A Curious Incident of Trains in the Rush Time

on 9 August 2019

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Outline

- How power system security is maintained
- Description of the event
- Should the security standards be reviewed?
- Comparison with other GB and worldwide blackouts
- Conclusions

Main sources:
How to prevent blackouts happening?

• You can NEVER prevent blackouts happening but you can reduce their probability

• Universal rule-of-thumb: (N-1) reliability criterion

• This presentation: only generation, not transmission

• Security and Quality of Supply Standard (SQSS): the system should be secure following a loss of the largest infeed (generation or import)

• Required fast reserve:
  • 1260 MW when Sizewell B operating
  • 1000 MW (the loss of interconnector) when Sizewell B is not running – as on 9 August 2019
  • No extra safety margin – just the loss without any consequent outages

• Reserve activated when frequency is falling indicating power deficit
Load shedding (Low Frequency Demand Disconnection LFDD)

• Last line of defence to prevent a blackout when frequency keeps falling
• Activated in stages
  • pre-planned automatic disconnections spread around the country executed by DNOs
  • Critical infrastructure (hospitals, rail, airports etc) exempted

<table>
<thead>
<tr>
<th>Frequency Hz</th>
<th>% Demand disconnection for each Network Operator in Transmission Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NGET</td>
</tr>
<tr>
<td>48.8</td>
<td>5</td>
</tr>
<tr>
<td>48.75</td>
<td>5</td>
</tr>
<tr>
<td>48.7</td>
<td>10</td>
</tr>
<tr>
<td>48.6</td>
<td>7.5</td>
</tr>
<tr>
<td>48.5</td>
<td>7.5</td>
</tr>
<tr>
<td>48.4</td>
<td>7.5</td>
</tr>
<tr>
<td>48.3</td>
<td></td>
</tr>
<tr>
<td>48.2</td>
<td>7.5</td>
</tr>
<tr>
<td>48.0</td>
<td>5</td>
</tr>
<tr>
<td>47.8</td>
<td>5</td>
</tr>
<tr>
<td>Total % Demand</td>
<td>60</td>
</tr>
</tbody>
</table>
Power System Conditions on 9 August

- Demand: 29 GW
- Transmission-connected generation: 32 GW, comfortable margin
- Wind generation: 30%
- Lightning strikes
Lightning strikes

• A lightning strike hits a transmission line at 16.52 causing a short-circuit
• Nothing unusual – the line tripped after 0.1 sec and reclosed after 20 secs
• The associated voltage and current disturbances as expected, voltage above Fault Ride Through profile
First stage (45 secs): infeed losses

- Lightning strike causes fast voltage phase angle changes
  - Loss of Mains: Vector Shift > 6°: **150 MW loss** of embedded generation – in line with expectations

- Hornsea offshore wind farm
  - Output 799 MW
  - Unexpected large swings in real and reactive power due to incorrect turbine control settings
  - Deloading from 799 MW to 62 MW: **737 MW loss**

- Little Barford CCGT
  - Steam turbine unit trips due to discrepancies in speed signal readings – **244 MW** lost

- Total **1131 MW** loss causes fast frequency changes
  - Loss of Mains: RoCoF > 0.125 Hz/s: **350 MW loss** of embedded generation - in line with expectations

- Total infeed loss 1,481 MW > 1000 MW secured
- Frequency falls quickly prompting release of frequency response
**Delivery of Frequency Response**

<table>
<thead>
<tr>
<th>Service</th>
<th>Provider type</th>
<th>% validated low frequency response delivered at 30 seconds versus Total MW response held</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic – Generation (Mandatory response)</td>
<td>BM</td>
<td>103% of 284 MW</td>
</tr>
<tr>
<td>Dynamic – Firm Frequency Response</td>
<td>BM &amp; Non-BM</td>
<td>74% of 259 MW</td>
</tr>
<tr>
<td>Dynamic – Enhanced Frequency Response</td>
<td>BM &amp; Non-BM</td>
<td>94% of 227 MW</td>
</tr>
<tr>
<td>Static – Firm Frequency Response</td>
<td>Non-BM</td>
<td>0% of 21 MW</td>
</tr>
<tr>
<td>Static – Low Frequency Response through auction</td>
<td>Non-BM</td>
<td>71% of 31 MW</td>
</tr>
<tr>
<td>Static - Interconnectors</td>
<td>BM</td>
<td>100% of 200 MW</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>89% of 1022 MW</td>
</tr>
</tbody>
</table>

