Six challenges in search of some order

Operating the future, net zero electricity system

Keith Bell

Holder of the ScottishPower Chair in Smart Grids
and a co-Director of the UK Energy Research Centre
http://www.strath.ac.uk/staff/bellkeithprof/

Electricity market challenges

High wholesale prices
- Dependency on natural gas
- Supplier vulnerability
- Consumer vulnerability

Build more renewable capacity
Develop low carbon flexible resources

Uncertainty for renewables investors

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

High network constraint costs
- Lack of network capacity
- Lack of strong locational signal

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

Lack of flexible demand
- Ability to provide it
- Ability to measure it

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

Half-hourly – "smart" – metering

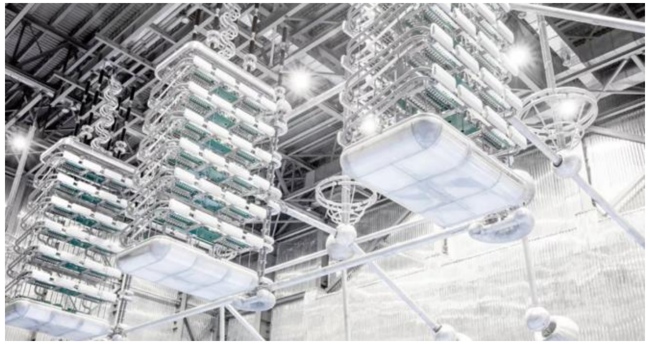
Lack of flexible/schedulable/persistent low carbon sources of energy

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?

University of Strathclyde Engineering

The August 9th 2019 GB system event

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'Wind power not to blame for major UK blackout,' says Scots professor

The major blackout that struck Britain was not due to the use of wind generation on the power network, scientists have said.

By Press Association
Saturday, 10th August 2019, 2:22 pm

Experts believe the disconnection of a gas-fired power plant and wind farm triggered the power cut that brought wide-spread disruption to the country on Friday.

Professor Keith Bell, expert in electronic and electrical engineering at the University of Strathclyde, said the country's power systems should be regularly reviewed as the UK sought to cut its carbon emissions.

