GB LOAD LOSS ON 9 AUGUST 2019

A note from Pöyry Management Consulting

23 August 2019

Introduction and summary

On 9th August, from around 4:54 pm, there were power cuts in Great Britain, affecting around 1GW (5%) of demand. This loss of load was the automated response to a low frequency incident (in which the system frequency fell to 48.9Hz or less), as a consequence of the near simultaneous tripping of two power stations, "each associated with[1]" a significant lightning strike on a transmission circuit. 1,378MW of transmission connected generation was lost due to these generator trips, alongside around 500MW of embedded generation, exceeding the 1,000MW of back-up reserves held by National Grid, and necessitating the interruption of demand to restore the system frequency to 50Hz.

In this short note we look at what led to this incident, and some early implications.

It should be emphasised that the demand interruption was the result of the system working as intended, not a failure, with the interruption designed to prevent a much larger and less controllable interruption. However, the way some demand responded to the frequency drop and the inability of some railway systems to restart once power/frequency was restored exacerbated the impact of the initial outage.

Lightning strikes should not result in the near simultaneous tripping of two transmission-connected power stations. Whether these trips were independent or related to one-another; and whether they were due to faulty equipment; incorrect settings or procedural errors is to be fully investigated in connection under various reviews being undertaken by National Grid ESO; the regulator, Ofgem; and BEIS, the relevant government department. On the issue of independence there are preliminary conclusions in the interim National Grid report.

Key issues to be addressed

A number of key issues will need to be addressed in response to this incident:

- Were the generation failures independent or not?
- Does the loss of 500MW of distributed generation in this incident have wider implications for our increasing distributed generation mix?
- Were the large generators which failed operating according to the Grid Code requirements?
- Will National Grid need to adapt its reserve protocols to maintain the future system?
- Some of the post-fault balancing actions instructed by National Grid were not delivered reliably and will require investigation.
- The low frequency demand disconnection appeared to work correctly but inevitably there will be a review of the protocols for reprioritising some users.

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[1] National Grid ESO's choice of words.

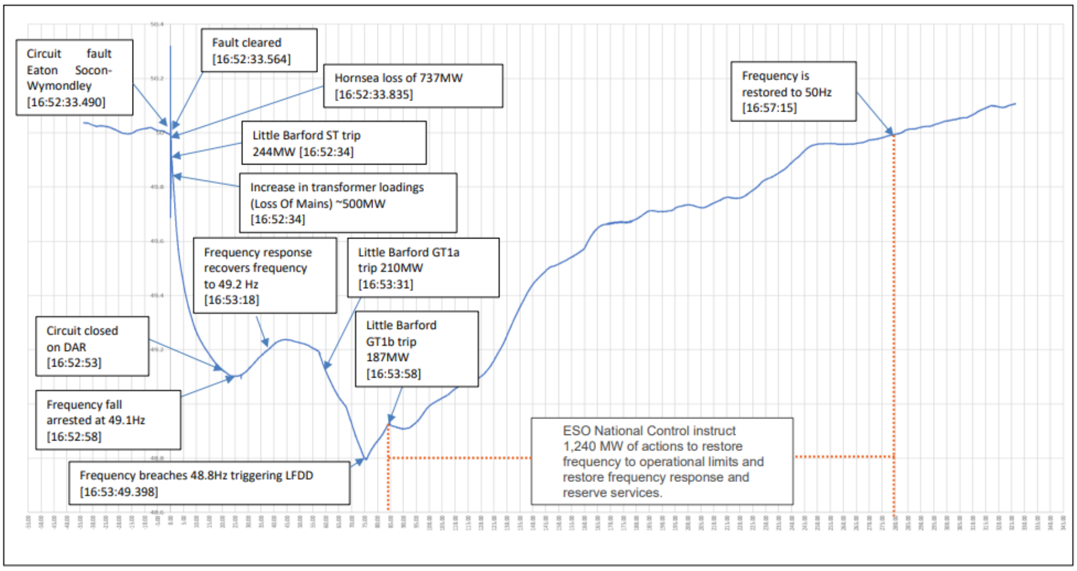
- Why was the rail infrastructure unable to restart once power/frequency was restored to the grid? Should the assets which shut themselves down due to frequency issues have done so?
- What changes will be required to back-up supplies at critical infrastructure and/or should National Grid carry for reserve provision.

