IMP/001/007/001 – Battery Energy Storage System Guidance Document

1. Purpose

The purpose of this document is to provide guidance on the connection of Battery Energy Storage Systems (BESS) to Northern Powergrid's distribution system. The document supplements existing technical requirements set out in Northern Powergrid policies, Engineering Recommendations and other external standards in order to provide practical work level guidance for design engineers.

2. Scope

This document applies to BESS connections that are designed to normally operate in parallel with Northern Powergrid's distribution system. Where there is any difference between this guidance and the underpinning Northern Powergrid policy, Distribution Code or ENA Engineering Recommendations, then the requirements of those documents takes precedence.

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3. Section Level Guidance

3.1. Background

3.1.1. Introduction

Electrical Energy Storage Systems, EESSs, provide storage for electrical energy so that it can be used later. They can come in a variety of forms and sizes and can be installed for one or a combination of the following main applications[1]:

- Energy response and energy reserve – services used by the System Operator to primarily maintain frequency within a defined range;
- Energy time shifting / price shifting – service used by a customer to manage the cost of energy consumed by storing energy when it is cheaper for use at a time when it is more expensive; and
- Network constraint management – service used by a system or network operator to control the flow of power in part of a network with the objective of managing a network capacity constraint.

These applications can be broken down into separate use cases that a storage operator may choose to combine depending upon their business model and the technical capability of their storage system. The use cases include:

- Increasing the 'self-consumption' of locally generated energy (also referred to as time-shifting or peak lopping). Examples of this use case include: customer domestic homes with rooftop PV and storage, community renewable energy schemes and commercial or industrial high energy consumers. Typically, some or all of the energy that would otherwise be exported can be retained in the EESS for use later in the day. This mode of operation is used to maximise the use of self-generated electricity to avoid importing electricity at times of high price. Similarly, it can be used to enhance the effective capacity of a network connection where the customers load or installed generation capacity is greater than the capability of the network connection; the EESS can absorb any excess generation (or supply excess load requirements). Such arrangement can also be used to mitigate the effects of curtailment due to network constraints;
- Arbitrage services – charging the storage system at times when electricity prices are lower and dis-charge at times of higher electricity prices;
- System Operator ancillary services – providing response and/or reserve services to manage and maintain system voltage and frequency within certain limits;
- Distribution network services – improving efficient management of the network and power quality by controlling active and reactive power; and
- Customer service - providing a back-up supply for customers in the event of a power cut.

Energy Storage Systems are classified according to the form of energy they use (mechanical, electrochemical, chemical, electrical and thermal) and are often characterised with regards to their capacity, operational characteristics (charging/discharging capabilities), voltage, maximum charge / discharge current, life span and response times[2] [3]. A storage operator may seek to stack a number of services to provide additional revenue for their development, provided that these services can run seamlessly without interfering with each other. Since the stacking of these services may vary over the

[1] IET Code of Practice for Electrical Energy Storage Systems, 2017.

[2] IET Code of Practice for Electrical Energy Storage Systems, 2017

[3] IEC Electrical Energy Storage White Paper accessible at: http://www.iec.ch/whitepaper/energystorage/

lifetime of the storage development, a discussion with the developer is important to fully understand their requirements which will in turn define the technical parameters of the connection.

Table 1 shows the typical response time according to the type and technology.

Type	Technology	Response Time
Mechanical	Pumped Hydro Storage	Minutes
Mechanical	Compressed Air Energy Storage	
Chemical	Synthetic Natural Gas	
Chemical	Hydrogen	Seconds/Minutes
Mechanical	Flywheel	Seconds
Electrochemical – Secondary[4] batteries	Lead Acid, Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH), Lithium Ion (Li-ion), Zinc Air, Sodium Sulphur (NaS), Sodium Nickel Chloride (NaNiCl)	
Electrochemical – Flow batteries	Redox Flow, Hybrid Flow	
Electrical	Superconducting Magnetic Energy Storage	

Table 1: Energy Storage System typical response times

As shown in the table above, one major difference in technologies is their response time, i.e. the time it will take them to start to export or import electricity to and from the network, with a number of technologies sharing similar times. The response time along with storage energy rating (also referred to as capacity) will dictate the likely commercial services the storage will be able to provide. Sections 3.1.3 and 3.1.4 provide more information on these.

This document focuses on electrochemical secondary batteries, predominantly due to their increasing popularity, and they will be referred to as Battery Energy Storage Systems, BESS.

3.1.2. Battery Energy Storage System Components and Configuration

Battery Energy Storage Systems are made up of different components and their functionality depends upon the configuration of those components and the purpose of the system or underlying business case. Depending on the functionality, they can operate on their own or together with generation within the same premises (for example solar PV). In general, there are three main connection configurations: network connected without generation, network connected with generation and network independent[5]. This document will consider the first two connection configurations only.

3.1.2.1. Network-Connected without Generation

A Network-connected BESS without generation are directly connected to the network via an inverter as shown in Figure 1 below (with or without any site load). This configuration allows for the BESS to import and/or export generation from the network (or import only if used as an Uninterruptible Power Supply (UPS)). A control system controls the charging and discharging rate of the BESS, with the inverter power rating (in Watts) defining the maximum amount of power the BESS can import/export (see Section 3.1.3 Rating). A typical example for this arrangement would be for the provision of System Operator ancillary services, possibly with a number of smaller BESS units wired together and connected to the network via at least one step-up transformer (the transformer is omitted from the diagram).

[4] A secondary battery is a rechargeable battery as opposed to a primary battery that is not rechargeable and designed to be discharged once.

[5] Network independent systems are out of scope. Such systems will typically operate independently of any other form of power supply. Any network connected systems that are also able to operate independently must have an automatic changeover switch which ensures they can only operate in one mode at a time (network independent or parallel) in accordance with EREC G59.

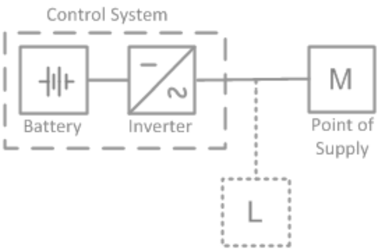

Figure 1: Network-connected BESS without generation

3.1.2.2. Network-Connected with Generation

Network-connected BESS with generation in the same premises may be configured in a number of ways. Figure 2 shows a network-connected system with a single control system where the BESS and generation (such as solar PV) are coupled together via a DC bus. Such a configuration allows the generation to charge the BESS and is typical for, but not limited to, new installations used for peak lopping or to increase 'self-consumption'. A control systems controls the charging and discharging rate of the BESS, with the inverter power rating (in Watts) and size of any on-site load, defining the amount of power that is imported from and/or exported to the network.

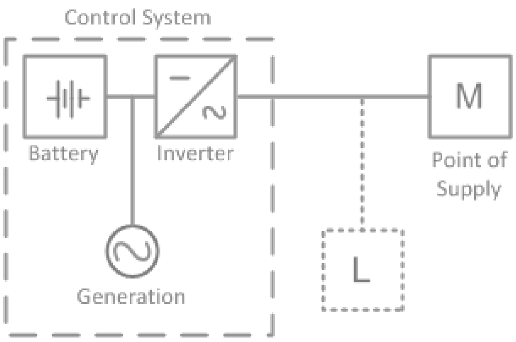

Figure 2: Network connected BESS with DC coupled generation

Figure 3 shows network-connected system with two separate control systems which in some cases may interact in order to form an Export Limiting Scheme (ELS)[6] [7] (see section 3.1.7 Export Limitation Schemes (ELS)). This type of configuration comprises a BESS and generation coupled together via an AC bus and allows for the generation (DC or AC) to charge the BESS, supply any local load and/or export directly to the network. This arrangement is typical for installations where a BESS is retrofitted after the local generation has been installed.

[6] In accordance with EREC G100 – Technical Requirements for Export Limiting Schemes.

[7] An Export Limiting Scheme, ELS, (also referred to as Export Limiting Device, ELD) measures the power at points within the customer's installation and uses this information to either restrict generation output and/or increase the demand in the customer's installation to ensure that the export from the customer's site to the distribution network does not exceed the Agreed Export Capacity.

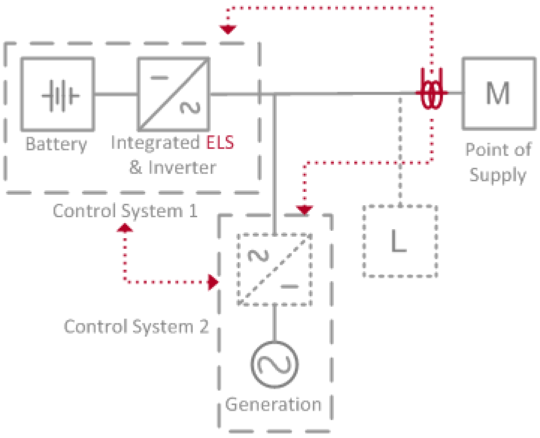

Figure 3: Network connected BESS with generation and integrated ELS

Figure 4 shows a system that is configured similarly but instead of the two control systems (one with an integrated ELS) interacting with one another, a standalone ELS is used to control and limit the amount of generation exported to the network by monitoring power at a single point.

This configuration comprises a BESS and generation coupled together via an AC bus and allows for the generation (DC or AC) to charge the BESS, supply any local load and/or export directly to the network. This arrangement is also typical for installations where a BESS is retrofitted after any generation has been installed and there is no direct communication link between the control units of the BESS and generation control systems.

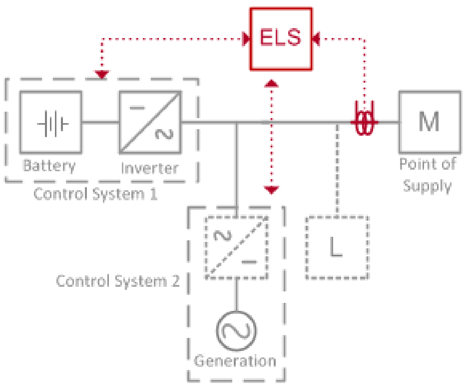

Figure 4: Network connected BESS with generation and separate ELS

An ELS may also be fitted to a BESS configured as per **Figure 1** to limit the export to the network by monitoring the power at a single point, **Figure 5**.

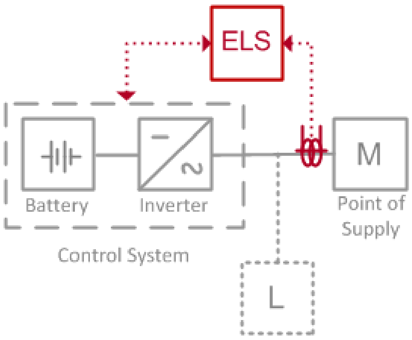

Figure 5: Network connected BESS without generation with an ELS

Finally, as opposed to the configurations shown in **Figure 3** and **Figure 4**, an ELS may control the BESS and generation by monitoring power at their output terminals. This arrangement typically neglects any on-site load hence it is often not preferred. The ELS may be either integrated, Figure 6 (a), or standalone, Figure 6 (b).

