A Curious Incident of Trains in the Rush Time

on 9 August 2019

Janusz Bialek
Professor of Power and Energy Systems
Newcastle University and Skoltech

Newcastle University

Skoltech

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:

Technical Report
on the events of 9 August 2019

nationalgridESO

GB POWER SYSTEM DISRUPTION – 9 AUGUST 2019

Energy Emergencies Executive Committee: Interim Report

Department for Business, Energy & Industrial Strategy

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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

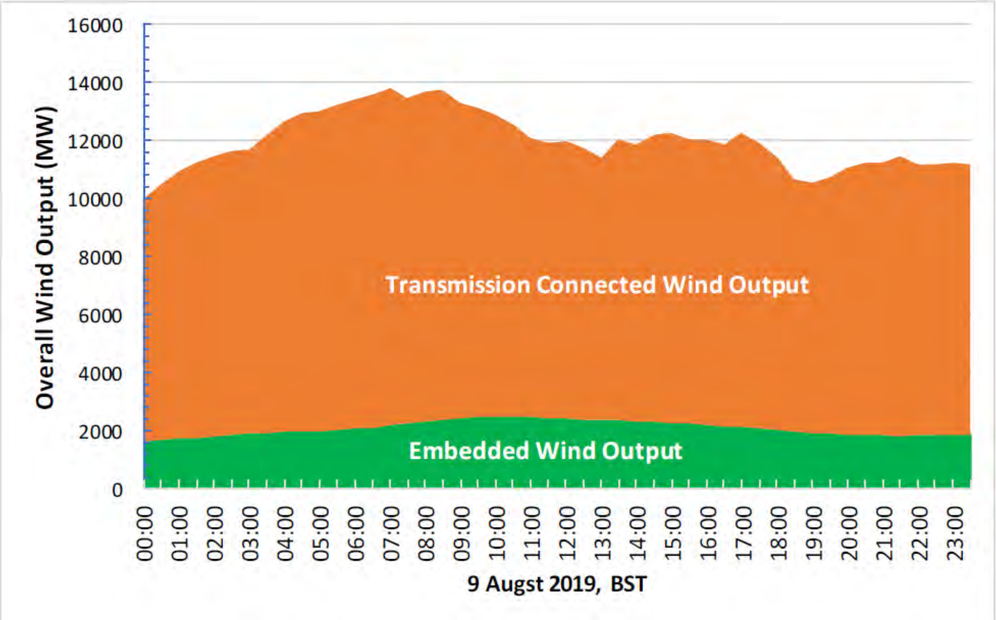
Load shedding (Low Frequency Demand Disconnection LFDD)

- 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

Frequency Hz	%**Demand** disconnection for each **Network Operator** in **Transmission Area**		
	NGET	SPT	SHETL
48.8	5		
48.75	5		
48.7	10		
48.6	7.5		
48.5	7.5	10	10
48.4	7.5	10	10
48.3			10
48.2	7.5	10	
48.0	5	10	10
47.8	5		
Total % **Demand**	60	40	40

