Department for
Business, Energy
& Industrial Strategy

GB power system disruption on 9 August 2019

Energy Emergencies Executive Committee (E3C): Final report

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Executive summary

On Friday 9 August 2019, over 1 million customers were affected by a major power disruption that occurred across England and Wales and some parts of Scotland. Though the power disconnection itself was relatively short lived – all customers were restored within 45 minutes - the knock-on impacts to other services were significant. This is especially true for rail services which experienced major delays that extended into Sunday 11 August. The wider disruptions were caused by automatic safety systems under the control of individual service providers, which reacted to frequency and voltage fluctuations, or problems with their back-up power supplies.

Following this event, the Secretary of State for Business, Energy and Industrial Strategy (BEIS) commissioned the Energy Emergencies Executive Committee (E3C) to conduct a review of the incident to identify lessons learnt and put in place a robust action plan for the prevention and management of further power disruption events. This report summarises actions taken already by the industry to ensure the continued security and integrity of the energy network; and is supported by a further implementation plan with future actions.

In parallel to this review, the energy regulator, Ofgem, has conducted its own investigation into the incident which focuses on lessons learnt for the industry and, in particular, on the performance of the Electricity System Operator (ESO), National Grid Electricity Transmission, Distribution Network Operators (DNOs) in England and Wales and the two generators involved. The findings of the Ofgem investigation have been published alongside this report.

In particular, five areas have emerged during the review which provide the greatest opportunity for further improvements, and on which the E3C intend to focus efforts in the future. These are discussed in detail in the paper, with the actions summarised below:

Loss of generation	• Disseminate lessons learnt to the wider generation community • Review and improve compliance testing and modelling processes for new and modified generation connections • Review embedded generators' understanding of, and compliance to, the Distribution Code; and assess whether the current governance, monitoring and enforcement processes are fit for purpose • Review the timescales for the Accelerated Loss of Mains Change Programme, and consider widening its scope
Reserve and Response	• Review the requirements for holding reserve, response and system inertia, including a costs and benefits analysis of holding different levels of reserves
Low Frequency Demand Disconnection	• Review the performance of the LFDD scheme including its application and administration by the DNOs, and present options for short- and long-term improvements
Impact on Essential Services	• Scope and define what an essential service is, and better understand their capacity to deal effectively with power disruptions • Develop and deliver guidance for essential services owners/operators, to support contingency, continuity and resilience planning
Communications Channels	• Develop and test a comprehensive communications strategy for use by industry and government • Develop and test revised operational protocols and frameworks

Introduction

Great Britain has a reliable energy system and its electricity supply comes from a diverse range of sources, from renewables to fossil fuels. Electricity supply is a fundamental part of our homes and industries; and enables the smooth running of services up and down the country. Whilst every effort is made to maintain supplies, no system can be completely free of risk, as demonstrated by the 9 August 2019 power disruption.

Although the energy system broadly performed as expected during this incident, with systems in place to protect supplies, there are a number of lessons to be learnt. The aim of this review by the Energy Emergencies Executive Committee (E3C), commissioned by the Secretary of State for Business, Energy and Industrial Strategy (BEIS), was to identify lessons learnt from the event and put in place a robust action plan for the prevention and management of further power disruption events. This report summarises the work undertaken to date by the E3C, as supported by the E3C Interim Report[1] published on 4 October 2019 and sets out an implementation plan on the future actions to be taken to maintain the security and integrity of the power network.

This report aims to distinguish between the direct impacts of customers being disconnected from the electricity network; and the wider disruption caused by automatic safety systems under the control of individual service providers, which reacted to frequency and voltage fluctuations.

Role of the Energy Emergencies Executive Committee (E3C)

The E3C is a partnership between government, the regulator and industry which co-ordinates resilience planning across the energy industry. It ensures a joined-up approach to emergency response and recovery, identifying risks and processes to manage the impact of emergencies affecting the supply of gas and/or electricity to consumers in Great Britain.

There are a number of key stakeholders in the energy sector that collaborate through the E3C forum and discuss the strategic drivers of future resilience. Some of the key stakeholders that are members of the E3C include:

- Department for Business, Energy and Industrial Strategy (BEIS)
- Office of Gas and Electricity Markets (Ofgem)
- National Grid Electricity System Operator (ESO)
- Distribution Network Operators (DNOs)
- Transmission Network Owners (TNOs)
- Generators and suppliers
- Gas Distribution Networks Operators (GDNs)

Each stakeholder plays a key role in further ensuring the security of the network and its resilience to ever evolving risk profiles. This is essential, given the interdependency between services in the UK and the reliance that other critical industries have on electricity supply.

[1] www.gov.uk/government/publications/great-britain-power-system-disruption-review

Scope of the review

The government and E3C are committed to learning lessons from the 9 August power outage and, where necessary and proportionate, to driving forward system wide changes to make sure our response to any future disruptions is robust and fit for purpose.

During the course of this review, the National Grid Electricity System Operator (ESO) has published its final technical report into the incident[2] and the E3C has had the opportunity to review this analysis. The E3C Review Steering Group has met regularly to systematically review the evidence and data; discuss lessons learnt; and agree a coordinated action plan. The report has also been informed by discussion with essential services providers such as Network Rail. In October 2019, the E3C met to discuss the findings of the review and the committee had the opportunity to ask questions and make comments.

The E3C Review Steering Group has focused closely on areas of the highest impact before, during and after the incident on 9 August. This report does not seek to provide a comprehensive review of energy resilience and emergency response; nor other interrelated issues such as the market response to the incident.