Cause of frequency drop

On 16th August National Grid submitted their interim report[2] on the Low Frequency Demand Disconnection (LFDD) incident to Ofgem, and this was made public on 20th August. The report describes three near-simultaneous outages, linked directly or indirectly (yet to be determined) to lightning strikes:

1. Protection systems at Hornsea (largely) shut production down in response to voltage issues caused by the lightning and consequent circuit faults, leading to a loss of 787MW. National Grid's report implies that this response was incorrect and that the protection settings have subsequently been altered so that it would continue operate in similar circumstances.
2. The loss of Little Barford Gas Power Station's 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 85 seconds.
3. The loss of 500MW of embedded generation (labelled as "Increase in transformer loadings" in the chart) due to disturbance caused by lightning. This was an expected response to lightning.

Figure 1 – Evolution of system frequency during and around the incident



Source: National Grid[2]

2 Interim Report into the Low Frequency Demand Disconnection (LFDD) following Generator Trips and Frequency Excursion on 9 Aug 2019. National Grid ESO, 16 August 2019. https://www.nationalgrideso.com/document/151081/download

The combined loss of around 1.9GW of generation exceeded the 1,000MW of reserve held by National Grid and the tools it had at its disposal to arrest the fall in the system frequency, including 472MW of batteries. The power cuts were automatically triggered by the LFDD (Low Frequency Demand Disconnection relays) once the frequency fell to 48.8Hz – overall this worked as intended. While the total loss of was around 1.9GW, the second GT of Little Barford tripped after the LFDD was triggered, so in reality the loss which triggered the LFDD was around 1.7GW.

The frequency was restored to 50Hz within 5 minutes of the incident and demand restoration was started within 13 minutes of interruption and fully completed within 44 minutes.

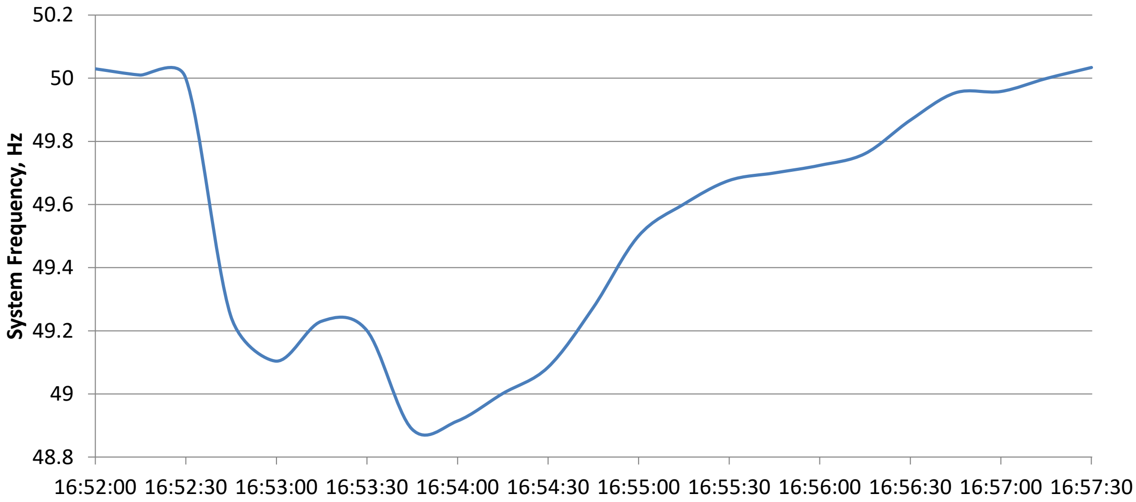
The SO generally only holds enough instantaneous frequency response to meet the loss of the largest single in-feed onto the transmission system – generally the 1200 MW Sizewell B. The situation on 9th August may have been made worse by Sizewell B not outputting at full capacity at the time. As a consequence there only needed to be enough frequency response capability for an outage of around 1GW, with BritNed being the largest infeed at about 950MW, though more provision may have just delayed the LFDD triggering, perhaps to after the 2nd GT at Little Barford tripped.

