

Six challenges in search of some order

Operating the future, net zero electricity system

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Electricity market challenges

High wholesale prices

- Dependency on natural gas
- Supplier vulnerability
- Consumer vulnerability

Uncertainty for renewables investors

High network constraint costs

- Lack of network capacity
- Lack of strong locational signal

Lack of flexible demand

- Ability to provide it
- Ability to measure it

Lack of flexible/schedulable/persistent low carbon sources of energy

Build more renewable capacity Develop low carbon flexible resources

Weak PPA market High network charges Consenting risk AR4 under way; AR5 coming

Locational TNUoS isn't done very well Distribution charging is disconnected from TNUoS Fear of stranded assets; no anticipatory transmission capacity

EVs and electric heat in well insulated homes not really happened yet

Half-hourly - "smart" - metering

- Need not really been signalled yet?



An engineer's perspective



- The system is changing to towards more use of variable renewables and 'inverter based resources'
 - The electrical technologies and the interactions between sources of energy and the electrical system are different
- As the electricity system transitions towards lower emissions intensities:
 - How can we make efficient use of whatever low carbon energy is available to meet demand?
 - How can we meet all demand pretty much all the time?
 - How can keep the system stable?
 - How can we do all the above at least cost?





Image: Hitachi Energy

Stuff happens... are renewables to blame?





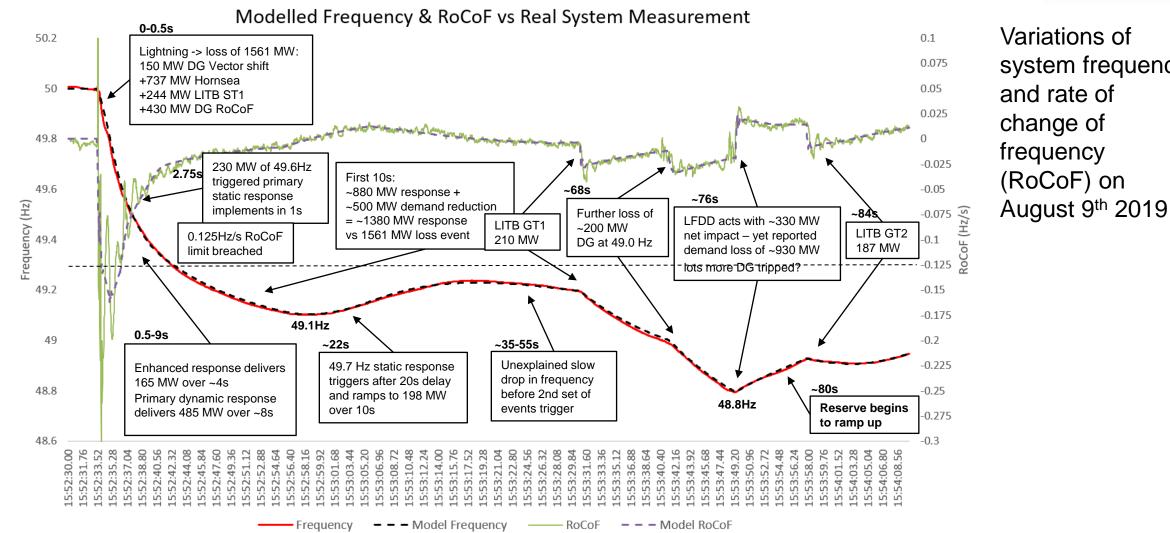


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1. Frequency stability and reduction of inertia



system frequency

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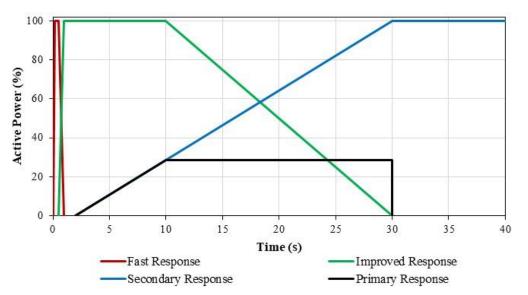
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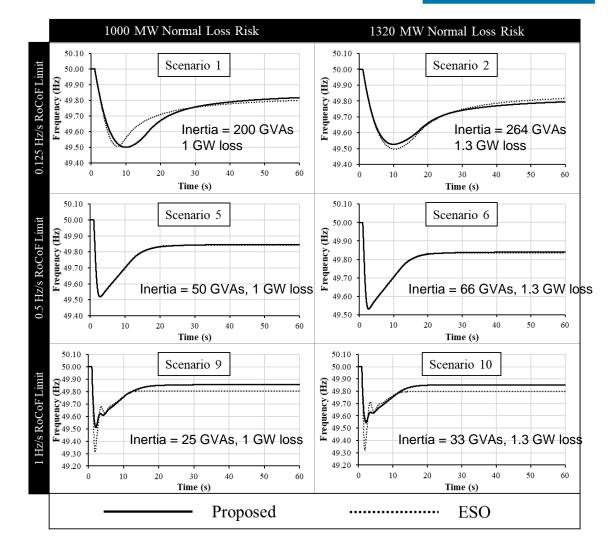
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1. Frequency stability and reduction of inertia

