Technical Report
on the events of 9 August 2019

6 September 2019

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Executive Summary

Introduction

At 4:52pm on 09 August 2019 approximately 1 million customers lost power as a result of a series of events on the electricity system. 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 due to the protection systems on some trains not operating as expected.

Following comprehensive internal analysis together with input and analysis from key stakeholders (technical reports from NGET, Orsted, RWE and Govia Thameslink Railway are included Appendix C, D, E and F respectively), the details of the events leading up to, during and following the loss of supply are now more fully understood.

Details of the event, impacts to consumers, and communications during and after the event are reviewed in detail in this, the ESO Final Technical Report to Ofgem. The report sets out conclusions, lessons learned and changes implemented by the ESO, and makes recommendations for consideration by BEIS, Ofgem and Industry in the context of the findings of this and other (e.g. E3C and Ofgem) reviews.

Summary of Event

Prior to 4:52pm on Friday 09 August Great Britain's electricity system was operating as normal. There was heavy rain and lightning storms around the transmission network north of London, 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.

A lightning strike occurred on a transmission circuit (the Eaton Socon – Wymondley Main) at 4.52pm. The protection systems operated correctly and cleared the lightning in under 0.1 seconds. The line then returned to normal operation after c. 20 seconds. The voltage profile of the network immediately after the fault was within standards and was not a factor in subsequent impacts.

Coincident with the lightning strike, there was a loss of c 150MW of small embedded generation connected to the distribution network, due to vector shift protection. Loss of embedded generation through vector shift protection is expected for a lightning strike on a transmission line.

However, immediately following the lightning strike, Hornsea offshore windfarm reduced its energy supply to the grid by 737MW and Little Barford power station's steam turbine tripped reducing its energy supply to the grid by 244MW. This generation would not be expected to trip off or de-load in response to a lightning strike. This therefore appears to represent an extremely rare and unexpected event.

The cumulative loss of 1,131MW of generation caused a rapid fall in frequency which in turn caused a further 350MW of embedded generation to disconnect from the system under rate of change of frequency (RoCoF) protection.

The ESO was keeping automatic "backup" power (response) at that time to cater for the loss of the largest infeed at 1,000MW – the level required under the regulatory approved Security and Quality of Supply Standards (SQSS).

However, the total generation lost from vector shift protection, the two transmission connected generators and subsequently rate of change of frequency protection was 1,481MW and as such was above what was secured for under the SQSS. This meant that the frequency fell very quickly and went outside the normal range of 50.5Hz – 49.5Hz to a level of 49.1Hz.

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) to stop the frequency fall (at 49.1Hz) and being recovering it towards 50Hz.

However, just as the frequency began to recover (and reach 49.2Hz) there was a further trip of a Gas Turbine at 210MW at Little Barford Power Station (due to high pressure in the steam bypass system following the failure of a bypass valve to operate correctly). This made the cumulative loss of generation 1,691MW.

All of the available “backup” power had already been deployed and the cumulative scale of generation loss meant that the frequency then fell to a level (48.8Hz) where secondary backup systems acted automatically to disconnect approximately 5% of demand (the Low Frequency Demand Disconnection, LFDD, scheme). This enabled the recovery of the frequency and ensured the safety and integrity of the network. (Note that following the LFDD schemes being triggered, the second gas turbine at Little Barford tripped at 187MW meaning the total loss of generation was 1,878MW).

The LFDD scheme 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 approximately 1GW of GB’s electricity demand was disconnected. 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 between 15 and 45 minutes.

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 at 50Hz by 4:57pm. Subsequently the DNOs commenced reconnecting customers and supply was returned to all customers by 5:37pm.

Immediate Consequences

The consequences of these events were significant and included:

- 1.1 million electricity customers without power for between 15 and 45 minutes.
- Major disruption to parts of the rail network, including blocked lines out of Farringdon and Kings Cross stations along with wider cancellations and significant delays impacting thousands of passengers. A major contributor to the disruption relates to a particular class of train operating in the South-East area – approximately 60 trains unexpectedly shut down when the frequency dropped below 49Hz, half of which required a visit from a technician to restart.
- Impacts to other critical facilities 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).

Conclusions and Recommendations

Based on our analysis we have identified the following areas where lessons can be learned:

- Communication processes and protocols, in particular during the first hour, should be reviewed to support timely and effective communication in any future event;
- The list of facilities connected to the LFDD scheme should be reviewed to ensure no critical infrastructure or services are inadvertently placed at undue risk of disconnection; and
- The settings on the internal protection systems on electric trains should be reviewed to ensure they can continue to operate through ‘normal’ disturbances on the electricity system.

While the processes and procedures in place on 09 August generally worked well to protect the vast majority of consumers, there was however significant disruption – over 1m customers were without power for up to 45 minutes, rail services were severely impacted and some critical facilities were without power. Therefore, reflecting on the scale of disruption caused to the public, there are some areas where we believe a wider review of policy, processes or procedures may be appropriate, this includes:

- A review of the security standards (SQSS) to determine whether it would be appropriate to provide for higher levels of resilience in the electricity system. This should be done in a structured way to ensure a proper balancing of risks and costs;
- Assessing whether it would be appropriate to establish standards for critical infrastructure and services (e.g. hospitals, transport, emergency services) setting out the range of events and conditions on the electricity system that their internal systems should be designed to cater for;
- A review of the timescales for delivery of the Accelerated Loss of Mains Change Programme to reduce the risk of inadvertent tripping and disconnection of embedded generation, as GB moves to ever increasing levels of embedded generation.

Where lessons have been learned by the ESO these will be embedded within the business to support the prevention and management of future power disruption events. Where recommendations are also made in respect of wider industry standards, processes and programs these should be considered by BEIS, Ofgem and wider industry in the context both of the findings in this report and those of the other reviews underway, including those being undertaken by Ofgem and the Energy Emergencies Executive Committee (E3C).

1. Introduction

On Friday 09 August at 16:52 a series of events on the electricity system resulted in the disconnection of approximately 1.1 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.

On Monday 12 August Ofgem wrote to the ESO requesting an Interim Report into these events by Friday 16 August and a full Technical Report to be delivered by Friday 06 September.

This full Technical Report builds upon the information provided in the Interim Report of 16 August, incorporating additional analysis and insights coming out of the reviews undertaken by ESO and other relevant parties.

We also set out conclusions, lessons learned and changes implemented by the ESO, and make recommendations for consideration by BEIS, Ofgem and Industry in the context of the findings of this and other (e.g. E3C and Ofgem) reviews.

The aim of this ESO review has been to understand the events of 9th August in detail (including the nature and scale of the impact and the drivers of the significant disruption) and based on that understanding to learn lessons and make recommendations in order to prevent or mitigate the impact of any future such incident.

This Report is therefore structured as follows:

- A summary of the Industry Frameworks Relevant to the Event. This includes the roles and responsibilities of the ESO, NGET, Generators and Distribution Network Operators.
- 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.
- Event Analysis. This includes information about the Transmission System and the impact of lightning strikes, along with Generation Performance across Transmission and Embedded Generation on the distribution network. There is additional analysis of frequency response and demand disconnection and restoration.
- Impact. This includes impacts on consumer supplies, and critical infrastructure.
- Communications. This section builds upon the information contained in the interim report and covers operational, BEIS, Ofgem and media communications.
- Conclusions and recommendations

Independent Assurance

A critical element in developing this report has been ensuring that our analysis and review has been thorough, diligent and robust. To assist with this, we retained DNV GL who have reviewed, scrutinised, and challenged the assumptions, logic and conclusions as presented by ESO in the final Technical Report. They concluded that “the technical analyses performed by ESO have been diligent and robust, and we support the findings and recommendations in the ESO Technical Report”. (See Appendix N for DNV GL letter confirming their review and conclusion).

2. Roles and responsibilities and the Industry Frameworks Relevant to the Events of 9 August

Roles and responsibilities in the electricity industry are defined by the Electricity Act 1989, licences and industry codes and standards.

2.1. Ofgem and BEIS

The Electricity Act 1989 provides that the principal objective of the Secretary of State (the Department for Business, Energy and Industrial Strategy (BEIS)) and the Gas and Electricity Markets Authority (Ofgem) in fulfilling their obligations under the Act is to protect the interests of existing and future consumers in relation to electricity conveyed by distribution systems or transmission systems. Those interests include consumers' interests in the security of the supply of electricity to them.

Ofgem works with, but is independent of, government, the energy industry and other stakeholders. It operates within a legal framework determined by the UK government (in particular BEIS in this context) and the European Union. Ofgem has a key role in approving amendments proposed to the legal frameworks discussed in this report (such as CUSC, Grid Code and SQSS).

2.2. ESO Roles and Responsibilities

The ESO is responsible for the operation of the National Electricity Transmission System (NETS) and real time balancing of electricity generation with demand. Any imbalance between generation input and demand will result in perturbations around the nominal system frequency of 50Hz. Changes in network configuration and the feeds to and from it, either in normal operation or due to equipment faults, will result in changes to system voltage.

National Grid ESO's responsibilities are predominantly set out in its licence and industry codes and standards, in particular the CUSC, Grid Code, and SQSS. The SQSS sets frequency and voltage control performance standards. The Grid Code specifies the voltage and frequency ranges that customers connecting to the transmission system will experience. The Grid Code also contains procedures that National Grid ESO use to provide assurance that transmission network users, including generators, can meet specific requirements of the Grid Code.

Principles of Managing Frequency

The quality measures that National Grid ESO is expected to meet for frequency are in the National Electricity Transmission System Security and Quality of Supply Standard (generally referred to as SQSS). It specifies the limits of frequency deviations for secured events, which include loss of output from a single generating unit, Combined Cycle Gas Turbine Module (CCGT), boiler, nuclear reactor or DC bi-pole lost as a result of an event. The specified limits are:

- Normal Infeed Loss Risk: Maximum frequency deviation should not exceed 0.5Hz
- Infrequent Infeed Loss Risk Frequency should not deviate outside the range 49.5Hz to 50.5Hz for more than 60 seconds.

The level of the normal infeed loss actually covered depends on the configuration of the system at the time (typically it is c. 1,000W). The current normal infrequent infeed maximum loss risk is 1,260MW for when Sizewell nuclear station is operating at full load.

For a larger generation loss than the Infrequent Infeed Loss Risk or a large generation deficit in an importing power island following a sudden system split, the National Low Frequency Demand Disconnection (LFDD) scheme (as described in Grid Code OC6.6) is designed to automatically disconnect demand using low frequency relays to contain the incident and prevent a total or partial shutdown of the GB electricity system.

