# Lessons Learned after British Power Disruptions

Why improbable combinations of events do happen

## A harmless stroke of lightning on a transmission line

At 16:52 on 09 August 2019, a lightning strike occurred on a transmission circuit (the Eaton Socon – Wymondley Main). All plants and facilities connected to the transmission system should be able to continue normal operation after this type of events.

Nevertheless, some unexpected events followed the lightning:

- Hornsea offshore windfarm reduced its energy supply to the grid by 737 MW.
- Little Barford power station's steam turbine tripped reducing its energy supply to the grid by 244 MW.
- Embedded generation was reduced by approximately 500 MW.
- Approximately 60 trains in the Southeast area shut down due to their internal protection systems being triggered.

Immediate consequences: 1.1 million electricity customers were without power for between 15 and 45 minutes and thousands of train passengers were affected by the disturbed train service for hours.

Such events are unavoidable. They give the electricity industry opportunities to examine if power stations and trains live up to the grid code and to individual specifications. The accumulated outcome will be more robust power systems.

## Course of events

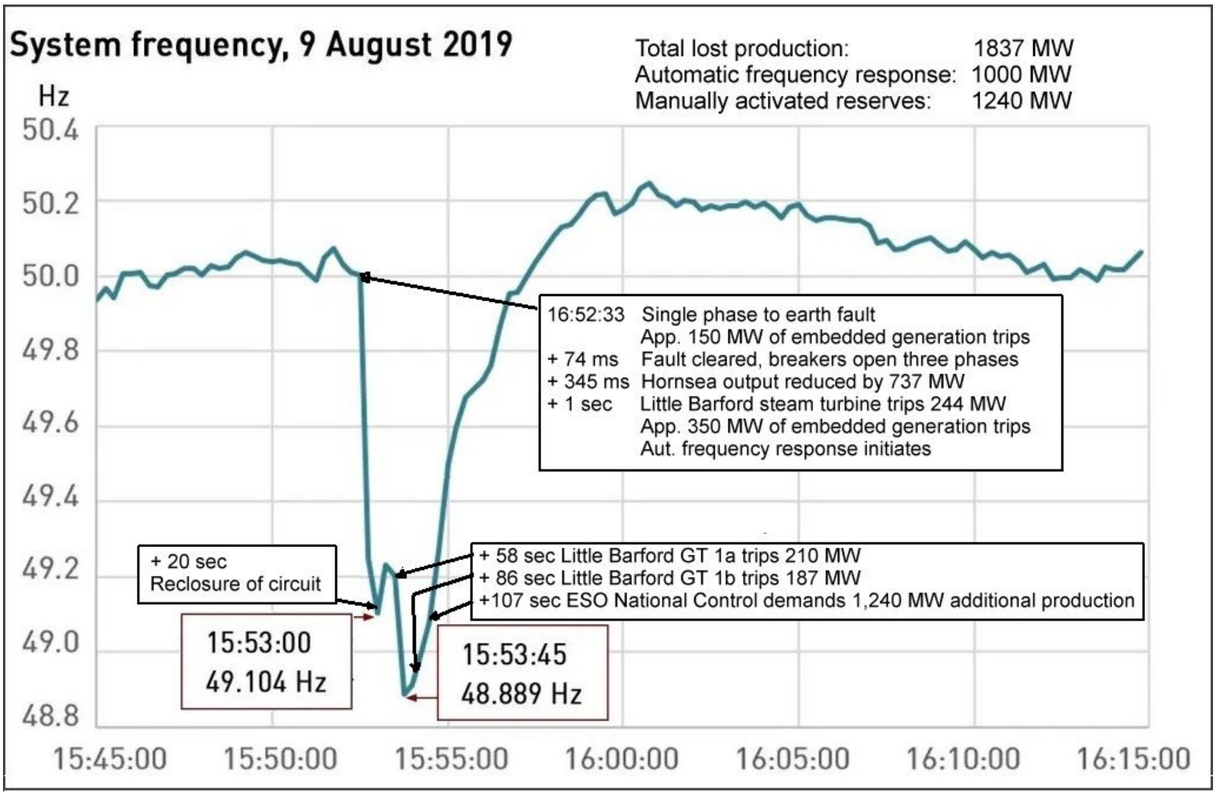


*Fig. 1 - Frequency diagram with selected events*

See further details in the technical report from NG ESO[1].

My observations:

- NG ESO seems to have handled the situation “by the book”.
- The NG protection systems worked as intended.
- Low frequency demand disconnection (LFDD) worked as intended.
- After the single-phase fault, the circuit was opened for all three phases, and reclosure was delayed for 20 seconds. This concept is reasonable for a highly meshed network, where the loss of a single line cannot disturb the stability of the system. In Denmark, a single-phase reclosure is attempted within a second.