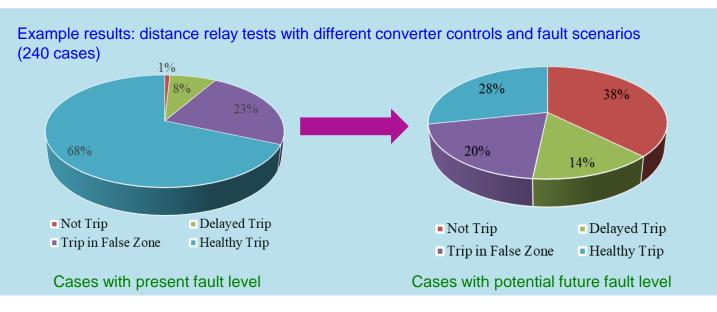
- Optimal use of different sources of energy
 - Batteries, interconnectors, wind farms
- Ancillary service reform: clarity on different time frames and transitions between them
- Signal to investment in different sources of response?
- Risks when exhausting a store of energy?

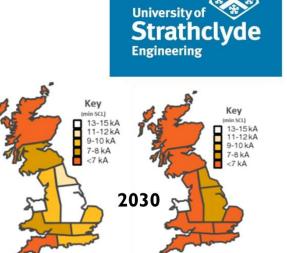


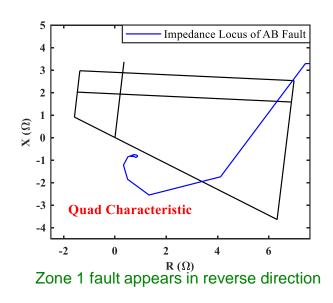


2. Lack of short circuit current

- Very different system behaviour during faults
 - Reduced magnitude of currents; different phase balance
 - Exact behaviour dependent on converter control strategies
- Risk of compromised distance protection performance
 - Significant error in impedance measurement
 - Issues with fault detection sensitivity and faulty phase selection.

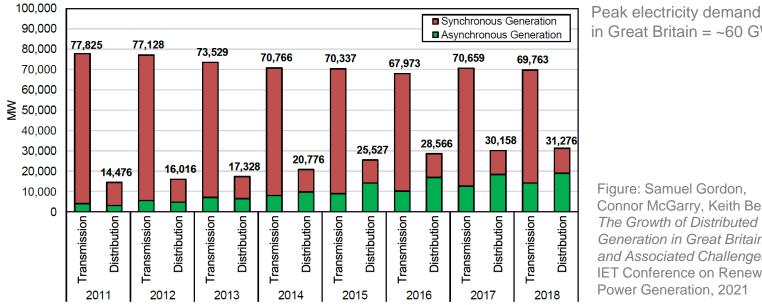






2020

3. Growth of distributed resources



in Great Britain = $\sim 60 \text{ GW}$

Figure: Samuel Gordon, Connor McGarry, Keith Bell, The Growth of Distributed Generation in Great Britain and Associated Challenges, IET Conference on Renewable Power Generation, 2021



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- Ensuring observability and controllability: Grid Code obligations and connection agreements
- Managed badly, distributed resources can threaten system operation
- Managed well, they can contribute to ensuring stable operation.
- Need clarity of a Distribution Network Operator's role with proper incentives and sufficiently strong IT systems. (Lots of data; large models; powerful optimisers)