Frequency control is achieved using Balancing Services, which National Grid ESO's licence allows it to use to manage the system. Balancing Services are paid for by larger generators and electricity suppliers and hence contribute to consumers' electricity bills.

2.3. Transmission System Owner Roles and Responsibilities

National Grid Electricity Transmission (NGET) is the onshore transmission owner in England and Wales. It provides the network infrastructure required to provide a transmission service and makes the network available for use. It does so in line with its licence obligations and statutory requirements.

NGET and the other TOs (onshore and offshore) design and build their network in accordance with the SQSS as required under their licence. The SO-TO Code (STC) defines how TOs work with National Grid ESO, including the way in which Grid Code requirements can be delivered to users of the networks.

2.4. Generator Roles and Responsibilities

Generators that make use of the transmission networks are entitled to do so because they are signatories to the CUSC and have a connection agreement with National Grid ESO. The CUSC in turn places an obligation on generators to meet the requirements of the Grid Code, including any site-specific criteria in their connection agreement.

The Grid Code sets out a range of capabilities that a generator must have, including voltage control and frequency control. It is the Grid Code that states what a generator is expected to do during and after a network fault. The Grid Code also sets out an extensive process for new generators to demonstrate that they can meet certain requirements to enable safe connection. The details are set out in the CP (Compliance Process) section of the code. It is for the generators to assure themselves of their compliance with the Grid Code requirements.

During the period when an offshore network and generation connection is being developed, the project is treated in the same way as a generator would be (the precise term is Offshore Transmission System Development User Works – OTSDUW) and is subject to Grid Code requirements.

Some larger generators connected to the distribution networks need to meet Grid Code requirements because of their size and impact on the transmission network. Most distribution connected generators are bound solely by the Distribution Code, the relevant engineering requirements and associated documents through their connection agreement.

2.5. DNO Roles and Responsibilities

There are six electricity distribution companies in Great Britain. Each company is responsible for developing and operating its network within a region in accordance with their licence. There are also 18 iDNOs which design, build and operate distribution networks.

Distributors are responsible for having the Distribution Code in place. It is the Distribution Code and its associated documents that set out the frequency and voltage ranges that those connected to the distribution networks can expect to see, and what they are expected to do in response. Generators connected to the distribution network are generally not licensed.

Grid Code Operating Code (OC) No 6, (Demand Control) is concerned, amongst other things, with the provisions to be made by DNO's to permit the reduction of demand in the event of insufficient active power generation being available to meet demand. Grid Code OC6.6 describes the automatic LFDD scheme and the arrangements that the DNO's are required to make in relation to this scheme. Following operation of this scheme, the DNO's must notify ESO of its operation and are not permitted to restore automatically disconnected demand without instruction from National Grid ESO.

3. Description of the Event

3.1. System Conditions Prior to the Event

A detailed summary of system conditions prior to the event is contained in Appendix A and is summarised here. The ESO runs a daily iterated planning process to provide comprehensive operational advices to the control room, including demand and generation forecasts, NETS outages and post-fault actions to ensure ESO is fully compliant with SQSS in both pre-fault and post-fault conditions.

3.1.1. Power System Condition

Prior to the initial fault there was approximately 32GW of transmission connected generation capacity available on the system. Over 30% of this capacity was being provided by wind generation with an expected peak output of 10GW, and 50% was being provided by conventional units. In aggregate this capacity was being offered by more than 250 Balancing Mechanism (BM) units and non-BM units. The overall demand was forecast to reach 29GW, which was similar to the outturn demand experienced on the previous Friday. Margins for the day were comfortable. As is normal for the Summer period, there were a number of transmission circuits out of service across various parts of the network. Post-event analysis does not indicate that the outages caused any further issues at the time of the event.

More details on the power system conditions are contained in Appendix A:

- Transmission system outages and the active transmission constraints which were being managed on the system.
- Out-turn demand
- Generation, solar and wind outputs
- A list of all Balancing Mechanism generators which were synchronised and generating at the time of the event. (Excluding interconnectors)

3.1.2. Weather for 9 August

The Met Office issued yellow warnings of wind for the South West England and South Wales, and yellow warnings of rain for all of England and Wales except North West Scotland and South East England. The Yellow Warnings provided by the Met Office are the lowest of the 3 Met Office warnings.

Weather conditions on 9 August were not unusual.

3.2. Summary of the Event

- At 16:52:33 on Friday 09 August 2019 there was a lightning strike on the Eaton Socon – Wymondley 400kV line. This was one of several lightning strikes that hit the transmission system on the day, but this was the only one to have a significant impact.
- 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 initiated the operation of Vector Shift protection resulting in the tripping of approximately 150MW of embedded generation.
- Two almost simultaneous unexpected power losses – at the Hornsea off-shore wind farm (737MW) and the steam turbine at the Little Barford gas-fired power station (244MW) – occurred independently of one another, but coincident with the lightning strike. As this generation would not be expected to trip off or de-load in response to a lightning strike, this represents an extremely rare and unexpected event.
- These events resulted in a cumulative level of power loss greater than the level required to be secured by the Security Standards (1,000MW based on the largest infeed at the time), and as such a large frequency drop outside the normal range occurred.

- The frequency drop caused the further tripping of approximately 350MW of embedded generation on Rate of Change of Frequency (RoCoF) protection.
- The total loss of generation at this point was 1,481MW, nevertheless the frequency fall was arrested at 49.1Hz and began to recover with the deployment of all of the response and reserve available.
- However, one of the gas turbines at Little Barford then unexpectedly tripped from 210MW bringing the cumulative loss of generation to 1,691MW[1]. There were no further reserves left and the frequency fell to 48.8Hz.
- The Low Frequency Demand Disconnection (LFDD) scheme was correctly triggered at 48.8Hz and automatically disconnected c.1.1m customers (c. 1GW).
- The disconnection of demand, coupled with the response and reserve in place along with further dispatch of fast acting plant by ENCC, enabled the frequency return to 50Hz within 5 minutes.
- The Distribution Network Operators quickly restored supplies within 40 minutes once the system was in a stable and secure position.

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[1] The second Gas Turbine at Little Barford tripped from 187MW after the initiation of LFDD bringing total generation lost through the event to 1,878MW. The effect of this second GT trip was absorbed by the action of LFDD and the additional plant dispatched by the ENCC.

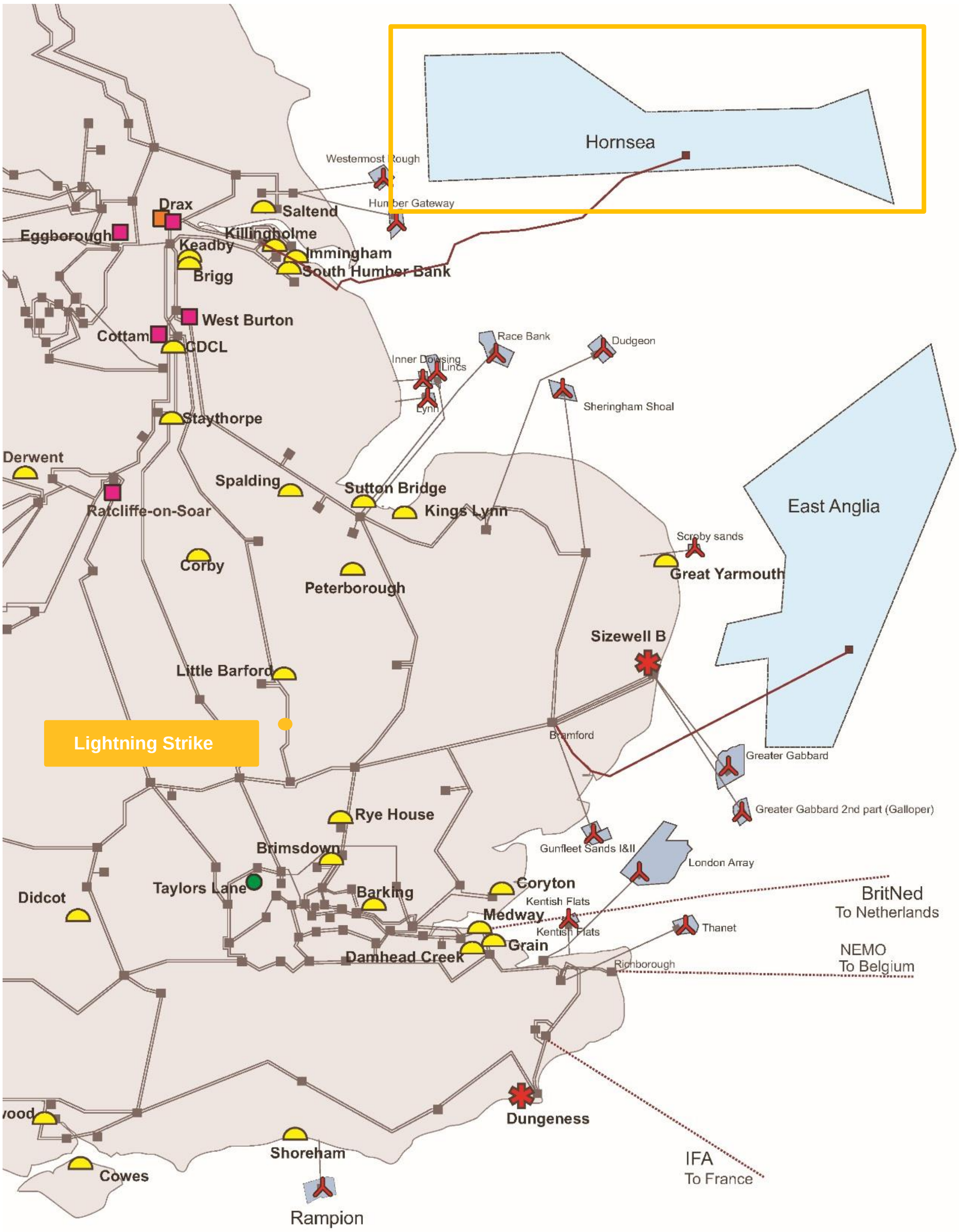


Figure 1 – Map of Hornsea, Little Barford and the Lightning Strike

3.3. Detailed Timeline

Through the ESO's systems and data, and information and data provided by NGET, Orsted, RWE, DNO's and others, the timeline of events is as follows:

