Interim Report into the Low Frequency Demand Disconnection (LFDD) following Generator Trips and Frequency Excursion on 9 Aug 2019

16th August 2019

Executive Summary

Summary of event

Prior to 4:52pm on Friday 9th August 2019, Great Britain's electricity system was operating as normal. There was some heavy rain and lightning, it was windy and warm – it was not unusual weather for this time of year. Overall, demand for the day was forecast to be similar to what was experienced on the previous Friday. Around 30% of the generation was from wind, 30% from gas and 20% from Nuclear and 10% from interconnectors.

At 4:52pm there was a lightning strike on a transmission circuit (the Eaton Socon – Wymondley Main). The protection systems operated and cleared the lightning in under 0.1 seconds. The line then returned to normal operation after c. 20 seconds. There was some loss of small embedded generation which was connected to the distribution system (c. 500MW) due to the lightning strike. All of this is normal and expected for a lightning strike on a transmission line.

However, immediately following the lightning strike and within seconds of each other:

- Hornsea off-shore windfarm reduced its energy supply to the grid
- Little Barford gas power station reduced its energy supply to the grid

The total generation lost from these two transmission connected generators was 1,378MW. This unexpected loss of generation meant that the frequency fell very quickly and went outside the normal range of 50.5Hz – 49.5Hz.

The ESO was keeping 1,000MW of automatic "backup" power at that time – this level is what is required under the regulatory approved Security and Quality of Supply Standards (SQSS) and is designed to cover the loss of the single biggest generator to the grid.

All the "backup power" and tools the ESO normally uses and had available to manage the frequency were used (this included 472MW of battery storage). However, the scale of generation loss meant that the frequency fell to a level (48.8Hz) where secondary backup systems were required to disconnect some demand (the Low Frequency Demand Disconnection scheme) and these automatically kicked in to recover the frequency and ensure the safety and integrity of the network

This system automatically disconnected customers on the distribution network in a controlled way and in line with parameters pre-set by the Distribution Network Operators. In this instance c. 5% of GB's electricity demand was turned off (c. 1GW) to protect the other 95%. This has not happened in over a decade and is an extremely rare event. This resulted in approximately 1.1m customers being without power for a period.

The disconnection of demand along with the actions of the ESO Control Room to dispatch additional generation returned the system to a normal stable state by 5:06pm. The DNOs then commenced reconnecting customers and supply was returned to all customers by 5:37pm.

Immediate consequences

There were a number of very significant consequences from these events, the most significant of which include:

- 1.1 million electricity customers were without power for between 15 and 50 minutes.
- A number of a particular class of trains operating in the South-East area were unable to stay operational throughout the event and, in a number of cases, required an engineer to be sent out to the individual train. This was likely a significant factor in the travel disruption on the rail network.
- Some other critical facilities were affected including Ipswich hospital (lost power due to the operation of their own protection systems) and Newcastle airport (disconnected by the Low Frequency Demand Disconnection scheme).

Preliminary findings

Our preliminary findings based on analysis to date are:

- Two almost simultaneous unexpected power losses at Hornsea and Little Barford occurred independently of one another - but each associated with the lightning strike. As generation would not be expected to trip off or de-load in response to a lightning strike, this appears to represent an extremely rare and unexpected event.
- This was one of many lightning strikes that hit the electricity grid on the day, but this was the only one to have a significant impact; lightning strikes are routinely managed as part of normal system operations.
- The protection systems on the transmission system operated correctly to clear the lightning strike and the associated voltage disturbance was in line with what was expected.

- The lightning strike also initiated the operation of Loss of Mains (LoM) protection on embedded generation in the area and added to the overall power loss experienced. This is a situation that is planned for and managed by the ESO and the loss was in line ESO forecasts for such an event.
- These events resulted in an exceptional cumulative level of power loss greater than the level required to be secured by the Security Standards and as such a large frequency drop outside the normal range occurred.
- The Low Frequency Demand Disconnection (LFDD) system worked largely as expected.
- The Distribution Network Operators quickly restored supplies within 31 minutes once the system was returned to a stable position.
- Several critical loads were affected for a number of hours by the action of their own systems, in particularly rail services.

Next steps

We have had excellent co-ordination, data and support from Distribution Network Operators, Transmission Owners, generation companies, Network Rail and relevant train operating companies in assisting our investigation to date. Looking ahead our focus will be in two key areas: 1) further analysis to inform our Final Report to Ofgem on 6th September and to learn lessons for the ESO, and 2) actively supporting the wider industry review by the Energy Emergencies Executive Committee (E3C).

Key areas for further analysis to inform our ESO Final Report to Ofgem include:

- Understanding the exact failure mechanisms at Little Barford and Hornsea, building on our current good level of understanding of the timing and levels of the various generation losses.
- Continuing to work with the DNOs to understand fully those demand side impacts, including the demand facilities that were disconnected via the LFDD scheme operation and those that lost supply for other reasons during the event.
- Review of ESO communication processes with industry, Government, Ofgem and media, to support timely and effective communication in any future event.

With respect to the wider industry impacts and implications of the 9th August events, we welcome the commissioning, by BEIS, of the Energy Emergencies Executive Committee (E3C) review into the incident – to identify lessons and recommendations for the prevention and management of future power disruption events. We look forward to engaging with and supporting that review.

The Main Report

Introduction

On Friday 9th August 2019 at 16:52 there were a series of events on the electricity system resulting in the disconnection of approximately 1 million customers. These events caused significant disruption to many people in their homes and businesses, and to commuters on a Friday evening with some rail services in and around London being particularly badly affected, along with Newcastle Airport and Ipswich Hospital.

On 12th August Ofgem wrote to the ESO requesting a report into these events to be delivered by 6th September with an Interim Report by 16th August.

This Interim Report is structured as follows:

Part 1: An overview, setting out a brief outline of how the system is managed and balanced, some of the key elements of that which are particularly relevant (frequency and protection systems), an overview of the event, and operation of key systems along with communications process before setting out the on-going and further work to be done before the Final Report is issued on 6th September 2019.

Part 2: The sequence of events and performance of key elements of the system, from 16:52 on Friday to 17:37 when all supplies were restored by the Distribution Network operators.

Part 3: Response to specific issues as set out in the Ofgem letter, including:

- A detailed timeline of events as they unfolded on 09 August 2019;
- The cause of the incident, including the reasons for, and the implications of, each of the generators coming off the system so quickly;
- The Electricity System Operator's planning assumptions and preparedness for such an incident;
- The Electricity System Operator's response and how this relates to regulatory and statutory requirements;
- The wider industry response and how the impact of the event was managed – and, in particular, the prioritisation criteria that were applied to curtail demand that was taken off the system and the implications for wider critical infrastructure;
- Communication by the Electricity System Operator and the wider industry about the incident with Government, Ofgem and the public;
- An estimate of the customer detriment that occurred as a result of the incident;
- Whether it highlights any systemic issues relating to the evolving generation mix; and
- Any other factors relevant to understanding this incident.

It is important for this investigation to understand the issue in detail, the nature and scale of the disturbance, lessons learned and next steps if necessary, to mitigate the impact of any future such incident.

Part One: Overview

Balancing the System

An AC power system must be operated within a certain band of frequency, in GB this is near to 50 Hz. This requires that moment by moment, the generation of power and demand are matched. If they aren't, the system frequency falls (when there is not enough generation) or rises (when there is too much). It is intended that market participants schedule their own generation to come on and off during the day to match the changing pattern of demand.