Each of the areas identified below constitutes a chapter of the report. The chapters are ordered chronologically according to when impacts were first seen in the timeline of the 9 August power disruptions. The order of the chapters does not represent the priority of actions being taken forward. The key areas of investigation are:

1. Loss of Generation
2. Reserve and Response Policy
3. Low Frequency Demand Disconnection
4. Impact on Essential Services[3]
5. Communication Channels

The report provides the latest analysis of events that led to the power disruption on 9 August, the response of the electricity system, an outline of the impacts to other services as well as a discussion of lessons learnt and actions for bolstering the system. The data presented in this report has been provided by members of the E3C Review Steering Group, unless otherwise stated.

In parallel to this review, a number of sector-led investigations are being carried out to better understand the wider disruption. For example, the rail industry has taken proactive steps to assess why a select number of trains stopped operating when the frequency on the power network dropped and are testing several engineering and incident response solutions to ensure resilience to future potential power disruptions. These are set out in the Office of Rail and Road's report on the rail disruption following the 9 August power disruption, which has been published alongside this report.

The energy regulator, Ofgem, has also conducted its own investigation into the incident which focuses on lessons learnt for the industry and, in particular, on the performance of the ESO, National Grid Electricity Transmission, Distribution Network Operators (DNOs) in England and

[2] www.nationalgrideso.com/information-about-great-britains-energy-system-and-electricity-system-operator-eso

[3] 'Essential service' has been used in this report to cover organisations that rely on electricity to provide important daily services to the general public as well as critical industries, for example hospitals, airports, oil refineries and the rail services.

Wales and the two generators involved – RWE Generation (Little Barford Power Station) and Ørsted (Hornsea Offshore wind farm).

The findings of Ofgem's investigation have been published alongside this report. This report is aligned with Ofgem's report in its account of the events of 9 August and the underlying facts. Where appropriate, the reports contain jointly agreed actions and recommendations; however, any resulting enforcement action are a matter for Ofgem.

The E3C will take the actions set out in this report, along with the findings from Ofgem's independent investigation, to develop a comprehensive work plan for relevant parties and the E3C Task Groups, specifically Electricity and Communications, to drive forward.

GB power system

Current landscape

Great Britain's electricity transmission network transmits high-voltage electricity from generators to where it is needed throughout the country. The system is made up of high voltage electricity networks that extend across Britain and nearby offshore waters.

The system as a whole is operated by a single electricity system operator. This role is performed by the ESO who is responsible for ensuring the stable and secure operation of the national electricity transmission system. The ESO ensures this by monitoring the supply of electricity, and balancing supply and demand on a second-by-second basis. The ESO has the power to take preventive actions to protect the electricity supply and the security of the network.

The ESO relies on the input of many key industry stakeholders to ensure the GB's energy system operates effectively, including:

- **Transmission Network Owners (TNOs)**: The GB power network consists of three onshore regional TNOs and a number of offshore TNOs. The role of the TNOs is to construct, maintain and operate the core infrastructure used to transmit electricity around Great Britain.
- **Distribution Network Operators (DNOs)**: On a more local level, 14 licensed DNOs carry the electricity from the transmission network through their regional distribution networks to customers.
- **Generators**: The generation of electricity is provided by a diverse range of sources. Electricity generators sell the electricity they produce in the wholesale market to electricity suppliers. Electricity suppliers have contracts with electricity generators to provide the energy their customers use. Generators can be connected to either the transmission network or the distribution network.

The **Office of Gas and Electricity Markets (Ofgem)**, a non-ministerial government department and an independent National Regulatory Authority, is charged with protecting the interests of existing and future electricity and gas consumers. BEIS, Ofgem and the ESO work together to ensure the industry effectively manages risks across the energy systems.

GB power system disruption

On Friday 9 August 2019, over 1 million customers were affected by a major power disruption that occurred across England and Wales and some parts of Scotland[4]. Though the power disconnection itself was relatively short lived – all customers were restored within 45 minutes - the knock-on impacts to other services were significant. This is especially true for rail services which experienced major delays that extended into Sunday 11 August. The wider

[4] SP Distribution erroneously disconnected 22MW of demand in Scotland when the system frequency fell to 48.8Hz. The Grid Code does not require Distribution Network Operators to disconnect demand until the frequency reaches 48.5Hz. The demand disconnection occurred due to an incorrect setting on SP Distribution's LFDD equipment and has since been corrected.

disruptions were caused by automatic safety systems under the control of individual service providers, as they reacted to frequency and voltage fluctuations.

The initial findings from the ESO's Technical Report[5] of 6 September show that the incident is thought to have been caused by a lightning strike to an overhead transmission line and the near simultaneous loss of a number of generators at approximately the same time. The system response (back-up generation) held by the ESO at the time of the incident was just over 1,000MW. However, the total generation lost from the affected power stations and a number of smaller generators, as part of the initial event, was at least 2,000MW, greater than the response held. This loss caused the system frequency to drop below the statutory limit of 49.5Hz to 48.8Hz.

Once the frequency of the system dropped to 48.8Hz, stage one (of nine) of the automatic protection system known as Low Frequency Demand Disconnection (LFDD) was triggered, which had the effect of disconnecting approximately 900MW of demand (equating to over 1 million customers), to arrest the fall in frequency. This was shared out across the different DNOs in England & Wales. See Annex A for an overview of the LFDD scheme.

Simulations detailed in the ESO Technical Report indicate that approximately 550MW of embedded generation was disconnected, either as part of the LFDD scheme or via another unidentified mechanism[6]. The ESO Technical report states that frequency was restored to normal operating conditions within 5 minutes of the initial lightning strike and all disconnected customers were restored within 45 minutes. However, a number of essential services experienced knock-on disruptions as a result of the frequency and voltage fluctuations, notably in the rail transport, health, water and oil sectors.