Fake news and misrepresentation

In the days following the event there was a lot of speculation about the incident, much of it badly informed, based on the frequency chart below, with only 15 second resolution. After the load loss it was quickly apparent that the drop in frequency was caused by outages at Little Barford, a gas CCGT and Hornsea, an offshore wind farm. It was initially understood that Little Barford had the first outage, followed by Hornsea around 1 minute later, based on the apparent double dip. This was not a full explanation, as Little Barford alone would not have been enough to reduce the frequency to 49.1Hz[3], and more of a recovery in frequency would have been expected before the second outage.

[3] The statutory minimum for events covered by frequency response, such as the outage of one large unit is 49.5Hz, and Little Barford was not the largest infeed at the time, the largest infeed was BritNed at about 950MW.

Figure 2 – Evolution of system frequency with 15 second resolution



Source: Pöyry Analysis, BMReports[4]

Many early reports on the power cuts suggested a possible cause to be the falling levels of system inertia caused by increasing penetration of wind and solar (and to a lesser extent falling demand and increasing imports). System inertia is discussed further in the Annex to this note.

Did the frequency control work as it is designed to?

Based on the National Grid report the system (beyond the power stations themselves) seems to have largely worked as intended, with frequency response being utilised relatively quickly with the aim of containing the frequency drop, though there may be some scope for small improvements, as it was noticeable that the BM providers (who are typically larger) had a better response rate than the non-BM (typically smaller) providers, though 100% response rates would not be expected. The ~24% failure rate for non-balancing mechanism units raises the question as to the sophistication of some smaller players providing critical grid services (in comparison to ~4% non-delivery for BMUs). The discrepancy in reliability of 20 percentage points could put upwards pressure on balancing service provision and consequently costs.

4 https://www.bmreports.com

Figure 3 – Holding and delivery of low frequency response

Frequency Response Type			Number of Units	Low Frequency	Low Frequency Delivered
Dynamic	Primary / High	BM	8	284	266
	Primary / High	NBM	36	280	231
	Enhanced Frequency Response	NBM	10	227	165
Static	Triggered at 49.7 Hz, delivered within 30 seconds	BM		0	-
		NBM	19	285	198
	Triggered at 49.6 Hz, delivered within 1 second	BM	2	200	200
		NBM	7	31	30

Source: National Grid[5]

More background to how frequency response is procured can be found in the Annex later in this note. Here there was 85 seconds between the outages and the LFDD being triggered, so the frequency response was fast enough, there simply wasn't enough to cope with a 1.7 GW outage. Whether it would have been possible to bring on any more generation not providing frequency response in these 85 seconds (particularly pumped storage and any batteries not providing frequency response) isn't clear.

5 https://www.nationalgrideso.com/document/151081/download

What were the consequences of the load loss?

Although power was restored in well under an hour, there was significant disruption caused, including 1.1 million customers without power:

- Ipswich hospital tried to switch to backup generators after detecting a dip in frequency (i.e. they disconnected themselves), but batteries involved in the switchover failed.
- Some Govia Thameslink trains also tripped themselves due to the drop in frequency. In some cases drivers were unable to start them, and technicians had to be called to restart them manually, causing long delays in resumption of journeys.
- There were frequency related trips at two locations on the rail network which National Grid is investigating.
- Newcastle Airport lost power supplies for 18 minutes, though standby generators ensured sufficient power for essential services. This was as a result of the LFDD operation. Northern Powergrid has subsequently received a request from the airport to be a protected site, and this has been granted.

Should this be a concern going forward?

If the two outages were entirely independent, having two outages near simultaneously is a very rare event, perhaps 1 in 30 years (with a gap of 10-20 seconds). However, in this case the outages appear not to be independent (in the statistical rather than regulatory sense – in that they had a common cause). It is hard to assess the probability of such an event, though the lack of similar events in recent years suggests it must be low. Additionally Hornsea (which has not yet officially commissioned) did not respond to the voltage issues as it was intended to, and it isn't clear whether Little Barford was correct to shut down.

Some commentators have suggested frequency response provision should be increased, beyond/earlier than that needed for Hinkley Point C, and there should be more provision from batteries (though provision from batteries is growing anyway). While this may reduce the probability of a similar incident in the future, it would not be cost effective to spend over £1bn (albeit over several years), if these sorts of events are 1 in 10 years. There is a need to ensure that any costly decisions are based on detailed analysis. National Grid will also need to consider if some of the slower forms of response, such as static response triggered 30 seconds after the frequency drops below 49.7Hz remain adequate in the future, but that timescale was easily quick enough for this incident.