However, National Grid Electricity System Operator (ESO) brings on extra generation or reduces it to get the balance right. The ESO also buys 'dynamic' and 'static' services: automatic controls on generators, interconnectors and embedded generators (batteries and demand) where system frequency is monitored, and power outputs are adjusted or triggered to balance the frequency. This is known as 'frequency response'. There are some energy storage facilities that also provide frequency response and, increasingly, large users of electricity can adjust their demand to contribute to the overall balance.

The general rule used by system operators around the world is not only to make sure that everything on the system is within acceptable limits but also that that will be true even after any single unplanned event, such as a short circuit fault on a branch of the network or a fault on a single circuit or a interconnector. System operators therefore carry enough frequency response to cover for the sudden loss of the single largest generator or interconnector import.

Frequency, Operational Reserve and Protection Systems

The ESO will hold enough response and reserve (from generators, batteries, interconnectors etc) to ensure that following the loss of the largest unit the overall system will remain stable and within normal limits (50.5Hz – 49.5Hz). It will also operate the transmission network such that following the loss of any one line or cable no other circuit will trip or be overloaded beyond its capabilities.

In addition to this, the ESO will also seek to ensure that, where there are multiple events on the system and generation losses are in excess of the single largest unit, that the integrity of the main system is preserved (frequency held above 47.5Hz), albeit that this may require secondary protection systems to be initiated, including the automatic disconnection of demand (which is initiated at 48.8Hz).

The mechanism to automatically disconnect demand is known as 'Low Frequency Demand Disconnection' (LFDD). Within the Grid Code, stipulations are made for the automatic shedding of load should the frequency levels hit certain trigger levels. In the first stage, it stipulates that LFDD should deliver a 5% reduction of demand across the England and Wales system. There are a total of 9 stages of demand disconnection, starting at 48.8Hz and moving down to 47.8Hz. These automated protection systems are in place to shed demand, to arrest the frequency fall, and save the system from further distress.

The specific obligations in respect of operational reserve and protection systems, as set out in regulatory approved industry documents including the Grid Code and the System Quality and Security Standards (SQSS), have served to deliver world class levels of reliability in the UK for many years. These documents are governed by Ofgem and any industry participant can raise a modification to these codes.

Friday 09 August - Summary of the Event

Weather conditions on 9th August were anticipated and were not unusual. The Met Office had issued yellow warnings of wind for the South West England and South Wales, and yellow warnings of rain for all of England and Wales. Lightning Risk 1 (very high) was in place in all parts of GB at the time except the South West of England.

The system was secured for the loss of the largest infeed unit at 1000MW with no unusual conditions on the transmission system, nor were there any notifications of issues from any of the Distribution Network Operators (DNO) or generators.

At 16:52:33 on Friday there were a number of lightning strikes on the transmission network north of London. This triggered the transmission line protection to disconnect and clear the disturbance (in c.70milliseconds) plus initiate its subsequent reconnection (automatically after c.20 seconds). This operated as normal and the voltage disturbance on the network from the lightning was within expected limits for such an event.

As would be expected in such circumstances there was the loss of some small embedded distributed generation (totalling ~500MW) associated with the transient voltage disturbance caused by the lightning.

Almost simultaneously, and unexpectedly, two large transmission connected generators reduced their output onto the system.

While the System Quality and Security Standards (SQSS) are designed to cover for an event such as the lightning strike the scale of subsequent loss of output from the two large generation stations was beyond the security standards and resulted in a large and fast fall in frequency.

This rapid fall in frequency initiated further small power sources on the distribution network to disconnect, increasing the loss of power generation and resulting in the frequency falling even further.

The total loss of generation over the first minute of the event was so large that the frequency fell to 48.8Hz, triggering Low Frequency Demand Disconnection (LFDD) relays across the DNO's (Distribution Network Operators). These acted to disconnect approximately 1GW of demand from the electricity network (c. 5% of total demand). This loss of demand arrested the frequency fall as designed and, alongside the response, reserve and rapid dispatch of additional generation, recovered the system security position within 5 minutes.

Power Loss

- The lightning strike and rapid frequency fall caused the loss of ~500MW of Distribution connected generation, likely to be solar and some small gas and diesel fired generation, due to the operation of the generation sources own protection systems (Loss of Mains Protection[i])
- Hornsea One offshore wind immediately lost Hornsea modules 2 and 3, totalling 737MW. Module 1 continued to operate smoothly at 50MW throughout the event.
- Little Barford Gas Power Station – near immediate loss of the Steam Turbine unit (244MW) and then, as a result of the loss of the steam unit, loss of the two Gas Turbine units (total station loss of 641MW) over the following 90 seconds.