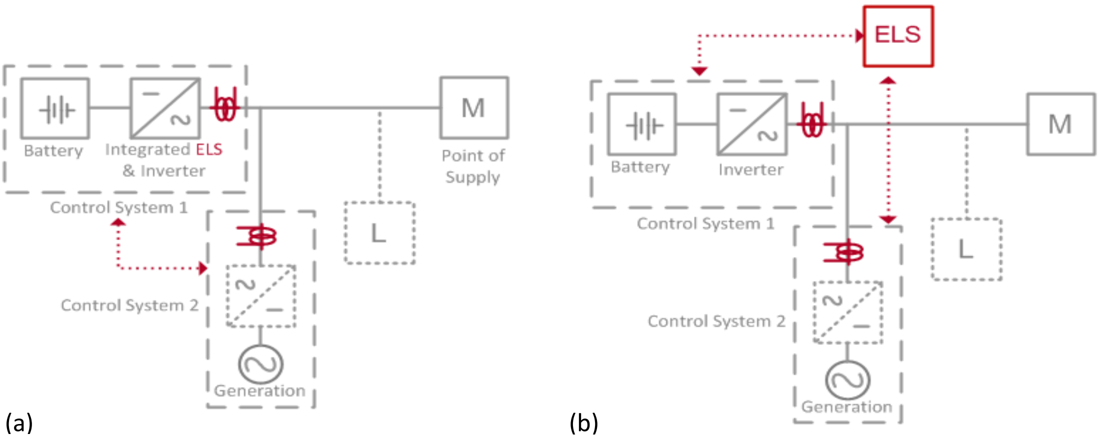

Figure 6: ELS monitoring the output terminals of BESS and generation

3.1.3. Rating

There are two key ratings that determine the characteristic of BESS, power rating and capacity. The BESS operator's use case will typically dictate these ratings.

3.1.3.1. Power Rating (kW or MW)

Storage systems generally have limits on the amount of power they can import from and export to the network (i.e. charge/discharge) due to either an inherit limit in the technology itself or in another component of the system. The limiting factor for a BESS can be the inverter, as this defines the amount of power it can import or export at any given time, or the battery technology itself, as some batteries can charge/discharge at a higher rate than others.

3.1.3.2. Capacity (kWh or MWh)

The capacity, also referred to as the energy rating, is the energy stored in a BESS. This value, together with the power rating, can be used to determine the operating time of a BESS (import or export) depending on the rate it charges/discharges. Traditionally, capacity was described in Ah (ampere-hours) at a particular discharge current. However recently there has been a shift to using kilowatt-hour (kWh) or megawatt hour (MWh). The minimum time it will take a BESS to go from a fully charged (or discharged) state to a fully discharged (or charged) one can be calculated by dividing its capacity by the power rating.

For example, a fully charged 3kWh BESS fitted with a 0.5kW inverter can export 0.5kW for up to 6 hours or a fully discharged system will take at least 6 hours to become fully charged.

3.1.3.3. C-Rate

A C-rate is a measure of the rate at which a battery can be charged or discharged. There are two types of C ratings in common usage, Cx and xC.

A Cx rating describes the charge/discharge rates of a BESS relative to the battery capacity, with 'x' referring to the number of hours. For example, a C20 rate equates to the current that will completely discharge the battery in 20hours. For a battery rated at 400Ah at a C20 rate, this relates to a charge/discharge current of 20 A (400/20).

A xC rating indicates how quickly a BESS can charge/discharge. A BESS rated at xC is expected to fully charge/discharge in 1/x hours. For example, a 2C battery is expected to be able to export its full rated capacity in 30minutes (1/2 an hour). Likewise, a 200kWh battery coupled with a 100kW inverter that is able to fully charge/discharge in 2 hours will be denoted as: $\frac{1}{2}$C, 0.5C or $\frac{C}{2}$.

3.1.3.4. Depth of Discharge (DOD), Effective Capacity and Round Trip Efficiency

Depth of Discharge (DOD) describes how fully a battery has been discharged during a discharge cycle and it is expressed as a percentage of nominal capacity. A high DOD can have a significant impact on battery life, particularly for some technologies such as lead-acid. In general, since the higher the DOD, the shorter the life, it is common for a BESS to be programmed so as to limit the DOD.

A discharge of around 80% represents 'deep cycle' operation and whilst it can have a significant impact on battery life for some technologies (such as lead acid) it may be insignificant for others (such as lithium-ion).

Since it is common for a BESS to be programmed to limit the DOD, the term 'effective capacity' (also known as 'usable capacity') is often used to describe the available capacity of the BESS and is less than the nominal, nameplate, capacity of the battery. For example, a 500kWh capacity, on a BESS programed to limit the DOD to 60%, the effective capacity is 500 x 0.6 = 300kWh[8].

All BESS are subject to losses during their charge-storage-discharge cycle. The charge/discharge efficiency of this cycle describes how effective a battery is throughout the full cycle. For example, a battery that is 90% efficient will export only 90kWh for every 100kWh it imports, with the remaining 10kWh being absorbed by losses (usually heat).

While charge/discharge efficiency is an important factor, it is the overall efficiency, round trip efficiency, of the complete BESS that is important to a BESS operator which considers the overall efficient of the battery, battery controls, inverter charger, thermal management systems etc.

3.1.4. National Grid Balancing Services

National Grid in its role as the System Operator of the National Electricity Transmission System procures services to balance demand and supply in order to ensure the security and quality of the electricity supply. These balancing services include, but are not limited to, frequency response, reserve services, reactive power services and demand side response.

A number of technologies are used by the System Operator to ensure system frequency is maintained at 50Hz ± 1% (49.5 and 51.5). Due to their short response times, BESSs are typically used for frequency response services; technologies which may take longer to respond are typically used for reserve services.

There are two categories of frequency response; dynamic, a continuously provided service used to manage the normal second-by-second changes in system frequency, and non-dynamic, where the

[8] This means that the customer might purchase a battery with greater kWh rating to compensate.

response triggered at a defined frequency variation. The following services form the frequency response market[9]:

- Mandatory Frequency Response, MFR, is made up of one or a combination of primary, secondary and high frequency response and provides an automatic change in power output in response to frequency changes;
- Firm Frequency Response, FFR, can provide both dynamic and non-dynamic response in frequency change and is also made up of one or a combination of primary, secondary and high frequency response; and
- Enhanced Frequency Response, EFR, is an active service where the active power changes proportionally in response to changes in system frequency.

Table 2 shows the response times required by the System Operator in 2017 and how long each service should be capable of running for, for each frequency response service, and reserve service for comparison[10 11].

Frequency Response		
Name	**Response time**	**Can be sustained for**
Primary Response	<10 seconds	20 seconds
Secondary Response	<30 seconds	30 minutes
High Frequency Response	<10 seconds	Indefinitely
Enhanced Frequency Response	<1 seconds	>15 minutes
Reserve Services		
Name	**Response time**	**Can be sustained for**
Fast Reserve	<2 minutes	>15 minutes
STOR (Short-term Operational Reserve)	20 minutes (up to 240 minutes)	>120 minutes

Table 2: NETSO Frequency Response and Reserve Services technical requirements

As shown in Table 2, the response times vary from seconds to minutes. When required to respond within minutes, generators typically ramp up to the desired output over the response time. However, when required to respond within seconds, the ramp rate will be very rapid. This instant change between states[12] could create a voltage step change which may impact other network users. The consideration and assessment of voltage step change as part of the connection design is discussed in Section 3.3.

3.1.5. Distribution Network Flexibility Services

Although services such as active/reactive power reserve and demand side response are currently procured by the System Operator only, it is expected that distribution network operators will start procuring such services to help manage network capacity issues.

3.1.6. Operating Power Factor

According to IMP/001/007[13], generators should normally be set to operate in PQ mode where generator controllers fix the power factor. In addition any generation that needs to comply with the Grid Code (power stations ≥ 50MW) shall be capable of operating throughout the range of 0.85 lagging to 0.95 leading power factor for synchronous generators and 0.95 leading to 0.95 lagging for non-

[9] https://www.nationalgrid.com/uk/electricity/balancing-services/frequency-response-services

[10] https://www.nationalgrid.com/uk/electricity/balancing-services/reserve-services/fast-reserve?technical-requirements

[11] https://www.nationalgrid.com/uk/electricity/balancing-services/reserve-services/short-term-operating-reserve-stor?technical-requirements

[12] For normal generators, the most onerous state change is between zero to maximum generation. For BESS this could be from maximum import to maximum export (or max export to import). Frequency Response services have a technical requirement to import and export as opposed to Reserve Services which only have to export.

[13] IMP/001/007 – Code of Practice for the Economic Development of Distribution Systems with Distributed Generation.

synchronous. Smaller scale power stations, < 50MW, shall be capable of operating throughout the range of 0.95 lagging to unity[14].

When exporting, a BESS should be capable of operating across the ranges set out above. Just like any other type of generation, the power factor of a BESS connected on the distribution network should ideally be set to the power factor of the network it is connected to as this reduces the reactive power flow in the system and hence network losses. For HV and EHV systems (i.e. at HV primary substation bars and EHV transformer feeders) the power factor can normally be obtained from the Distribution Load Estimates (DLEs) and a BESS connected to HV primary substation busbars or an EHV feeder should be set so that it operates at that power factor. For a HV connected BESS, where the power factor cannot be obtained (i.e. along an HV feeder), it is acceptable to allow the BESS some degree of flexibility and let them operate between 0.95 and unity. Typically customers elect to operate their plant close to unity power factor.

Regardless of the BESS's operational power factor network assessments should be performed based on a 0.95 lagging power factor. This provides future flexibility for Northern Powergrid to require the BESS to operate at any point in the range 0.95 lagging to unity and be confident that the distribution network would operate efficiently and within the statutory requirements.

Where a BESS cannot achieve compliance across the full operating range, either because it would require additional equipment on site to do so (e.g. capacitors) or because the customer prefers to be assessed against a specific power factor (if that is different to 0.95 lagging), operation at a specific power factor may be permitted. However, the customer must accept that should Northern Powergrid ask them to operate at a lower power factor in the future, they will have to do so even if this results in a reduction of the maximum active power that can be exported to the Northern Powergrid system. Such an arrangement shall be recorded in the Connection Agreement.

An agreed operating power factor should normally refer to the BESS's point of supply unless the site is supplied via a long circuit (>10km), where consideration should be given to the reactive characteristics of the circuit. In such circumstances the BESS may be required to operate at a power factor that accounts for the reactive characteristics of the circuit.

3.1.7. Export Limitation Schemes (ELS)

Export limiting schemes limit the export from a customer's installation by either restricting generation output and/or increasing demand by measuring power at a single or multiple points within the customer's installation. Typically, where there is a requirement for customers to limit the export from their installation to an Agreed Export Capacity[15], an Export Limiting Scheme, ELS[16], compliant with EREC G100 should be fitted on the customer's side of the point of supply.

Where a customer owned ELS does not comply with EREC G100[17], Northern Powergrid might be able to fit additional network protection (such as an overvoltage or a reverse power relay) at the point of supply. Doing so will ensure the timely disconnection of the site from the network if the customer owned ELS fails to operate, and will maintain the integrity of the distribution network in terms of safety and quality[18] [19].

[14] Although this is currently stated in IMP/001/007, the range is likely to become 0.95 lagging to 0.95 leading in the next revision of the policy.

[15] The maximum amount of Active Power (expressed in kW or MW) that is permitted to flow into the distribution network through the connection point.

[16] sometimes referred to as Export Limiting Devices, ELD

[17] For example, a customer owned ELS might not meet the maximum installed capacity requirements set in EREC G100. However, provided it does meet all other requirements, a non-compliant G100 ELS might still be able to limit export to the Agreed Export Capacity and hence maintain an electricity supply, prior to the Northern Powergrid protection scheme operating and disconnecting the site.

[18] Works required to fit network protection at the point of supply depends on the type of switchgear installed. In some cases it may be necessary to replace the existing switchgear to accommodate the new protection.

[19] This possibility is only applicable for connections at HV and above as it is not physically practicable to provide appropriate arrangements at LV.

3.1.7.1. EREC G100 Requirements

A customer owned ELS measures the power at points within the customer's installation and uses this information to either restrict generation output and/or increase the demand in the customer's installation to ensure that the export from the customer's site to the distribution system does not exceed the Agreed Export Capacity.

For an ELS to be an acceptable means of ensuring that the Agreed Export Capacity is not exceeded, Northern Powergrid must be satisfied that the scheme will limit the export under all circumstances. The ELS shall therefore comply with EREC G100 and the customer will be required to confirm that the ELS meets these requirements by submitting a Testing and Commissioning form (Appendix 7) upon commissioning. The ELS settings shall be recorded in the Connection Agreement and shall only be changed with the written agreement from Northern Powergrid.