Key questions to be answered

National Grid ESO has issued an interim technical report[6] into the events, but a number of key issues are still open:

- Were the generation failures independent or not (in the regulatory sense – meaning did the outage of one plant or set of plants cause the others)? National Grid is expected to hold reserve cover for a single incident but not the independent occurrence of separate incidents (in this case three losses: 737 MW at Hornsea, 641MW at Little Barford, and around 500MW of distributed generation). If the events were indeed connected, then National Grid's reserve dimensioning policy will need re-

6 https://www.nationalgrideso.com/document/151081/download

examination. Any two of the above generation losses would have exceeded the 1000MW largest infeed loss that the system was secured against at the time. The National Grid report states that the outages were independent, though this is described as a preliminary conclusion.

- The loss of about 500MW of embedded generation is notable (especially given that it was 5PM with moderate output from solar, around 3GW, somewhat lower than a few hours earlier): how well does NG understand the make-up of distributed generation, and provide reserve cover for the potentially higher loss on other occasions? How much of the 13GW of installed PV capacity (peak output) and other embedded generation is vulnerable to similar disturbances (noting that the loss of embedded generation is also thought to be voltage related, and voltage issues are extremely unlikely to simultaneously effect the whole country)? Are these installations operating according to the required standards, and are these standards adequate for the future?
- Did the large generators which failed operate according to Grid Code requirements? National Grid reports that there has been some 'fine tuning' of controls at Little Barford but it isn't clear whether their operation at the time was in accordance with requirements.
- A wider question is how National Grid will adapt its reserve protocols to be able to maintain the system in future as inertia drops[7] and (in time) the largest infeed increases with Hinckley Point? Certainly, the frequency seems to have fall faster than on previous occasions and this is a growing challenge as large power plants which provide inertia are replaced by generation which is not synchronously connected. Balancing actions to manage inertia are increasing and National Grid is continuing to develop new products and services from non-conventional sources. This is discussed further in the Annex, including actions National Grid is already taking.
- Some of the instructed balancing actions post-fault were not delivered reliably. This will certainly trigger investigation.
- The low frequency demand disconnection appeared to work correctly but inevitably there will be a review of the protocols. Newcastle Airport has now gained 'protected' status against similar incidents, although we consider this a red herring: the vast majority of outages relate to location-specific distribution faults, and such installations still need working backup procedures.
- The consequential impact on the railway network, with trains stranded for several hours and needing track-side visits by engineers before they could re-start as well as signalling problems, will certainly lead to changes in protocol. However, the various reviews will need to establish whether this is an electricity industry or rail industry issue.
- Contingency backup supplies are necessary for critical infrastructure. A knee-jerk reaction to the events would be to demand that National Grid should increase costly reserve provisioning, for which all customers would pay. A more sensible response is to ensure that the protection systems and safety protocols are working correctly, and for customers who depend on reliable electricity to have robust procedures for the very rare occasions when the power system fails to deliver.

7 Further details are in the Annex.

- There must definitely be scrutiny of the reserve holding and dispatching policy by National Grid, the protection settings of the generators which failed and of the performance of the balancing service providers entrusted with restoring the system frequency. However, nothing is 100% reliable, and by focusing on the most rare events it would be easy to spend large sums of customers' money while neglecting the more common causes of loss of supply.

ANNEX: FURTHER INFORMATION

The effect of falling system inertia

Inertia is primarily provided by synchronous spinning generation, which in GB is Nuclear, CCGTs, biomass, coal, and (in some cases) pumped storage and hydro. However, in this case the system inertia was not particularly low; around the time of the outage thermal plant (nuclear, CCGT, Biomass and coal) were generating 16.6GW, whereas at 3:00 pm on the 17th August, when both wind and solar output were high, the thermal output was only 9.3GW. The effect of inertia is to slow the rate at which system frequency changes. If the frequency falls too quickly then embedded generation can trip, making the situation worse. National Grid currently tries to have enough inertia to keep the Rate of Change of Frequency (ROCOF) below 0.125Hz/s, though a lot of the embedded generation can now withstand faster changes in frequency. That said, the initial loss of about 1.5GW of generation does appear to have caused the frequency to drop at more than 0.125Hz/s, though there is nothing in the National Grid report to suggest this caused any further outages.