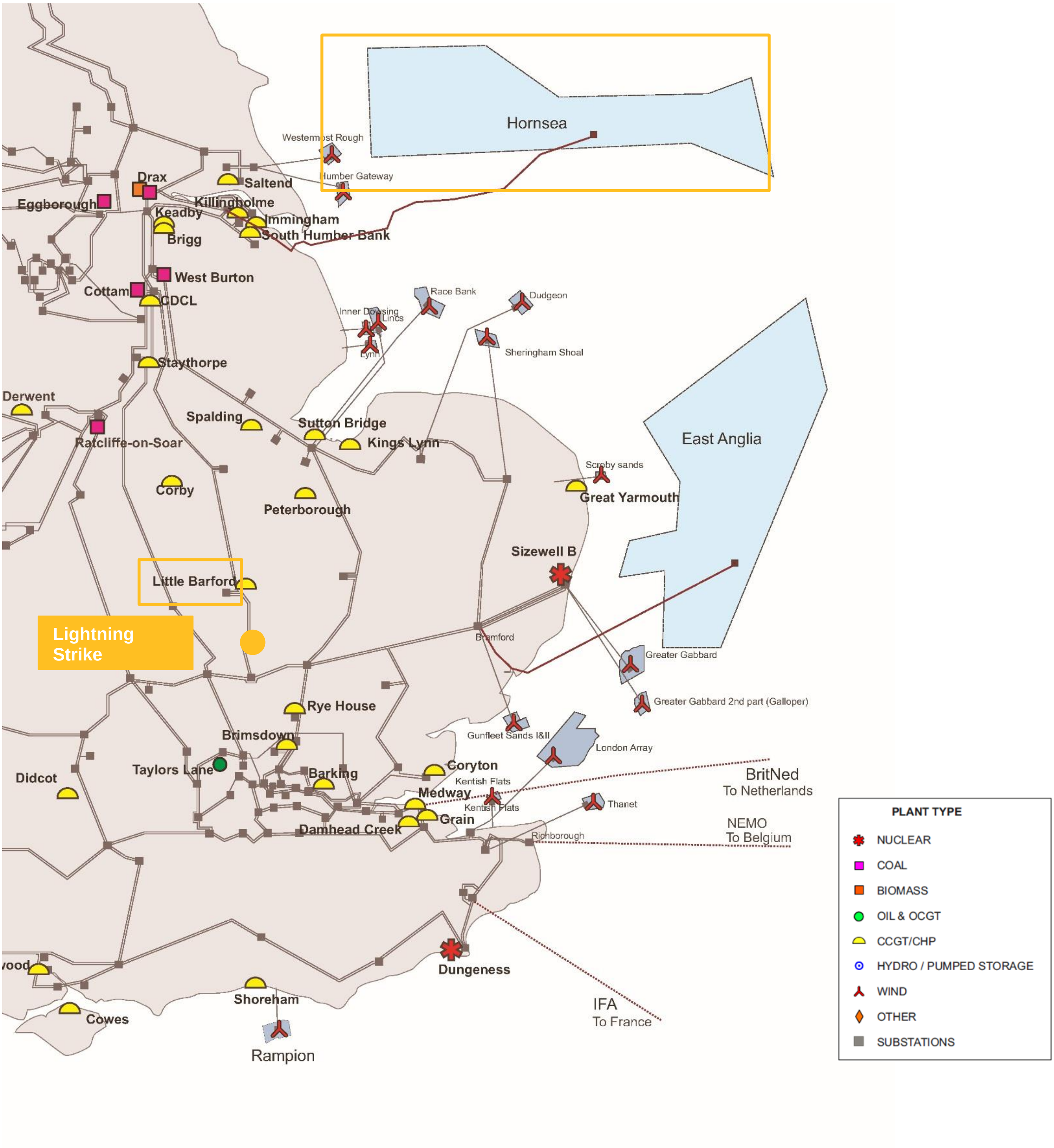

Figure 1 – Geographic map showing key locations

Response and Reserve

Automatic frequency response services acted to try and arrest the fall in system frequency and worked correctly but the loss was too large. Initially the frequency fell to 49.1Hz after approximately 15 seconds before beginning to rise again with the action of frequency response. However, the further loss of generation supply resulted in a second drop in frequency to 48.8Hz at which low-frequency demand disconnection (LFDD) systems are triggered.

The initiation of the LFDD system acted correctly to protect the remaining demand and along with dispatch of additional generation from national control, restored the system frequency by 17:00. The disconnected demand was then reconnected by the DNO's over the following 40 minutes, with all supply points being restored by 17.37.

Loss of supply and associated disruption

As a result of necessary action of the automatic LFDD relays, many local areas, homes and business, (amounting to approximately 5% of national demand), experienced a power cut from the time of the LF relays firing at 16:54hrs until the gradual restoration of their local supply between 17:06 and 17:37 when the last supplies losses associated with the LFDD relays were reconnected to the electricity network.

The most notable impacts were around the disruption to the railways, especially in the South East, and the shorter-term loss of power at Ipswich Hospital and Newcastle Airport.

There was significant disruption experienced on the rail network, both in and around London and in some localised areas around the country. Disruption continued through the evening and into the next day as systems, appliances and in particular trains, needed to be reset. Whilst Network Rail and the DNOs have confirmed that no track supplies were lost due to the DNO's LFDD protection operation, initial investigations suggest that the lengthy disruption was caused by a combination of: frequency-related trips which occurred at two DC traction locations; eight signal power supplies in principally rural locations suffering minor outages (with minimal passenger impact); but most of all, because a particular type of train (of which there were ~60 in use) reacted unexpectedly to the electrical disturbance. Half of these trains did not restart and required an engineer to physically attend the train to do so. All other classes of train were unaffected. These issues are the subject of ongoing investigations by Network Rail and Govia Thameslink Railway (GTR).

The issues at Ipswich Hospital and Newcastle Airport are detailed later.

The losses of electricity supply set out above seen across GB during the event are associated either with the severity of the frequency fall or the initiation of the LFDD relays (in some very limited cases there may also have been separate unrelated local issues but for this analysis it is assumed all supply losses were linked to the event).

Communications

Operational communications with connected parties, generators etc. was handled in real time by the control room in line with standard operating procedures.

Following control room activity to manage the incident and restore the system to normal operations during the period immediately following the event wider stakeholder communications were initiated. The first update was provided by the ESO Power System Manager to BEIS at 17:41, followed by Ofgem at 17.50. Engagement with BEIS and Ofgem continued through the evening and into the weekend.

Wider external communications commenced 90 minutes after the event and ramped up through the evening and into the weekend. Ongoing active management of external communication included media statements, broadcast media, and discussions with impacted parties.

Initial notification to key stakeholders (BEIS and Ofgem) was impacted by the availability of key personnel given it was 5pm on a Friday evening and therefore was slower than it should have been. Similarly, issuing the first media statement (90 minutes after the event) was later than would have been liked. Once underway, communications were handled proactively and effectively.

Preliminary findings

Our preliminary findings based on analysis to date are:

- Two almost simultaneous unexpected power losses at Hornsea and Little Barford occurred independently of one another - but each associated with the lightning strike. As generation would not be expected to trip off or de-load in response to a lightning strike, this appears to represent an extremely rare and unexpected event.
- This was one of many lightning strikes that hit the electricity grid on the day, but this was the only one to have a significant impact; lightning strikes are routinely managed as part of normal system operations.
- The protection systems on the transmission system operated correctly to clear the lightning strike and the associated voltage disturbance was in line with what was expected.
- The lightning strike also initiated the operation of Loss of Mains (LoM) protection on embedded generation in the area and added to the overall power loss experienced. This is a situation that is planned for and managed by the ESO and the loss was in line ESO forecasts for such an event.

- These events resulted in an exceptional cumulative level of power loss greater than the level required to be secured by the Security Standards and as such a large frequency drop outside the normal range occurred.
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Part Two: Timeline of Events and Performance

Timeline of Events

Through our own ESO systems and data, and information and data provided by National Grid Electricity Transmission, Orsted, RWE, DNO's and others, we understand the timelines of events to be as follows:

Time	Activity	Source
16:52:26	Frequency at 50.0Hz, ESO securing (as per SQSS) a loss of power infeed of 1000MW	ESO
16:52:33	There were three lightning strikes detected in very close proximity to the Eaton Socon – Wymondley circuit.	MeteoGroup
16:52:33.490 (GPS)	A single (blue) Phase to Earth fault on Eaton Socon - Wymondley circuit (fault infeed approximately 21kA (RMS) from Wymondley and 7kA (RMS) from Eaton Socon) with an estimated 50% voltage depression on the blue phase during the fault. This is consistent with a lightning strike on Eaton Socon - Wymondley circuit	NGET
16:52:33.531	Hornsea was generating 799MW and absorbing 0.4MVAR	Orsted
16:52:33.560	70ms after fault, Wymondley end opens to clear the fault	NGET
16:52:33.564	74ms after fault, Eaton Socon end opens to clear the fault	NGET
16:52:33.728	Hornsea started deloading	Orsted
16:52:33.835	Hornsea stabilised at 62MW and injecting 21 MVAR [737 MW of cumulative infeed loss]	Orsted
16:52:34	Little Barford Steam Turbine trips 244MW instantaneously. Source: RWE [981MW of cumulative infeed loss]	RWE
16:52:34	Frequency response initiates. Systems recorded a net ~ 500MW increase of transformer loadings (expected cause is a loss of injection of MW from embedded generation). [1481MW of cumulative infeed loss]	ESO
16:52:44	Frequency Response has delivered at least 650MW of power to stabilise the frequency.	ESO
16:52:53	Eaton Socon - Wymondley circuit energised on DAR	NGET
16:52:58	Frequency drop is arrested at 49.1Hz due to the delivery of frequency response products	ESO
16:53:04	Frequency Response has delivered 900MW of power to stabilise the frequency	ESO
16:53:18	Frequency recovers to 49.2Hz, due to the continued delivery of frequency response	ESO
16:53:31	Little Barford GT1A tripped as per correct operation of the generators protection settings, caused by the loss of ST1C, 210MW instantaneously disconnected. [1691MW of cumulative infeed loss]	RWE/ESO
16:53:31	All frequency response is being delivered at this point attempting to restore the frequency to operational limits.	ESO
16:53:49.398	Frequency breaches 48.8Hz trigger level resulting in LFDD. 931MW of demand is disconnected from the system by the DNOs.	DNOs
16:53:58	Little Barford GT1B tripped with 187MW generation lost instantaneously. This loss was subsumed by the LFDD reductions and	RWE