Time	Activity	Source
16:52:26	Frequency at 50.0Hz, ESO securing for 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	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	Approximately 150MW of embedded generation trips on vector-shift protection	ESO
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	Orsted
16:52:34	Little Barford Steam Turbine trips 244MW instantaneously. Source: RWE [1,131MW of cumulative infeed loss]	RWE
16:52:34	Approximately 350MW of embedded generation trips on RoCoF protection [1,481MW cumulative infeed loss]	ESO
16:52:34	Frequency response initiates.	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
16:52	Contracted response service from Low Frequency Gas Turbines initiated	ESO
16:53:04	Frequency Response has delivered 900MW of power to stabilise the frequency	ESO
Since 16:53	Short Term Operating Reserve (STOR) units were instructed; overall amount 400MW	ESO
16:53:18	Frequency recovers to 49.2Hz, due to the continued delivery of frequency response	ESO

16:53:31	Little Barford GT1A generator protection settings tripped and 210MW instantaneously disconnected. [1,691MW 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 automatically disconnected.	DNOs
16:53:58	Little Barford GT1B tripped with 187MW generation lost instantaneously. This loss was subsumed by the LFDD reductions and the additional energy sources being instructed by ESO. [1,878MW cumulative infeed loss]	RWE
16:54:20	Control room initiate instructions to generation to restore the system frequency and response levels to stabilise the system	ESO
16:57:15	Frequency returns to 50Hz following over 1,000MW of response and a further 1240MW of control room actions to restore frequency and stabilise the situation	ESO
16:58 – 17:16	ESO progressively instructs the DNO's that they can commence demand restoration	ESO
17:37	All DNO's have confirmed that demand restoration has been completed	DNO's

Table 1 – Timeline of Events

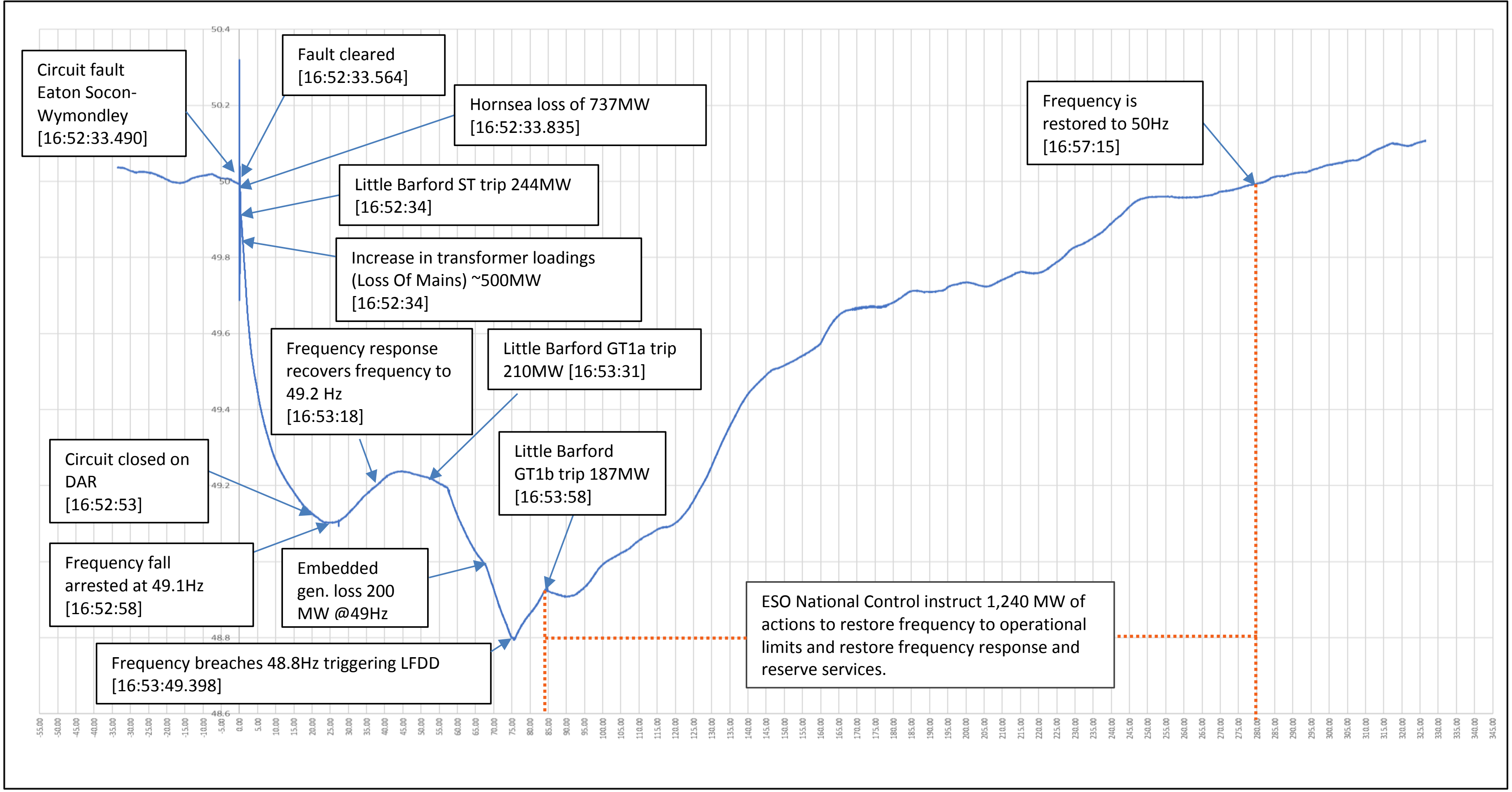
Below is the detail of the cumulative losses of infeed

Generation Unit	Infeed Loss	Cumulative Infeed Loss
Little Barford ST1C	244 MW	244 MW
Hornsea Offshore Windfarm	737 MW	981 MW
Estimated, Embedded generation infeed loss due to Vector Shift Loss of Mains Protection	150 MW	1,131 MW
Estimated, Embedded generation infeed loss due to RoCoF Loss of Mains Protection	350 MW	1,481 MW
Little Barford GT1A	210 MW	1,691 MW
Little Barford GT1B	187 MW	1,878 MW

Table 2 – Table of cumulative infeed losses

3.4. Impact on Frequency

Figure 2 – Annotated Frequency Trace of the Event



4. Event Analysis

4.1. Transmission System

Transmission System Reaction to Lightning Strike

Meteogroup have advised that in the 24 hours of 9 August there were 12,370 lightning strikes across mainland UK. In the 2 hours preceding 17:00hrs there were 2,106 strikes across mainland UK.

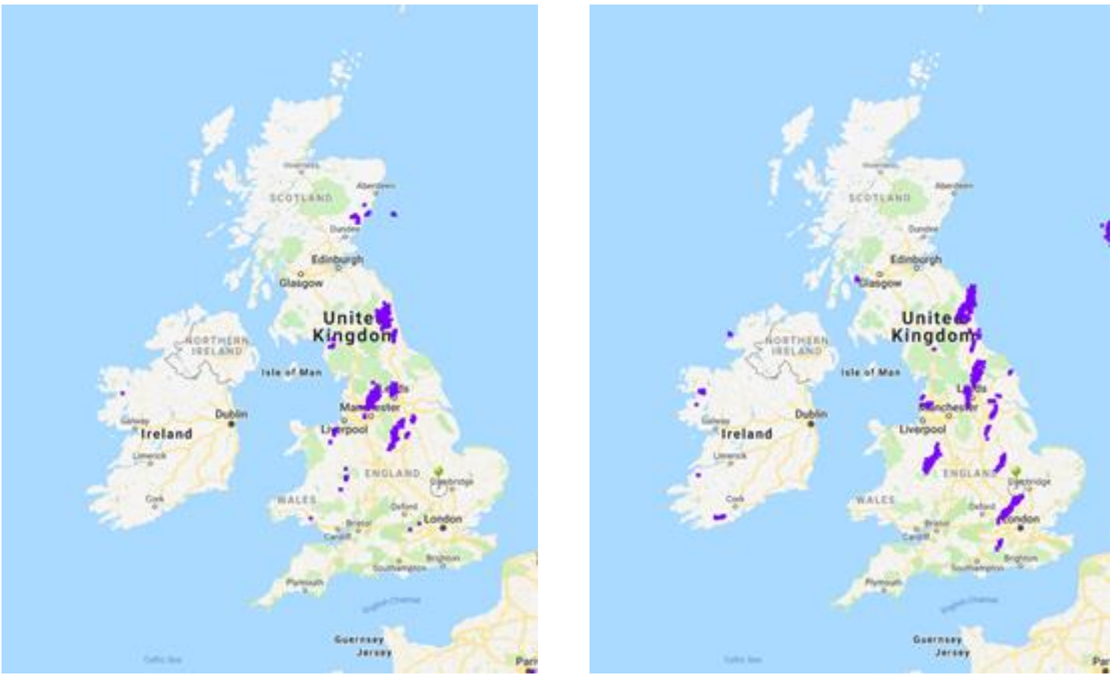


Figure 3 - Lightning Activity on 9 August 2019 – Left: Lightning records15:00-16:00hrs and Right: Lightning records 16:00-17:00hrs. Data Source: Meteogroup

At 16:50:44hrs, a lightning struck the Blyth – Eccles – Stella West 400kV circuit near Longframlington, Northumberland. The circuit tripped and closed with no power losses associated. At 14:23hrs, the Harker – Stella West 275kV circuit was also tripped and automatically returned to service. Lightning was observed active in the vicinity. There were no adverse effects to the transmission system following this fault.

The Eaton Socon – Wymondley circuit is a 35km long, 400kV double circuit overhead line running from Eaton Socon Substation near St Neots in Cambridgeshire, to Wymondley Main Substation near Stevenage in Hertfordshire. Each of the double circuits is made up of 3 conductors (phases) hanging on each side of the lattice steel towers. An earth wire is at the top of the tower.

At 16:52:33hrs, three almost simultaneous lightning strikes were recorded adjacent to the Eaton Socon – Wymondley circuit. The figure below shows the location of the three strikes in relation to the circuit, close to Willian Arboretum, at the Wymondley end of the circuit. The red circles show the radius of uncertainty for the location of the direct hit. Any of the three strikes could have hit the circuit. The largest strike had a current amplitude of 33.7kA. NGET by analysing their protection data confirmed that these lightning strikes were the cause of the circuit trip and reclose.

Figure 4 - Three simultaneous lightning strikes close to Willian Arboretum at 15:52hrs – Data Source: Meteogroup

Transmission System protection measurements

The lightning strike triggered the transmission line protection system to disconnect and clear the disturbance on the Eaton Socon – Wymondley 400kV circuit within 74ms plus initiate its subsequent automatic energisation and reconnection after 20 seconds. The transmission system protection operated in line with the design and in compliance with the Grid Code requirements on fault clearance.