The case for change

The following chapters set out what we know about the GB power disruption on 9 August 2019, including both the systems and processes that worked as planned; and those that failed to perform to the expected standard to minimise disruption to the public.

The actions in this report are focused on the areas of highest impact before, during and after the incident. As the UK continues to lead the world in becoming the first major economy to pass legislation to reduce emissions to net zero by 2050, this report forms part of a wider programme of work to ensure the continued security and resilience of our energy system. Significant work is already underway, across industry and government, to ensure the UK's continued transition to clean, secure and affordable energy.

[5] www.nationalgrideso.com/information-about-great-britains-energy-system-and-electricity-system-operator-eso

[6] It is important to consider that within any modelling you would expect there to be errors related to simplification of complex areas, hence there will be errors around the value of embedded generation derived by the ESO.

1. Loss of generation

The electricity network is built to be resilient; however, disruptions can occur for a number of reasons, including faults at power stations, or on transmission and distribution assets.

Generators that connect to the transmission network are required to comply with the Connection and Use of System Code[7] and the Grid Code[8]. These documents set out the range of capabilities that a generator must have, including voltage control and frequency control, and what a generator is expected to do during and after a fault on the network.

The Grid Code sets out an extensive process that new generators must meet to demonstrate that they can have safe and resilient connections to the transmission network; it is the responsibility of the generators to ensure compliance with the Code.

Similar to transmission connected generators, embedded generators that connect to the electricity distribution network are required to comply with the Distribution Code[9]. This sets out the requirements that the generator must meet to be able to export electricity onto the distribution network. It also includes the frequency and voltage ranges that those connected to the distribution network should be able to operate within and how generators should respond to a network disturbance. Some larger embedded generators are used by the ESO to balance the network; and, as a result, they also have to comply with the Grid Code.

Under the Distribution Code, embedded generators are required to install protection systems which detect when the generator is islanded[10] from the electricity distribution network and safely shut down the plant. This is predominantly achieved by either monitoring the rate of change of frequency across the electricity system, or the change in voltage phase angle (also known as vector shift).

New requirements for embedded generators under the Distribution Code were introduced in 2014 which required all generators with a capacity greater than 5MW, to install rate of change of frequency protection systems with specific settings to reduce the risk of embedded generation inadvertently shutting down in response to small network disturbances. This was implemented across all relevant sites in 2018 and the Accelerated Loss of Mains Protection programme was initiated in 2019 to implement similar changes across embedded generators with a capacity between 5MW – 50kW.

GB power disruption: lessons learnt

Lightning strikes are a frequent occurrence on the electricity network and rarely cause significant disruption. On 9 August, a lightning strike at 16:52 on a 400kV overhead

[7] The Connection and Use of System Code (CUSC) is the contractual framework for connection to, and use of, the National Electricity Transmission System. www.nationalgrideso.com/codes/connection-and-use-system-code-cusc
[8] The Grid Code is the technical code for connection and development of the National Electricity Transmission System. www.nationalgrideso.com/codes/grid-code
[9] The Distribution Code covers the technical aspects relating to the connection and use of the electricity distribution networks. www.dcode.org.uk/
[10] This means disconnected from the wider energy network

transmission line in Cambridgeshire was followed by generation losses of at least 2,000 MW. This comprised:

- **Little Barford**, a gas fired power station connected to the electricity transmission network;
- **Hornsea-1**, an offshore windfarm also connected to the electricity transmission network; and
- **A significant number of smaller generators** connected to the distribution network also known as embedded generators.

Little Barford Power Station

Little Barford is a 740MW Combined Cycle Gas Turbine power station. It has two gas turbines that feed two boilers, the steam from the boilers then turns a single steam turbine.

Though the protection system on the transmission network operated correctly to clear the lightning strike and the associated electrical disturbance, this event was followed by the near simultaneous loss of the steam turbine at Little Barford power station.

Generation at Little Barford was lost in three stages over a minute and half. The first turbine trip was due to a discrepancy between speed readings of the turbine shaft; the second to an excessive build-up of steam pressure in the pipework; and the third to a manual shut down by the plant operator due to steam safety valves opening from continued build-up of steam pressure.

The initial cause behind the discrepancy between speed readings is still unknown due to data limitations, however since the outage, RWE (the owner of Little Barford power station) has undertaken a review into this sequence of events and identified a number of areas for improvement. These include:

- Identifying measurement system tolerances and adjusting associated sensitivities to increase resilience and maintain safety;
- Balancing steam flows between the two boilers that feed the steam turbine; and
- Verifying the pressure capability overhead of the system and allowing use of this margin to achieve greater resilience.

RWE have confirmed to the E3C that these fixes have all been applied. As a result, if a similar event was to occur again RWE are confident that Little Barford Power Station would not suffer a trip of any of its generators.

Hornsea-1 Windfarm

Hornsea-1 is a 1200MW offshore windfarm consisting of 3 separate 400MW units. At the time of the incident on 9 August 2019, the windfarm was in the process of demonstrating compliance with the Grid Code as required by all new generators, before being allowed to export at maximum capacity onto the transmission network. Two of the units had passed the compliance tests, with the remaining unit permitted to export up to 20% whilst awaiting further testing. These limits were granted by the ESO based on the testing and studies submitted at the time.