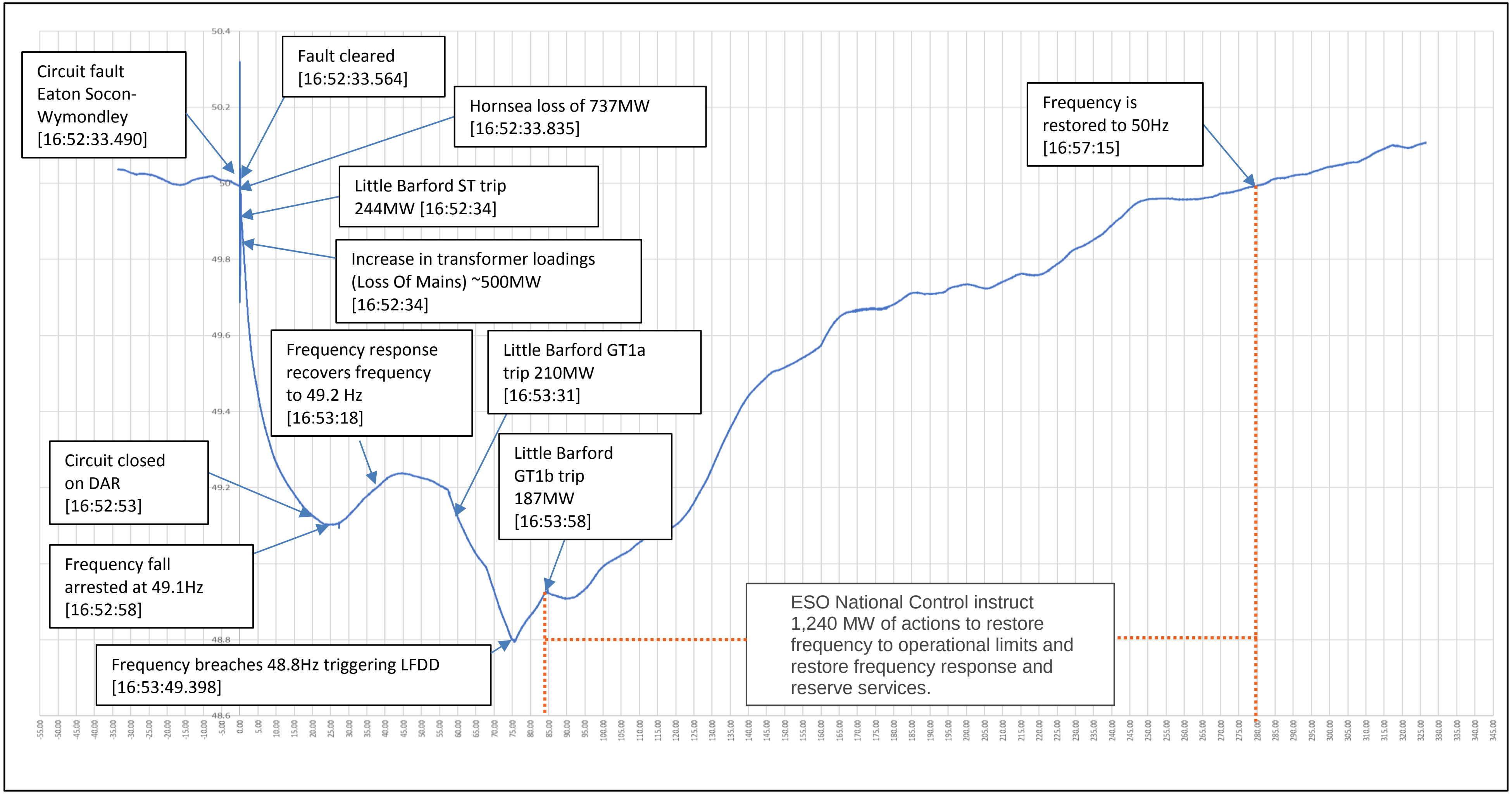
	the additional energy sources being instructed by ESO. [1878MW of cumulative infeed loss]	
16:57:15	Frequency returns to 50Hz following over 1000MW of response and a further 1240MW of control room actions to restore frequency response levels and stabilise the situation	ESO Data
17:06	ESO instructs the DNO's that they can commence demand restoration	ESO data
17:37	All DNO's have confirmed that demand restoration has been completed	DNO's

Table 1 - Timeline of Events

Below is the detail of the cumulative losses of infeed

Generation Unit	Infeed Loss	Cumulative Infeed Loss
Little Barford ST1C	244 MW	244 MW
Hornsea Offshore Windfarm	737 MW	981 MW
ESO Security Standards and Planning Required an infeed loss 1,000 MW loss to be covered		
Estimated, Embedded generation infeed loss due to Loss of Mains Protection	~500 MW	~1481 MW
Little Barford GT1A	210 MW	~1691 MW
Little Barford GT1B	187 MW	~1878 MW

Table 2 - Table of cumulative infeed losses



Circuit fault
Eaton Socon-
Wymondley
[16:52:33.490]
Fault cleared
[16:52:33.564]
Hornsea loss of 737MW
[16:52:33.835]
Little Barford ST trip
244MW [16:52:34]
Increase in transformer loadings
(Loss Of Mains) ~500MW
[16:52:34]
Frequency response
recovers frequency
to 49.2 Hz
[16:53:18]
Little Barford GT1a
trip 210MW
[16:53:31]
Little Barford
GT1b trip
187MW
[16:53:58]
Circuit closed
on DAR
[16:52:53]
Frequency fall
arrested at 49.1Hz
[16:52:58]
Frequency breaches 48.8Hz triggering LFDD
[16:53:49.398]
Frequency is
restored to 50Hz
[16:57:15]
ESO National Control instruct
1,240 MW of actions to restore
frequency to operational limits and
restore frequency response and
reserve services.

Transmission System Performance

The faults induced by the lighting strikes on the Eaton Socon–Wymondley circuit were cleared within 74ms which is in line with the design of the automatic protection systems installed on the circuit. This caused a transient voltage depression on the network in line with expectations and the requirements of the SQSS.

There were a number of lightning strikes on the power system on this day one of which initiated the trip and close of the Stella West – Eccles-Blyth circuit. However, none of the other lightning strikes caused any generation to be lost.

Generation Performance

Immediately following the lightning strike on the Eaton Socon–Wymondley circuit ~500MW of embedded generation was lost, typically this would be solar, and some small gas and diesel fired generation, due to the operation of the generation sources own protection systems (Loss of Mains Protection)

The transmission system can be subject to hundreds of thousands of lightning storms each month particularly across the summer months and protection systems are in place to deal with lightning strikes caused by these storms. On Friday 9th August, in terms of lightning activity (source: Blitzortung.org) there were over 68,000 strikes across mainland Europe and in the North Sea.

Prior to the initial fault, there was approximately 32GW of transmission connected generation capacity operating with more than 30% capacity from wind generation and 50% from conventional units. The generation capacities were provided from more than 250 Balancing Mechanism (BM) units and non-BM units. All generation units operated as expected except for the unexpected failures at Hornsea offshore wind farm and Little Barford.

Hornsea One Offshore wind farm

Hornsea offshore wind farm, owned by Orsted, is a 1200MW wind farm connected to the main transmission system at Killingholme 400kV substation, which at the time of the event had a declared capability of 800MW.

