the predicted operational levels do not exceed the rating levels set out in Condition 1 and will include a scheme of mitigation where required. All mitigation measures which form part of the approved scheme shall be completed before the approved use commences and shall be retained throughout the life of the development, unless otherwise agreed in writing with the planning authority.
3. In the event that the planning authority receives a complaint relating to operational noise from the development, the operator shall, at the planning authority’s request, employ a suitably qualified acoustician to undertake a noise assessment at the complainant’s property. Prior to undertaking the assessment, the survey and assessment methodology shall be agreed in writing with the planning authority. The noise assessment report should be submitted to and approved by the planning authority. If the report identifies a need to attenuate noise levels, mitigation measures and an associated timetable for their implementation shall be set out and agreed with the planning authority. The approved mitigation shall be implemented in accordance with the approved timetable and retained throughout the life of the development unless otherwise agreed in writing with the planning authority.

A way forward

The authors are proposing that these conditions are used for solar and BESS developments and consider them an improvement

of current practice. We would welcome these conditions being tested and evolved through planning decisions and appeals,

and feedback from members and other interested stakeholders will be sought as part of the guidance document consultation. 🗣️