As shown in Figure 3 and Figure 4, an ELS may be comprised of a stand-alone piece of equipment or an integrated within the inverter(s). Components of an ELS should preferably be hard-wired together or interconnected using a secure radio-link licensed by OFCOM and with planned availability of 99.9%.

An ELS shall be fail-safe and respond within 5 seconds to ensure that the Agreed Export Capacity is not exceeded if any single piece of equipment, including the communication links fail or lose power. The overall accuracy with regard to measurement and control of active power and, where applicable, voltage should be determined by the manufacturer of the system and stated in its operating manual. Tolerances should, as far as possible, take account of sensing/measurement, processing, communication and control errors. Where the ELS is unable to operate within 5 seconds, a back-up system shall be installed that does operate within 5 seconds. This back-up system should have an active power measurement accuracy of +/-3% or better.

A separate reverse power protection relay shall be installed and owned by the customer at the point of supply where the point of supply is at HV or above. Reverse power protection shall disconnect either the generation or BESS or both operating in parallel with the distribution system within 5 seconds if the Agreed Export Capacity is exceeded. The equipment that should be disconnected should be established at the design stage and should be recorded in the Connection Agreement.

The witness testing and commissioning requirements depend upon the aggregated registered capacity and the number of generation and/or BESS units installed. Where the aggregated registered capacity is less than or equal to 3.68kW/phase (for both single and multiple LV installations), witness testing is not required. If the aggregated registered capacity is greater than 3.68kW and less than or equal to 50kW, Northern Powergrid reserves the right to witness test the operation of the fail-safe functionality. Where the aggregate registered capacity is greater than 50kW or if the point of supply is at HV, Northern Powergrid will normally require an engineer to witness test the functionality of the fail-safe capability. However, where the aggregated registered capacities greater than 50kW but less than 200kW, Northern Powergrid may choose not to do so, if there are several similar ELSs connected to the Northern Powergrid distribution network which have been proven to have satisfactory performance.

Where Northern Powergrid confirms that witness testing is not required, the customer will be required to confirm that the ELS meets the requirements set in EREC G100 by submitting a Test and Commissioning form in addition to the forms submitted to meet the requirements of EREC G83 or EREC G59 as appropriate[20]. If Northern Powergrid chooses to witness the testing of the ELS, the customer will be required to complete the Testing and Commissioning form (Appendix 7) as part of the witness testing process. Table 3 in Appendix 5 provides a summary of these testing requirements.

Witness testing and commissioning tests shall be carried out in accordance with EREC G100.

[20] After May 2019, EREC G98 and EREC G99 will be applicable for all new installations instead of EREC G83 and EREC G59. Between May 2018 and May 2019, new installations can comply with the requirements of either EREC G83/G98 or EREC G59/G99 (as applicable).

3.1.7.2. Maximum Installed Capacity

Since an ELS may take up to 5 seconds to sense, operate and restrict the site export, greater than the Agreed Export Capacity may be exported causing the network voltage to exceed limits or network current to exceed overcurrent protection settings. To prevent equipment ratings from being exceeded and protection equipment from mal-operating, a check must be performed to determine the Maximum Installed Capacity permitted, even where an ELS is installed.

To prevent protection mal-operation, the Maximum Installed Capacity of the generation/BESS shall be no greater than:

- 1.25 x Agreed Import Capacity[21]; or
- 1.25 x Agreed Export Capacity;

whichever is the higher.

The Maximum Installed Capacity shall also be assessed to ensure that the highest network voltage when exporting at the Maximum Installed Capacity (less the minimum demand) does not exceed statutory voltage limit + 1% (of the Nominal Voltage) before ELS operates. The minimum network demand shall be assumed to be zero, unless appropriate evidence is provided by the customer that demonstrates that an alternative value should be used[22].

More information on customer owned ELS as well as practical examples of protection and voltage assessments can be found in EREC G100.

3.1.8. Impact on Network Voltage

The ability of a BESS to change rapidly between importing and exporting (and vice versa) power has the potential to cause significant voltage fluctuations on the distribution network. The mode of BESS operation for anticipated use cases, as shown in Table 2, could result in instantaneous changes in state and hence step voltage changes of significant magnitude.

3.1.8.1. Electromagnetic Compatibility (EMC)

Northern Powergrid is responsible for the overall coordination of permitted voltage fluctuation and disturbance to ensure electromagnetic compatibility (EMC) on the network. To minimise the risk of equipment malfunction, damage and/or customer complaints, all equipment connected to the network must have:

- a level of immunity to voltage fluctuations –i.e. to at least the immunity level [23]; and
- a level of disturbance less than the emission level[24].

To ensure compatibility between equipment, EREC P28 specifies:

- emission limits – maximum emission levels for particular equipment or installation;
- planning levels for assessing the disturbance and emissions from any disturbing equipment and/or installations; and
- a compatibility level – a reference level in the supply system for setting of emission and immunity limits to ensure EMC.

Planning levels are dependent upon the nominal voltage of the network and are used for determining emission limits for individual installations by taking into consideration emissions from other

[21] The maximum amount of power (expressed in kW) that is permitted to flow out of the distribution system through the connection point.

[22] A voltage assessment is not required for any fast-track G59 applications – see section 3.2.2

[23] The level of a given electromagnetic disturbance below which equipment or systems remain capable of operating normally.

[24] The level of a given electromagnetic disturbance emitted from a particular device, equipment, system or fluctuating installation as a whole.

installations (background levels). Planning levels should be used for evaluating the acceptability of disturbance levels at a local site or specific location.

The compatibility level is the reference level in the supply system used for setting of emission and immunity limits to ensure the EMC in the whole system. The compatibility level should be used for evaluating system-wide disturbance and is such that there is a low probability, typically 5%, that measured disturbance in the wider area system would exceed the specified levels based on a statistical distribution of measurements varying both in time and location. The planning and compatibility levels are different for flicker and Rapid Voltage Changes (RVCs).

Figure 7 and Figure 8 below illustrate the concept of compatibility levels, planning levels and disturbance levels. On a local site basis, as shown in Figure 7, specifying suitable planning levels should ensure there is no overlap between disturbance and immunity levels.

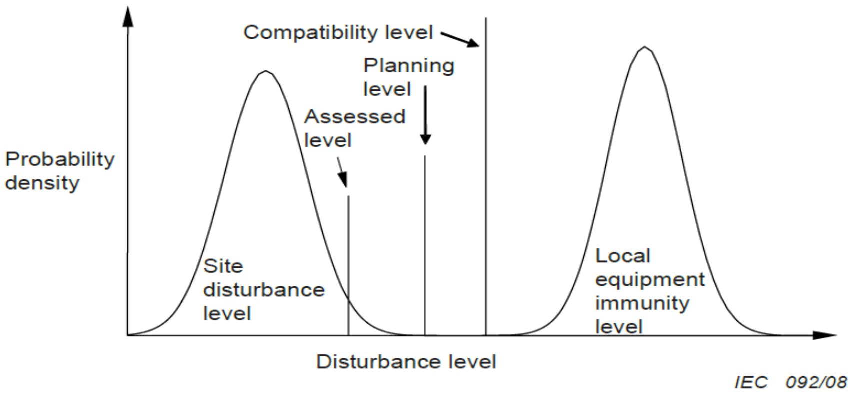

Figure 7: Illustration of EMC concepts relevant to a local site

At a system level, as shown in **Figure 8**, actual disturbance levels could exceed the specified compatibility levels resulting in interference. This is a recognition that the network operator cannot control emissions at all points of the network at all times.

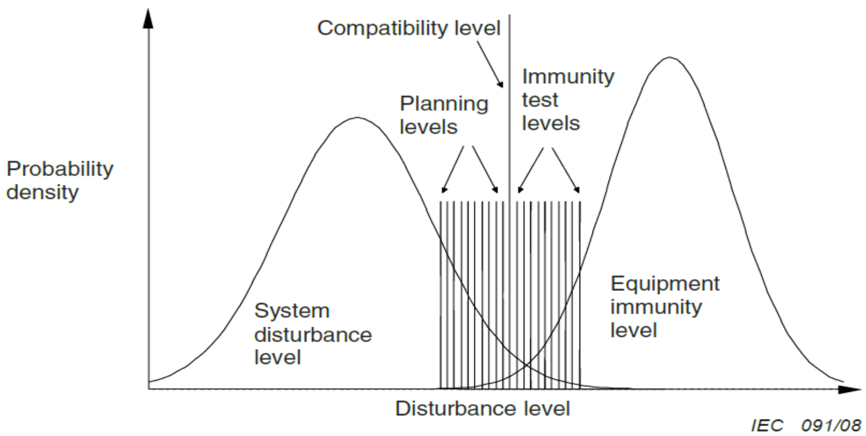

Figure 8: Illustration of EMC concepts relevant to the system

3.1.8.2. Flicker and Rapid Voltage Change (RVC)

Voltage fluctuations of sufficient frequency and/or magnitude can result in annoyance and/or affect the performance, or even damage, electrical equipment. Flicker is a result of repetitive voltage fluctuations which can be observed by changes in luminance. The severity of flicker is quantified using flicker severity levels P_{st} and P_{lt} where P_{st} is the short-term flicker measured over a period of 10 minute interval and P_{lt} the long-term severity measured over a 2 hour interval.

In addition to flicker, fast changes in network voltages of sufficient magnitude, duration and frequency are known as Rapid Voltage Changes (RVCs) and can cause mal-operation of and damage to equipment as well as similar annoyance as flicker. Such events are characterised as frequent, infrequent or very infrequent and can occur randomly or at fixed time intervals as a result of normal equipment operation or energisation/de-energisation of equipment (e.g. tripping of load/generation, switching in/out large loads). RVCs events occur in timescales shorter than the operating time of an on-load tap changer, hence the RVC event is complete before an on-load tap changer has time to detect a voltage variation and operate to restore it (tap changers typically take between 90-120 seconds to operate and restore voltage).

A BESS can cause both RVCs and flicker and should therefore be assessed for both in accordance with EREC P28. The maximum allowed RVC (a voltage change between two steady state voltage conditions[25]) should not exceed 3%. In addition to not exceeding this value, voltage changes should also meet the flicker limits measured or calculated at the Point of Common Coupling, PCC[26] [27]. However, if voltage change is ramped up/down instead of being an instantaneous step change, a RVC may be allowed to occur more frequently.

3.1.8.3. EREC P28 Requirements

Compliance with and demonstrating compliance with EREC P28 is the customer's responsibility and as such the customer should provide sufficient information demonstrating compliance to Northern Powergrid. Where necessary, Northern Powergrid will do an assessment based on the maximum 3% and/or using any additional information the customer has provided to confirm compliance with EREC P28 requirements.

EREC P28 has a three-stage approach for assessing the acceptability of the connection of disturbing equipment and/or fluctuation installations, which ensures that there is only a small probability, typically 5%, that actual disturbance levels in the entire system will exceed the specified compatibility level.

Stage 1 is a simple assessment process for assessing equipment connected to the LV network based on equipment standards. It is not applicable for HV connections or for assessing multiple pieces of equipment that will work together as a system. Individual or multiple pieces of equipment, where there is no indication that they will be operating at the same time, can be assessed and connected under the Stage 1 process, provided they conform to the relevant BS EN 61000 product standards.

The Stage 2 process assesses the equipment's disturbing level against a specified planning level. A Stage 2 assessment does not require the existing flicker background level to be taken into account. Disturbing equipment and/or fluctuating installations can be connected under Stage 2 providing they do not exceed the emission limits of P_{st} for the network voltage level concerned. Where the assessment indicates the disturbance exceeds the limit in Stage 2, the equipment may be eligible for a Stage 3 assessment.

The Stage 3 process assessment requires background and emission levels from the disturbing equipment and/or fluctuating installation at the PCC to be taken into consideration.