Power System Conditions on 9 August

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



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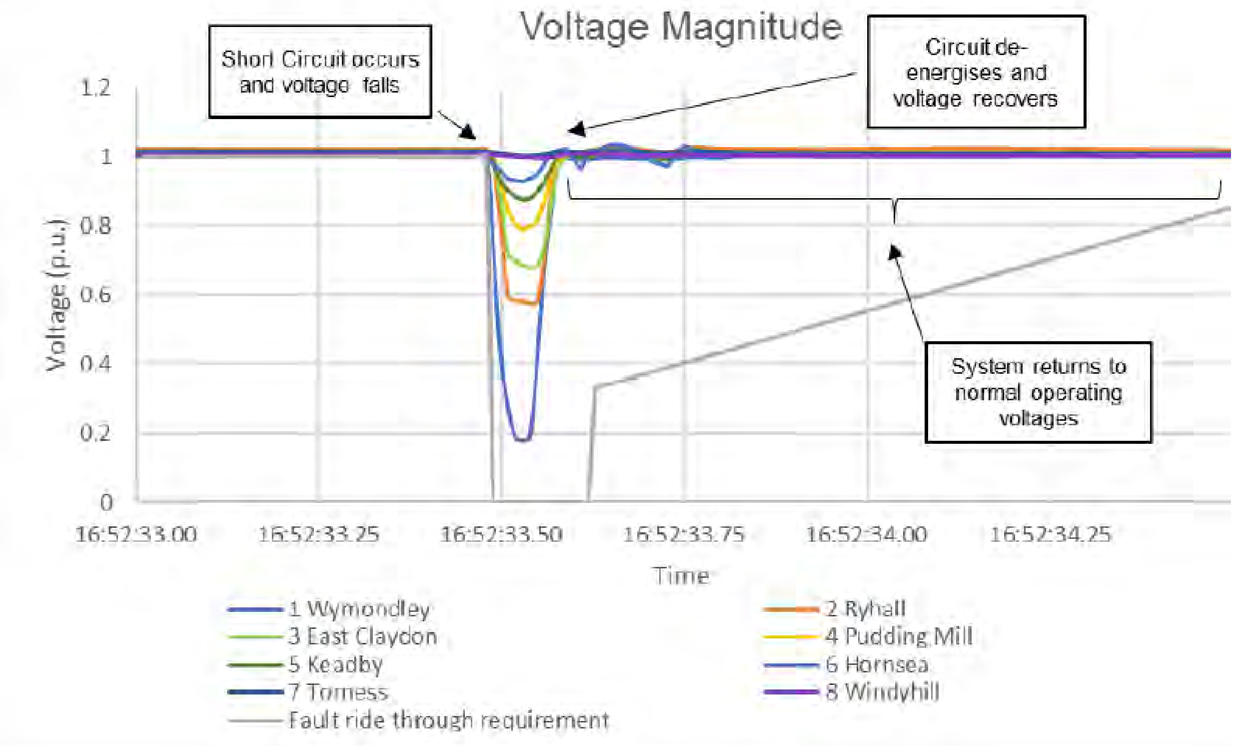
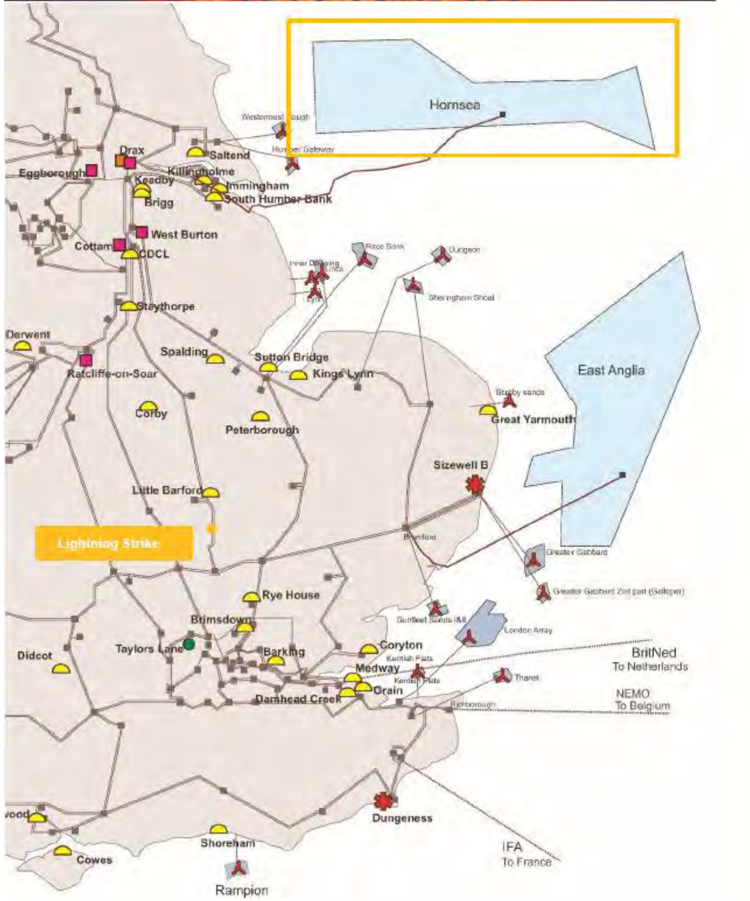
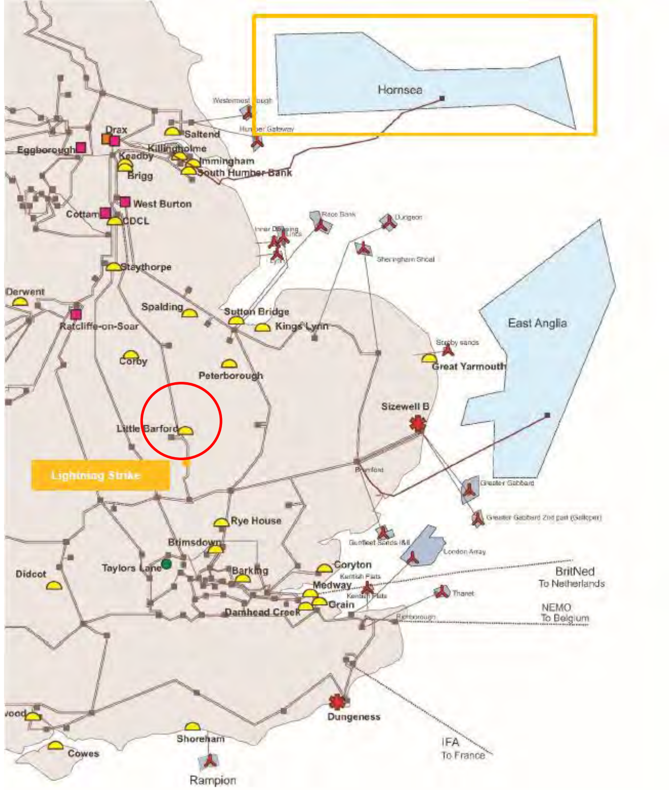
Lightning strikes