The lightning strike caused a voltage fluctuation across the transmission network. Which prompted a response from Hornsea-1 overall voltage control system in an attempt to help correct the voltage. The overall voltage control system initially did correct the voltage (local to Hornsea-1), however, the control system then responded unexpectedly which ultimately led to Hornsea-1 offshore voltage being depressed to a point where protection systems were activated on the two units that were at maximum output at the time. This rapidly de-loaded Hornsea-1 overall output from 799MW to 62MW post-fault.

The manufacturer of the offshore assets identified that this unexpected control system response could be mitigated by implementing a software update that the manufacturer had already prepared as a performance enhancement of the control system, thereby improving damping of system oscillations (which can affect system voltages). Oscillations are a normal inherent feature of electrical power systems and not problematic when adequately damped.

Such oscillations were expected to occur when Hornsea-1 reached 1200MW capacity later in the construction phase, predicted by software modelling of Hornsea-1 when responding to voltage fluctuations. A control system software update was prepared by the manufacturer to address this and was due to be installed on 14 August, well in advance of Hornsea-1 reaching 1200MW capacity. Following the events of 9 August, the manufacturer identified that the unexpected response from the control system was caused by the same root cause that would lead to the oscillations mentioned earlier. Hence, on the 10 August the manufacturer and Ørsted installed the software update, thereby ensuring that should the same or worse voltage fluctuation occur on the transmission system, Hornsea-1 will not de-load.

Embedded generation

Embedded or distributed generation is an electricity generating plant that is connected to a distribution network rather than the transmission network.

There are many types and sizes of embedded generation, including Combined Heat and Power (CHP) plants, wind farms, hydro-electric power, or one of the new smaller generation technologies such as solar.

On 9 August, there were five significant modes of embedded generator loss. The first two modes of loss were triggered by planned protection systems: vector shift[11], which disconnected approximately 150MW; and the rate of change of frequency[12] (RoCof) protection, which disconnected between 350-430MW. The third loss was due to embedded generation shutting down at a frequency of 49Hz; this was not expected and resulted in a further net reduction of 200MW. The ESO Technical Report identified that an unexpected increase in electricity demand occurred in parallel with the loss of generation. This has been attributed to the de-loading or tripping of 100MW of embedded generation but the cause for this loss is unknown at present. The final loss, as reported in the ESO Technical Report, of 550MW occurred when the LFDD scheme was triggered. In total across the event, the loss of embedded generation is estimated to be in the range of 1300MW to 1500MW.

Although the loss of embedded generation due to the operation of the rate of change of frequency protection system worked as intended, the losses on the day were higher than expected. This unexpected loss of generation raises the concern that some generators are operating incorrect protection settings.

[11] This is a form of Loss of Mains protection, which disconnects the generator from the system safely when it detects a fault. The trigger for vector shift relays operating is voltage phase angle and not the rate of change of system frequency.
[12] A form of Loss of Mains protection which disconnects generators from the system if the RoCoF is greater than 0.125Hz/s, disconnecting them from the system safely.

There is a significant possibility that the total volume of loss of embedded generation on 9 August is in excess of the transmission connected generation lost during the event. Given the continued growth of embedded generation, further detailed investigation into their compliance with Distribution Code requirements is necessary, as well as the need for further monitoring. This will be a key focus on the Distribution Network Operators' transition into their roles as Distribution System Operators. The implementation timescales for the latest approved changes to the Accelerated Loss of Mains Protection programme settings should also be reviewed.

Actions

Action 1: The E3C, in collaboration with the relevant trade associations and generators, to disseminate lessons learnt to the wider electricity connected generation community.

Timing: This action should be completed by end January 2020.

Action 2: The ESO, in consultation with large generators and transmission owners, should review and improve compliance testing and modelling processes for new and modified generation connections, particularly for complex systems.

Timing: The ESO to provide a progress report to the E3C by April 2020.

Action 3: The E3C, in collaboration with relevant trade associations and the DCRP, to review embedded generators' understanding of, and compliance with, the Distribution Code; and assess whether the current governance, monitoring and enforcement processes are fit for purpose.

Timing: E3C to provide a progress report to BEIS and Ofgem by March 2020.

Action 4: The ESO and DNOs through the Energy Networks Association (ENA), should review the timescales for the Accelerated Loss of Mains Change Programme, and consider widening its scope to include distributed generation that unexpectedly disconnected or de-loaded on 9 August.

Timing: The ENA to put forward recommendations to the E3C by April 2020.

2. Reserve and response policy

The ESO is responsible for balancing electricity supply and customer demand on a second-by-second basis. Any imbalance between the two could cause significant damage to the electricity network and result in widespread blackouts. As a result, there is a comprehensive set of standards that the ESO must adhere to, to ensure a stable and reliable electricity supply.

These standards are set out in the National Electricity Transmission System Security and Quality of Supply Standards[13] (SQSS) and include the type of faults (or combinations of faults) that the transmission system must be able to withstand and the frequency range the electricity system must operate within.

Frequency plays an important role in the operation of the electricity system; if electricity generation and customer demand are not in balance, the system frequency falls (where demand is greater than generation) or rises (where generation is greater than demand). The ESO therefore brings on extra generation or reduces it to get the balance right. It also buys 'frequency response' (back-up generation) services from generators, energy storage facilities and demand response providers who monitor the frequency of the electricity system and automatically adjust their power output or consumption to fine tune the balance.

The SQSS states that the ESO must maintain the system frequency between 49.5 and 50.5 Hz to maintain the integrity of the network. In order to meet this requirement, the ESO defines the amount of response on hold taking account of the prevailing system conditions. At a minimum, this must cover the power output and frequency deviation expected from the loss of the most onerous power infeed; typically, the largest single generator or interconnector feeding power to the grid at that time.