[25] The maximum allowed voltage change between two steady state voltage conditions, V_0 and V_1.

[26] The point which is electrically closest to the installation concerned and to which other customers are or might be connected. The Point of Common Coupling is typically assumed to be the same as the Point of Supply, PoS.

[27] The step change measured at the customer's supply terminals or equipment terminals could be greater. For example, the voltage change limit stated in BS EN 61000-3-3 and BS EN 61000-3-11 is 3.3% when measured at the equipment terminals.

3.2. Application Procedure

The application procedure for a BESS depends on:

- its power rating, measured (Watts) not its energy rating (Watthour);
- the presence of any other generation within the same premises; and
- the presence of an ELS.

Due to its exporting capabilities, a BESS must satisfy the requirements of either EREC G83 or EREC G59 as appropriate.

As discussed in section 3.1.2 "Battery Energy Storage System Components and Configuration", the export potential from an installation depends on the configuration on site and the presence of generation within the same premises. The rating of the BESS and any on-site generation will determine the type of the application procedure.

The application procedure set out in EREC G83 is applicable where:

- each BESS and any generation is type tested to EREC G83;
- the installation complies with EREC G83; and
- the aggregate registered capacity of all exporting plant is ≤ 16A/phase (3.68kW/phase)

In all other cases the application procedure is set out in EREC G59.

For a BESS application with no generation on-site, the inverter power rating measured in amps (or the aggregate of multiple inverter ratings where multiple inverters are installed) will determine the application procedure.

For BESS application with generation on-site, the aggregated registered capacity of all exporting plant (BESS and generation) should be used to establish the application procedure unless there is an ELS limiting the total export to an Agreed Export Capacity. In this case the Agreed Export Capacity should be used to establish the application procedure.

3.2.1. EREC G83 Application Procedure

Where the EREC G83 Stage 1 (single premises) application procedure is appropriate, no application prior to installation is required. However, the installer has a requirement to notify Northern Powergrid within 28 days of commissioning.

Where EREC G83 Stage 2 (multiple premise) application procedure is appropriate the installer shall discuss the installation project with Northern Powergrid. This will typically require an assessment of the impact that these connections may have on the network and specify any conditions for their connection.

3.2.2. EREC G59 and Fast-track EREC G59 Application Procedure

Where the EREC G83 application procedure is inappropriate, the procedure set out in EREC G59 applies. This requires the customer/installer to apply to Northern Powergrid prior to commencing works. The application will be assessed within 45 days for a connection at HV or 65 for a connection at EHV.

An EREC G59 application can be fast-tracked and given approval to connect within 10 working days if it meets the following ***eligibility criteria***[28] [29]:

[28] The planned commissioning date on the application must be within 10 working days and 3 months from the date the application is submitted. Confirmation of the commissioning of each **combined generation and storage system** will need to be made no later than 28 days after commissioning.

[29] DNOs will retain the authority to audit any application post approval. If connection is found to non-compliant and disturbing the power quality and voltage on the network, DNOs reserve the right to ask the customer to disconnect the equipment.

- The application is a single premise application (not applicable for multiple premises applications);
- The total aggregated capacity of all generating units (including BESS) is between 16A per phase and 32A per phase;
- The total aggregated capacity of the generating units (excluding BESS) is ≤ 16A per phase **and** the total aggregated capacity of the BESSs is ≤ 16A per phase[30];
- All generating units (including BESS) are EREC G83 type tested units;
- An ELS is present that limits export capacity to 16A/phase (3.68kW/phase) which complies with EREC G100;
- The generating units will not operate in island mode; and
- The customer submits a ELS Enquiry form (Appendix 6 of this document and also available in Appendix A of EREC G100) which includes a single line schematic diagram of the proposed scheme.

On completion of the installation the installer must submit the commissioning sheets, as required in EREC G100 alongside the EREC G83 forms.

Where there is already generation on the premises, since the Connection Agreement is technology based, a separate application is required to connect a BESS on its own or with any generation (if it is to replace any existing generation).

3.2.3. Application Procedure Examples

The flowchart in Appendix 1 illustrates the application procedure and Appendix 5 provides a summary of the application process.

The following examples illustrate the application process:

- A G83 compliant BESS (power rating ≤ 3.68kW) is notifiable post commissioning within 28 days;
- A BESS with power rating > 3.68kW on its own is not EREC G83 compliant and requires an EREC G59 application;
- A BESS with power rating ***1.0 kW*** alongside a generator with power rating ***2.3 kW*** is EREC G83 compliant since ***3.3 ≤ 3.68kW;***
- More than one BESS units with total power rating ***1.3 kW*** (e.g. 2x 0.65kW) alongside a generator with power rating ***2.3 kW*** is EREC G83 compliant since ***3.6 ≤ 3.68 kW***;
- A BESS with power rating ***2.0 kW*** along a generator with power rating ***2.5 kW*** does not comply with EREC G83 since ***4.5 ≥ 3.68kW***. However, if fitted with an EREC G100 compliant ELS and application meets the eligibility criteria stated above, it can be processed within 10 working days under a **"fast tracked G59"** (as opposed to the normal 45 day standard); and
- More than one BESS units with total power rating ***2.0 kW*** (e.g. 2x 1.0 kW) along a generator with power rating ***2.5 kW*** which are fitted with an EREC G100 compliant ELS and application meets eligibility criteria stated above, it can be processed under a **"fast tracked G59".**

Note: Where a BESS or a generator is decommissioned, the customer shall notify Northern Powergrid of the permanent decommissioning. Where the presence of a BESS and/or a generator is indicated in a bespoke Connection Agreement, it will be necessary to amend it to reflect this change.

[30] Not applicable for applications where generating units are greater than 16A per phase or where applications are made up solely of one technology

3.3. Connection Assessment Process

A BESS is considered to be demand when importing power (charging) and generation when exporting (discharging), and should therefore be assessed against both scenarios; as load and generation.

As stated above, BESS applications following the EREC G83 or 'fast-track' EREC G59 procedure can be connected without a network impact assessment[31]. An assessment to determine whether the existing distribution network can accommodate their connection is required for all other applications (i.e. multiple EREC G83 and all other EREC G59).

Any reinforcement work required to allow the connection of BESS applications following the EREC G83 or 'fast-track' EREC G59 procedure will typically be covered by Northern Powergrid, provided they meet the relevant criteria set out in the Common Connection Charging Methodology. Any works required to allow the connection of other BESS will be chargeable to the customer (or apportioned where applicable).

When assessing a BESS application, the following should be taken into consideration:

- Thermal ratings;
- Voltage;
- Fault level; and
- Harmonics.

3.3.1. Thermal Ratings

The design and assessment of the BESS connection should ensure that the network and its components operate within the ratings set in the following Codes of Practices:

- Code of Practice for Overhead Line Ratings and Parameters, IMP/001/011
- Code of Practice for Underground Cable Ratings and Parameters, IMP/001/013;
- Code of Practice for Transformer Ratings, IMP/001/918; and
- Guidance on the assessment of major substation firm capacity, IMP/001/920.

Although assets have a continuous rating, the time-limited ability of a BESS to import/export power means that it may be appropriate to consider whether a bespoke static rating (higher continuous or cyclic rating) can be used, by taking into consideration the total time the full BESS output can be sustained. The above Codes of Practice provide instructions on how to calculate bespoke static ratings for transformers, underground cables and overhead lines.

Transformer ratings depend on a number of transformer design parameters, the ambient temperature and the load duty. A transformer bespoke static rating may be permitted based on these factors, the duration of peak load and its pre-loading conditions. Some transformers do not have same reverse power ratings as the forward power rating and therefore maximum reverse power through a substation may be limited depending on the particular transformer's capabilities.

For underground cables and overhead lines, the bespoke static rating depends on their thermal time constant. Similar to transformers, underground cables have a long thermal time constant which allows for cyclic loading. For underground cables, a bespoke rating can be determined by considering site specific factors (depth of laying, soil thermal resistivity, whether they are laid in ducts etc.) and the load duty. The Crater or Crater Lite design tool may be used to factor in these different parameters.

[31] For 'fast-tracked' EREC G59 applications a check is required to confirm an ELS is present which meets the technical requirements set out in EREC G100.

Overhead lines have a short thermal time constant and therefore they only have a continuous rating[32]. However, a higher site specific bespoke rating could be derived by considering factors such as ground clearance, environmental and loading conditions.

Where a BESS requires full operational capability (i.e. no restrictions in the services that the BESS can provide or its modes of operation), a square wave suggesting a continuous cycle between charging and discharging may be used to determine the cyclic capabilities of network assets. More information on the thermal assessment based on continuous and cyclic asset ratings can be found in Appendix 4.

Where a bespoke rating assessment does not result in an adequate rating, the use of real time measurements (e.g. wind speed) can be used as input into an Active Network Management system. However, this may result in lower dynamic ratings for some of the time and is therefore only appropriate for customers that request a constrained connection.

Switchgear only has a maximum or continuous rating for loading and maximum fault level ratings (break and make). Whilst exceeding the thermal rating may be permitted for a short term in certain circumstances[33], the fault level shall not be exceeded.

3.3.2. Voltage

3.3.2.1. Steady-State and Voltage Rise

Connections should be designed such that the operation of a BESS does not produce voltage rise in excess of the statutory limits stated in the ESQCR and repeated in IMP/001/909 – Code of Practice for Distribution System Parameters and IMP/001/915 – Code of Practice for Managing Voltages on the Distribution System. However, it is accepted that a BESS operating with a EREC G100 compliant ELS (see section 3.1.7) may result in network voltages exceed statutory voltage limits by up to 1% for short duration periods (<5s).

3.3.2.2. Step Voltage Change and Flicker

The ability of a BESS to change rapidly between importing and exporting electrical power has the potential to cause significant voltage fluctuations on the network. The customer's equipment shall therefore comply with EREC P28.

A BESS can cause both RVCs and flicker and should therefore be considered for both in accordance with EREC P28. Compliance with and demonstrating compliance with EREC P28 is the customer's responsibility and as such the customer should provide sufficient information demonstrating compliance to Northern Powergrid. Where necessary, Northern Powergrid will do a compliance test based on the maximum 3% step voltage change, and/or using any additional information the customer has provided, to ensure the BESS is compliant with the requirements set out in EREC P28.

When calculating the magnitude of voltage fluctuations, maximum system impedance values should be used as these values generally represent the worst case normal operating conditions[34]. For the assessment of voltage fluctuations imposed on other customers, only the supply system impedance up to the PCC should be taken into account. For a BESS connection provided at LV, the source impedance upstream of HV/LV transformer may be ignored, unless this is a low rating pole mounted transformer. In general, a low fault level suggests a high system impedance and vice versa.

[32] In reality they have a limited potential for application of cyclic rating, typically lasting a few minutes. For more info, see IMP/001/011 Section 3.4.2

[33] Up to a 10% enhancement to switchgear continuous rating for a maximum of one hour is acceptable to allow time to implement DSR only, which acknowledges the permissible increase in current ratings when switchgear is operated at reduced ambient temperatures.

[34] Normal operating conditions include those where the network is designed to remain within statutory limits, i.e. credible outage conditions including planned and/or fault outages where there is a requirement to secure demand as required by security of supply standards. For an arrangement where there are two network transformers in parallel, a planned outage of one would generally result in the worst-case normal operating conditions. Considerations of outages may be disregarded when assessing LV connected equipment. These requirements don't apply for second circuit outage conditions (N-2) or emergency conditions.

3.3.2.2.1. Step Voltage Change

Step voltage changes occur before an-load tap changer has time to detect a voltage variation and operate to restore it. The rate at which a BESS varies its power output has a direct impact on the step voltage change and therefore on the overall voltage variation experienced by customers connected to the network. Unless the BESS customer states a lower limit for power swing, the voltage step change should be assessed based on an instantaneous power swing from full export at 0.95 lagging power factor to full import at 0.95 lagging power factor[35]. As operation of the BESS in this way is expected to be a normal operational event, the maximum permitted voltage change between two steady state voltage conditions **should not exceed 3%** at the PCC[36 37 38].