- 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

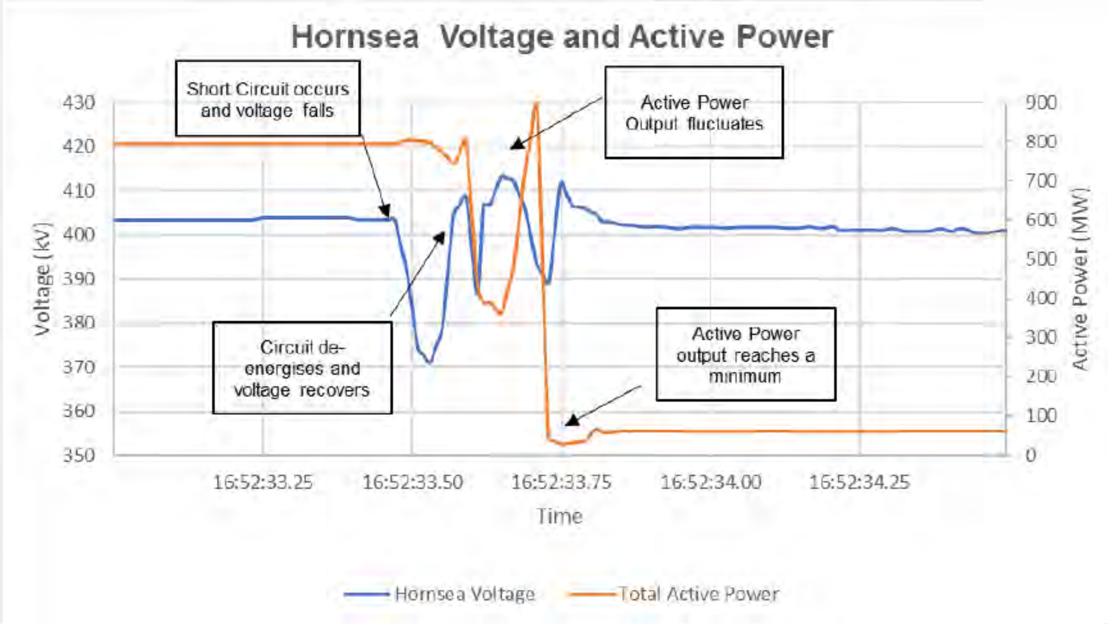




First stage (45 secs): infeed losses



- Lightning strike causes fast voltage phase angle changes
  - Loss of Mains: Vector Shift > 6^0: **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