GB power disruption: lessons learnt

At the time of the event on 9 August, the ESO was holding response to cover a 1,000MW loss, matching the largest infeed on the electricity system at that time in order to keep the frequency above 49.5Hz in the event that this generator or interconnector was lost.

The cumulative loss of Hornsea-1 Windfarm, the steam turbine at Little Barford Station and a number of smaller embedded generators exceeded the reserve and response being held and as a result, the frequency of the electricity system began to fall and frequency response services were automatically triggered which initially arrested the frequency at 49.1Hz.

The system frequency began to recover however the additional loss of the Little Barford gas turbine caused a second drop in system frequency to 48.8Hz, triggering the operation of the LFDD automatic protection system to restore the balance between generation and demand, by disconnecting demand. This resulted in the disconnection of over 1 million customers.

The LFDD scheme enabled the frequency to recover to 48.9 Hz before the loss of the second gas turbine at Little Barford. Over the next three minutes, to restore the system to normal

[13] The Security and Quality of Supply Standards set out criteria and the methodology for planning and operating the National Electricity Transmission System. www.nationalgrideso.com/codes/security-and-quality-supply-standards

operating conditions, the ESO instructed an additional 1,240MW of reserve and response to restore the frequency back to 50Hz.

Following the incident on 9 August, consideration should be given to the economic impact of increasing additional reserves. In doing this, it will be important to consider the cost of increasing the minimum reserve and frequency response holding that the System Operator is required to hold, the consequential impact on customer bills, the frequency of this type of event and the cost of introducing wider measures, for example on large electricity users, to significantly reduce the impact of demand disconnections on the rare occasions that they occur.

Coincident losses of generation causing this level of distribution are rare with only one previous event, on 27 May 2008, over the past 25 years. The frequency response and reserve services cost the ESO more than £270 million in 2018/19, which is funded through consumer bills. However, in light of the events on 9 August, E3C agrees consideration should be given to the economic impact of increasing additional reserves to a level that for the volume of generation lost on 9 August the frequency would not drop below 48.8Hz and result in customer disconnections.

Actions

Action 5: The ESO, in consultation with industry, should undertake a review of the SQSS requirements for holding reserve, response and system inertia. This review should consider:

- the explicit impacts of distributed generation on the required level of security;
- whether it is appropriate to provide flexibility in the requirements for securing against risk events with a very low likelihood, for example on a cost/risk basis; and
- the costs and benefits of requiring the availability of additional reserves to secure against the risk of simultaneous loss events.

Timing: The ESO should put forward modification proposals to the SQSS by April 2020.

3. Low Frequency Demand Disconnection scheme

Under normal operating conditions the ESO is obligated to maintain the frequency of the electricity system between 49.5 and 50.5 Hz. In the event that the frequency deviates from these limits for a sustained periods of time[14], the LFDD is the last line of defence with each of the nine stages of this protection system being preprogramed to disconnect – through a series of relays - a defined amount of demand to balance electricity supply and demand.

The Grid Code requires Distribution Network Operators to install these relays across the Distribution Network. If the frequency continues to drop, the LFDD can automatically disconnect a total of up to 60% of demand across the network.

On 9 August, stage one of the LFDD scheme was successfully triggered when the system frequency dropped to 48.8Hz; this helped stabilise the falling frequency, enabling further recovery mechanisms to be enacted by the System Operator.

This action should have resulted in around 5% of national electricity demand being disconnected, however the DNOs have indicated that 4.0% of demand was actually disconnected equating to over 1 million customers. This could be attributed to a number of reasons:

- The 5% demand figure is based on forecasted peak demand during an average cold spell. On 9 August, actual electricity demand would have been less than forecasted peak demand during a cold spell.
- The frequency did not drop below 48.8 Hz for long enough to trigger the relays to operate, indicating that only the demand required to arrest the fall in frequency was disconnected from the network.
- The growth of embedded generation connected to the distribution network. If the level of embedded generation output is high when a relay is triggered, the amount of demand disconnected may be lower than expected, as the embedded generator is exporting electricity onto the system. Simulations detailed in the ESO Technical Report indicate that approximately 550MW of further embedded generation[15] was disconnected, most likely as a result of the LFDD scheme.

GB power distribution: lessons learnt

The 9 August event also saw significant knock-on impacts to other sectors, in particular the rail sector. The primary purpose of the LFDD is to stabilise the system. Therefore, the Grid Code contains no requirement for the DNOs to afford particular groups of customers, for example essential services, any form of protection. Although DNOs have some discretion in how they disconnect demand, this is largely dictated by the architecture of the system. Further work is

[14] The SQSS allows for a deviation below 49.5Hz provided that the frequency is returned to 49.5Hz within 60 seconds.
[15] This 550MW is included in the total estimated of 1,300MW – 1,500MW embedded generation lost during the power disruption as referenced in chapter 1.

required to establish if we can and should make any modifications and enhancements to the LFDD.

The LFDD offers a last line of defence when the system experiences significant disruption but it will never be a catchall solution to every disruption; therefore, it is important that essential service providers have robust business continuity plans in place, to deal with a range of scenarios, including those outages triggered by the LFDD system. Given the scale of the disruption on 9 August, we will review the level of support offered to essential services to minimise any future disruption.

In this instance the LFDD worked broadly as expected, although the anomalies highlighted above indicate that a more detailed review of the performance of the LFDD scheme is required to identify possible enhancements.

Actions

Action 6: The E3C, through the DNOs and the ENA, to undertake a fundamental review of the LFDD scheme including its application and administration by the DNOs, and present options for short- and long-term improvements.