The step voltage change caused by a BESS can be calculated using available network modelling tools by modelling both a generator and a load (each equivalent to the power rating of the BESS) connected to the distribution network and switching between the two, whilst maintaining the tap changer on fixed-tap. Such a scenario should reflect the step voltage change the network will experience before the tap changer will have time to operate and restore voltage[39].

Where the normal operation of a BESS would result in a step voltage change less than 3%, it is permissible for multiple step voltage events to occur caused by consecutive operations provided that the aggregate step voltage change does not exceed 3%. Any further operation that would take the aggregate voltage step change above 3% would need to be deferred until the network tap changer has had time to operate to restore the voltage to nominal. Tap changers typically take between 90-120 seconds to detect, operate and restore voltage.

As per section 3.1.7.2, for LV connected BESS that do not come under the EREC G83 or 'fast-track' EREC G59 application procedure, and BESS's connected at HV and above fitted with an ELS, a voltage assessment has to be performed to ensure the voltage will remain within 1% of the upper statutory limit in case the ELS fails to operate. This requirement is **not** applicable for 'fast-track' EREC G59 applications.

3.3.2.2.2. Flicker

Flicker occurs as a result of repetitive voltage fluctuations. EREC P28 has a three-stage approach for assessing the acceptability of the connection of disturbing equipment and/or fluctuation installations.

Stage 1 assessment – LV equipment

Given the typical LV network source impedance, any single or multiple BESS installation rated at ≤ 16A per phase which conform with BS EN 61000-3-3 is classed as being EREC P28 compliant (unless there is an indication that all the BESS's will be operating at exactly the same time – such as where they are controlled by an aggregator to provide the same System Operator ancillary service). Any single or multiple BESS installation rated at ≤ 75A per phase also conforming with BS EN 61000-3-3 can be connected to the LV network on the condition that the service current capacity is confirmed as being adequate to supply the equipment.

BESS installations rated >16A per phase and ≤ 75A per phase, not conforming to the technical requirements in BS EN 61000-3-3, are subject to conditional connection and can be connected to the LV network provided they conform to the technical requirements in BS EN 61000-3-11 and:

[35] This is a requirement for the most onerous service required by National Grid - Enhanced Frequency Response (EFR).

[36] A voltage change greater than 3% may be allowed for a very short period of time (this varies from 100ms for frequent events up to 2 seconds for infrequent and very infrequent events) provided that it returns to within 3%. However, such scenario is not envisaged to be applicable for BESS providing services to National Grid. It is more relevant to equipment that draw more current at the time of energisation. EREC P28 provides further details.

[37] A step voltage change of up to 10% may be permitted for BESS / generating equipment when tripping as such an event could be regarded as being infrequent and unplanned (e.g. due to a fault). However, this is not applicable as a planned operational activity of a BESS / generator.

[38] It is not envisaged that a 3% voltage change will cause any protection nuisance tripping.

[39] Alternatively, Section 6.3.5 of EREC P28 provides a simplified formula for calculating the percentage voltage change caused by disturbing equipment.

- The LV supply impedance at the customer supply terminals is measured or calculated as being equal to or less than the value (Z_{max})[40] declared by the equipment manufacturer in the equipment manual or on customer's application form; or
- At the customer terminals:
  - The service current capacity is confirmed as being rated at ≥ 100 A per phase[41]; and
  - The LV supply impedance is measured as being equal to or less than 0.25 + j0.25 Ω (|Z| = 0.35 Ω) for single phase connections or 0.15 + j0.15 Ω (|Z| = 0.212 Ω) for three-phase connections[42].

Stage 2 assessment

Any LV connections that do not come under Stage 1 assessment and all HV connections should be assessed under the Stage 2 assessment procedure. No measurement is required for Stage 2 assessment.

Under Stage 2 assessment, any BESS that is assessed to result in flicker with $P_{st} \leq 0.5$ under the worst case normal operating condition at the PCC can be connected without further assessment[43]. For simple step change voltage patterns, ramp voltage change patterns or a combination of the two, a simple approximation of P_{st} may be calculated using the 'memory time' technique.

Figure 9 in Appendix 2 shows the limit $P_{st} = 0.5$[44] for the maximum allowable magnitude of step voltage change with respect to the time between each change. Since the maximum allowed step voltage change should not exceed 3%[45], a operation of a BESS that results in a flicker severity at any point on or below the curve in the graph can be connected without further detailed assessment. However, to ensure that a repetitive operation would also not cause unacceptable flicker, there should be a delay between each consecutive operation of at least the amount of time indicated on the x axis of the graph for that particular point on the curve[46]. See a worked example in Appendix 3.

Ramp voltage changes are less noticeable, in terms of flicker, than step voltage changes of the same magnitude. Using Figure 10 in Appendix 2, an equivalent step voltage change of a ramped voltage change with different ramp up/down times can be derived[47]. The equivalent step change can be calculated by multiplying the maximum voltage change, dmax, (that the BESS is expected to cause) by the shape factor corresponding to the time it will take the BESS to ramp up/down. This new equivalent step change equivalent percentage can be used in

Figure 9 to determine whether a reduced time interval between each consecutive operation is permissible (a ramped change would cause less annoyance than a step change hence can be permitted to occur more frequently). See the worked example in Appendix 3.

Although a ramped up/down voltage change of greater than 3% could lead to an equivalent step voltage change of 3% or less, such a connection shall **not** be permitted.

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[40] This value should be stated in the customer's application form.

[41] A fuse rated at 100 A per phase does not necessarily mean that the service has a current capacity of ≥ 100 A per phase.

[42] The LV supply impedance for single phase connections is the phase-neutral loop impedance not the earth loop impedance.

[43] Connection of up to 8 individual disturbing loads each with $P_{st} = 0.5$ and exponent a = 3 summate to a resultant $P_{st} = 1$.

[44] The limit does not represent the maximum tolerable P_{st} at the PCC but is a value that generally shows individual items of disturbing equipment, which conform to this limit at the PCC, to be connected without any significant probability that the planning level would be exceeded.

[45] The maximum allowed voltage change between two steady state voltage conditions, say V_0 and V_1. A greater voltage change may be permitted for both frequent and none frequent events, provided that the voltage returns within 3% of its original steady state, V_0. For example, for frequent events a voltage change of up to 6% is allowed, provided that the voltage returns within 3% of its original steady state, V_0, within 100ms. However, this is more applicable for equipment that draw a greater current at start-up before returning to a steady state within milliseconds (such as D.O.L motors) and therefore it is not expected to be applicable for a BESS.

[46] Note: a step voltage increase followed by a step voltage decrease constitutes two separate voltage changes.

[47] EREC P28 provides additional shape factor curves for different profiles. However, it is not envisaged that they will be applicable to a BESS providing the current balancing services.

Stage 3 Assessment

Any disturbing equipment seeking a connection at EHV and any disturbing equipment that is not permitted to be connected under Stage 2 should be subject to a Stage 3 assessment, where a detailed assessment of existing flicker background levels and projected flicker severity should be carried out with the addition of the expected BESS disturbance.

However, such an assessment may not be practicable for BESS connection enquiries so a Stage 2 assessment should be carried out first. Although measurements could be collected following the successful installation and commissioning of a BESS to ensure the system is compliant with EREC P28, it is not envisaged that a Stage 3 assessment will be performed unless there is evidence that a connection might not be compliant. A Stage 3 assessment is more applicable for disturbing equipment whose operational requirements are known (e.g. furnaces, welders).

Where a Stage 3 assessment is required, this should be carried out in accordance with EREC P28.

3.3.2.3. Aggregating Voltage Step Changes and "Dirty Connections"

A maximum of 3% voltage change is permitted across each voltage network[48]. Where it is expected that more than one BESS will be connected to the same voltage network and could have the same operating regime (for example offering the same service to the System Operator), their aggregated voltage step change must be taken into consideration. Where the aggregated voltage step change of BESS already connected to the network and a BESS application is greater than 3%, the new BESS must either be connected to a different voltage network or reinforcement will be required to ensure that the voltage step change does not exceed 3%. If there are multiple BESS applications seeking a connection to the same voltage network, it may be necessary to make the connection offers interactive.

Unless it is clearly stated that they will be part of an aggregation scheme contracted to offer services to the System Operator, all EREC G83 and 'fast-tracked' EREC G59 applications should be assessed without considering aggregation of the voltage step change.

Where there are any restrictions on the services that a BESS may be used to provide, these should be recorded in the Connection Agreement.

At present[49] the voltage step changes associated with BESS connected at different voltages or different voltage networks should not be aggregated.

For the purpose of the economic development of the network, the Point of Common Coupling is assumed to be the same as the Point of Supply, PoS,[50]. However, if the PoS is remote from a primary or EHV substation and connected via a dedicated circuit, the voltage swing at the PoS may exceed 3%. This is subject to the voltage staying within statutory limits at the PoS and a voltage step change of < 3% at the PCC. Any such designs shall be carefully considered to ensure that such arrangements will not sterilise the network and prevent Northern Powergrid from fully utilising its network assets.

3.3.2.4. Fault Level

The fault level contribution of a BESS depends on the inverters connected on site. The fault level contribution of a BESS should be calculated using the initial symmetrical short-circuit current of the inverter, I''_k. This is a multiple of the nominal rated current of the inverter, I_N, and it can vary between 1.1x and 1.6x of I_N. Where this information is not available from the customer, the higher multiplying factor should be used to calculate the total fault level contribution of the BESS.

[48] A voltage network is defined as the network between the lower voltage windings of a transformer and the normal open point(s). This should include all contributions from BESS connected both directly on the busbar as well as along feeders.

[49] This might change in the future when there is better understanding of the distribution of frequency events and hence the associated voltage step changes.

[50] The supply terminals at the interface between Northern Powergrid's network and the customers installation.

When a BESS is connected in the same premises as other generation, the fault level contribution of both the BESS and generation is determined by the configuration on site. In DC-coupled systems, Figure 2, the total fault level contribution is limited by the inverter. In AC-coupled systems, Figure 3 and Figure 4, the fault level contribution will be the sum of both the BESS and the local generation. An ELS does not limit the fault level contribution of a BESS.

3.3.2.5. Harmonics

Inverters and other power electronic equipment are normally sources of harmonic distortion. Therefore in addition to the power quality requirements set out in EREC P28, all BESS installations shall comply with the requirements set in EREC G5. Customers are expected to demonstrate compliance with EREC G5 as part of the connection process, based on the site's expected emissions. Where necessary, existing background harmonic levels measured at the nearest available measurement point will be provided to the customer to which the projected emissions from the BESS can be added to calculate the total harmonic distortion. If studies indicate that planning levels are likely to be exceeded, it may be necessary for the customer to include suitable mitigation within their design (e.g. filters).

3.3.3. BESS Operational Considerations

The network assessments required and costs associated with a BESS connection depend on its operational capability and connection requirements.

All BESSs capable for providing Frequency Response services, where they are expected to change rapidly between importing and exporting states, should be assessed against all criteria stated in 3.3. Typically, the requirement to comply with EREC P28 will increase the costs associated with the provision of such connection.

Similarly, a BESS capable of providing Reserve Services, where the import requirements are limited and typically less than the export requirements, should also be assessed against all criteria stated in 3.3. However, a cheaper connection might be possible since such services allow for a managed power increase (i.e. ramping the exported power over a longer period of time; as shown in Table 2; Reserve Services have longer response times than Frequency Response services).

Where a BESS is used to manage self-consumption (e.g. load shifting, peak lopping), and export is limited by an ELS, network assessments will not be as onerous and as such network connection costs are expected to be the least.