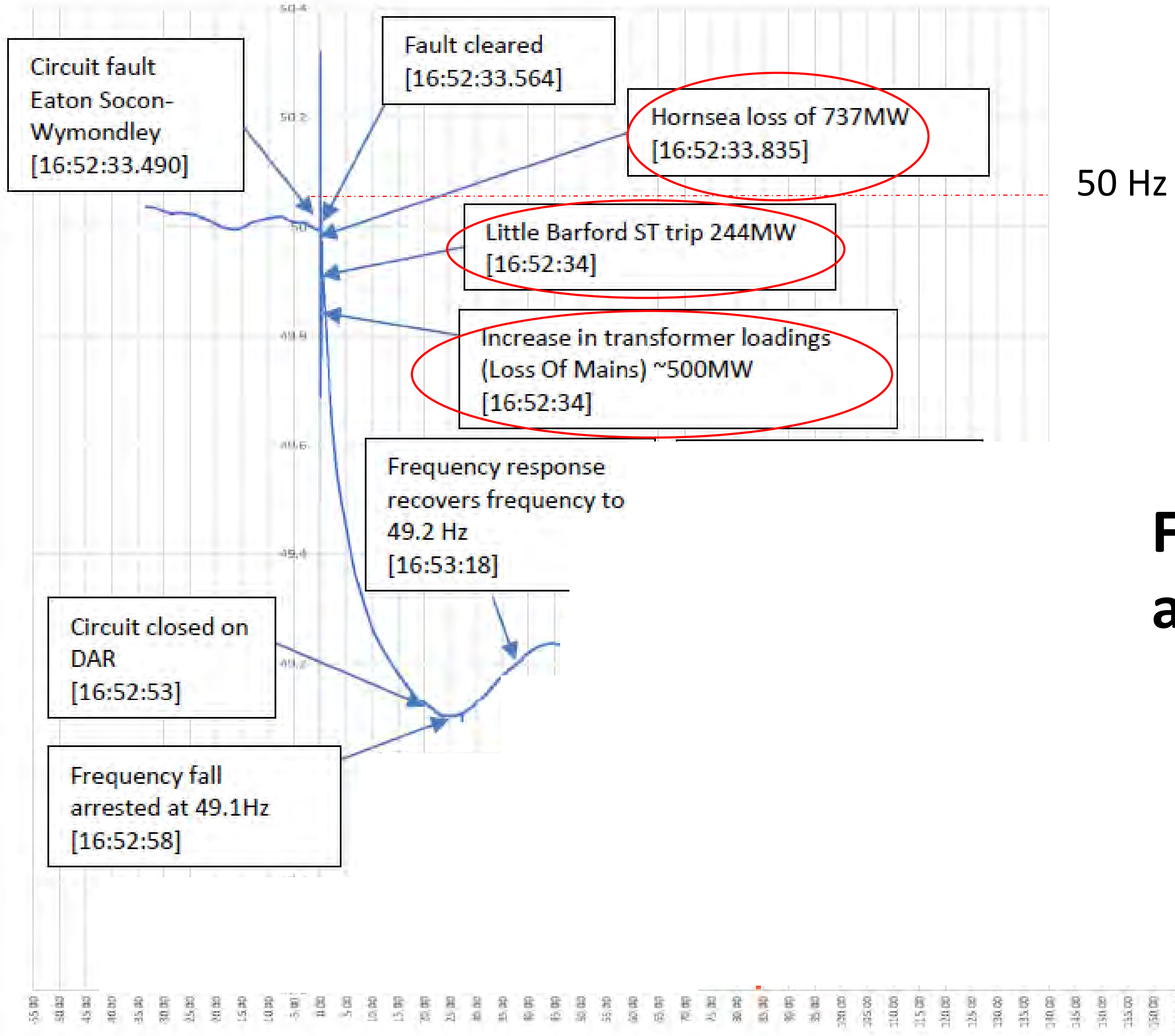
Delivery of Frequency Response

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% of 