Following the lighting strike Hornsea immediately de-loaded from 799MW to 62MW. Hornsea have confirmed the following: The equipment at Hornsea saw a system voltage fluctuation with unusual characteristics coincident with the lightning. The initial reaction from Hornsea's systems was as expected in attempting to accommodate and address the system condition, but very shortly afterwards as the reaction expanded throughout the plant, the protective safety systems activated. Following an initial review, adjustments to the wind farm configuration, and fine tuning its controls for responding to abnormal events, the wind farm is now operating robustly to such millisecond events.

Little Barford

Little Barford, owned by RWE, is a 740MW CCGT connected to the transmission system at Eaton Socon 400kV substation.

Near instantaneous to the deloading at Hornsea, Little Barford Gas Power Station tripped with the immediate loss of the Steam Turbine (STC1) unit (244MW). RWE have confirmed the following: After approximately 1 minute the first gas turbine tripped due to excessive steam pressure in the steam bypass system. This trip occurred automatically and shut the gas turbine down. The second gas turbine was manually tripped by the by RWE operational staff in response to high steam pressures around 30 seconds later. In total this meant a total loss at Little Barford of 641MW.

The causes provided by RWE for the initiation of the trip of Little Barford steam turbine (ST1C) was due to discrepancies on three independent safety critical speed measurement signals to the generator control system..

Frequency Response

As detailed later in the document ESO use frequency response products to manage the network. The table below highlights the frequency response holding and the current best view of the low frequency response performance, this is subject to change.

Frequency Response Type			**Number of Units**	**Low Frequency Holding**	**Low Frequency Delivered**
Dynamic	Primary [Secondary] / High	BM	8	284 [325]	266
	Primary [Secondary] / High	NBM	36	280 [270]	231
	Enhanced Frequency Response	NBM	10	227	165
Static	Triggered at 49.7 Hz, delivered within 30 seconds [Secondary]	BM		0	-
		NBM	19	[285]	198
	Triggered at 49.6 Hz, delivered within 1 second	BM	2	200	200
		NBM	7	31	30
Demand effect*				350	
Total (Excluding demand effect)				1022 [1338]	1090

Table 3 - Operational Response Performance Data for SP34 09/08/2019

*Demand varies due to frequency, as some devices such as synchronous motors use slightly less power when frequency is slightly low, and vice versa when frequency is slightly high. For 29 GW demand, this effect is approximately 350MW at 49.5 Hz. This effect is unrelated to LFDD.

Demand Disconnection & Restoration

The LFDD relays operated correctly at 48.8Hz as designed and disconnected approximately 5% demand as per the Grid Code requirements. Once the system was stable ESO commenced demand restoration instructions with DNOs at 17:06. The earliest DNO restoration was achieved at 17:07 and all DNOs completed demand restoration by 17:37.

Part Three: Response to specific questions raised in Ofgem's letter of 12th August

ESO's planning assumptions and preparedness

The ESO is responsible for managing the security of the National Electricity Transmission system and balancing generation and electricity demand, in its role as the GB system operator. Any imbalance between generation and demand will result in a disturbance of the frequency from the nominal 50Hz.

The control of system frequency is a continuous process undertaken against variability and uncertainties of demand movement, and system infeed loss, aiming to satisfy the requirement of frequency control standards at all times. Hence the frequency control strategy is accomplished within the procedural framework provided by the Grid Code and SQSS.

This strategy involves the assessment ahead of time of overall generation margins, response and reserve holdings and risk such as Loss of Mains Protection, loss of conventional generation, demand forecast errors etc. From this assessment it is possible to calculate the real time economic instruction of response holdings.

Planning policy Generation Margin

The ESO is required to highlight to the market through an Electricity Market Notice if there is insufficient margin to cover requirements ahead of real time. The requirement is to cover plant losses or demand forecast errors if they occur in advance of the time being planned. Closer to real-time the emphasis becomes on the operating reserve holding. These requirements were met in all timescales ahead of real-time. Below is a chart of the real time surplus, the amount of additional generation available which was not required to meet demand forecast requirements, during Friday 9th August. The figure at 17:00 was ~4GW which is above normal levels.

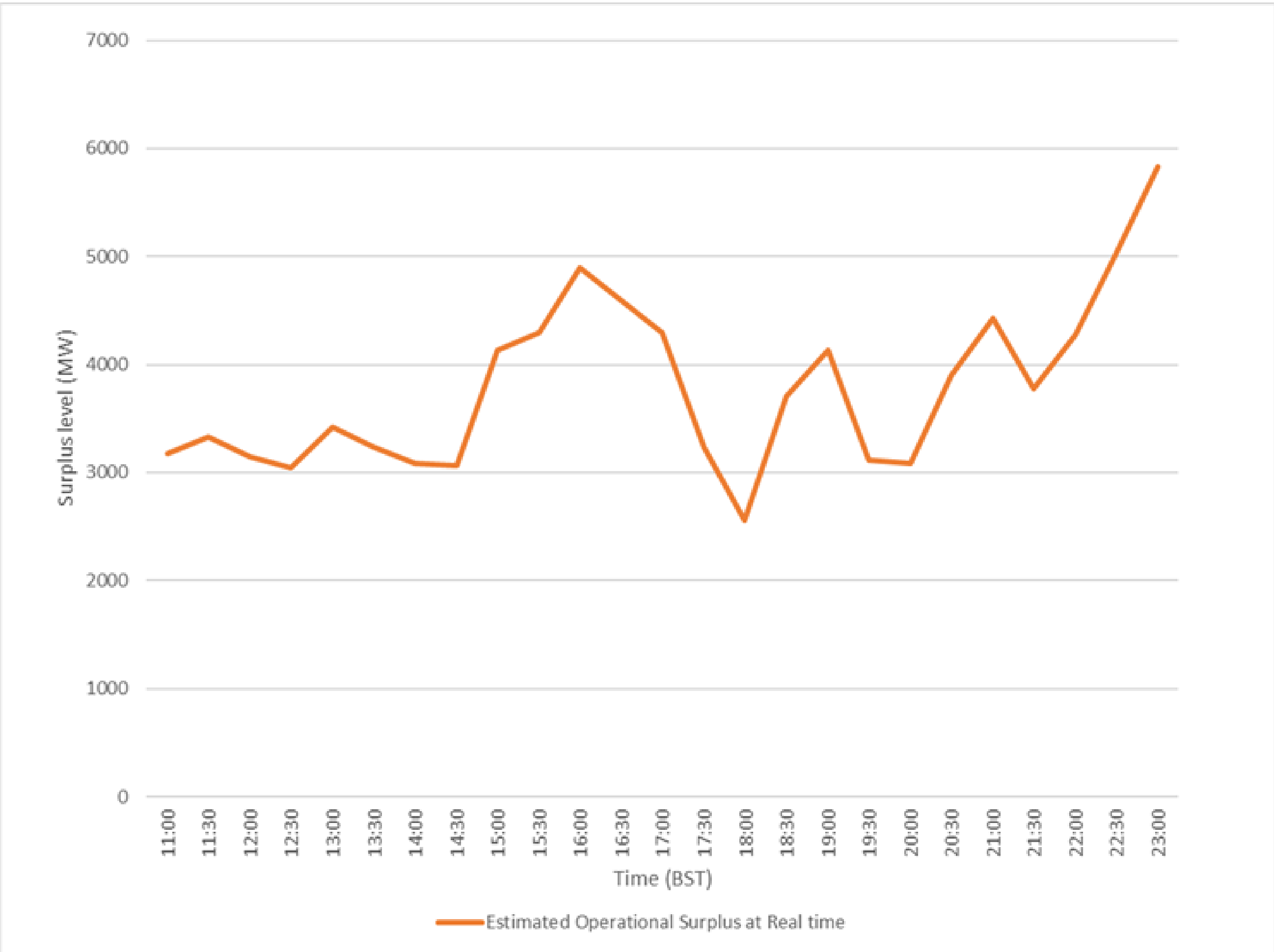


Figure 2 - Operational Surplus for 09/08/2019

Response holding for secured events

The National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS and from now on "SQSS") specifies the limits of frequency deviations for secured events, which includes loss of output from a single generator, Combined Cycle Gas Turbine Module (CCGT), boiler, nuclear reactor or DC bi-pole (interconnector) lost as a result of transmission fault.