Timing: The E3C to provide a progress report to BEIS and Ofgem by March 2020.

4. Impact on essential services

As detailed in chapter 3, the Grid Code contains no requirement for the DNOs to afford a particular group of customers, for example essential services, any form of protection. There is currently no agreed definition of what constitutes an essential service in this context. In this report 'essential service' has been used to cover organisations that rely on electricity in order to provide important daily services as well as critical industries, for example hospitals, airports, oil refineries and rail services.

With the increasing dependency between utilities and services, it is important to understand where there are cross-sector dependencies and proportionately mitigate them through strong and adaptable business continuity measures in sectors such as health, transport and water.

Through the UK's National Risk Register[16], the government is able to explain the risks and major emergencies that could affect the UK and provides resilience advice and guidance to the public and industry. Presently industry refer to these services as 'essential', but the application of this term is inconsistent and not universally applied.

GB power outage: lessons learnt

Whilst the 9 August power disruption was relatively short-lived, several sectors experienced impacts and did not resume operations for several days. Some essential services experienced disruption due to being directly disconnected from the electricity network through the LFDD mechanism. However, others experienced disruption as a result of their automatic safety systems reacting unexpectedly to the frequency and voltage fluctuations affecting their electricity network or having insufficient business continuity measures in place. Impacts were reported in the transport, health, water and wider energy sector:

- The rail sector reported disruptions because Thameslink class 700 and 717 trains systems were overprotective to frequency drops on the electricity network and shut down. A number of trains required manual engineer intervention to restart trains and the complexity of the restart process caused significant disruptions translating to 371 cancelled services, 220 part cancelled services and 873 delayed services.
- It was also reported that power supplies to the local Wirral Line were interrupted by the LFDD scheme causing a 428 minute delay for passengers.
- Three Transport for London stations were also disconnected as a result of LFDD operations. Traction supplies to these sites were maintained throughout the incident, resulting in minimal impact to passengers.
- Eight rail signalling assets were also affected, principally in rural locations across England and Wales, with minimal customer impact. 2 assets were disconnected as a result of the LFDD scheme with investigations ongoing into the cause of disruption for the remaining six assets.

[16] National Risk Register of Civil Emergencies (2017 Edition): www.gov.uk/government/publications/national-risk-register-of-civil-emergencies-2017-edition

- Two railway traction substations in the South of England were also disrupted as a result of the drop in frequency on the electricity network; these assets automatically switched to back-up generation with no impacts to customer services.
- Four hospitals were impacted by the power outage; two were disconnected by the LFDD scheme and a further two hospitals were disconnected by their internal safety systems. All hospitals automatically switched to back-up power supplies to ensure continued operation.
- The water sector experienced minimal impacts. This included two water treatment works being disconnected; one through the LFDD scheme and one as result of the company's internal safety systems. Additionally, one water company reporting a reduction in water pressure to 3000 customers due to booster water pumping stations failing to automatically switch to back-up power. This was reduced to c.180 customers within 30 minutes.
- Wider industry reported the disconnection of an oil refinery and chemicals manufacturing plant due to internal safety systems detecting the drop-in frequency. To protect the assets, both plants safely shutdown operations; it took several weeks for the refinery to resume full operations.
- Two airports were impacted following the power disruptions. Newcastle airport was disconnected from the electricity network following the LFDD and utilised back-up generation. The second airport was not impacted by the LFDD but switched to back-up power supplies and was restored within a few minutes. A fault with the on-site internal network disrupted some services like the check-in hall for ~50 minutes.

A number of investigations are being carried out by the impacted industries to better understand why internal safety systems reacted to the frequency and voltage fluctuations in the way that they did and whether any mitigations are available. For example, the rail industry has taken proactive steps to assess why a select number of trains stopped operating when the frequency on the power network dropped and are testing several engineering and incident response solutions to ensure resilience to future potential power disruptions. These are set out in the Office of Rail and Road's report on the rail disruption following the 9 August power disruption, which has been published alongside this report.

Impacts were further exacerbated by the ineffectiveness of essential services' business continuity plans. The E3C will consider how best to work with impacted sectors to reiterate the importance of strong business continuity plans to a range of credible power disruption scenarios, especially services affected by 9 August disruption, including: rail services, hospitals, water supplies, oil refineries and airports. This will enable essential services to adapt business continuity measures and ensure their preparedness and resilience to a range of possible power disruption scenarios.

Actions

Action 7: E3C to scope and define what an essential service is, and better understand their capacity to deal effectively with power disruptions.

Timing: The E3C to agree a definition by end March 2020.

Action 8: E3C to develop and deliver guidance for essential services owners/operators, to support contingency, continuity and resilience planning.

Timing: The E3C to agree draft guidance by end March 2020.

5. Communication channels

During any emergency response, including to power disruptions, effective communications between industry, government, the public and media are a critical function. It is vital that communications are co-ordinated, consistent, clear and timely. Communications during the 9 August power system disruption can be broadly categorised into the following areas:

- **Operational communications**: These lines of communication, for example between ESO and DNO control rooms, are key to the operation of the energy system, where the flow of information and communication is essential to decision making and response during incidents.
- **Wider Industry communications**: This refers to industry communications that are beyond operational, for example between network control rooms, energy generators and suppliers, where information flows are important to improved situational awareness during incidents.
- **External communication**: these are public-facing communications provided by government and industry, that seek to update the public on incident progress and to provide reassurances regarding incident response.
- **Industry-to-government communications**: this refers to communication between industry and government (e.g. industry to Ofgem and BEIS) to provide situational awareness during incidents, and to provide timely updates on incident impacts and actions taken.