1022 MW	88% of 1314 MW

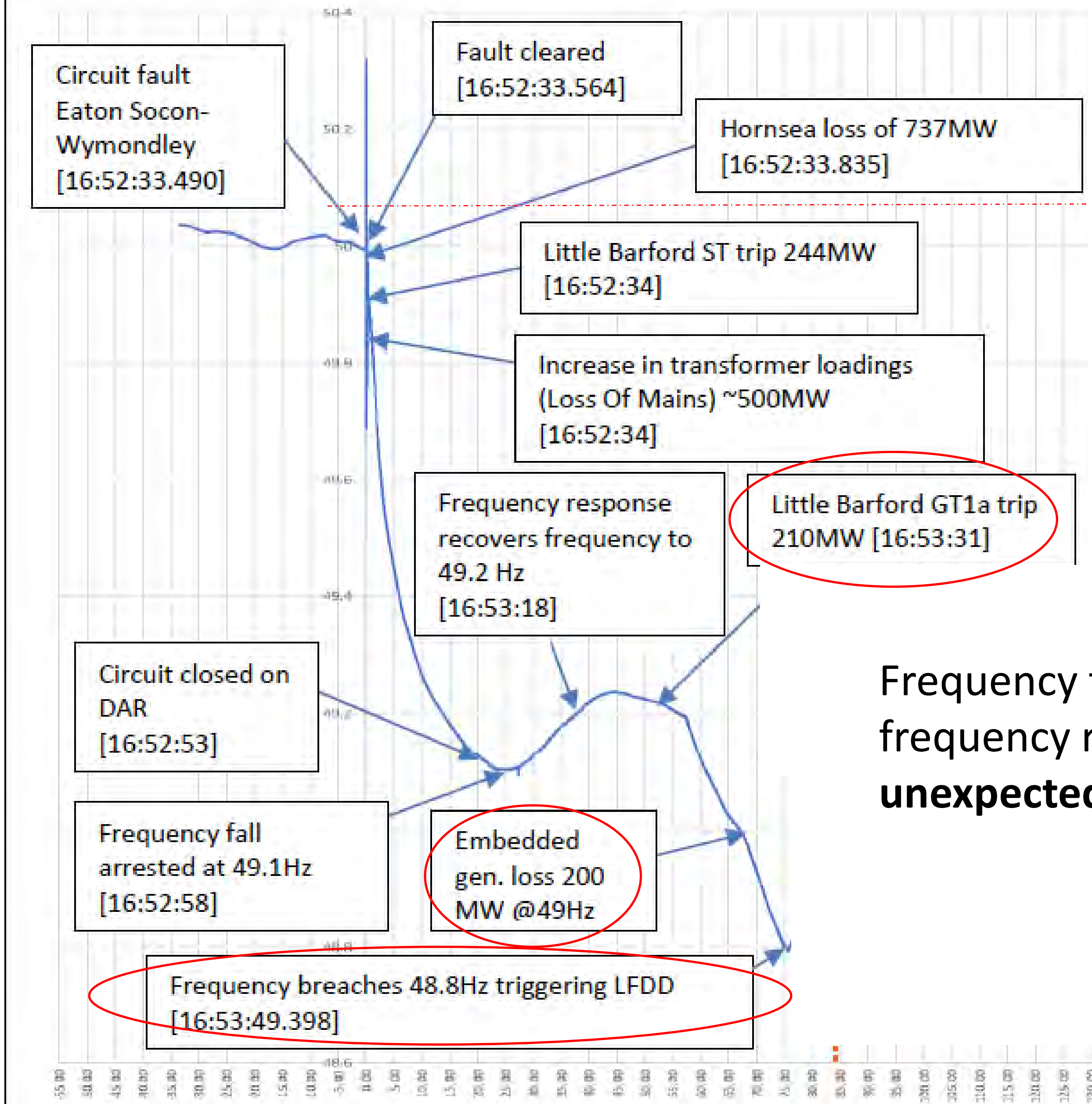
Table 5 – Validated Frequency Response Performance