The quantity of response which is required to be held depends upon the largest loss risk of generation and demand as result of credible system faults to ensure the frequency deviations is within SQSS control standard.

The amount of forecast embedded generation that could be lost through the LoM protection should also be considered. This loss is considered as independent of the largest infeed loss and so the response holding should cover the larger of the two but does not need to cover both events. The ESO must also consider the inertia of the system and ensure enough response to prevent operation of the RoCoF LoM protection.

We were forecasting ~500 MW of generation which was appropriate for a risk of a Transmission fault in the area.

Distributed Generator Protection Systems

Distributed generators, generally small-scale generators connected to distribution networks, are required to ensure that they shut themselves down safely in the event of a disruption to their local network. They use 'Loss of Mains' protection to achieve this. Two common types are described below. Both of these can have an impact on system frequency because they can trigger the simultaneous shutdown of significant amounts of generation in response to a system disturbance.

Loss of Mains – RoCoF (Rate of Change of Frequency)

In low inertia conditions the system frequency is likely to move faster in response to a disturbance such as a loss of generation or increase in demand. The ESO has adapted to manage the system to ensure the rate at which the frequency moves are below the level of user's protection settings. Users connected to the distribution network may have RoCoF protection settings.

If the rate of change of frequency is allowed to surpass the RoCoF protection setting levels (0.125Hz/s) then this can cause users of the electricity system to disconnect as their automatic protection systems interpret the sudden change as a risk to the safety of their equipment.

To ensure that, in the event of a loss, the rate of change of frequency does not result in the disconnection of users the ESO can decide to increase the total system inertia (which would slow down changes in frequency) or reduce the size of potential generation and demand losses that could credibly occur. A smaller sized loss will result in a correspondingly smaller RoCoF in low inertia conditions. The optimal approach is to reduce the size of credible system infeed losses on generation, demand or interconnectors. This approach is more cost effective than increasing the level of inertia.

Loss of Mains - Vector Shift

In the same way that Embedded Generation with RoCoF protection is known to be sensitive to events on the transmission system, embedded generation with Vector Shift protection settings can also be susceptible to system conditions. For Vector Shift, the trigger is not related to system frequency but instead to voltage phase angles created by a fault on the transmission circuits.

Frequency Response

Response can be delivered by variable providers as part of the balancing services procured by NGESO, to help arrest frequency deviations within 10 seconds of the initial change in frequency and maintained for a further 20 seconds for primary response and indefinitely for high response. For secondary response, the service must be available within 30 seconds and sustained for a further 30 minutes. This helps to ensure the frequency is maintained within the statutory levels.

Response can be provided either through Firm Frequency Response contracts or through mandatory services in the Balancing Mechanism.

The Table below summarises the frequency response holdings at the time of the event. These were enough for the secured loss risks of 1000MW generation (low frequency) and 560MW demand (high frequency).

Frequency Response Type			Low Frequency	High Frequency
Dynamic	Primary [Secondary] / High	BM	284 [325]	440
	Primary [Secondary] / High	NBM	280 [270]	207
	Enhanced Frequency Response	NBM	227	227
Static	Triggered at 49.7 Hz, delivered within 30 seconds	BM	0	0
		NBM	[285]	0
	Triggered at 49.6 Hz, delivered within 1 second	BM	200	0
		NBM	31	0
Demand effect*			350	350
Total (Excluding demand effect)			1022	874

Table 4 Operational Response Holding Data for SP34 09/08/2019

*Demand varies due to frequency, as some devices such as synchronous motors use slightly less power when frequency is slightly low, and vice versa when frequency is slightly high. For 29 GW demand, this effect is approximately 350MW at 49.5 Hz. This effect is unrelated to LFDD.

Electricity System Operator's Regulatory and Statutory requirements

National Electricity Transmission System Security and Quality of Supply Standard

The SQSS sets out the coordinated planning and operating criteria and methodologies used by ESO in the operation of the National Electricity Transmission System (NETS).

Following the loss of supply event on Friday 9th of August we have reviewed the incident against the SQSS.

At the highest level, SQSS operational criteria looks at what the prevailing system conditions are, then defines a range of secured events known as contingencies (faults) that can credibly occur on the network, and in the event of such contingencies occurring stipulates what conditions must not happen.

During the incident the following events occurred;

- Single circuit fault trip event of the Eaton Socon - Wymondley 400kV circuit
- Loss of infeed power of 737 MW from Hornsea Offshore Windfarm
- Loss of infeed power of 641 MW from Little Barford Power Station

There were no further transmission system impacts from the single circuit trip event.

Security and Quality of Supply Standards

The GB SQSS specifies that unacceptable frequency conditions should not arise from secured faults, which include loss of output from a single generating unit, Combined Cycle Gas Turbine Module (CCGT), boiler, nuclear reactor or DC bi-pole (interconnector) lost as a result of transmission fault. It defines unacceptable frequency conditions as:

1. the steady state frequency falls outside the statutory limits of 49.5Hz to 50.5Hz; or
2. a transient frequency deviation on the transmission system persists outside the above statutory limits and does not recover to within 49.5Hz to 50.5Hz within 60 seconds.

Transient frequency deviations outside the limits of 49.5Hz and 50.5Hz shall only occur at intervals which ought to reasonably be considered as infrequent.

Applying these requirements in real-time meant that we were securing a largest infeed (generation) loss risk of 1000MW and a demand loss risk of 560MW.

The response holding discussed in the previous chapter in this document discussed the response level holdings that were planned and enacted by ESO. This was more than sufficient for the 1000/560 infeed and demand losses respectively.

Grid Code requirements

The Grid Code connection conditions stipulate the following requirements for frequency control and generation units with regards to frequency and voltage.

Grid Frequency Variations (text in italic taken from the Grid Code)

CC.6.1.3 The System Frequency could rise to 52Hz or fall to 47Hz in exceptional circumstances. Design of GB Code User's Plant and Apparatus and OTSDUW Plant and Apparatus must enable operation of that Plant and Apparatus within that range in accordance with the following:

Frequency Range	***Requirement***
51.5Hz - 52Hz	*Operation for a period of at least 15 minutes is required each time the Frequency is above 51.5Hz.*
51Hz - 51.5Hz	*Operation for a period of at least 90 minutes is required each time the Frequency is above 51Hz.*
49.0Hz - 51Hz	*Continuous operation is required*
47.5Hz - 49.0Hz	*Operation for a period of at least 90 minutes is required each time the Frequency is below 49.0Hz.*
47Hz - 47.5Hz	*Operation for a period of at least 20 seconds is required each time the Frequency is below 47.5Hz.*

Table 5 - Frequency Range requirements

For the avoidance of doubt, disconnection, by frequency or speed-based relays is not permitted within the frequency range 47.5Hz to 51.5Hz, unless agreed with The Company in accordance with CC.6.3.12.