4. Extremes of the demand duration curve



2040 ST

43.0

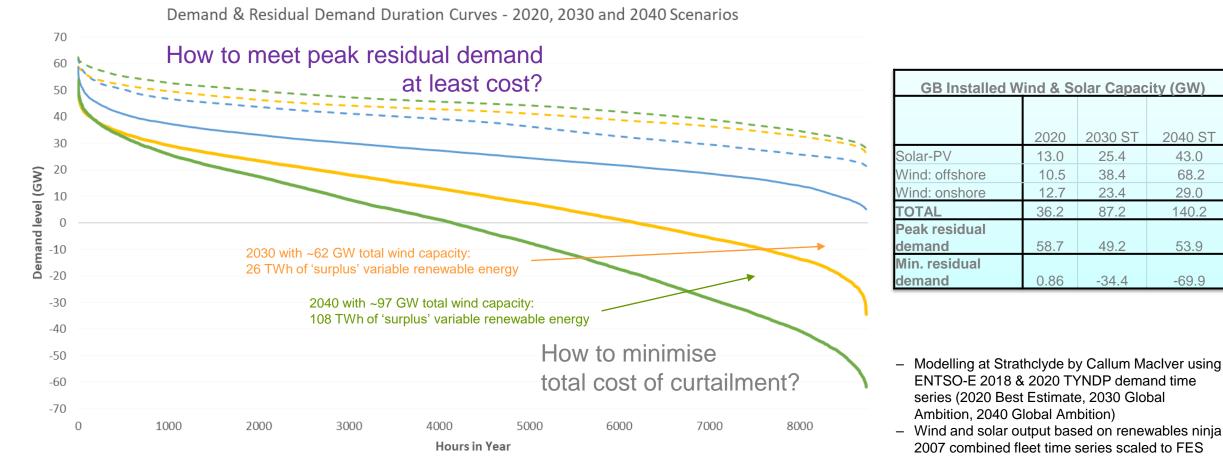
68.2

29.0

140.2

53.9

-69.9



Demand 2020 - - Demand 2030 - - Demand 2040 - Residual Demand 2020 -Residual Demand 2030 — Residual Demand 2040

* in each hour residual demand = total demand – (wind + solar + run of river hydro)

- ENTSO-E 2018 & 2020 TYNDP demand time series (2020 Best Estimate, 2030 Global
- Wind and solar output based on renewables ninja 2007 combined fleet time series scaled to FES 2021 System Transformation capacity scenarios
- Run of river Hydro modelled from historic trends

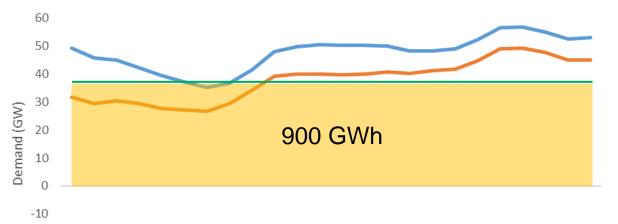
We need flexible sources of energy

Why flexible? They need to adjust their output, some of them quickly at times

Winter day with moderate wind output and high residual demand

- Maximum total wind output: 16.6 GW (minimum 3.0 GW)
- Maximum residual demand: 49.2 GW

2030 Scenario Demand vs Residual Demand: 15th Nov



A week of similar days would require 6.3 TWh of energy



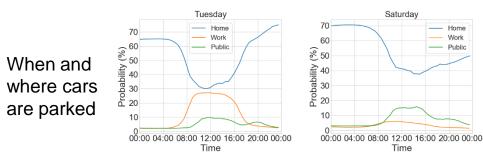
 If all 32 million passenger cars in the UK were electric with a 40 kWh battery, there would be 1.28 TWh of storage

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- Average daily driving distance = 33 km/day
- Energy used in driving ≈ 0.18 kWh/km
- Energy used per day ≈ 6 kWh
- Average energy left per battery ≈ 34 kWh
- Total energy left in batteries across the fleet ≈ 1.09 TWh
- If 30% of cars are at home and all are plugged in, in theory 330 GWh of energy available





What might provide flexibility?



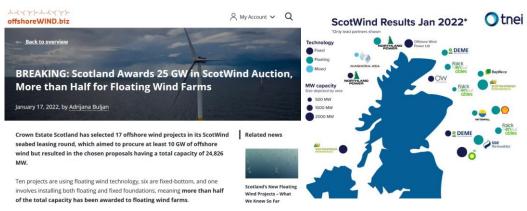
	requency Inment Reserve	ency Restoration Reserve	Ramping Standing reserve / capacity
	Flexible?	Schedulable?	Persistent?
Wind	If it's windy, yes	No	Sometimes
Nuclear	No, not really	Yes, for the most part	Yes
CCGT burning blue or green H ₂	Yes	Yes, for the most part	Yes, if fuel is available
CCGT burning CH ₄ , with CCS	Perhaps, but at a cost	Yes, for the most part	Yes, if fuel is available
Batteries	Yes	Yes, for the most part	To an extent, if power is rationed
Pumped hydro	Yes	Yes, for the most part	Only if power is rationed
Flexible demand	Yes	Depends what it is	Not beyond a few hours?
Interconnection	Yes	Yes, for the most part	Yes, depending on conditions at the far end