Madeleine Bell
10 August · Edited

Who wants to tell them that Keith Bell is English? 😂

14 · 3 comments

Haha · Comment · Share

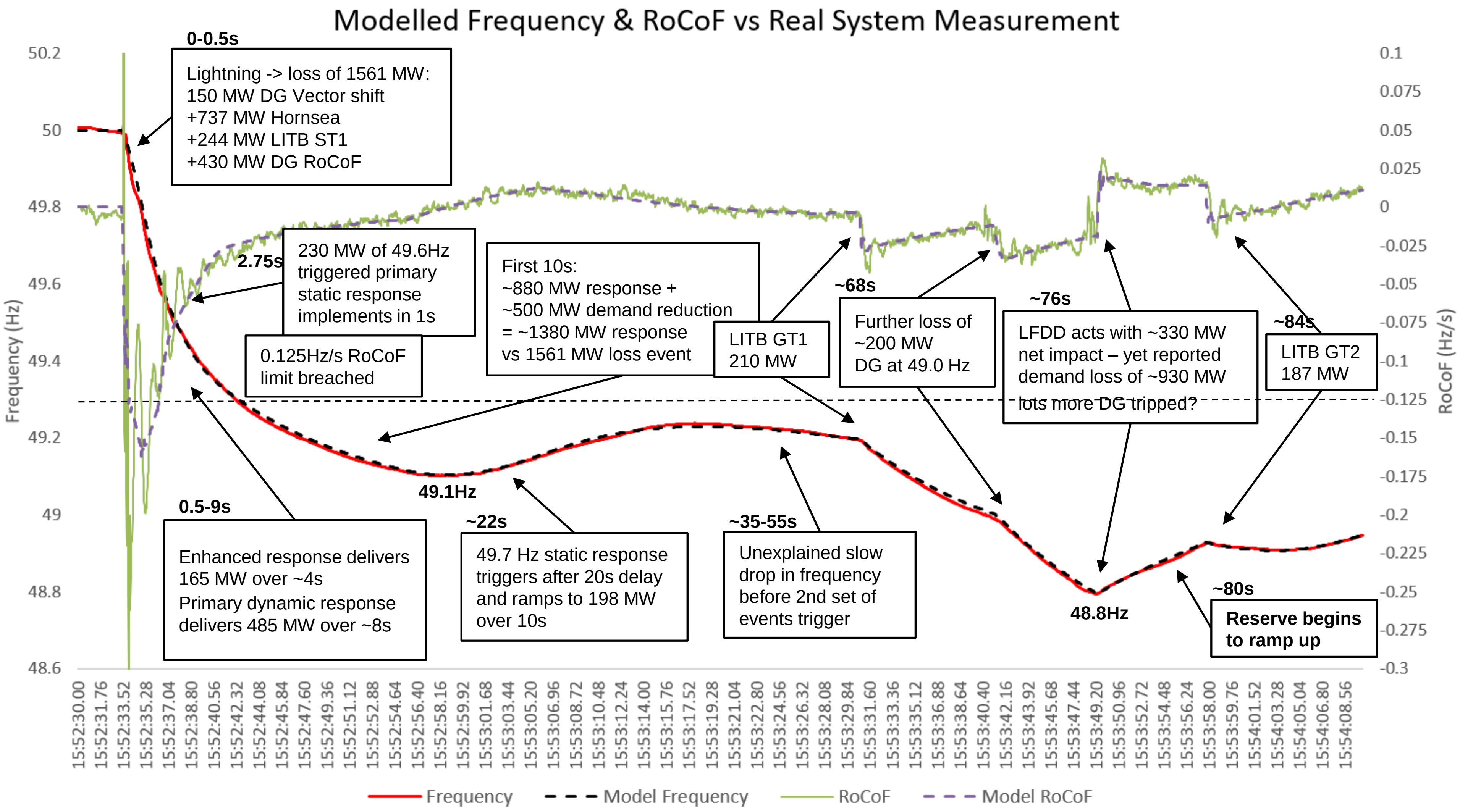
Sarah Bell 😂😂😂😂😂😂😂
Like · Reply · 11w

Lynsey Armitage You would think the accent would give it away! X
Like · Reply · 11w