- 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



Next 11 secs



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

Frequency falls again causing embedded net generation loss when frequency reached 49 Hz: **200 M**W loss on under-frequency protection **unexpected**

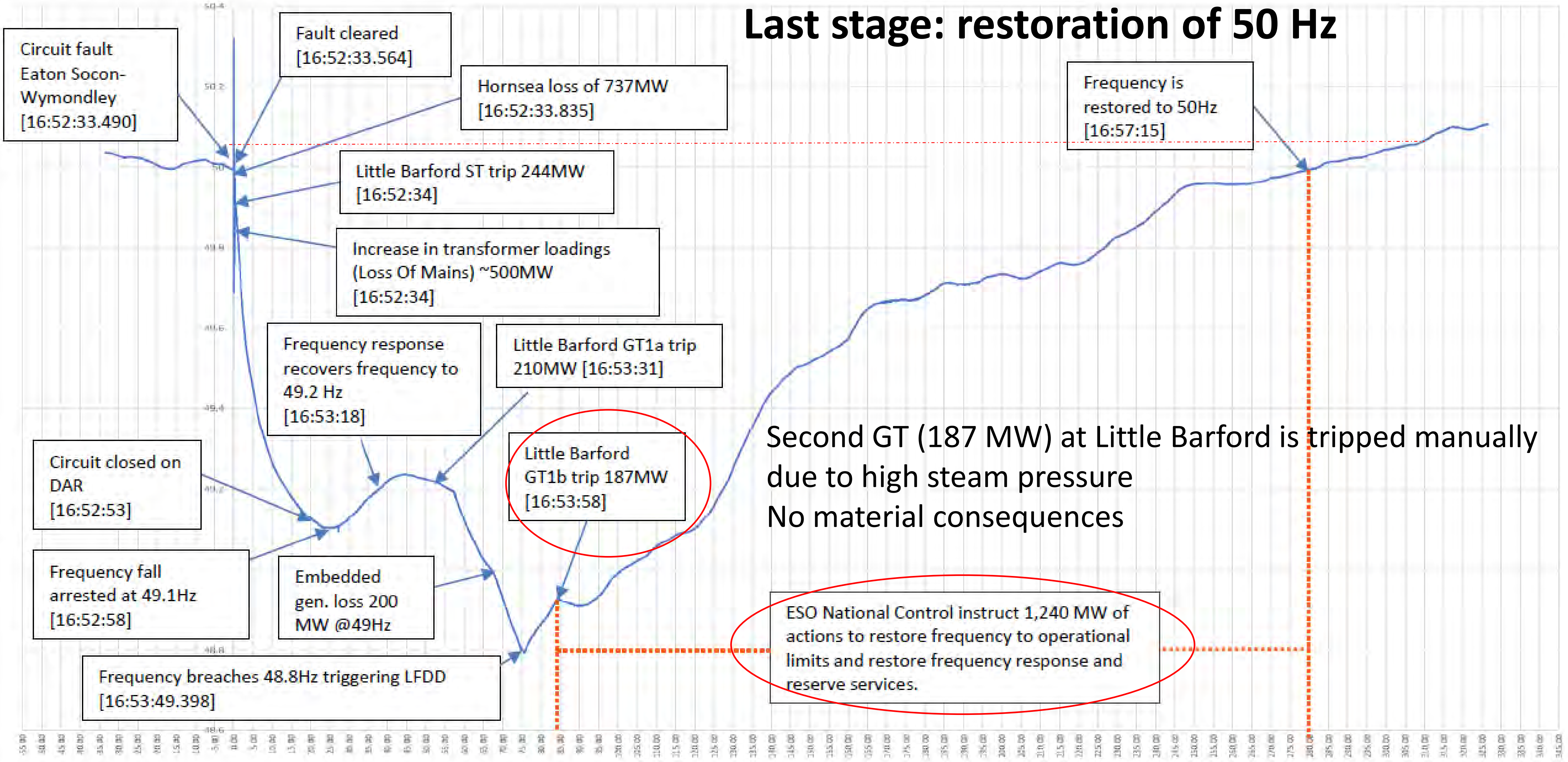
Load shedding (LFDD)