The associated voltage and current disturbance on the network from the lightning was within expected limits for such an event. In all other recorded instances of strikes on the transmission network this protection protocol has protected the network successfully and led to no adverse consequences.

Figures below show the time-sequence 3 phase currents during the short circuit and protection operations at Wymondley and Eaton Socon Substations.

NGET indicates (see Appendix C) that the lightning strike hit the Eaton Socon – Wymondley circuits approximately 4.5km along the circuit from the Wymondley Main Substation end. At Wymondley site, a short circuit current of 21kA was seen and was cleared within 70ms. At Eaton Socon Substation, the short circuit current was 7kA and was cleared within 74ms.

Transmission System Performance

The short circuit had an impact on the electricity system which can be observed on system measurements from a variety of units available to ESO. Measurements supplied by Orsted taken at the Transmission Interface Point for the Hornsea connection at Killingholme have been of significant assistance. Measurements labelled ‘Hornsea’ are those provided by Orsted. Figure 5 shows where voltage measurements discussed here were taken from.

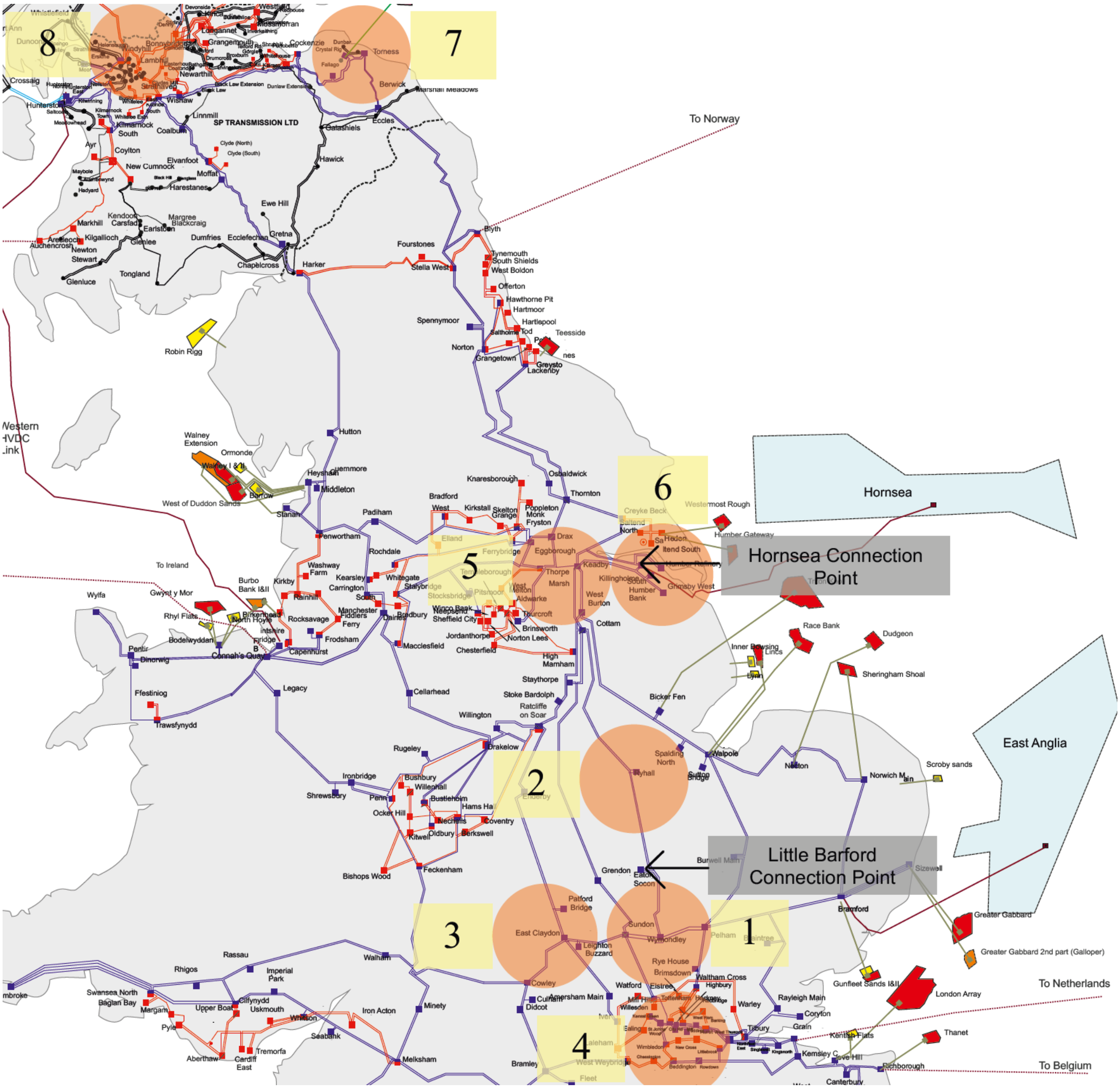


Figure 5 – location of voltage measurements

The system response seen at 16:52 is consistent with expectations for a lightning strike on the Eaton Socon-Wymondley circuit. Figure 6 below shows voltages measured at locations highlighted in Figure 5.

The measurements in Figure 6 show voltages at the time of the short-circuit on the Eaton Socon-Wymondley overhead line and recovering to normal less than 100ms later after the circuit is de-energised. The voltage dip is larger at locations near to the short-circuit, with the largest dip observed at Wymondley. All measurements indicate voltages stayed above the Fault Ride Through profile specified in the Grid Code and returned to within steady state limits after the event.

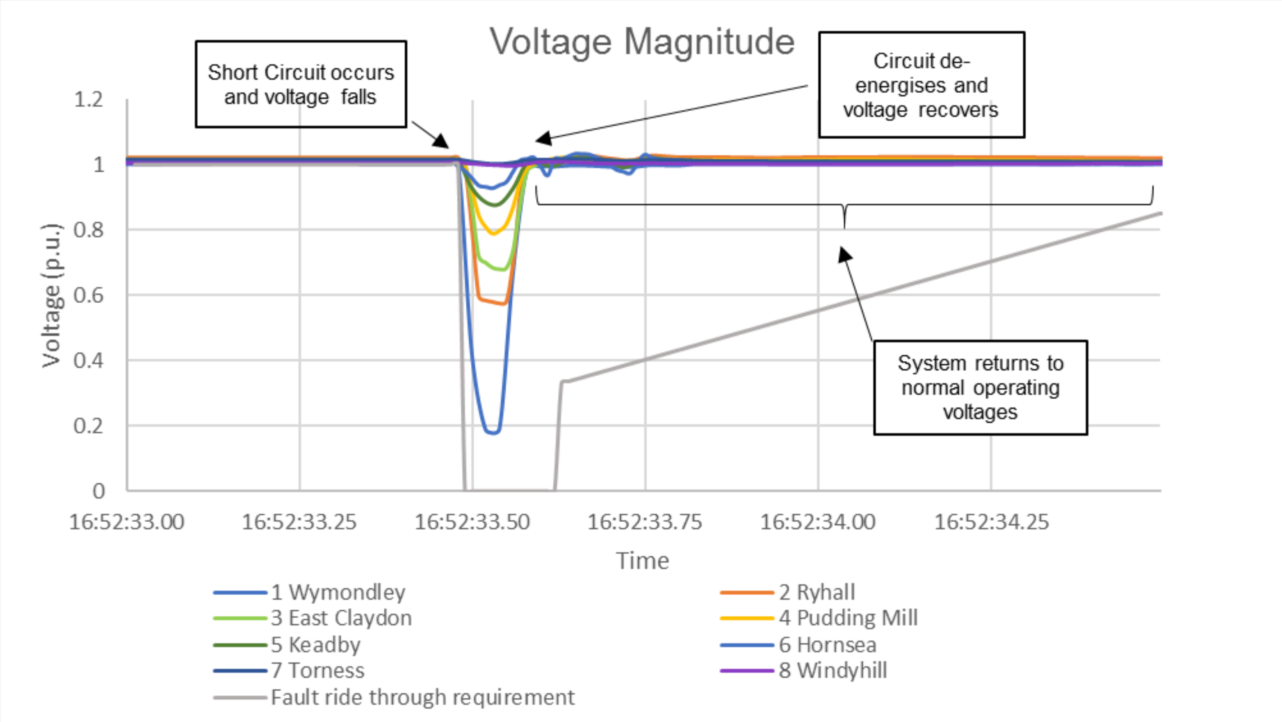


Figure 6 – single phase voltage profile at various locations

4.2. Generation Performance

4.2.1. Hornsea

Hornsea offshore wind farm owned by Orsted is a 1,200MW 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 lightning strike (and clearance of the fault) on the Eaton Socon-Wymondley circuit, Hornsea immediately de-loaded from 799MW to 62MW. The timing and magnitude of the active power reduction are shown in Figure 7.

Hornsea have confirmed that a system voltage fluctuation was seen at the onshore connection point coincident with the fault and clearance. The reaction to the voltage dip resulting from the fault by Hornsea's control systems was as expected in attempt to accommodate and address the system condition. We can see this response in Figure 8.

However, very shortly afterwards when the transmission system voltage recovered on clearance of the short circuit, as shown in Figures 7&8, the reaction of Hornsea wind farm as seen at the onshore connection point showed unexpected large swings in active power and reactive power which should not have occurred. Similar large swings are seen in data recorded at the offshore wind farm.