- Flexibility: able to adjust production or consumption quickly and at short notice. (How quick is quick?)
- Schedulability: we can schedule power to be produced at any given time on a given day in the future
- Persistence: increase in production or decrease in consumption can be sustained for a period of time (energy)

It's not enough just to value capacity when seeking 'flexibility'

• Value is a function of power, energy and ability to change power

5. Getting enough network capacity

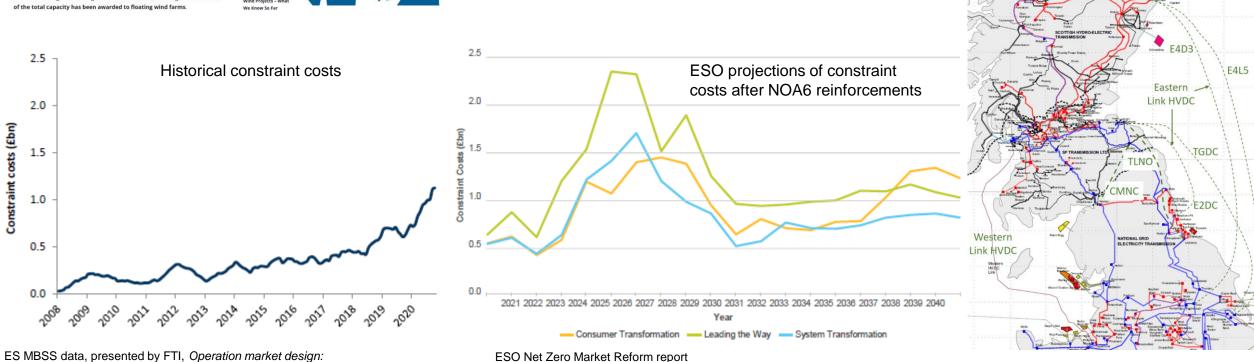


Dispatch and Location, January 17th 2022



Peak Scotland-England flows could be as high as 14 GW with connection of 10 GW of new wind

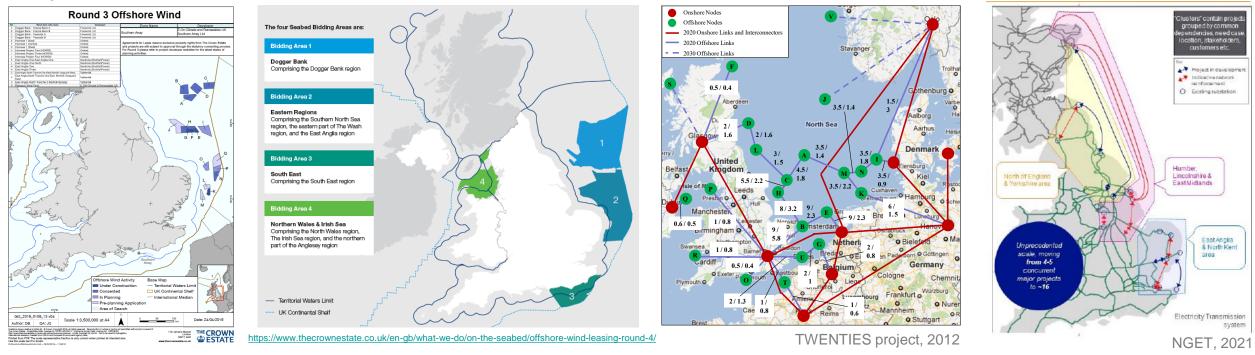
- Export capability today ~6.5 GW
- With 4 × 1.4 GW HVDC links, capability grows to ~12 GW



5. Getting enough network capacity



e.g. How to accommodate 40 GW of offshore wind in British waters by 2030?



Don't just need to work out the offshore network design

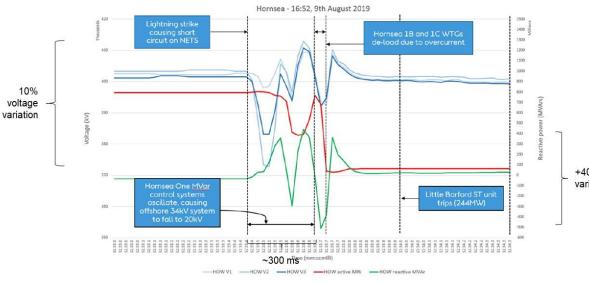
How will power get across the onshore network?