- **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

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

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

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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

Ipswich Hospital blackout caused by faulty battery

15 August 2019 Share

The power loss affected outpatients, X-rays, scans and pathology for nearly half an hour

A faulty battery led to a back-up generator failing to kick in when a hospital lost power during a UK-wide power outage, it has been revealed.

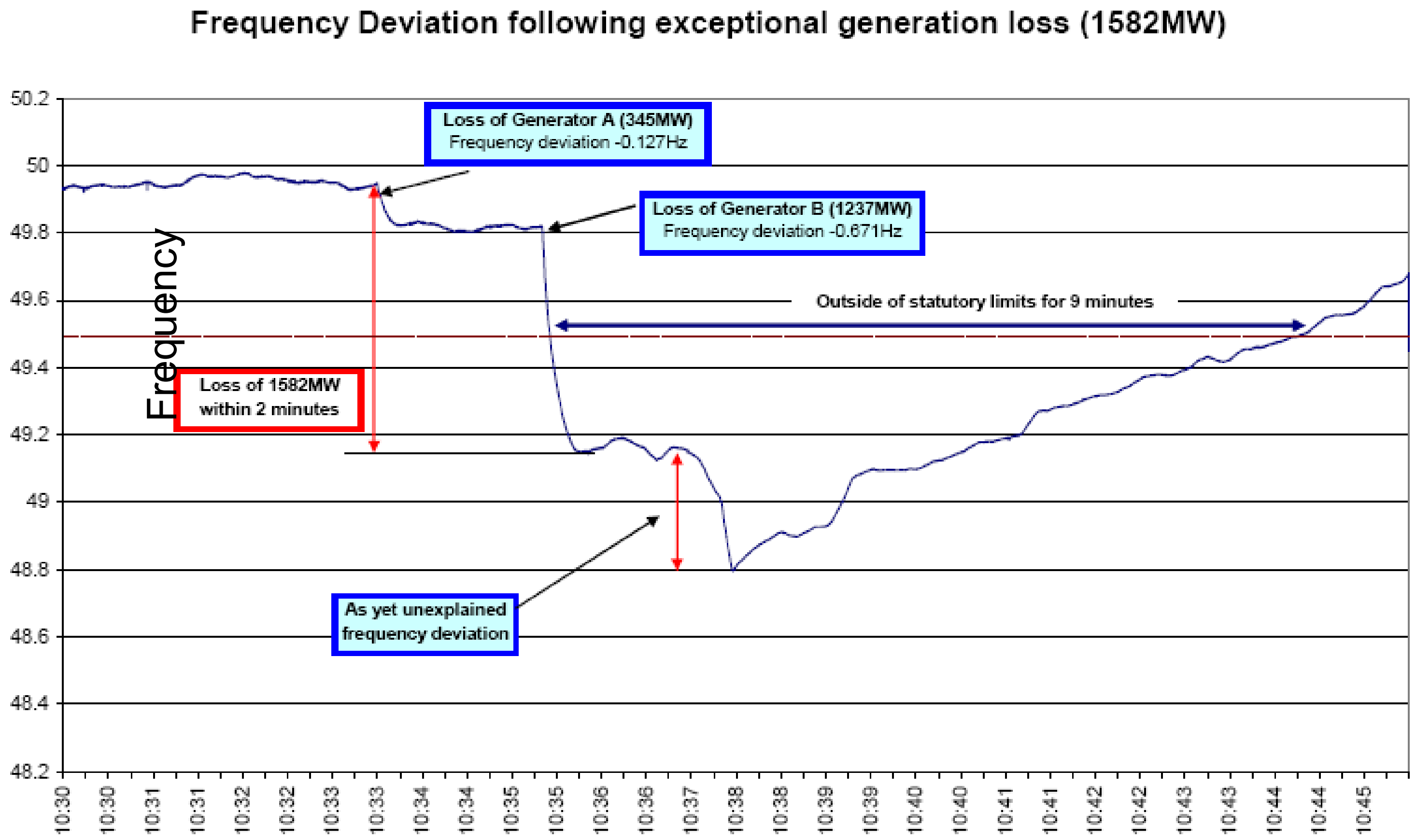
Post-mortem analysis and ESO recommendations