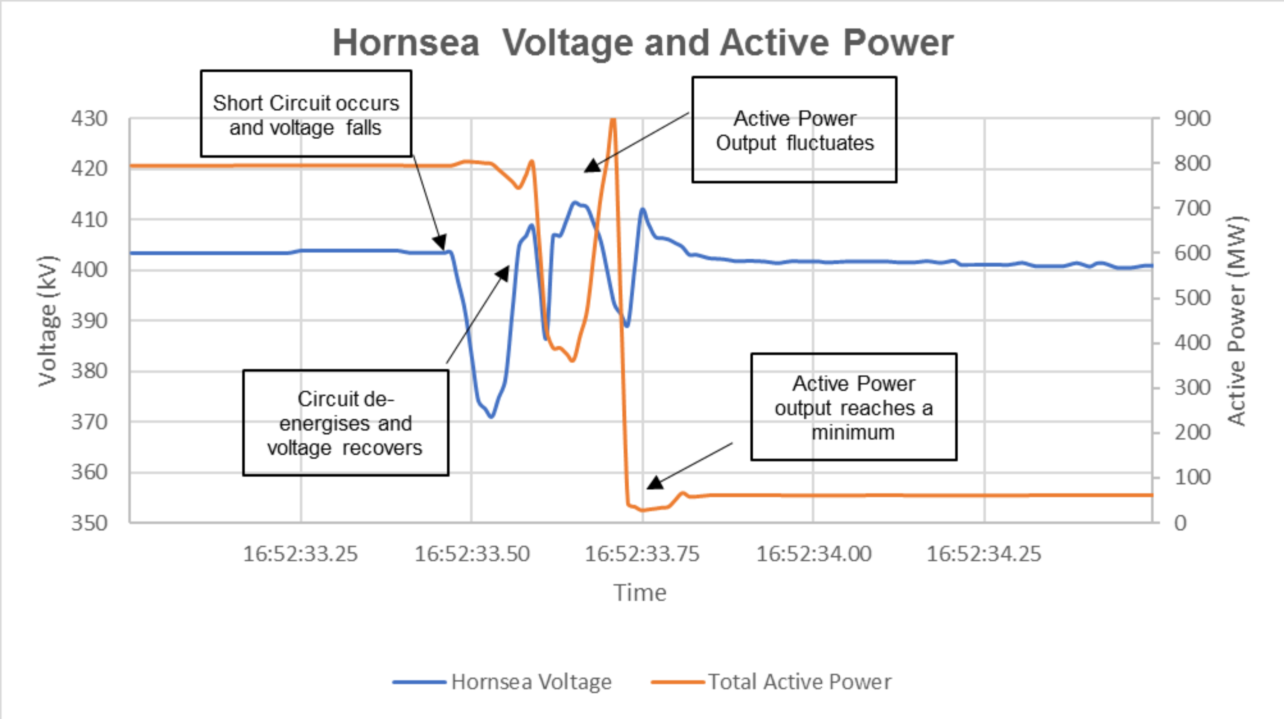


Figure 7 – Voltage and Active Power at Hornsea

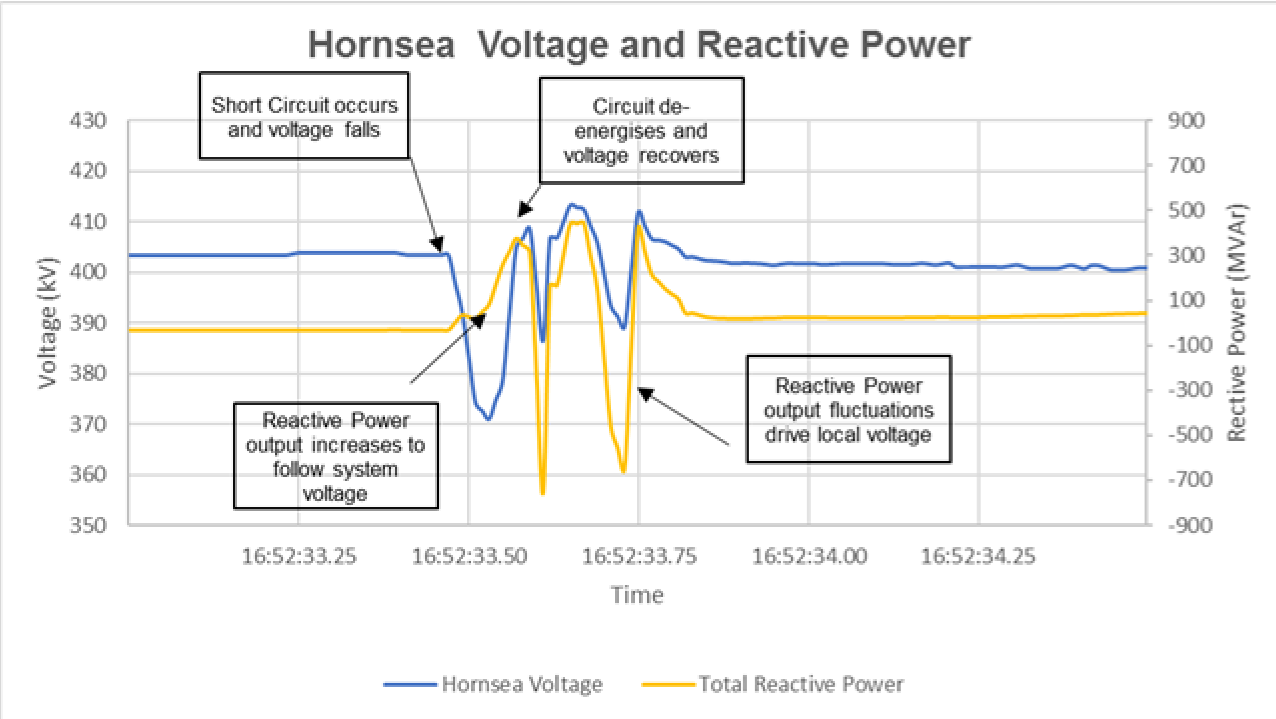


Figure 8 – Voltage and Reactive Power at Hornsea

Orsted have carried out an investigation and provided a Hornsea Technical Report which can be found in Appendix D.

Orsted's report advises the following:

Initially, Orsted understood that the Dynamic Reactive Compensator (DRC) was responsible for the rapid de-load of Hornsea-1. Orsted have since concluded that the DRC worked as designed and was not the cause of the de-load.

The configuration of the Hornsea network, with one SGT and one offshore transmission system user asset (OTSUA Circuit) on outage, was a contributory factor as it created a weak internal network environment. Subsequently Orsted have reviewed and reconfigured their network.

The wind turbine settings were standard settings from the manufacturer. During the incident, the turbine controllers reacted incorrectly due to an insufficiently damped electrical resonance in the sub-synchronous frequency range, so that the local Hornsea voltage dropped and the turbines shut themselves down.

Orsted have since updated the control system software for the wind turbines and have observed that the behaviour of the turbines now demonstrates a stable control system that will withstand any future events in line with Grid Code and CUSC requirements.

Appendix G provides the Compliance Testing report for Hornsea and Little Barford.

4.2.2. 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 lightning strike on Eaton Socon – Wymondley line, the Steam Turbine (ST1C) unit at the Little Barford Gas Power Station tripped with the immediate loss of 244MW.

Little Barford's preliminary technical report submitted by RWE is included Appendix E. The report advises the following:

The initiation of the trip of Little Barford steam turbine (ST1C) was caused by a discrepancy between the measurements from three speed signals. A review of hardware, software, fault handling and diagnostic coverage for the conditions that the Steam Turbine was subjected to is ongoing.

Normal operation of Little Barford power station following the loss of the steam turbine is for the steam generated from the Gas Turbines to be fed directly into the condenser in a steam bypass mode of operation. RWE have confirmed that for reasons presently unknown, after approximately 1 minute the first gas turbine tripped due to a high-pressure excursion in the steam bypass system. This trip occurred automatically and shut the gas turbine (GT1A) down. The second gas turbine (GT1B) was manually tripped by the 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.

RWE have confirmed that their Uninterrupted Power Supply (UPS) functioned correctly to enable continuity of supply to plant equipment. RWE do not believe the UPS operation was related to the subsequent turbine trips detailed below. During a forthcoming outage in September 2019, the OEM will undertake resilience testing to reaffirm the functionality of the system.

A physical inspection of the bypass system is now planned during a forthcoming outage in September 2019 to determine the root cause of the pressure excursions.

Appendix G provides the Compliance Testing report for Hornsea and Little Barford.

4.2.3. Embedded Generation

Analysis undertaken by ESO has shown that some parts of the system may have experienced a rate of change of frequency of 0.125Hz/s or above and/or a Vector Shift exceeding 6^{O}, which is likely to have led to RoCoF and/or Vector Shift events.

Post event, ESO contacted all DNO's and requested data related to the volume of embedded generation that was disconnected or changed output during the power system event on 09 August.

DNOs were asked to indicate the reason for the change of output, for example RoCoF, Vector Shift, Active Network Management (ANM) operation.

All DNOs have responded to this request and indicated a combined total of 462MW of embedded generation was lost during the event. In providing their analysis some DNOs noted challenges in obtaining the data due to the way it is collected or stored and without confirmation from generators, DNOs were unable to determine whether a specific generator tripped due to RoCoF or Vector Shift.

Post-event Power System studies undertaken by the ESO have indicated that, for an event such as this, a loss of embedded generation on Vector Shift protection of approximately 150MW would be expected. Therefore, based on this plus the data provided by the DNO's, it is estimated that approximately 350MW of embedded generation was lost due to RoCoF[2].

A number of embedded generators and demand customers have advised that their protection operated when the frequency reached 49Hz and as such they were disconnected from the system. The net effect of this disconnection has been modelled as a 200MW loss of generation. Protection operating at this frequency was not expected and has not previously been observed.

4.3. Demand disconnection and restoration

The Grid Code, requires each DNO to make arrangements that will enable automatic disconnection of demand if the frequency on the transmission system drops below 48.8Hz. The amount of demand that is disconnected is in staged "Blocks" (5%, 7.5% and 10%) to increase the amount of demand disconnected if the frequency continues to drop. This scheme is the Lower Frequency Demand Disconnection (LFDD) scheme. The DNO's have indicated that 931MW (3.2%) of demand was automatically disconnected by the operation of the LFDD scheme.

The LFDD process worked largely as expected. While the process provided slightly lower than 5% of demand this did not materially impact the function of the LFDD in returning the frequency to normal operational parameters.

4.4. Frequency Response

4.4.1. Response Holding on August 9th 2019

The largest secured loss on the event day was 1,000 MW. In order to keep the frequency above 49.5Hz for this level of infeed loss, the response holding was calculated and planned as below.

Service	Provider type	Lower Frequency response held (MW)	
		Primary response	Secondary response
Dynamic – Generation (Mandatory response)	BM	284	325
Dynamic – Firm Frequency Response	BM & Non-BM	259	270
Dynamic – Enhanced Frequency Response	BM & Non-BM	227	227
Static – Firm Frequency Response	Non-BM	21	261
Static – Low Frequency Response through auction	Non-BM	31	31
Static - Interconnectors	BM	200	200
Total		**1022**	**1314**

Table 3 - Frequency response holding

[2] Note - ESO simulation data indicates that the overall total embedded generation loss could be slightly higher (580MW v 500MW) – see also section 4.4.2

An explanation of how frequency response requirement and procurement is managed is explained in Appendix H.