GB power outage: lessons learnt

Overall communications on the day fell below the standard expected which unnecessarily compounded the severity of the incident. The review highlights that in the immediate aftermath of the outage, there were infrequent and disjointed updates to the general public on the preventative actions taken to maintain the power systems integrity and security. In some instances, there were also ineffective communications with the public on the actions taken to restore the system and the anticipated restoration time scales.

In particular, as highlighted in the ESO's review into the 9 August disruptions, there was a lack of public-facing and external updates during the event from the ESO, which meant communications were only issued post event. The first public announcement from ESO was issued at 18:27, which was following the event and once the system had stabilised. By this time, many DNOs had used twitter to provide area updates that were widely circulated. The public would have benefitted from a cohesive message from the DNOs and the ESO in terms of universal announcements.

Furthermore, the prevailing use of social media as a public engagement tool means industry should look to utilise social media platforms to share power disruption updates with the public. Whilst some DNOs sent timely updates, industry should look to set guidelines for social media updates (the frequency and the timeliness of updates) and reiterate the importance of central updates from the ESO during the event. However, it is important to acknowledge that since the

2013 Christmas Event[17], there was a significant uptake and usage of the 105 Single Emergency Number during the 9 August disruptions, managed by Energy Network Association (ENA) on behalf of members. This shows that some improvements have been made to communications with the public.

Strong industry-government communications are important to ensuring effective situational awareness, and so that government can be ready to respond to public and media requests for information. Initial lessons learnt suggest that these communications can be further strengthened by earlier, more frequent updates from industry.

Some aspects of the operational communications worked well during the event. For example, there were effective lines of communication from control engineer to control engineer to arrest the fall in frequency on the network by the ESO and the DNO.

However, electricity generators received no communication during the events of 9 August that would have made them aware of the system condition. As a matter of principle, communication channels with these parties should be reviewed so that any commercial decisions made by generators that might be to the detriment of the system recovery process (such as precautionary shut down) are not unintentionally actioned through lack of awareness. We are aware that industry has already commenced a potential solution through Grid Code Modification GC0133. This was raised by SSE on 16 October and would require the ESO to publish the state of the electricity system to market participants. This will be reviewed for its appropriateness through the Grid Code review process and Action 10 of this report.

In terms of next steps to address the above issues, a review is required to put in place a new framework for public communications for use by all the key electricity industry stakeholders at times of significant incidents. This should cover the utilisation of social media platforms to convey timely updates.

To ensure lessons are learnt, operational communications also need to be reviewed, to assess communications between the ESO, DNOs, TNOs and Offshore TNOs. This includes updating the operational communication protocols for significant events so that clear lines of communication and accountability are provided in future. These protocols and lessons learnt should be reflected in updates to the gas sector, recognising the synergies in this area.

Actions

Action 9: E3C, through the Communications Task Group (CTG), to develop and test a comprehensive communications strategy for use by industry and government.

Timing: The CTG to put forward a new strategy to the E3C by February 2020.

Action 10: E3C, through the CTG, to develop and test revised operational protocols and frameworks for communications between wider industry during incident response scenarios.

Timing: The CTG to put forward a new strategy to the E3C by February 2020.

[17] www.gov.uk/government/publications/severe-weather-christmas-2013-electricity-distribution-industry-performance

6. Next steps

The E3C will take the actions set out in this report, along with the findings from Ofgem's independent investigation, to develop a comprehensive work plan for the E3C Task Groups, specifically Electricity and Communications, to drive forward. The E3C will coordinate input from government, the regulator and industry to ensure well evidenced, timely and proportionate action is taken to prevent and manage further power disruption events.

The E3C will report progress to the Department of Business, Energy and Industrial Strategy and Ofgem on a quarterly basis, with the first report due by the end of March 2020.

For comments or questions, please email ercorrespondence@beis.gov.uk.

Annex A: Low Frequency Demand Disconnection

Frequency plays a very important role in power transmission and distribution in relation to the balance between the demand and generation requirements of the electricity system. The maintenance of system frequency within set levels is required to maintain stability and prevent a full system collapse.

The Low Frequency Demand Disconnection (LFDD) scheme is designed to limit the fall in frequency for extreme events beyond those defined as ‘secured’ events in the SQSS and Operating Code OC6 (Demand Control) of the Grid Code.

Under normal operating conditions the Electricity System Operator (ESO) is obligated to maintain the system frequency between 49.8 and 50.2 Hz. If the network generation is higher than the demand the frequency rises, however conversely if generation is lower than the demand the frequency reduces. As the generation at any instant is unlikely to equal the demand the frequency constantly varies. The variation in frequency is normally small and has little impact on customers. Any variation in frequency must be controlled to enable certain items of equipment (e.g. clocks) to operate correctly. The ESO continuously monitors the frequency and dispatches the appropriate generator output. Should the total dispatch of generation available be insufficient to meet the demands due to a fault or loss of generation or an unexpected increase in demand, the frequency will fall.

Under exceptional circumstances (e.g. loss of a large generator) the frequency should not deviate outside the range 49.5 to 50.5Hz for more than 60 seconds. In order to achieve this, ESO contracts frequency response to secure the power system for a number of events.

There may be certain circumstances where the contracted frequency response may not be sufficient to maintain the system frequency between the statutory limits where the total loss of generation exceeds the amount secured for and a deficit of generation arises.

In order to reduce the generation deficit (or excess in demand) to maintain stability, Distribution Network Operators (DNOs) have low frequency relays to disconnect demand. This procedure is called LFDD and is described in Operating Code OC6 (Demand Control) of the Grid Code.