4. References

4.1. External documentation

Reference	Title
Engineering Recommendation G100	Technical Requirements for Customer Export Limiting Schemes
Engineering Recommendation P28	Voltage fluctuations and the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom
IEC White Paper	Electrical Energy Storage White Paper
IET Standards	Code of Practice for Electrical Energy Storage Systems
SI 2002 No. 2665	The Electricity Safety, Quality and Continuity Regulations
Engineering Recommendation G59/3/3	Recommendations for the connection of generating plant to the distribution systems of licensed distribution network operators
Engineering Recommendation G83/2	Recommendations for the connection of type tested small-scale embedded generators (up to 16A per phase) in parallel with low-voltage distribution systems
Engineering Recommendation G5/4-1	Planning levels for harmonic voltage distortion and the connection of non-linear equipment to transmission systems and distribution networks in the United Kingdom

4.2. Internal Documentation

Reference	Title
IMP/001/007	Code of Practice for the Economic Development of Distribution Systems with Distributed Generation
IMP/001/011	Code of Practice for Overhead Line Ratings and Parameters
IMP/001/013	Code of Practice for Underground Cable Ratings and Parameters
IMP/001/103	Code of Practice for the Methodology of Assessing Losses
IMP/001/909	Code of Practice for Distribution System Parameters
IMP/001/911	Code of Practice for the Economic Development of the LV System
IMP/001/912	Code of Practice for the Economic Development of the HV System
IMP/001/913	Code of Practice for the Economic Development of the EHV System
IMP/001/914	Code of Practice for the Economic Development of the 132kW System
IMP/001/915	Code of Practice for Managing Voltages on the Distribution System
IMP/001/918	Code of Practice for Transformer Ratings
IMP/001/920	Guidance on the assessment of major substation firm capacity

4.3. Amendments from Previous Version

Reference	Description
Whole Document	Doc approved by email Mark Callum 07/11/2023 Doc republished to grid and externally - LB 28/02/2024

5. Definitions

Term	Definition
Agreed Export Capacity	The maximum amount of Active Power (expressed in kW) that is permitted to flow into the Distribution Network through the connection point.
Agreed Import Capacity	The maximum amount of Active Power (expressed in kW) that is permitted to flow out of the Distribution Network through the connection point.
BESS	Battery Storage Energy System.
Compatibility level	Specified electromagnetic disturbance level used as a reference level in a specified environment for coordination in the setting of emission and immunity limits.
EESS	Electrical Energy Storage Systems.
Emission level	Level of a given electromagnetic disturbance emitted from a particular device, equipment, system or fluctuating installations as a whole, assessed and measured in a specific manner.
Emission limit	Maximum emission level specified for a particular device, equipment system or disturbing installations as a whole.
Export Limiting Scheme (ELS)	Export Limiting Scheme – the system comprising of one or more functional units, sensors and control signals that interfaces with the Customer's generation and/or load to control the net flow of electricity into the Distribution System at the Connection point so as not to exceed the Agreed Export Capacity.
Flicker	Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time.
Immunity level	Maximum level of a given electromagnetic disturbance on a particular device, equipment or system for which it remains capable of operating with a declared degree of performance.
Point of Common Coupling (PCC)	Point of Common Coupling – the point which is electrically closest to the installation concerned and to which other customers are or might be connected.
Planning level	Level of a particular disturbance in a particular environment, adopted as a reference value for the limits to be set for the emissions from the installations in a particular system, in order to coordinate those limits with all the limits adopted for equipment and installations intended to be connected to the electricity system.
Rapid Voltage Change (RVC)	The change in root mean square (r.m.s) voltage over several cycles.
Step voltage change	Change from the initial voltage level to the resulting voltage after all generating unit automatic voltage regulator (AVR) and static VAR compensator (SVC) actions and transient decay (typically 5 seconds after the fault clearance or system switching) have taken place, but before any other automatic or manual tap-changing and switching actions have commenced. Step voltage changes can occur following system switching, a fault or a planned outage which produces an instantaneous change in steady state voltage.
System Operator	National Grid Electricity System Operator.
Type Tested	A product which has been tested to ensure that the design meets the relevant EREC requirements (G83 or G59), and for which the manufacturer has declared that all similar products supplied will be constructed to the same standards and will have the same performance. The manufacturer's declaration will clearly define the extent of the equipment that is subject to the tests and declaration. In the case where protection functionality is included in the tested equipment, all similar products will be manufactured with the same protection settings as the tested product. Examples of products which could be Type Tested include Generating Units, Inverters and the protection system. A report compiled by the Manufacturer that can be used to demonstrate compliance with this document.

6. Authority for Issue

6.1. CDS assurance

I sign to confirm that I have completed and checked this document and I am satisfied with its content and submit it for approval and authorisation.

		Date
Liz Beat	Governance Administrator	28/02/2024

6.2. Author

I sign to confirm that I have completed and checked this document and I am satisfied with its content and submit it for approval and authorisation.

Review Period - This document should be reviewed within the following time period.

Standard CDS review of 3 years	Non Standard Review Period & Reason	
Yes	Period: n/a	Reason: n/a
Should this document be displayed on the Northern Powergrid external website?		Yes
		Date
Paris Hadjiodysseos	Smart Grid Development Engineer	12/04/2018

6.3. Technical assurance

I sign to confirm that I am satisfied with all aspects of the content and preparation of this document and submit it for approval and authorisation.

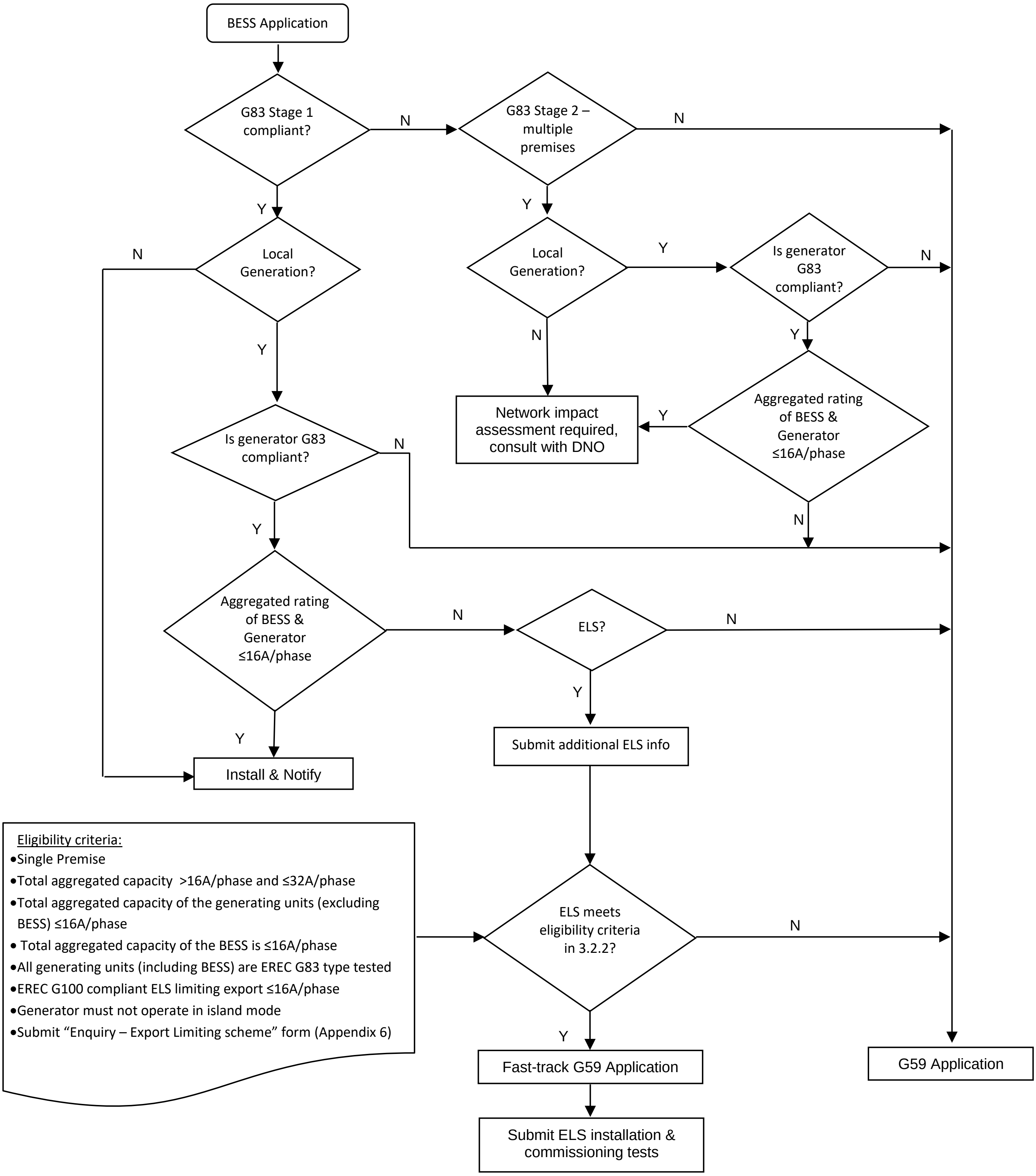
		Date
Alan Creighton	Senior Smart Grid Development Engineer	11/04/2018
David van Kesteren	Senior Asset Management Engineer	10/04/2018

6.4. Authorisation

Authorisation is granted for publication of this document.