4.4.2. Modelling of Frequency Holding

The ESO has performed frequency simulation studies for the system configuration on 09 August to answer the questions:

1. Can the frequency trace of the event be explained using a simulation?
2. Would the frequency have remained within limits if the loss had been limited to the 1,000MW, the maximum loss for which the system had been secured?

Answering the first question provides confidence that the model can represent the dynamics of the system whist answering the second demonstrates that the security standard had been applied correctly on the day. In addition, the frequency performance during an actual 1,000MW event on a similar day has been analysed.

1. Simulation of the 9th August event

The Frequency Simulation Engine (FSE) is used by the ESO to calculate the frequency response holding required to keep frequency within limits for a given loss and set of system conditions. This has been used to simulate the 09 August incident.

An event such as this is complex with many different things happening and so it is unlikely that we can explain all of the movements in the imbalance. It is useful to analyse this trace to understand whether we can infer more about what happened. Appendix I provides further detail on the modelling and simulations conducted.

Key elements of the trace are due to the known losses at Hornsea and Little Barford together with the embedded generation disconnected through Vector Shift and RoCoF. A number of asset owners, both demand and generation, have highlighted that their under-frequency protection operated at 49Hz, disconnecting both demand and generation. Analysis of the frequency trace indicates that the net effect of this protection operation was a reduction of generation of approximately 200 MW.

Our simulation maps closely to the actual frequency trace – see Figure 9 below – where the dotted line is the simulation results and the black line is the actual smoothed frequency from the event.

Note: Modelling inputs complete at 16:54 hence the deviation of the trace from this point onwards.

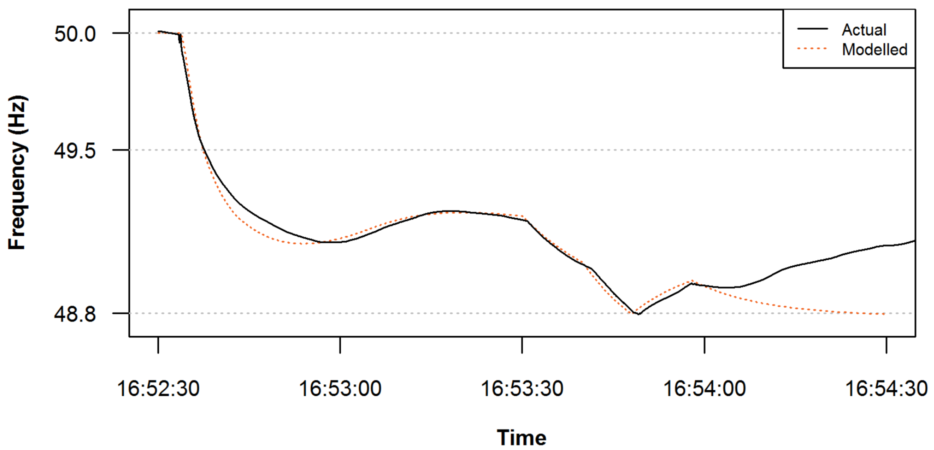


Figure 9 – Frequency Trace of the event vs Modelled Frequency Trace

2. Modelling a 1,000 MW loss

Two simulations have been carried out for a loss of 1,000MW using the same inertia and demand as for the simulation of the incident. In the first simulation, the frequency response has been modelled using the fully available contracted volume for that period of the day. A second simulation has then been carried out using the actual delivery of the contracted volume of frequency response on 09 August. The results of the simulation are plotted below. In both cases the frequency does not go below 49.5Hz, is restored to operational limits and so the system would have remained secure for a 1,000MW loss as planned.

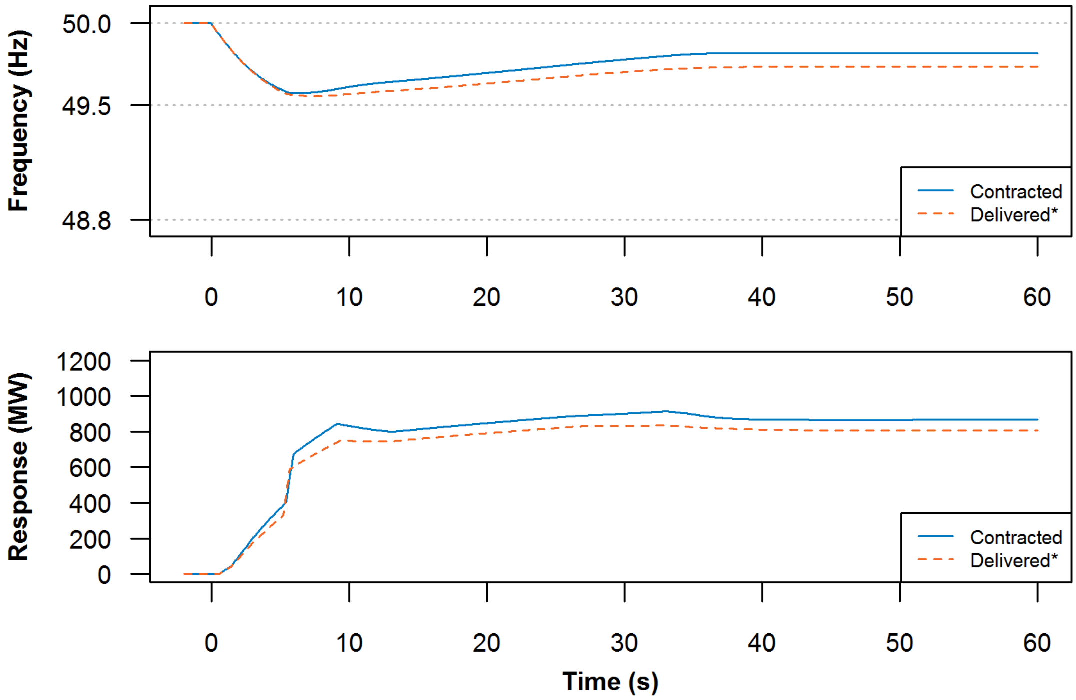


Figure 10 - Simulation of 1,000 MW loss in FSE

3. Comparison with historical days

The simulations outlined above indicate that the system frequency would have remained within limits on 09 August for a loss of 1,000MW as planned. This provides confidence that the security standards were applied correctly. The ESO has augmented this analysis with an examination of historical data.

On 1st July at 08:27 the NEMO interconnector tripped while importing 1,000MW from Belgium to GB resulting in an instantaneous loss of 1,000MW on the system. The system conditions were very similar to those of 09 August as shown in the table below.

	01 July	09 August
Demand	28 GW	29 GW
Inertia	201 GVAs	210GVAs
Largest planned loss	1,000 MW	1,000 MW
Frequency Response Holding	1,087 MW	1,022 MW

Table 4 – Comparison of system conditions between 1st July and 9th August

The same procedure was used on both days to set the volume of frequency response. The actual frequency trace for the instantaneous loss of 1,000MW on 01 July is shown in the figure below. The frequency remains above 49.5Hz. This gives further confidence that the security standards have and are being applied correctly to size the volume of frequency response. Given the system conditions on 01 July were very close to those on 09 August, this strongly suggests that the frequency would have remained above 49.5Hz for a trip of 1,000MW on 09 August.

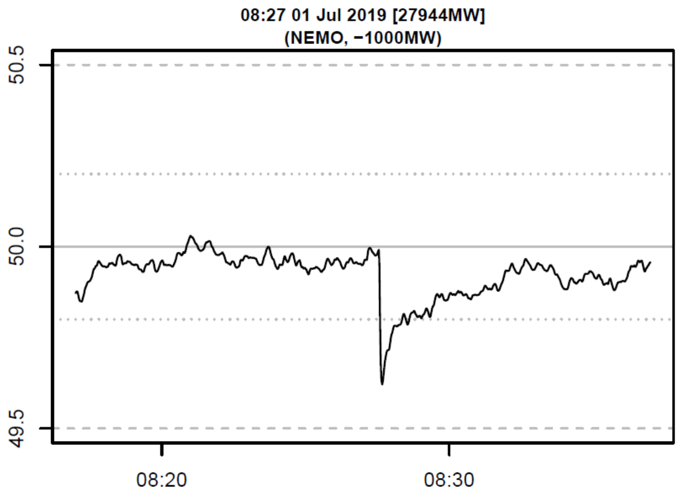


Figure 11 – Frequency Trace from 1st July 2019

4. Modelling Conclusion

From the simulations and the analysis of a similar historical day, it can be concluded that frequency would have remained above 49.5Hz on 09 August for the loss of the single largest infeed of 1,000MW.

4.4.3. Delivery of Frequency Response

At the time of the event the amount of low frequency response being held was 1,022MW primary and 1,314MW secondary. This response is held across both BM and non-BM providers and is either dynamic (continuously responding to frequency) or static (acting at a specified trigger level). The performance of response providers by frequency response service type can be found in table below:

To date, of the 1,022MW and 1,314MW of response holding, the ESO has worked with providers and used internal data to validate the performance of 91% of all primary and secondary that was being held at the time (i.e. 945MW and 1,202MW respectively). See table 5 over.

Of the validated response holding the ESO can confirm that 89% of primary (841MW) and 88% of secondary (1055MW) response performed as expected and in line with its contractual obligations.

In the operation of the system and provisioning of response conservative modelling assumptions are employed to ensure there is contingency if not all contracted response delivers. The overall response performance on 09 August was broadly in line with these planning assumptions. Nevertheless, there was some under-performance and this is being followed-up with the specific providers.

Service	Provider type	% validated low frequency response delivered at 30 seconds versus Total MW response held	
		Validated Primary response	**Validated Secondary response**
Dynamic – Generation (Mandatory response)	BM	103% of 284 MW	102% 325 MW
Dynamic – Firm Frequency Response	BM & Non-BM	74% of 259 MW	81% of 270 MW
Dynamic – Enhanced Frequency Response	BM & Non-BM	94% of 227 MW	94% of 227 MW
Static – Firm Frequency Response	Non-BM	0% of 21 MW	67% of 261 MW
Static – Low Frequency Response through auction	Non-BM	71% of 31 MW	71% of 31 MW
Static - Interconnectors	BM	100% of 200 MW	100% of 200 MW
Total		**89%**	**88%**

Table 5 – Validated Frequency Response Performance

5. Impact

Through the events of the evening of Friday 09 August over a million customers and thousands of commuters were directly affected. The ESO and 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.