Resilience of the network to extreme weather? (What else is needed to preserve essential services?) Coordinated offshore and onshore network design and 'anticipatory' investment?

6. Managing control interactions



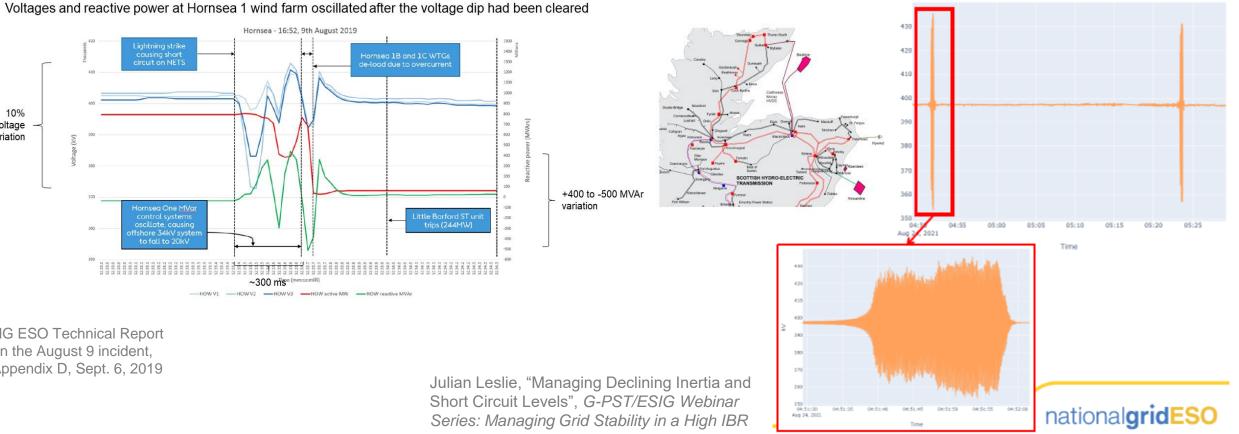
August 9th, 2019



NG ESO Technical Report on the August 9 incident, Appendix D, Sept. 6, 2019

Julian Leslie, "Managing Declining Inertia and Short Circuit Levels", G-PST/ESIG Webinar Series: Managing Grid Stability in a High IBR Network, January 2022

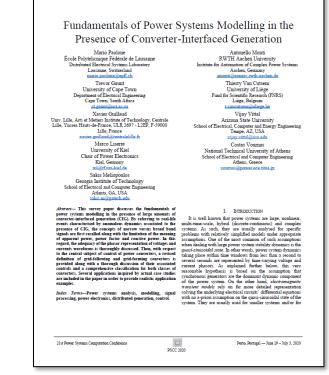
August 24th, 2021



6. Managing control interactions

- Inverter connected resources bring opportunities and challenges
- Behaviour of inverter connected resources
 - Uncertain responses during network faults
 - Reduce dependency on phase-locked loops
 - Define transitions between current limiting mode and grid-forming mode
 - New characterisations
 - · Variation of effective impedance with change in frequency
 - New methods for tuning controls
- System operator needs access to new kinds of models
 - The right models at the right times, standardised APIs, open access to models?
 - Enhanced education and training of staff
- Clarify responsibilities between plant owners and system operators
- Enforce grid codes





What I've not talked about

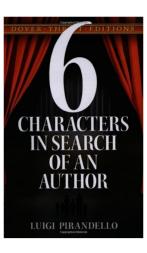


- System strength
 - What is a "weak system"?
 - Low short circuit current
 - Low inertia
 - High variability of voltage
 - How weak would the system need to be for us to worry about it?
 - What are the impacts of these different aspects of a "weak system"?
- What are the possible solutions?
 - Synchronous compensators
 - Control of an inverter with any source of energy
 - Modified network protection
 - 'Over-sized' inverters
- "System strength" is a term that should be retired.

Six challenges in search of some order Operating the future, zero emissions electricity system

- 1. Reduction of inertia and maintenance of frequency stability
- 2. Lack of short circuit current
- 3. Growth of distributed resources
- 4. Extremes of the residual demand curve
- 5. Getting enough network capacity
- 6. Managing control interactions





Opportunities

- Do we know how to harness them?
- Are we investing enough to get the right knowledge and skills within the sector?

- The levelised cost of renewable energy is low
- End uses of electricity are more efficient than those of fossil fuels
- Distributed generation can do a lot for us
- EV charging promises a lot of flexibility
- Costs of batteries and electrolysers are coming down
- Control of power electronic converters is extremely flexible
- Information and communication technologies are more powerful than ever