To comply with the requirements of the Grid Code, the DNOs are obligated to install LFDD schemes. The schemes are designed to automatically disconnect at least 60% in England & Wales and 40% in Scotland of the total DNO demand on a stage by stage basis.

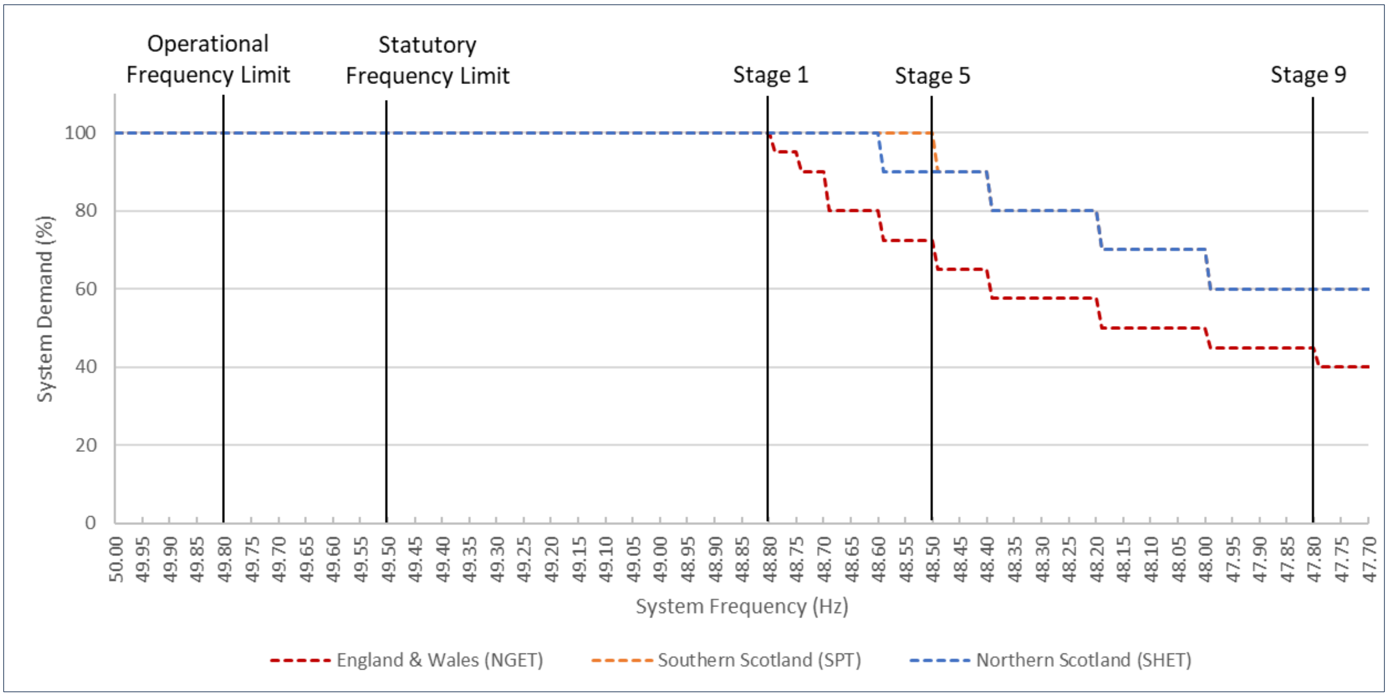
The demand subject to automatic low frequency disconnection is divided into 9 predetermined discrete MW blocks which are disconnected at defined low frequency levels. Each block of demand is distributed across each DNO license area, so far as reasonably practical, so that the demand at different Grid Supply Point (GSP) sites is reduced evenly, as shown in the Table 1 below.

The current settings were updated in April 2007 after a technical Grid Code Review Panel concluded that the LFDD ranges need to all be activated within a 1Hz range from 48.8 to 47.8Hz (previously the range was from 48.8 to 47.0Hz) due to concerns that the lower stages may not disconnect demand sufficiently rapidly to safeguard the GB Electricity System under extreme events.

Table 1: Low Frequency Demand Disconnection settings for each frequency disconnection stages

		% of Demand disconnection in each transmission Area		
LFDD Stages of Customer Disconnection	**Frequency (Hz)**	**England & Wales (NGET)**	**Southern Scotland (SPT)**	**Northern Scotland (SHET)**
Stage 1	48.80	5		
Stage 2	48.75	5		
Stage 3	48.70	10		
Stage 4	48.60	7.5		10
Stage 5	48.50	7.5	10	
Stage 6	48.40	7.5	10	10
Stage 7	48.20	7.5	10	10
Stage 8	48.00	5	10	10
Stage 9	47.80	5		
Total % Demand		**60**	**40**	**40**

Chart 1: LFDD stages of system demand disconnection against a fall in system frequency



Appendix: Glossary of terms

Below is a list of acronyms used in this report. Where possible acronyms have been spelt out in text.

Acronyms	Definition
BEIS	Department for Business, Energy and Industrial Strategy
CTG	Communications Task Group
Customer	Electricity consumers
DNO	Distribution Network Operator
E3C	Energy Emergencies Executive Committee
ESO	Electricity System Operator
ETG	Electricity Task Group
LFDD	Low Frequency Demand Disconnection
NETS	National Electricity Transmission System
OC6	Operating Code 6
Ofgem	Office of Gas and Electricity Markets
RoCoF	Rate of Change of Frequency
SQSS	Security and Quality of Supply Standards
TNO	Transmission Network Operator
TS	Transmission System
VS	Vector Shift – type of loss of mains protection that detects changes in voltage

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