We have been working with the DNOs, Network Rail and Govia Thameslink Railway to understand the impacts in more detail. The latest understanding of the demand impacts is set out below; recognising that in some cases investigations are still ongoing.

5.1. Distribution Demand

Table 7 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 13 August 2019 at 12:00.

The total loss of demand, due to LFDD relay operation was 1,152,878 customers or 931MW, which represents 3.2% of national transmission demand at the time of the event (29GW).

Demand restoration was initiated by the ESO with instruction to regional DNOs starting at 16:58 and reported completed by 17:37. However, disruptions following demand restoration continued beyond 17:37 while customers continued to recover their own systems.

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

5.2. Critical Infrastructure

5.2.1. Rail

The DNOs confirmed that no track supplies were lost due to the DNO's LFDD protection operation. Through their investigation, Network Rail have stated that their supply disruption was likely to have been caused by supply interruption from the DNO networks. Network Rail are to undertake key discussions with the DNOs to explore further. However, there were significant impacts on the rail network during the event as noted below:

- 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.
- 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 supply related trips which occurred at two DC traction locations which Network Rail are investigating further.
- Eight signal power supplies in principally rural locations suffered minor outages with minimal passenger impact. Network Rail are reviewing resilience at these locations with the DNOs.

Govia Thameslink Railway (GTR) have provided a detailed technical report from their investigation which can be found in Appendix F. The report sets out a summary of events and identifies the cause of the shutdown of the trains which is summarised below.

The report sets out that all Desiro City Class 700 and Class 717 trains that were operating on AC power suffered a protective shutdown when the frequency deviation fell below 49Hz. Of the approximately 60 Class 700 and Class 717 trains that shutdown, half were restarted by the driver on site performing a reboot of the train, which takes c10mins. The remaining 30 trains required a technician to attend each train with a laptop to reset the trains.

GTR have stated this was not how the train system had been specified to operate and the event should not have caused a permanent lockout fault on the trains. The technical specification for the trains states that the trains will continue to operate with supply frequency drops down to 48.5Hz for short periods of time. All other GTR classes of train were unaffected.

The effects were exacerbated as the fleet was undergoing a software change which meant the train drivers could not recover trains which were operating on the new software. The train manufacturer, Siemens, are developing a patch which will allow the drivers to recover the trains themselves without the need for a reboot or technician to attend site. In addition Siemens will investigate how the train could be made to operate for a short time with a supply frequency of 48.5Hz.

The impact to the rail network was that there were 23 train evacuations and 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 17:35hrs. UKPN have confirmed that LFDD did not impact the Victoria line. The UKPN control room made contact with LUL who confirmed they did not lose power supplies at any stations, but they had an internal traction issue.

5.3. Other Priority Loads Affected

We are aware of other impacts two of which we have investigated are:

5.3.1. Ipswich Hospital

Ipswich Hospital internal protection operated coincident with the timeframe of the lightning strike. 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.

5.3.2. Newcastle Airport

Newcastle Airport is connected to the 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.

6. Communication

ESO communication activities can be categorised in 3 broad areas: 1) operational communications; 2) engagement with government and the regulator; and 3) external communications with media and wider industry.

6.1. Operational Communications

ESO control room commenced communication with DNOs and NGET control room within 2 minutes of the initial fault. Table below lists the operational calls following the fault and until the final restoration was reported to the ESO control room.

Timestamps of the key operational communications are summarised below.

[16:56] First report of demand disconnection from DNO was 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.

[16:58 to 17:16] Demand restoration instruction to DNOs was initiated by the ESO control room. The demand was instructed to restore in a progressive manner.

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

[17:32] ESO control room informed NGET control room that DNOs had started restoration.

[17:34] 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.

[18:34 and beyond] Last report from DNO informing their demand restoration was received. Demand and lost customer figures continued to be supplied by DNOs.

<table>
<tr><th></th><th colspan="12">DNO Areas</th></tr>
<tr><th></th><th>SSE</th><th>SPED</th><th>ENW</th><th>NPG North East</th><th>NPG Yorkshire</th><th>UKPN SPN</th><th>UKPN EPN</th><th>UKPN LPN</th><th>WPD South West</th><th>WPD South Wales</th><th>WPD West Midland</th><th>WPD East Midland</th></tr>
<tr><th>When was ESO informed demand loss</th><td>17:01</td><td>17:01</td><td>17:01</td><td>17:01</td><td>17:01</td><td>17:04</td><td>17:04</td><td>16:58</td><td colspan="2">16:56</td><td>17:02</td><td>16:57</td></tr>
<tr><th>When did ESO instruct restoration</th><td>17:06</td><td>17:13</td><td>17:10</td><td>17:08</td><td>17:10</td><td>17:13</td><td>17:14</td><td>16:58</td><td colspan="2">17:08</td><td>17:05</td><td>17:16</td></tr>
<tr><th>When did restoration complete</th><td>17:07</td><td>17:17</td><td>17:17</td><td>17:18</td><td>17:12</td><td colspan="3">17:37</td><td colspan="4">17:30</td></tr>
</table>

Table 7 – DNO Areas Communication times

Operational communications were generally efficient and effective during the demand restoration process and in the demand loss and restoration reporting process. ESO control room experienced no communication issues with customers or with communication systems.

Whilst some DNOs incorrectly called the NGET control room, NGET control room correctly referred DNO's to the ESO, with no impact on the restoration process.

Indications are that DNOs did ask specific permission from the ESO control room to restore demand. While verbal instructions to DNOs to restore demand did not follow agreed phraseology, they were clear and understood.

6.2. Engagement with government and the regulator

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 communication between the ESO control room and BEIS was at 17:41hrs. At this point the event was generally understood, demand restoration was in progress and further disturbances were considered unlikely.

The first communication with Ofgem was made at 17:51hrs with further communication at 18:17hrs and 18:45hrs and then throughout the weekend.

Further updates to BEIS from the ESO control room were made at 18:09hrs, 19:29hrs and 19:38hrs respectively.

Engagement with BEIS and Ofgem officials continued through Friday evening and into the weekend, via a series of update calls from ESO leadership. Wider 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 held with Minister of State for Business and Energy on Sunday.

Communications continued throughout week commencing 12 August with a primary focus on the ESO internal review ahead of publication of the ESO Interim Report on 16 August. Communication was also maintained with the office of the Minister of State for Business and Energy, ahead of the Minister's previously arranged visit to the electricity control room on 16 August.

6.3. External Communications with Media and Wider Industry

The first ESO external communication was issued at 18:27hrs on 9 August. Communication with media continued both proactively and in response to media contacts through the evening and into the weekend. Communication with wider industry (parties not directly involved, but interested in the event) commenced Monday 12 August, continued through to delivery of the Interim Report on Friday 16 August and beyond.

Table 8 provides the timeline of external communication with media and wider industry.

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.
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.
20:11	A video from Julian Leslie offering further explanation issued on Twitter.
SATURDAY	
08:00 – 13:00	Broadcast interviews – Radio 4 Today Programme, Five Live, ITV, BBC Breakfast and Sky.
08:33	Third Statement – Further explanation of events 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 news desks. Shared with BEIS and Ofgem.
12:22	Update to senior BEIS officials.
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 news desks. Shared with BEIS and Ofgem.
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 and BEIS Minister of State Kwasi Kwarteng MP.
W/C 12 AUG	
	ESO Media team direct engagement with ENA and relevant members. Setting out preliminary technical findings related to the networks and discussing the planned approach to media and communications ahead of publication of the Interim Report. Materials published on the ESO website to aid understanding of the role of the ESO and the incident on 9 August.

Table 8 – Timeline of external communications

6.4. Communications by industry and consumers

Media statements by others

In the ~90 minutes immediately following the initial fault on the network (starting at 17.09hrs) statements were issued by some DNOs and rail companies stating that the loss of power and subsequent disruption was the result of a National Grid fault. These statements were issued ahead of any communication by the ESO and without engagement or coordination with the ESO communications team.

These public-facing communications did not impact the speed with which the incident was resolved but did drive a large volume of media queries to the ESO.

The following is an example of public facing communication via a repeated tweet over the weekend:

“The failure of the UK National Grid caused widespread disruption across the country, not least to your journeys on a Friday evening.”

In the absence of information from the ESO, statements made by DNOs and others were taken by the media and consumers to be factually correct. Communications issued by the ESO starting at 18:27 Friday evening and continuing through the weekend sought to give reassurance to the public and clarify the facts of the incident.

Call volumes to DNO’s

Electricity customers across GB can dial the ‘105’ customer helpline to get emergency help and advice, free of charge on mobile and landline phones. Typically, customers will call 105 in the event of a power outage to seek information on likely restoration timelines. Analysis of the volume of calls to the 105 helpline provides a useful indicator of the scale of customer impact across the DNOs and the timeframe for disruption to power supplies with calls dropping off dramatically post 6pm.

DNO	SSEPD	ENW	SPEN	NPG	UKPN	WPD	TOTAL
TIME							
16:00	265	473	632	1,008	1,030	2,074	5,482
17:00	1,140	2,643	2,699	5,292	6,341	15,151	33,266
18:00	81	64	75	238	200	162	820

Table 9 - Calls received by the 6 largest DNOs, during the period 4pm to 7pm on 9th August

7. Report Findings

- At 16:52:33 on Friday 09 August 2019 there was a lightning strike on the Eaton Socon – Wymondley 400kV line. This was one of several lightning strikes that hit the transmission system on the day, but this was the only one to have a significant impact.
- 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.
- Two almost simultaneous unexpected power losses – at the Hornsea off-shore wind farm (737MW) and the steam turbine at the Little Barford gas-fired power station (244MW) – occurred independently of one another, but coincident with the lightning strike. As this generation would not be expected to trip off or de-load in response to a lightning strike, this represents an extremely rare and unexpected event.
- The lightning strike also initiated the operation of Vector Shift protection resulting in the tripping of approximately 150MW of embedded generation.
- These events resulted in a cumulative level of power loss greater than the level required to be secured by the Security Standards (1,000MW based on the largest infeed at the time), and as such a large frequency drop outside the normal range occurred.
- The frequency drop caused the further tripping of approximately 350MW of embedded generation on Rate of Change of Frequency (RoCoF) protection.
- Levels of embedded generation tripping due to RoCoF and vector shift were broadly in line with what was expected.
- The total loss of generation at this point was 1,481MW, nevertheless the frequency fall was arrested at 49.1Hz and began to recover as all the response and reserve available was deployed.
- However, one of the gas turbines at Little Barford then unexpectedly tripped from 210MW bringing the cumulative loss of generation to 1,691MW[3]. There were no further reserves left and the frequency fell to 48.8Hz.
- The LFDD scheme was correctly triggered at 48.8Hz and automatically disconnected c.1.1m customers (c. 1GW).
- The disconnection of demand, coupled with the response and reserve in place along with further dispatch of fast acting plant by ENCC, enabled the frequency return to 50Hz within 5 minutes and the system to be sufficiently stable and secure to enable ENCC to permit the re-connection of demand within 15 minutes.
- Reserve providers in aggregate delivered approximately 90% of contracted levels. While this is broadly in line with our modelling assumptions, there were variations across the portfolio and there will be specific follow-up with any provider who fell short of their contracted position.
- The DNO's quickly restored supplies within 40 minutes once the system was in a stable and secure position.
- Several critical loads were affected for a longer duration by the action of their own systems, in particularly rail services.
- The ESO contacted BEIS at 17:40 and Ofgem at 18:00. The initial media statement by the ESO issued at 18:27 with a subsequent statement at 20:06 and a video from the Head of National Control being posted at 20:11.
- The disruption to rail services extended through Friday evening and into Saturday morning due to the fact that approximately 30 trains stopped operating and could not be restarted following the original frequency drop to 49Hz. Restarting them required a technician with a laptop to attend each train which took some time. With these trains stopped on the tracks there were severe delays across the rail network.