Technical Report
on the events of 9 August 2019

nationalgridESO

- 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 indepedently
  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

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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

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Should (N-1) criterion be reviewed?

National Electricity Transmission System
Security and Quality of Supply Standard

Version 2.4
1 April 2019

- 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

article	people affected (millions)	location	date
2012 India blackouts	620	India	July 30–31, 2012
2001 India blackout	230	India	January 2, 2001
2014 Bangladesh blackout	150	Bangladesh	November 1, 2014
2015 Pakistan blackout	140	Pakistan	January 26, 2015
2019 Java blackout	120	Indonesia	August 4–5, 2019
2005 Java–Bali blackout	100	Indonesia	August 18, 2005
1999 Southern Brazil blackout	97	Brazil	March 11–June 22, 1999
2009 Brazil and Paraguay blackout	60	Brazil, Paraguay	November 10–20, 2009
2003 Italy blackout	56	Italy, Switzerland	September 28, 2003
Northeast blackout of 2003	55	United States, Canada	August 14–28, 2003
2019 Argentina, Paraguay and Uruguay blackout	48	Argentina, Paraguay, Uruguay	June 16, 2019
2002 Luzon blackout	40	Philippines	May 21, 2002
1978 Thailand blackout	40	Thailand	March 18, 1978
2001 Luzon blackout	35	Philippines	April 7, 2001
Northeast blackout of 1965	30	United States, Canada	November 9, 1965
2019 Venezuelan blackouts	30	Venezuela	March 7–ongoing
	21	Sri Lanka	March 13, 2016

Northern California Goes Dark

Government needs to be more hands-on when it comes to keeping the lights on and shutting them off.

Last week more than 700,000 homes and businesses, customers of Pacific Gas & Electric (PG&E) in northern California, lost power. Traffic lights went dark causing numerous traffic accidents. People with medical needs struggled to find power for essential devices. Schools closed, requiring parents to scramble to make arrangements for their kids. Power wasn't shut down by a hurricane or roiling storm. Instead, the utility flipped the switches and shut off power in many areas.

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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