In periods with low Inertia one method National Grid employs to manage the ROCOF risk is to decrease the size of larger in-feeds[8], for example by reducing the imports on the interconnectors, which also creates room to bring on more thermal plants. If the same sequence of events had occurred in a period with lower inertia, the drop in frequency would have been quicker; perhaps causing ROCOF relates outages of embedded generation. However, National Grid is currently working to increase the maximum ROCOF the system can cope with, and much of the embedded generation above 5MW can now handle larger ROCOFs, so this may not be as big an issue going forward as some have made out.

The largest infeed will increase with the commissioning of Hinkley Point C, which will offset some of the benefit of the change in ROCOF, albeit the additional reserve would also limit the risk of black outs caused by near simultaneous outages of multiple units, such as here.

Going forward, in the 2030s low inertia may be more of an issue when renewable output is high if there is less nuclear and (to a lesser extent) biomass on the system, though there are technologies such as synchronous condensers or flywheels that can provide inertia without generating and other ultra-fast response technologies which might substitute for true inertia.

Background: Frequency response procurement

In Great Britain frequency response is provided from a range of sources and procurement methodologies. Frequency response is split into dynamic and static provision. For dynamic provision, provision is dependent on the system frequency (roughly speaking, increasing linearly with the deviation from 50Hz, until full provision is reached) though there is only a small deadband). Static providers are more binary, being fully triggered at a particularly frequency.

[8] For this purpose Sizewell B is counted as 2 units.

Dynamic provision is from a mixture of sources, but is primarily from batteries, pumped storage and part-loaded thermal plant, though there is also increasing provision from wind. Static providers include reciprocating engines and demand side management.

There are a number of procurement methodologies:

4 year contracts – Enhanced Frequency response

This was a tender to procure fast-acting frequency response that could be activated with a second of a drop (or increase) in frequency. This is entirely provided by batteries. This service has been discontinued for new participants.

Firm frequency response

These are shorter contracts, with the response procured in advance, through pay-as-bid tenders. Historically the duration has been one month to 2 years (sometimes only covering certain parts of the day), though now shorter term contracts are available. This is open to both BM and non-BM generators. The dynamic part of the latter is also mainly batteries.

Static provision is also through firm frequency response.

Mandatory Frequency response

Any residual requirement for dynamic response can be procured by National Grid positioning units in the balancing mechanism. Units would typically be paid (or pay, if it reduces their fuel consumption) for their output level being moved, if necessary, and then a price for frequency response, which the generators can set themselves – those that set a high price don't tend to be utilised.

Future of frequency response

As part of National Grid ESO's SNAPS (System Needs and Product Strategy) initiative, the fundamental design of services and their procurement is under review. Frequency response is one area currently under review with a number of products expected to be launched replacing the current suite of services:

- **Dynamic regulation (symmetrical service)** – continuous response to compensate for normal frequency fluctuations. The purpose of this product is to keep frequency stable in normal operation of the grid (well within NGESO operational limit of +-0.2hz).
- **Dynamic balancing (symmetrical service)** – activated once frequency deviates outside tight/normal operating limits (0.1hz), very fast response & ramp time (0.5 seconds). The purpose of this product is to support dynamic regulation of frequency when there is a slightly larger mismatch between supply/demand than under normal operating conditions but still within the NGESO operational limit.
- **Dynamic containment (non-symmetrical service)** – Activated once frequency deviates by 0.2hz (relatively rare events, outside of operational limits) with a very fast response & ramp time (0.5s). The purpose of this product is to contain frequency deviations, generally post-fault, with the ability to respond very quickly once a fault is detected.

- **Static containment (non-symmetrical service)** – Activated once frequency passes a given threshold (offered by the participant in the tendering process), generally fast response time (1s). The purpose of this product is to support dynamic containment in the prevention of frequency deviations outside statutory limits (+-0.5hz). Static containment is activated once the system reaches the contracted 'trigger' frequency, these triggers will only be procured for levels outside of operational limits.

For non-symmetrical services, providers can tender for either upwards or downwards response. For symmetrical services, providers must be able to provide the service in both directions.

Frequency response which can respond quickly will become increasingly important when the change in ROCOF discussed previously takes place. For example, if embedded generation could withstand deviations of close to 0.5Hz/s, that means the frequency could drop from 50Hz to 49Hz about 2 seconds, so a sufficient frequency response provision also needs to be able to act within 2 seconds.

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