Caroline Hutchings Yes but he's also got Irish heritage x
Like · Reply · 11w

Write a comment…

1. Frequency stability and reduction of inertia

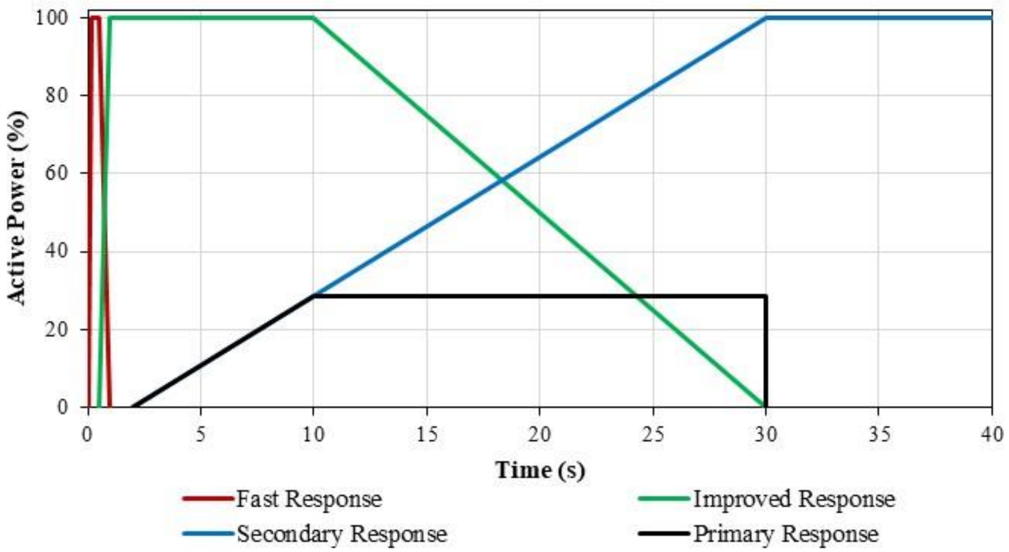


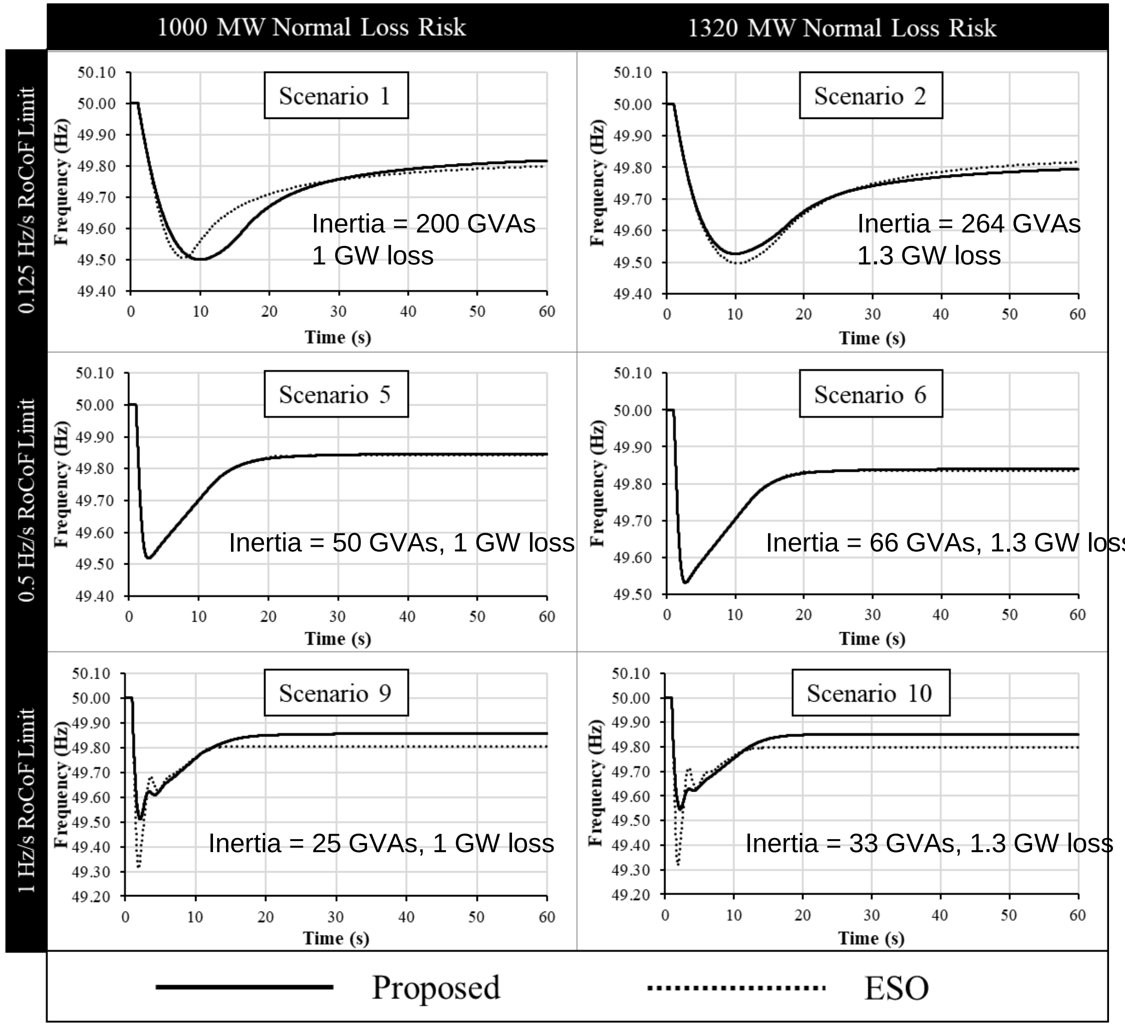
Variations of system frequency and rate of change of frequency (RoCoF) on August 9th 2019

Figure: Callum MacIver, University of Strathclyde

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?