Preliminary conclusions in respect of regulatory and statutory requirements

Our preliminary conclusions are as follows:

- The combined losses of power generation, resulting from three independent actions associated with the lightning strike, were greater than the secured single infeed loss which was a 1000 MW at the time of the event. This was an exceptional occurrence, with three separate generation losses.
- The resultant exceptional generation loss was beyond the levels to which we are required to secure the system, as set out by the SQSS and the Grid Code.
- The voltage performance of the National Electricity Transmission System was within SQSS and Grid Code requirements.

As such the analysis shows that the transmission system operated in line with the Security Standards and the Grid Code.

Impacts on demand, wider critical infrastructure and estimate of customer detriment

Through the events of the evening of Friday 9th August over a million customers and thousands of travellers were directly affected. The industry are acutely aware of the level of disruption surrounding the incident and have been actively working with key stakeholders in order to understand, in detail, the nature and scale of that disruption and ensure that lessons can be learned by ESO and across the wider industry.

Some critical customer demand was lost from the system together with further disruption following the LFDD protection relays operating. We have been working with the DNOs, Network Rail and Govia Thameslink Railway to understand this in more detail. Our current understanding of the demand impacts are set out below; recognising that the DNOs, Network Rail and Thameslink investigations are all ongoing.

Distribution Demand

Table 6 summarises the customer impact in terms of total demand lost, customers affected and final restoration time. The information is based on DNO reported data as of 13th August 2019 at 12:00. Demand lost on Low Frequency Demand Disconnection (LFDD) may be subject to change as embedded generators may have been offsetting demand within the group that was disconnected by LFDD.

Demand restoration was initiated by the ESO with instruction to regional DNOs starting at 17:06 and reported completed by 17:37. However, disruptions following demand restoration would have continued beyond 17:37 while customers continued to recover their own systems.

The data provided represents the best possible information available at the time of the report. Reported embedded generation lost may change as further data is received by the DNO. All times are in British Summer Time (BST), number of significant digits and times as reported by DNO providing the data.

Reporting DNO		MW of disconnected demand by LFDD	Customers Affected	Final Restoration Time of Demand
Scottish Hydro Electric Power Distribution (SHEPD)		0		
Scottish Power (SP)		22	23 117	16:59
Northern Power Grid (NPG)	North East	76	93 081	17:18
	Yorkshire	14	10 571	17:12
Electricity North Limited (ENW)		52	56 613	17:17
SP Manweb		130	74 938	17:15
Western Power Distribution (WPD)	East Midlands	122	150 445	17:25
	West Midlands	160	187 427	17:37
	South Wales	36	29 060	17:11
	South West		110 273	17:22
UK Power Networks (UKPN)	Eastern	69	79 390	16:56
	London	174	239 861	17:37
	Southern	69	81 358	17:15
Scottish Electric Power Distribution (SEPD)		7	16 744	17:07
Totals		**931**	**1 152 878**	**17:37**

Table 6 DNO customers affected by LFDD relays

Rail

Network Rail and the DNOs have confirmed that no track supplies were lost due to the DNO's LFDD protection operation. However, there were significant impacts on the rail network during the event as noted below:

1. While the built-in resilience of Network Rail's electrical power infrastructure meant traction power was maintained to the vast majority of the railway throughout the incident, there were frequency-related trips which occurred at two DC traction locations which Network Rail are investigating.
2. Eight signal power supplies in principally rural locations suffered minor outages with minimal passenger impact. Network Rail are reviewing resilience at these locations;
3. Class 700 and 717 trains shut down north of Farringdon and Kings Cross stations due to their internal protection systems being triggered. The Network Rail overhead line power supply operated continually. The shutdown of these trains had a knock-on impact by delaying all other trains behind them requiring the temporarily closure of London St Pancras and Kings Cross stations which led to Friday rush hour overcrowding.

Govia Thameslink Railway (GTR) have advised that their Class 700 and Class 717 trains that were operating on AC power were affected by the frequency deviation below 49Hz. They are investigating with the manufacturer the reason for the trains stopping when the frequency dropped below 49Hz. Of the approximately 60 Class 700 and Class 717 trains operating on overhead power supply, half were restarted by the driver and the remainder required a technician for reset. All other GTR classes of train were unaffected. GTR will provide further information, relevant to the technical report, once their investigation has concluded.

The impact to the rail network was that thousands of passengers had their journeys delayed with 371 trains cancelled, 220 part cancelled, and 873 trains delayed. London St Pancras and King's Cross stations had to close for several hours due to overcrowding and London Euston went exit only for a period of time.

London Underground have confirmed there were impacts on the London Underground Victoria Line, which was suspended as a result of the event and service was restored at 17.35.

Other Priority Loads Affected

We are aware of impacts at Ipswich Hospital and Newcastle Airport.

Ipswich Hospital

Ipswich Hospital internal protection operated coincident within the timeframe of the system fault. Time stamped data from UKPN shows that the hospital's load reduced by half in a period of 14 seconds.

UKPN have confirmed that the hospital was not part of their LFDD protection zone and that the LFDD did not affect the substations supplying the hospital.

Newcastle Airport

Newcastle Airport is connected to the Northern Power Grid's (NPG) Network. NPG have confirmed that the airport was disconnected as a result of the LFDD operation. The LFDD scheme operated by NPG worked as planned. NPG are nonetheless reviewing all LFDD allocations. As far as NPG are aware, no Protected Sites under the terms of the Electricity Supply Emergency Code (ESEC) were affected by the incident.

Newcastle International Airport was affected, losing supplies from the network for 18 minutes between 16:53 and 17:11. NPG indicated that the airport's Uninterruptable Power Supply (UPS) and standby generator resilience arrangements for their essential services operated smoothly. On 12 August 2019 Northern Powergrid (Northeast) Limited received a request from Newcastle International Airport to be categorised as a Protected Site under ESEC and it has now been registered as such.

Communication by the Electricity System Operator and the wider industry about the incident with Government, Ofgem and the public

Our communication efforts can be categorised in 3 broad areas - operational communication with industry, engagement with government and the regulator, and wider external communications.

Operational Communications

ESO control room commenced communication with DNOs and NGET control room within 2 minutes of the initial fault. Based on the current best understanding, the summary below highlights the timestamps of the key operational communications from and to the ESO control room.

[16:54] Initial reports of demand disconnection were received by the ESO control room. Reports continued to arrive with number of customers and load lost. Enquires were received about when demand restoration could begin.

[17:06] Demand restoration instruction to DNOs was initiated by the ESO control room. The demand was instructed to restore in a progressive manner.

[17:22] ESO control room informed NGET control room that DNOs had started restoration.

[17:23] The first Significant Incident Report (SIR) request (Grid Code OC7 and OC10) was received from DNOs requesting information about the event.

[18:17] First DNO report was received that their demand had been fully restored. Post-event analysis indicated the earliest restoration was completed at 17:07 and the last customers were reconnected at 17:37.

[18:43 and beyond] Last report from DNO informing their demand restoration was received. ESO informed NGET control room that all demand had been restored. Demand and lost customer figures continued to be supplied by DNOs.

BEIS and Ofgem

Following control room activity to manage the incident and restore the system to normal operations during the period immediately following the event wider stakeholder communications were initiated. The first update was provided by the Power Systems Manager to BEIS at 17:41. The first communication with Ofgem followed at 17.50.