**Table 5 – Validated Frequency Response Performance**

- Mandatory Frequency Response (Grid Code obligation) and commercial response contracts with ESO
- Delivery in line with expectations
- Some room for improvement
First 45 secs: frequency fall arrested by frequency response

- Circuit fault Eaton Socon-Wymondley [16:52:33.490]
- Fault cleared [16:52:33.564]
- Hornsea loss of 737MW [16:52:33.835]
- Little Barford ST trip 244MW [16:52:34]
- Increase in transformer loadings (Loss Of Mains) ~500MW [16:52:34]
- Frequency response recovers frequency to 49.2 Hz [16:53:18]
- Circuit closed on DAR [16:52:53]
- Frequency fall arrested at 49.1Hz [16:52:58]
Frequency falls again causing embedded net generation loss when frequency reached 49 Hz: **200 MW** loss on under-frequency protection unexpected.

Little Barford CCGT

Build-up of steam pressure due to a failure of a steam by-pass system

One (out of two) Gas Turbine unit trips due to high steam pressure – **210 MW** lost
Load shedding (LFDD)

- **931 MW** or 3.2% of demand, **1.15M customers**
  - Less than 5% expected but didn’t matter
- Only England and Wales
- Took up to 40 mins to restore supply

<table>
<thead>
<tr>
<th>Reporting DNO</th>
<th>MW of disconnected demand by LFDD</th>
<th>Customers Affected</th>
<th>Final Restoration Time of Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scottish Hydro Electric Power Distribution (SHEPD)</td>
<td>0</td>
<td>23,117</td>
<td>16:59</td>
</tr>
<tr>
<td>Scottish Power (SP)</td>
<td>22</td>
<td>93,081</td>
<td>17:18</td>
</tr>
<tr>
<td>Northern Power Grid (NPG)</td>
<td>North East 76</td>
<td>10,571</td>
<td>17:12</td>
</tr>
<tr>
<td></td>
<td>Yorkshire 14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity North Limited (ENW)</td>
<td>52</td>
<td>66,613</td>
<td>17:17</td>
</tr>
<tr>
<td>SP Marweb</td>
<td>130</td>
<td>74,938</td>
<td>17:15</td>
</tr>
<tr>
<td>Western Power Distribution (WPD)</td>
<td>East Midlands 122</td>
<td>150,445</td>
<td>17:25</td>
</tr>
<tr>
<td></td>
<td>West Midlands 160</td>
<td>187,427</td>
<td>17:37</td>
</tr>
<tr>
<td></td>
<td>South Wales 36</td>
<td>29,060</td>
<td>17:11</td>
</tr>
<tr>
<td></td>
<td>South West 110,273</td>
<td>17:22</td>
<td></td>
</tr>
<tr>
<td>UK Power Networks (UKPN)</td>
<td>Eastern 69</td>
<td>79,390</td>
<td>16:56</td>
</tr>
<tr>
<td></td>
<td>London 174</td>
<td>239,861</td>
<td>17:37</td>
</tr>
<tr>
<td></td>
<td>Southern 69</td>
<td>81,358</td>
<td>17:15</td>
</tr>
<tr>
<td>Scottish Electric Power Distribution (SEPDP)</td>
<td>7</td>
<td>16,744</td>
<td>17:07</td>
</tr>
<tr>
<td>Totals</td>
<td>931</td>
<td>1,152,878</td>
<td>17:37</td>
</tr>
</tbody>
</table>

Table 6 - DNO customers affected by LFDD relays
Last stage: restoration of 50 Hz

Second GT (187 MW) at Little Barford is tripped manually due to high steam pressure
No material consequences