Figures: Marcel Nedd, University of Strathclyde

2. Lack of short circuit current

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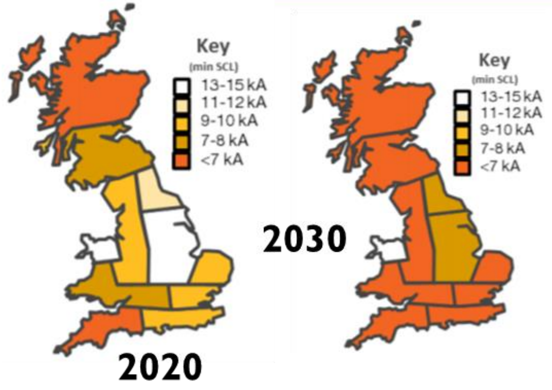
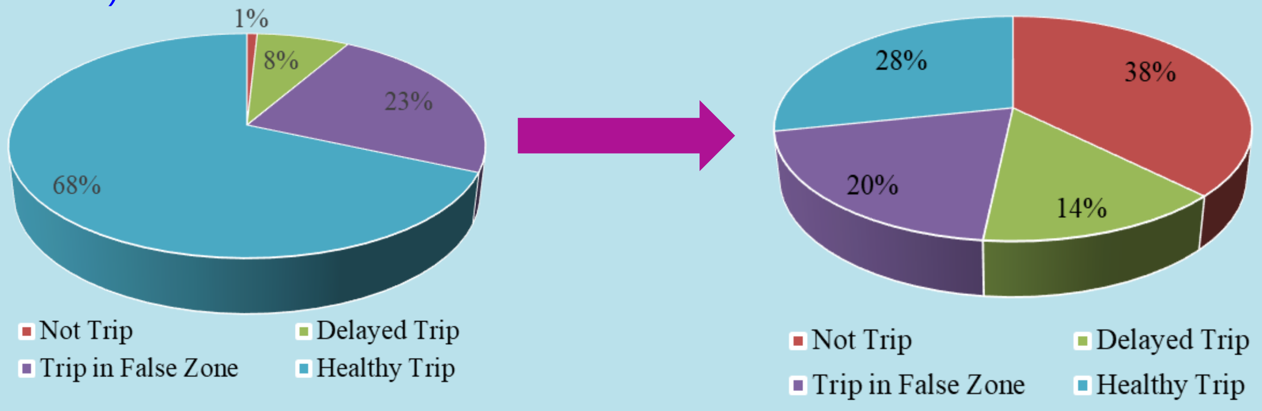
- Very different system behaviour during faults
  - Reduced magnitude of currents; different phase balance
  - Exact behaviour dependent on converter control strategies
- Risk of compromised distance protection performance
  - Significant error in impedance measurement
  - Issues with fault detection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

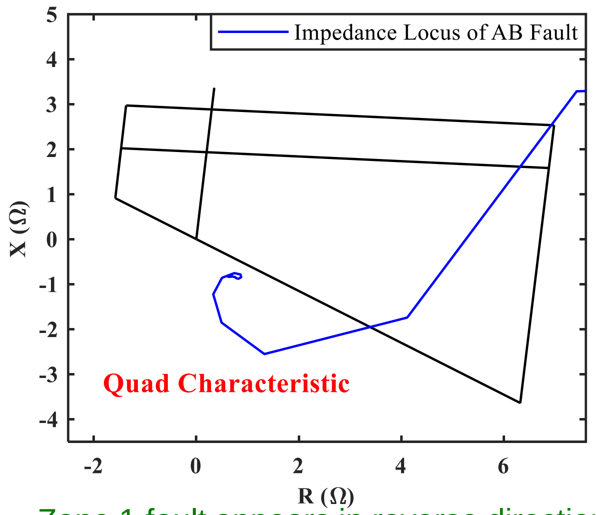


Example results: distance relay tests with different converter controls and fault scenarios (240 cases)