## Voltages within fault-ride-through requirements

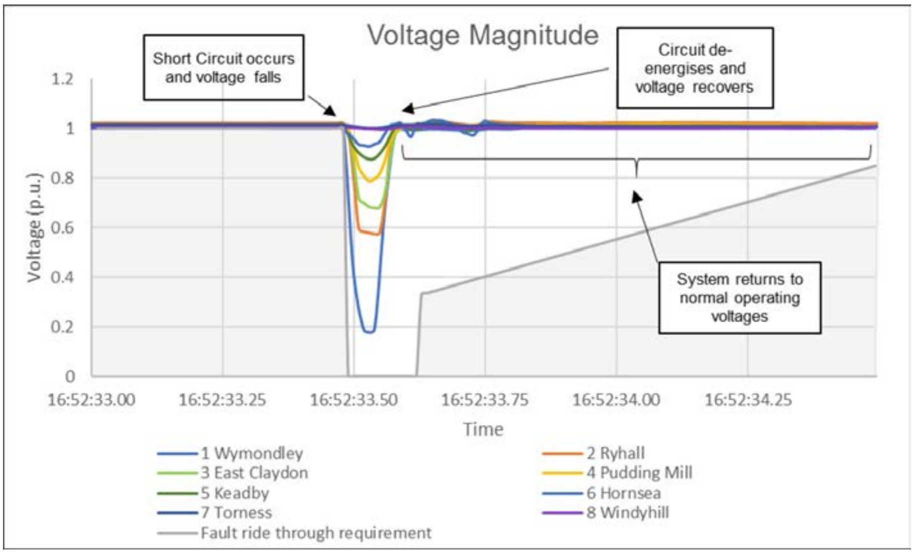


*Fig. 2 - Single phase voltage profile at various locations*

Fig. 2 shows voltages on the “blue” phase at the time of fault on the Eaton Socon-Wymondley overhead line. The Little Barford power station is connected between the Wymondley (1) and Ryhall (2) substations. The connection point of the Hornsea offshore windfarm is number 6, where the voltage dip was less than 10%.

All recorded voltage dips are well within the fault-ride-through (FRT) requirements (see the profile in fig. 2). Therefore, the voltage dips during the fault cannot justify tripping of any production unit.

## Unexpected events

### Hornsea offshore windfarm lost 737 MW

Prior to the lightning strike, Ørsted’s Hornsea offshore windfarm produced 799 MW.

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. Undamped swings in active and reactive power (about 8 Hz) began. Most of the wind turbines shut down and output stabilized at 62 MW.

[1] National Grid Electricity System Operator: Technical Report on the events of 9 August 2019, 6 September 2019

The resonance problem was detected before the event on 9 August as the response to a voltage variation, but as a damped oscillation, and Ørsted had agreed with the manufacturer on an update of the control system software for the wind turbines. The update was made on 10 August

**Little Barford CCGT power station lost 641 MW.**
Little Barford owned by RWE is a 740 MW CCGT. 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.

This explanation is rather diffuse.

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.

**Approximately 500 MW embedded generation lost**
According to Danish experience, parts of the embedded generation can be vulnerable to irregularities on the grid. The protection systems are set correspondingly in order to prevent engine damage.

Some parts of the British system may have experienced a RoCoF[2] of 0.125Hz/s or above and/or a Vector Shift exceeding 6º, which is likely to have led to RoCoF and/or Vector Shift events.

It is estimated that approximately 150MW of embedded generation was lost due to Vector Shift protection and approximately 350MW due to RoCoF.

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

**Irregular train service for hours**
No track supplies were lost due to LFDD protection operation. There were supply related trips, which occurred at two DC traction locations, which Network Rail are investigating further.

Class 700 and 717 trains north of Farringdon and Kings Cross stations, which were operating on AC power, suffered a protective shutdown when the frequency deviation fell below 49Hz. 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.

[2] RoCoF: Rate of Change of Frequency

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 about 10 minutes. The remaining 30 trains required a technician to attend each train with a laptop to reset the trains.

Govia Thameslink Railway 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. All other classes of train were unaffected.

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.


*Fig. 3 - British DNO areas*

## Low frequency demand disconnection (LFDD)

The automatic frequency response is managed by the DNOs[3]. Each DNO has equipped certain demands blocks with LFDD relays, which disconnect load in a number of steps depending on frequency.

On 9 August, a total of 931 MW was disconnected affecting 1,152,878 consumers. The contribution from the London area was 174 MW affecting 239,861 consumers.

The restoration procedures began at 16:56 and ended at 17:37 (table 2).

| | DNO Areas | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SSE | SPED | ENW | NPG North East | NPG Yorkshire | UKPN SPN | UKPN EPN | UKPN LPN | WPD South West | WPD South Wales | WPD West Midland | WPD East Midland |
| When was ESO informed demand loss | 17:01 | 17:01 | 17:01 | 17:01 | 17:01 | 17:04 | 17:04 | 16:58 | 16:56 | | 17:02 | 16:57 |
| When did ESO instruct restoration | 17:06 | 17:13 | 17:10 | 17:08 | 17:10 | 17:13 | 17:14 | 16:58 | 17:08 | | 17:05 | 17:16 |
| When did restoration complete | 17:07 | 17:17 | 17:17 | 17:18 | 17:12 | 17:37 | | | 17:30 | | | |

*Table 1 – Restoration process by DNO*

## Why improbable combinations of events do happen

Immediate after the incident, national Grid ESO called it “a rare and unusual event, the almost simultaneous loss of two large generators”.

The report supports the view that a single initiating event, the lightning strike, caused all the disturbing consequences on 9 August.

[3] DNO: Distribution Network Operator

It is interesting that **immature software** in new installations has been identified as a common cause for two of the four unexpected events, discussed in this note:

- Tripping of the Hornsea offshore windfarm
- Shutdown of a class of train units.

Ørsted has updated the control software of the wind turbines in order to improve the damping of oscillations in the local offshore grid.

Siemens are developing improved software for the trains.

Software for control of new installations will still more complex. Real operation is the most efficient test environment. Therefore, security standards should consider possible software problem, particularly when identical units are installed in large numbers.

It is unclear from the report why the Little Barford steam turbine tripped.

For embedded generation the distribution code allows for historical reasons a RoCoF setting of 0.125 Hz/second and a Vector Shift setting at 6 degrees. These values may have been exceeded on 9 August. A certain loss of embedded generation will probably always follow severe system faults.

The result of increasing shares of wind and solar power will be decreasing short circuit capacities and rotating inertia. This will in turn lead to more rapid frequency changes and less stable voltage vectors and it can be necessary to install stabilizing units, such as synchronous compensators.

The conclusion is that improbable events do happen. Such events offer useful opportunities to improve system stability and robustness.