		Date
Mark Callum	Smart Grid Development Manager	07/11/2023

Appendix 1 – Battery Energy Storage System application procedure



Appendix 2 – P_{st} curves and shape factors

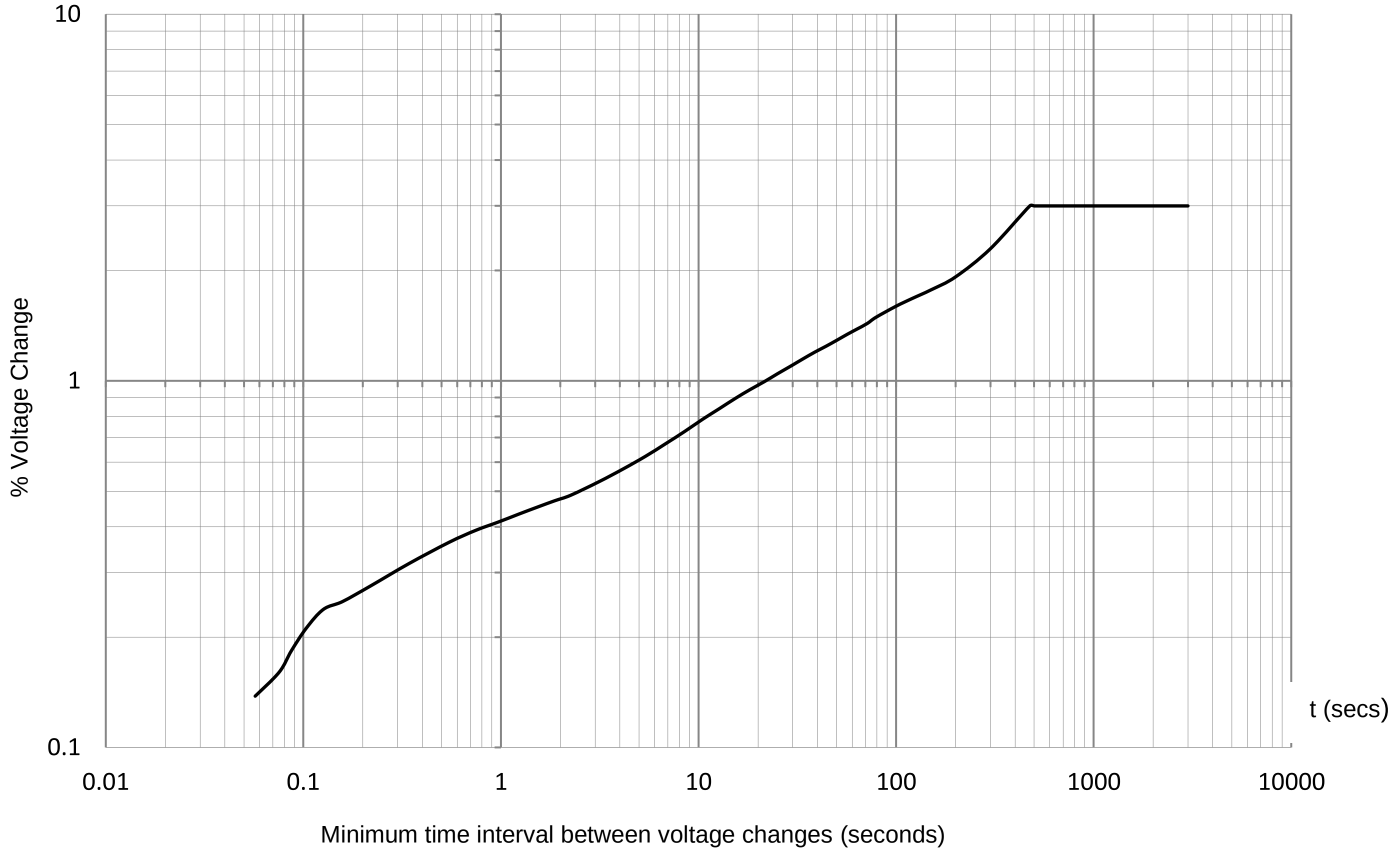


Figure 9: Pst = 0.5 curve for rectangular voltage changes

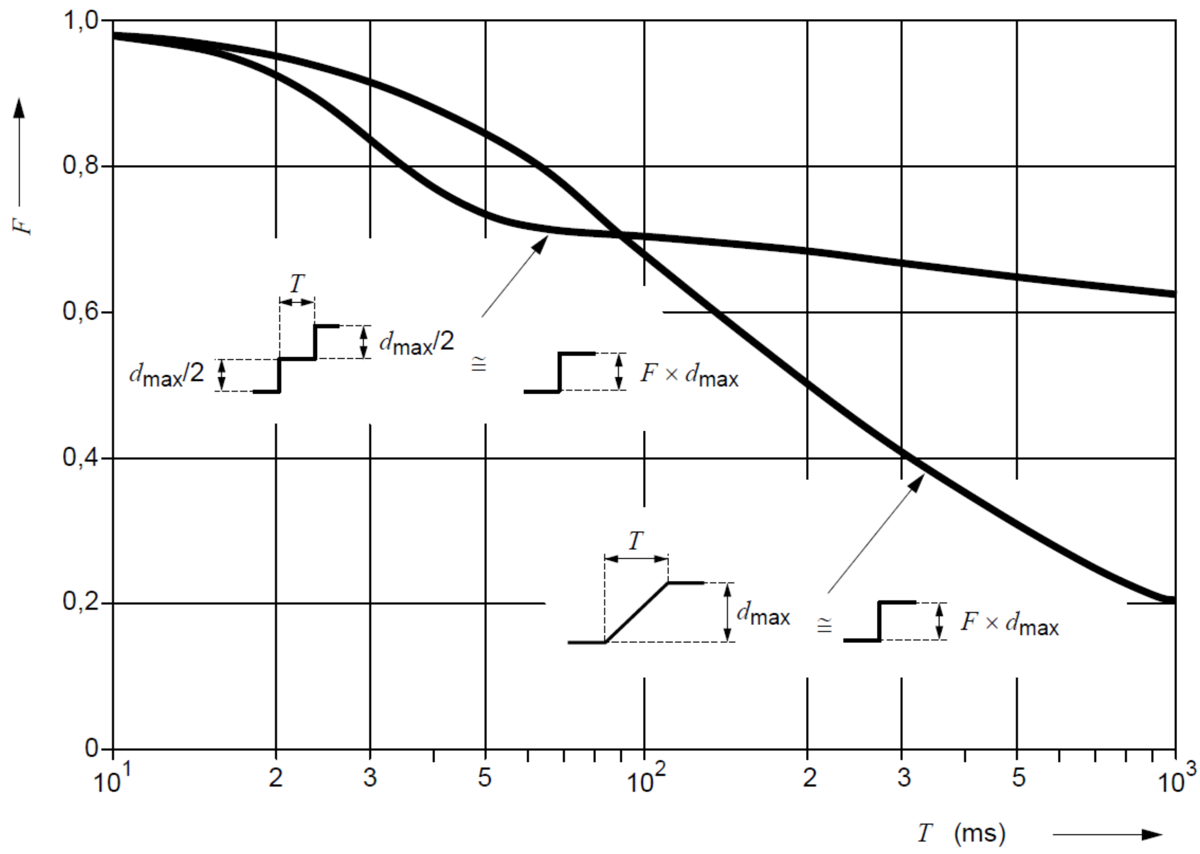


Figure 10: Shape factor (F) for ramp type voltage characteristic

NOTE: Equivalent to Figure 3 in BS EN 61000-3-3.

Appendix 3 – Voltage Assessment

Any equipment connected to the distribution network that could cause voltage fluctuations of sufficient frequency and/or magnitude to cause a disturbance must comply with the requirements set in EREC P28. The voltage change between two steady state voltages will be defined by its magnitude, rate of change of magnitude and frequency of occurrence. The curve in

Figure 9 can be used to determine the minimum time interval between consecutive voltage changes of certain magnitude.

For example, according to

Figure 9, the minimum time interval between step voltage changes following a calculated or modelled step change of 2% is 200 seconds. Therefore, if equipment causes a voltage step change of 2%, it will have to wait for 200 seconds before it causes another change (of any magnitude) to be compliant with EREC P28.

However, where a BESS is controlled to ramp up/down between two states (as opposed to changing states instantly) the time interval between consecutive operations could be reduced. Using the shape factor in Figure 10, and equation below, an equivalent step voltage change for a ramped voltage change can be derived, based on its ramp up/down time.

$$Equivalent\ step\ voltage\ change = F\ x\ d_{max}$$

Where:

F: the shape factor obtained from Figure 10

d_{max}: the maximum modelled or calculated voltage step change

T: the ramp time

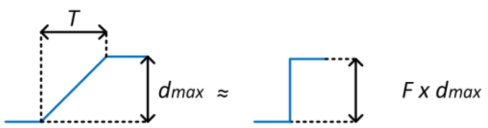


Figure 11: Ramp type voltage characteristic

For example, a BESS that would normally cause a step change of 2% is instead controlled to ramp up from one state to another (worst case scenario would be from its maximum import to its maximum export - or vice versa) over a period of 0.5s (500ms), will have a shape factor, *F*, of approximately 0.35 (as per Figure 10).

Using the formula above, the equivalent step voltage change of a 2% ramped change is 0.35 x 2% = 0.7%. Therefore, using

Figure 9, the minimum time interval between voltage changes (of any magnitude) following a 0.7% step voltage change would be 8 seconds.

Note: Compliance with and demonstrating compliance with EREC P28 is the customer's responsibility and as such the customer should provide sufficient information indicating their compliance. Where necessary, Northern Powergrid will carry out a compliance assessment based on the maximum 3% and/or using any additional information the customer has provided to confirm their compliance with EREC P28 requirements.

Appendix 4 – Thermal Assessment – Continuous and Cyclic Ratings

Although assets have a continuous rating, the time-limited ability of a BESS to import/export power means that it may be appropriate to consider whether a bespoke static rating (higher continuous or cyclic rating) can be used, by taking into consideration the total time the full BESS output can be sustained.

Where a BESS requires full operational capability[51], a square wave representing a continuous cycle changing between charging and discharging modes may be used to determine whether the continuous and/or cyclic capabilities of an asset will be exceeded. Figure 12 shows an illustration of the square wave where power rating is the amount of power a BESS can import and/or export (time *t*), and energy rating its capacity or energy duration (how long a BESS can run for).

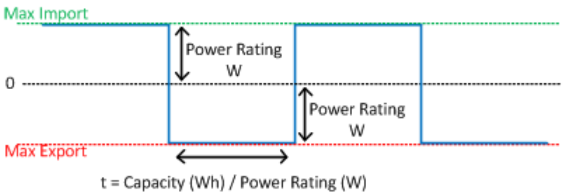


Figure 12: BESS operational capability

Any asset that is directly connected to the BESS (transformer, cable, overhead lines[52]) and not supporting any other load will only have a continuous rating as the asset will experience a constant load profile consisting of 2 opposite power flows (importing when the BESS charging and exporting when discharging). Examples of assets that will only have a continuous rating are highlighted as purple in Figure 13. However, when embedded within the network, the BESS could reduce the load profile seen by some assets and possibly allow for cyclic ratings (reduce load when exporting and reduce export when importing).

For example, when BESS 2 (Figure 13) cycles between import and export, circuit C2 should only be assessed against its continuous rating, as opposed to circuit C3 and transformers T1 and T2, which will experience a varying load profile (BESS 2 will be supplying part of the import requirements of substations S1 and S2 when exporting). Similarly, when BESS 3 is exporting, transformers T1 and T2 will experience similar varying load, and hence assessed against their cyclic rating, as opposed to T3 and circuit C4, which should be assessed only against their continuous rating.

Cyclic rating takes into consideration the cyclic nature of a typical distribution daily load profile (as shown in Figure 14).

However, since a BESS could potentially import power at any given time, including the time of peak load, the importing assessment should be performed assuming a network peak load as this would be the most onerous credible scenario. Provided that the total import (peak load plus BESS import requirements) does not exceed the continuous rating of that asset the BESS can be connected without any cyclic assessment. See Figure 14 for illustration.

[51] A connection where the customer would like to have a connection that allows participation in any of the System Operator existing services and therefore there will be no constraints in the operating regime of the BESS.

[52] Overhead lines do not have a cyclic rating, they only have a continuous rating.