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[3] The second Gas Turbine at Little Barford tripped from 187MW after the initiation of LFDD bringing total generation lost through the event to 1,878MW. The effect of this second GT trip was absorbed by the action of LFDD and the additional plant dispatched by the ENCC.

- Based on our analysis we have identified the following areas where lessons can be learned:
    - Communication processes and protocols, in particular during the first hour, should be reviewed to support timely and effective communication in any future event;
    - The list of facilities connected to the LFDD scheme should be reviewed to ensure no critical infrastructure or services are inadvertently placed at undue risk of disconnection; and
    - The settings on the internal protection systems on electric trains should be reviewed to ensure they can continue to operate through ‘normal’ disturbances on the electricity system.

8. Conclusions and Next Steps

System Resilience Standards

Two almost simultaneous unexpected power losses at Hornsea and Little Barford occurred independently of one another but each coincident with a lightning strike. This caused a significant loss of power from the grid and represented an event beyond the standards to which the system is normally secured.

The scale of generation loss exceeded the normal automatic protection systems and reserve holdings and resulted in automatic disconnection of 1GW of demand in order to preserve the system (and allow supply to continue for the remaining 28GW of demand). These systems worked in line with their design to protect as much electricity demand as possible. However, there was significant knock-on disruption from the event (see conclusion on rail services below) and to other critical infrastructure.

Recommended Action: *Review the security standards (SQSS) to determine whether it would be appropriate to provide for higher levels of resilience in the electricity system. This should be done in a structured way to ensure a proper balancing risks and costs.*

Rail Services and Critical Infrastructure

It would appear that the major transport infrastructure impacts were caused by unexpected operation of individual train protection systems (and not LFDD) which resulted in a number of trains north of London stopping. A proportion of these stopped trains had a very slow restart process, leading to significant congestion and delays in stations and the rail network serving routes north out of London. It was this unexpected operation of train protection and slow restart which appears to have caused the major transport impacts.

Recommended Action: *Assess whether it would be appropriate to establish standards for critical infrastructure and services setting out the range of events and conditions on the electricity system that their internal systems should be designed to cater for.*

Embedded Generation

During the event, approximately 500MW of embedded generation tripped on Loss of Mains protection (vector shift and Rate of Change of Frequency). The ESO has recently initiated a three-year programme to change this protection across the many thousand embedded generation facilities to ensure it does not trip in such circumstances.

Recommended Action: *Review the timescales for delivery of the Accelerated Loss of Mains Change Programme to reduce the risk of inadvertent tripping and disconnection of embedded generation, as GB moves to ever increasing levels of embedded generation.*

Communications

Communication during such an event, to the public and key parties such as BEIS and Ofgem, particularly in the first hour is critical. Although the immediate electrical event was over within an hour, the communications arrangements in place should be improved to help ensure a clear understanding of the event is communicated to all parties.

Recommended Action: *In addition to the changes in its first-hour communications processes that the ESO has initiated, there should also be a wider industry review, including BEIS, Ofgem, the ENA and other stakeholders to establish new and enduring communication arrangements for similar events.*

Recommendations made should be considered by BEIS, Ofgem and wider industry in the context both of the findings in this report and those of the other reviews underway, including those being undertaken by Ofgem and the Energy Emergencies Executive Committee (E3C).

9. Glossary of Terms

- **Active Network Management (ANM):** This is a term used to describe control systems that manage generation and load to keep system parameters such as voltage and frequency within predetermined limits. This is usually through an automated system.
- **Balancing Mechanism Unit (BMU):** A BM unit is a grouping of generation and / or demand that trades within the balancing mechanism, altering the flows onto or off the National Electricity Transmission System (NETS), in order to maintain system balance in real time.
- **Non BMU:** If a company supplies a balancing service to the Electricity System Operator but isn't registered as a BMU then they are classified as a Non Balancing Mechanism (non-BM) unit. These providers tend to be smaller generators / demand turn down sources.
- **Connection and Use of System Code (CUSC):** This code is the contractual framework for connection to, and use of, the National Electricity Transmission System (NETS).
- **Combined Cycle Gas Turbine (CCGT):** A common term to describe modern gas fired power stations which combines gas turbines with a steam turbine, to optimise output.
- **Distribution Network Operators (DNOs):** 14 licensed Distribution Network Operators (DNOs) carry the energy generated by power stations and transmitted through the network to their regional distribution services area.
- **Distributed Generation:** Distributed generation (often referred to as embedded or dispersed generation) is electricity generating plant that is connected to a distribution network rather than the transmission network and includes: Combined Heat and Power (CHP) plants, wind farms, hydroelectric power, or one of the new smaller generation technologies.
- **Dynamic Reactive Compensator (DRC):** A device used to provide reactive power and voltage control capability which can respond automatically to changes in system voltage
- **Energy Emergencies Executive Committee (E3C):** The E3C is the principal forum for identifying both the risks and mitigating processes and actions necessary to manage the impact of emergencies affecting the supply of gas and/or electricity to consumers in Great Britain. The Secretary of State for Business, Energy and Industrial Strategy has commissioned the E3C to undertake a review of the events of 9th August.
- **Electricity System Operator (ESO)** As system operator, ESO ensures the flow of energy around Great Britain, monitors the supply of energy provided by powers stations, and instructs generators in order balance demand and supply one second by second basis. The ESO can take preventive actions to ensure the protection of critical assets but does not own power station infrastructure and is not responsible for their maintenance.
- **Energy Networks Association (ENA):** The ENA is a trade association who represents regulated gas and electricity network owners as well as the Electricity System Operator.
- **Electricity Network Control Centre (ENCC):** The Electricity National Control Centre is responsible for the real time operation of the Great Britain (GB) power system. The control room balances demand for energy with supply from generators on a second by second basis.
- **Firm Frequency Response (FFR):** This is a commercial provision of frequency response. It can either be primary response (delivers within 10 seconds) or secondary response (delivers within 30 seconds). This response can also be dynamic (continuously provided service to manage the normal fluctuations in the frequency) or static (a discrete capability delivered at a specific frequency set point).
- **Mandatory Frequency Response (MFR):** As a condition of their licence, generators are obliged to comply with the Grid Code, which stipulates that they need to provide mandatory frequency response.
- **Grid Code:** The Grid Code specifies technical requirements for connection to, and use of, the NETS. Compliance with the code is a requirement under the CUSC.

- **Infeed Loss (Normal):** This is the volume of Megawatts that the system is secured against for the instantaneous loss of generation on the system which is calculated to make sure that the maximum frequency deviation should not exceed 0.5Hz.
- **Infeed Loss (Infrequent):** Securing against an infrequent infeed loss of generation, is set at a level so that frequency should not deviate outside the range of 49.5Hz to 50.5Hz for more than 60 seconds. The current maximum upper limit for an infrequent infeed loss risk is 1800MW.
- **Independent Distribution Network Operator (iDNOs):** These organisations develop, operate and maintain local electricity distribution networks which are directly connected into the Distributed Network Operator (DNO) networks.
- **Low Frequency Demand Disconnection (LFDD):** The electricity system operator has the ability through Grid Code Operating Code No.6 ("OC6") to instruct demand controls in instances where Voltage Reduction (VR) or Demand Disconnection (DD) is required to balance energy running through the system. There are several reasons why the ESO would instruct this action, including ensuring overall integrity of the NETS during major system disturbances. The Low Frequency Demand Disconnection is an automatic back-up system for exceptional events. It is set up in agreement with the ESO by DNOs to reduce their demand in 5% stages of total demand (up to 40% available) to help reduce the fall in frequency in the event of losses in generation or interconnector infeeds.
- **Loss of mains (LOM):** Small generators connected to the distribution network, have protection relays installed to safely stop generating when it is detected that they are no longer connected to the main electricity system. These relays will detect loss by either monitoring the rate of change of frequency or the change in voltage phase angle.
- **National Electricity Transmission System (NETS):** This is the system consisting of high voltage electricity lines owned or operated by the three transmission licensees within Great Britain. The term also encapsulates a number of offshore transmission lines.
- **Offshore Transmission Owners (OFTOs):** operate and maintain electrical transmission assets. In some cases, they also design and build these assets. In other cases, Generators design and build the electrical transmission assets and then transfer them to OFTOs at constructions completion.
- **RoCoF:** This stands for Rate of Change of Frequency. These relays are intended to protect embedded generators against a loss of mains. These relays disconnect the generators if the RoCoF is greater than 0.125Hz/s, disconnecting them from the system safely.
- **Security and Quality of Supply Standards (SQSS)**. The Security and Quality of Supply Standards set out criteria and the methodology for planning and operating the National Electricity Transmission System (NETS).
- **System Operator – Transmission Owner Code (STC):** This code regulates the relationship and specifies the operational procedures between the System Operator and Transmission Operators.
- **Transmission Operator (TO):** The UK power network consists of three onshore Transmission Operators (TOs): National Grid Electricity Transmission Plc (NGET) (England, Wales), Scottish Power Transmission Limited (southern Scotland) and Scottish Hydro Electric Transmission Plc (northern Scotland, Scottish islands groups). Transmission operators maintain, operate and develop the core electrical transmission infrastructure used to transmit electricity around Britain.
- **Vector Shift:** This is another 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.

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