50 Hz restored within 5 mins
Effects on infrastructure: rail

- LFDD did not cut off track supplies
  - But two unexplained trips at DC traction locations
- Main effect: sixty Desiro Class 700 and Class 717 trains tripped when frequency fell below 49 Hz
  - GTR stated that the trains should have operated down to 48.5 Hz
- Half were restarted by the driver within 10 mins but half had to wait for a technician to arrive to restart it with a laptop
- Knock-on effect:
  - 371 train cancelled, 220 part cancelled,
  - London St Pancras and Kings Cross closed for several hours (Friday 5 pm!)
- Disruption continued through Friday evening and into Saturday morning
- Victoria line suspended (internal traction issue)
- Public anger!
Other priority loads affected: minor effects

- Hospitals
  - Ipswich: not affected by LFDD but incorrect protection operation, one of back-up generators failed to start
  - Two other hospitals affected by LFDD but their back-up generators kicked in
- Airports
  - Newcastle disconnected by LFDD – the owners had forgotten to apply for Protected Site status
  - Another one in Midlands, unaffected by LFDD, switched to back up supplies but restoration of some of its systems took 50 mins
- Water
  - 3,000 customers experienced water supply disruptions due to booster water pumping stations failing to switch over to back-up supplies
  - Majority of customers were restored within 30 mins
- Energy: one oil refinery disconnected due to fall in frequency to protect equipment, it took a few weeks to restore operation
Post-mortem analysis and ESO recommendations

• The power system responded largely as expected to a non-secured contingency (> 1000MW)

• Recommendations:
  - SQSS: review system resilience standards to review if it would appropriate to provide for higher levels of resilience
  - Rail services and critical infrastructure: establish standards to ride through a “normal” disturbance
  - Embedded generation: review the timescales of delivery of Accelerated Loss of Mains Change Programme to reduce the risk of inadvertent tripping
  - Improve communications procedures and protocols, especially for the first hour after an event
Comparison with a remarkably similar event in May 2008

• First Longannet and then Sizewell B trip independently
  Total loss 1582 MW > 1320 MW planned

• The resulting frequency drop caused further loss of wind generation

• Frequency dropped below 48.8 Hz triggering LFDD: 581 MW (62% of 2019 event), 580k customers (50% of 2019)

• But no critical infrastructure affected

• Ignored by media
Three significant power cuts in 2003

• All local

• August, south London, 724 MW lost, 410k people + **Tube & Rail at rush hour**
  • Headline news

• September, east Birmingham, 250 MW lost, 220k people.
  • Ignored by media

• October, Cheltenham and Gloucester, 165 MW lost, 100k people.
  • Ignored by media
Do power cuts matter?

- Only if they affect London and critical infrastructure (especially transport in rush hour!)
- But media don’t really care about anything happening north of Watford Gap
Should (N-1) criterion be reviewed?

- Previous similar (N-2) disturbance 11 years ago – maybe (N-1) is appropriate?
- But 2008 was indeed a fluke – was 2019 a fluke too?
- ESO (2019): “...this represents an extremely rare and unexpected event.” I don’t agree - a common mode of failure

- SQSS was developed in the 1990s
  - The system and its equipment well-known, few surprises, “known unknowns”
  - (N-1) was appropriate as indeed two plants tripping at the same time would be very rare

- Last 10 years
  - A lot of new gear on the system: wind (offshore!), solar, active demand, batteries etc
  - Smart grids – new controls with unknown interactions and modes of failure
  - Lower system inertia
  - Little operational experience

- Consequence: new and unknown modes of failures, many potential “unknown unknowns”
- (N-2) would be an overkill but maybe it should be say (N-1.2) criterion?
  - CBA needed
Comparison with big worldwide blackouts

- GB power cuts were tiny by comparison
- Rare and short-duration with trivial consequences
- Why?
  - Moderate climate with no extremes
  - Transmission system well-designed and operated
- By far the most common is a local distribution failure
- But generation adequacy remains a long-term problem

Source: Wikipedia, A. Campbell
Conclusions for a Curious Incident of Trains in the Rush Time

- Power cut was caused by two plants tripping following a lightning strike
- The situation was aggravated by a consequent loss of embedded generation
- Power supplied were restored by combination of frequency response and LFDD
- Power system reacted largely as expected to a non-secured contingency
- But unexpected train failures caused wide-spread disruption and public anger
- Interactions between the power system and critical infrastructures should be reviewed
- New technologies on the system cause emerging of new unknown modes of failures – SQSS with its (N-1) criterion should be reviewed