Engagement with BEIS and Ofgem officials continued through the evening and into the weekend, via a series of update calls from ESO leadership. Broader government engagement included letters to Secretary of State for Business and Energy and Secretary of State for Transport on Saturday evening. A briefing call was then held with Minister of State for Business and Energy on Sunday.

External Communication with Media

The incident happened at just before 17:00 on a Friday evening. The ESO prepared an external communication seeking to give reassurance to the public which issued at 18:27 once it was established that the DNOs had reconnected all customers.

The ESO proactively engaged with the media and stakeholders throughout the evening and arranged broadcast interviews for Saturday from 08:00 into lunchtime in addition to providing background briefing and answering multiple media enquiries.

Please see here for a link to all information that we have provided externally:
https://www.nationalgrideso.com/information-about-energy-system-and-electricity-system-operator-eso

Time	Event
FRIDAY	
18:27	**First Statement** – Confirmed that whilst 2 generators had disconnected the system was now functioning properly. Published on twitter @NG_ESO and sent to all national energy correspondents, and national print, TV and Radio newsdesks. Shared with BEIS and Ofgem too.
20:06	**Second statement** – Explained why there had been a power cut and confirmed again that the system had been restored at an NTS and DNO level Published on twitter @NG_ESO and sent to all national energy correspondents, and national print, TV and Radio newsdesks. Shared with BEIS and Ofgem too.
20:11	A video from Julian Leslie offering further explanation issued on Twitter
SATURDAY	
08:00 – 13:00	**Broadcast interviews –** We did interviews on Radio 4 Today Programme, Five Live, ITV, BBC Breakfast and Sky.
08:33	**Third Statement –** Further explanation of events on Friday and clarification that National Grid does not generate electricity Published on Twitter @NG_ESO and to all national energy correspondents, and national print, TV and Radio newsdesks. Shared with BEIS and Ofgem too.
12:22	Update sent to senior BEIS officials including a copy of Statement 3
19:31	**Fourth Statement –** Expressed support for Energy Emergency Executive Committee investigation and highlighted that ESO was in process of internal investigation. Published on Twitter @NG_ESO and to all national energy correspondents, and national print, TV and Radio newsdesks.
20:00	**Emails** sent to Secretary of State for BEIS and Department for Transport and Minister of State Kwasi Kwarteng at BEIS providing update on situation.
20:30	**Emails** forwarded to Senior Officials and Special Advisors at BEIS, Transport and Number 10
SUNDAY	
11:00	**Phone Call** between ESO senior team (Fintan, Duncan & Kayte) and BEIS Minister of State Kwasi Kwarteng MP

Table 7 External engagement

Review of any Systemic issues related to the evolving generation mix

The evolution of the electricity generation mix in Great Britain since 2008 has been significant. Traditionally, conventional technologies such as nuclear, coal and gas fired power stations as well as hydro, pumped storage and interconnectors have met the vast majority of our electricity demand. In the last decade the generation mix has shifted to include a greater amount of electricity generation from renewables, mainly in the form of wind and solar. Currently there is approximately 21GW of wind and 13GW solar connected to the GB power system. These new sources have displaced much of the older conventional coal and gas generation, meaning the proportion of electricity from conventional technologies has correspondingly declined.

Similarly, the level of interconnection has increased with the amount of interconnection between Great Britain and mainland Europe at 4GW, plus the 1GW to the island of Ireland. Further interconnectors to France, Norway and Denmark are planned to connect in the future.

Wind generation, solar and interconnectors are different to the conventional electricity generation sources, in that they do not provide much inertia. Today, we operate the system with lower levels of inertia than we have in the past.

In low inertia conditions the system frequency is likely to move faster in response to a disturbance such as a loss of generation or increase in demand. As ESO we have adapted to manage the system to ensure the rate at which the frequency moves is below the level of users protection settings. Users connected to the distribution network have Loss of Mains protection settings in the form of either RoCoF (Rate of Change of Frequency) or Vector Shift. (These protections have been described in previous sections).

As the energy mix has evolved the ESO has improved its ability to understand credible losses and take appropriate and cost-effective actions to secure the system against them. The processes to accommodate the changing generation mix are well understood and practiced by ESO operational teams.

- Through work on future energy scenarios and system operability the ESO is predicting continued changes in the generation mix: more wind, solar, interconnectors and storage. As a result, there is a forward plan of works which includes significant changes and improvements to the tools and methods to efficiently manage this transition. This is all captured in our ambition to be capable of operating an electricity system with periods of zero carbon output in 2025.
- Operating the system in low inertia conditions and with a generation mix that has moved away from conventional sources and incorporates a greater share of renewables and imports is already the new normal and business as usual for the ESO.

In order to facilitate further evolution of the generation mix the ESO is working across the wider industry on several initiatives specific to the control and stability of frequency, including:

- A programme to facilitate distribution connected generators to change their LoM protection settings therefore reducing the volume at risk of disconnection in response to a large loss
- A ‘pathfinder’ project looking at how new sources of inertia and other stabilising capabilities can be provided to the system
- The development of new frequency response services that will facilitate greater market competition, participation and provide us with the fast-acting services we need in low inertia conditions
- Inertia monitoring services to give us world leading information on the dynamic characteristics of the system

Preliminary Conclusions and Further Work

Preliminary findings

Our preliminary findings based on analysis to date are:

- Two almost simultaneous unexpected power losses at Hornsea and Little Barford occurred independently of one another - but each associated with the lightning strike. As generation would not be expected to trip off or de-load in response to a lightning strike, this appears to represent an extremely rare and unexpected event.
- This was one of many lightning strikes that hit the electricity grid on the day, but this was the only one to have a significant impact; lightning strikes are routinely managed as part of normal system operations.
- The protection systems on the transmission system operated correctly to clear the lightning strike and the associated voltage disturbance was in line with what was expected.
- The lightning strike also initiated the operation of Loss of Mains (LoM) protection on embedded generation in the area and added to the overall power loss experienced. This is a situation that is planned for and managed by the ESO and the loss was in line ESO forecasts for such an event.
- These events resulted in an exceptional cumulative level of power loss greater than the level required to be secured by the Security Standards and as such a large frequency drop outside the normal range occurred.
- The Low Frequency Demand Disconnection (LFDD) system worked largely as expected.
- The Distribution Network Operators quickly restored supplies within 31 minutes once the system was returned to a stable position.
- Several critical loads were affected for a number of hours by the action of their own systems, in particularly rail services.

Next steps

We have had excellent co-ordination, data and support from Distribution Network Operators, Transmission Owners, generation companies, Network Rail and relevant train operating companies in assisting our investigation to date. Looking ahead our focus will be in two key areas: 1) further analysis to inform our Final Report to Ofgem on 6th September and to learn lessons for the ESO, and 2) actively supporting the wider industry review by the Energy Emergencies Executive Committee (E3C).

Key areas for further analysis to inform our ESO Final Report to Ofgem include:

- Understanding the exact failure mechanisms at Little Barford and Hornsea, building on our current good level of understanding of the timing and levels of the various generation losses.
- Continuing to work with the DNOs to understand fully those demand side impacts, including the demand facilities that were disconnected via the LFDD scheme operation and those that lost supply for other reasons during the event.
- Review of ESO communication processes with industry, Government, Ofgem and media, to support timely and effective communication in any future event.

With respect to the wider industry impacts and implications of the 9th August events, we welcome the commissioning, by BEIS, of the Energy Emergencies Executive Committee (E3C) review into the incident – to identify lessons and recommendations for the prevention and management of future power disruption events. We look forward to engaging with and supporting that review.