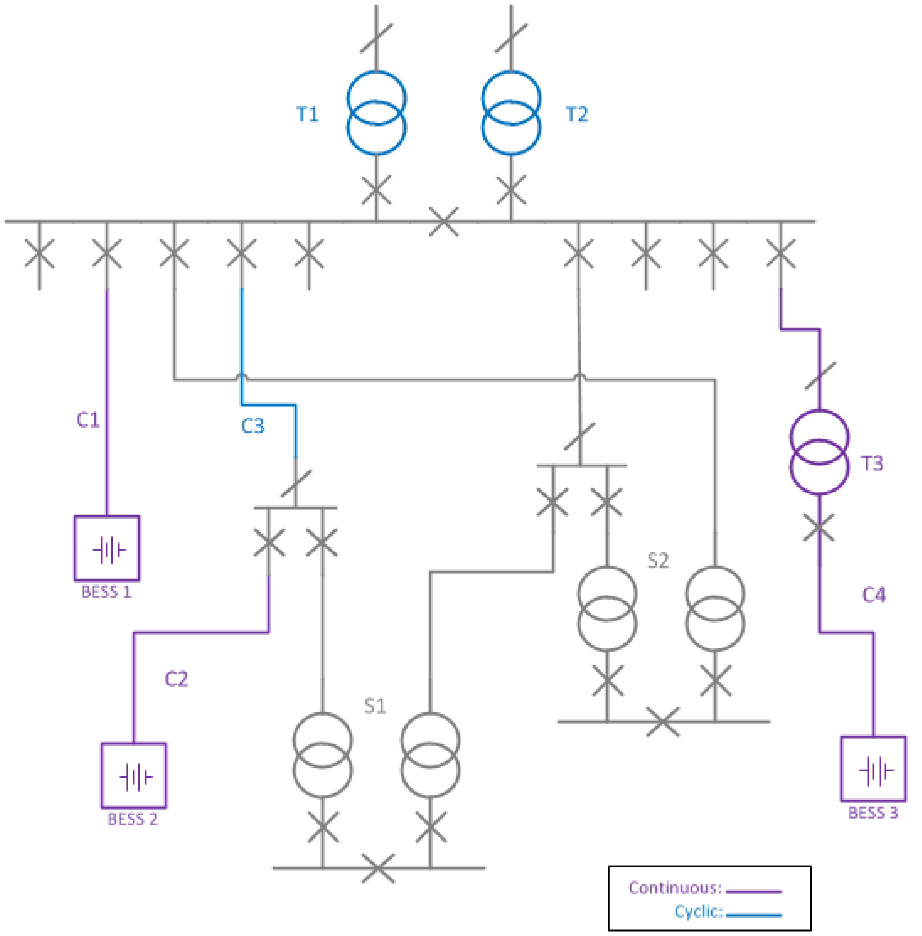


Figure 13: Continuous and cyclic rating schematic

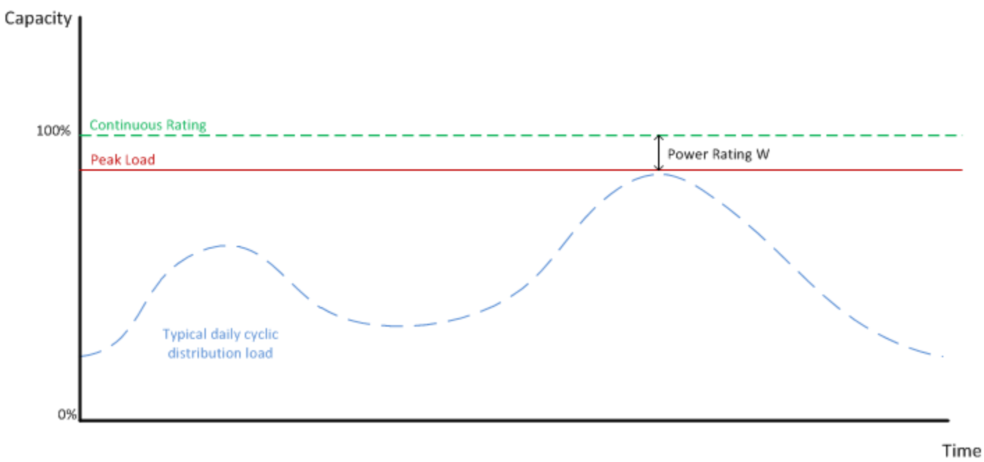


Figure 14: Typical daily load profile of a distribution network and continuous rating

Where the total import exceeds the continuous rating of the asset, if the BESS is embedded within the network, the cyclic capabilities of the asset can be taken into consideration. The profile shown in Figure 15, assumes a worst case and by assuming the BESS is always importing and hence adding its power rating on top of the cyclic load profile as per in Figure 15 (a). Whilst an unrealistic scenario, this may be accommodated within the cyclic rating of the network assets.

Where the above assessments fail, the time-limited ability of the BESS to import, as per Figure 15 (b) can be taken into consideration. This will involve a more detailed assessment of the capacity and power rating of the BESS and the effect a BESS would have on the cyclic shape of the load profile.

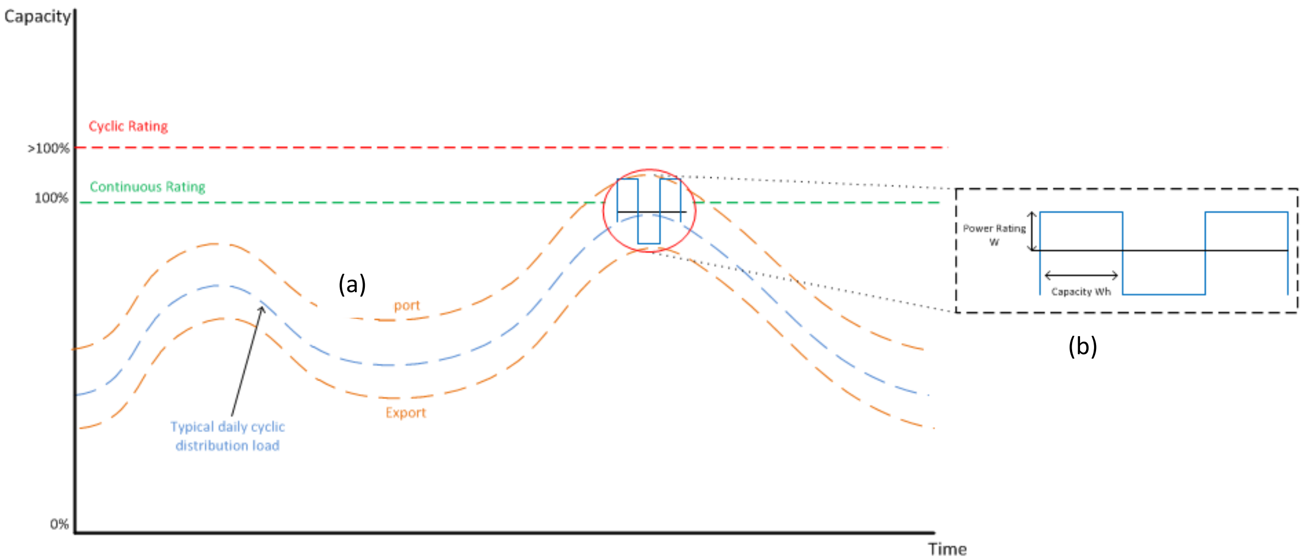


Figure 15: Typical daily load profile of a distribution network and cyclic rating

A similar assessment can be performed when the BESS is exporting and is embedded within the network, taking into consideration the minimum load (which should assumed initially to be continuous) and where the asset is a transformer, its reverse power flow capabilities.

Note: For the purposes of assessing load, the apparent power should be used to calculate the overall utilisation of the equipment.

Appendix 5 – Summary of guidance for LV, HV and EHV

	Installation Type	Type of Application Required[1]	Network Impact Assessment [2]	ELS Designed to EREC G100	EREC G100 Witnessing Testing
1	LV installation where total aggregated registered capacity is ≤ 16A/phase and use type tested inverters	EREC G83 Stage 1 – Notification	No	No	No
2	Multiple LV installations where total aggregated registered capacity is ≤ 16A/phase and uses type tested inverters	EREC G83 Stage 2 - Application for approval	Yes	No	No
3	LV installation where total aggregated registered capacity is > 16A/phase but generation is ≤ 16A/phase and BESS is ≤ 16A/phase and all use type tested inverters[3] but export is limited to a maximum of 16A/phase	EREC G59 – Fast Track	Fast-track	Yes	No
4	Multiple LV installation where total aggregated registered capacity is > 16A/phase but generation is ≤ 16A/phase and BESS is ≤ 16A/phaseand all use type tested inverters[3]	EREC G59	Yes	Yes	First devices
5	LV installation where total aggregated registered capacity is > 16A/phase but ≤ 17kW (single phase) or 50kW (three phase) and all use type tested inverters and do not meet the requirements of 3 or 4 above[3]	EREC G59	Yes	Yes as a means of mitigating a material impact on the network	Not normally but at DNO discreation
6	LV installations where total aggregated registered capacity is > 17kW (single phase) or 50kW (three phase) and all use type tested inverters	EREC G59	Yes	Yes as a means of mitigating a material impact on the network	Yes normally, but at DNO discreation
7	HV & EHV installations of any size	EREC G59	Yes	Yes as a means of mitigating a material impact on the network	Yes

[1] All non-type tested equipment require a EREC G59 application regardless of size. [2] All non-type tested equipment requres a network assessment regardless of size. [3] Under EREC G5/4-1 customer's LV equipment having an aggregate load or rated current > 16A per phase will need to cpmply with the emission limits of Stages 1 or 2 of IEC TR 61000-3-4 to allow connection without assessment, subject to the fault level at the point of common coupling being at least equal to the minium value requried in that TR.

Table 3: Summary of application process and ELS witness testing requirements

Appendix 6 – Enquiry – Export Limitation Scheme

This form should be used by all applicants considering installing an **ELS** as part of their connection application. This form should accompany your application for a connection.

Customer Name _____________	**Project Name** : ____
ENA Form Application submission date: _ _ / _ _ / _ _ _ _	**DNO Ref No** _______________________________________

The following information should be submitted with the enquiry:

Copy of Single Line Diagram of **Export Limitation Scheme**
Explanation / description of **Export Limitation Scheme** operation including a description of the fail-safe functionality e.g. the response of the scheme following failure of a: • **Power Monitoring Unit** • **Control Unit** • **Generator Interface Unit** • **Demand Control Unit** • **Communication Equipment** *Note, fail-safe tests are not required at installations where all generating units are EREC G83 type tested and aggregated capacity is not more than 32A per phase and export capacity is limited to 16A per phase.*
Is additional reverse power protection to be provided (mandatory for connection voltages above 1,000V) Yes / No* * (delete as necessary)
Required Import Capacity (kW):
Proposed Export Capacity (kW) if known:
Total **Power Station Capacity**** (kW): ** aggregate kW rating of all the electrical energy sources (**Generating Units** including storage)

Appendix 7 – Export Limitation Scheme installation and commissioning tests.

Commissioning test requirements for Export Limitation Schemes, in addition to those required by EREC G83 or G59.

DNO Ref. No.:[53]	________	**MPAN (21/13-digits):**	________________________________
Customer name	………………………………………………………………		
Customer address **(where equipment will be used)**	……………………………………………………………… ……………………………………………………………… ……………………………………………………………… ………………………………………………………………		
Installer name	………………………………………………………………		
Installer address	……………………………………………………………… ……………………………………………………………… ……………………………………………………………… ………………………………………………………………		

Information to be provided	
Description	Confirmation
Single Line Diagram of as installed Export Limitation Scheme	Yes / No*
Explanation of Export Limitation Scheme operation	Yes / No*
Description of the fail-safe functionality (Interruption of sensor signals, disconnection of load, loss of power, internal fault detection etc.)	Yes / No*
Agreed Export Capacity that the Export Limitation Scheme is configured to operate for, at the Connection Point	______kW
Maximum Installed Capacity	______kW
Export Limitation Scheme – export setting (when metering accuracies are taken into account.	______kW
The Export Limitation Scheme has hard-wired communication links between the various component parts of the export limitation scheme as specified in section 5.1.3 of EREC G100	Yes / No*
Commissioning checks	
The Export Limitation Scheme is fail-safe and limits export if any of the discrete units or communication links that comprise the Export Limitation Scheme fail or lose their source of power. All components have been tested in line with section 7 of EREC G100	Yes / No*
When the Export Limitation Scheme operates it reduces the exported Active Power to a value that is equal to, or less than, the Agreed Export Capacity within 5 seconds.	Yes / No*
A reverse power relay is fitted which will disconnect the generation within 5 seconds if the Agreed Export Capacity is exceeded by 5%. (not required for fail-safe LV metered connections).	Yes / N /N/A Setting _______kW Time ________Sec
On completion of commissioning all settings are restored to normal operating values and password protected or sealed to prevent user access. A description of the scheme, its settings, and a single line diagram is displayed on site.	Yes / No*

* Circle as appropriate. If "No" is selected the Export Limiting Scheme is deemed to have failed the commissioning tests and the Export Limiting Scheme shall not be put in service.

[53] DNO reference number will be provided by the DNO at the initial assessment.

Additional Comments / Observations:

Insert here any additional tests which have been carried out.

Declaration – to be completed by Generator or Generators Appointed Technical Representative.	
I declare that the Export Limiting Scheme and the installation comply with the requirements of this document and the additional commissioning checks noted above have been successfully completed in addition to those required by EREC G83 or G59 as applicable.	
Signature:	Date:
Position:	
Declaration – to be completed by DNO Witnessing Representative	
I confirm that I have witnessed the tests specified in this document on behalf of ______________________________________and that the results are an accurate record of the tests.	
Signature:	Date:

This form should be appended to those provided in Appendix 3 in EREC G83 or Appendix 13.2 and 13.3 in EREC G59 as appropriate.