Cases with present fault level

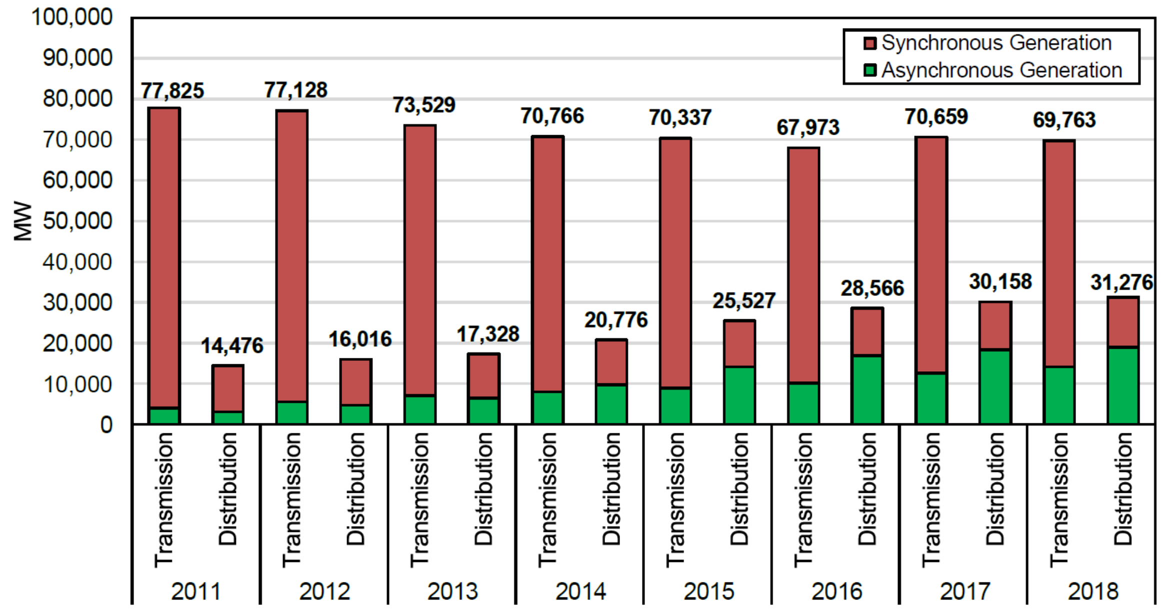
Cases with potential future fault level



Zone 1 fault appears in reverse direction

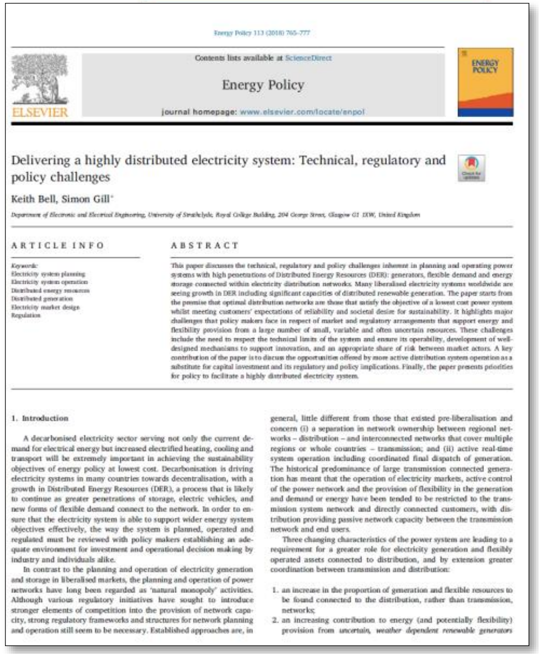
Slide courtesy of Qiteng Hong, University of Strathclyde

3. Growth of distributed resources



Peak electricity demand in Great Britain = ~60 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


Energy Policy 113 (2018) 765–777

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Energy Policy

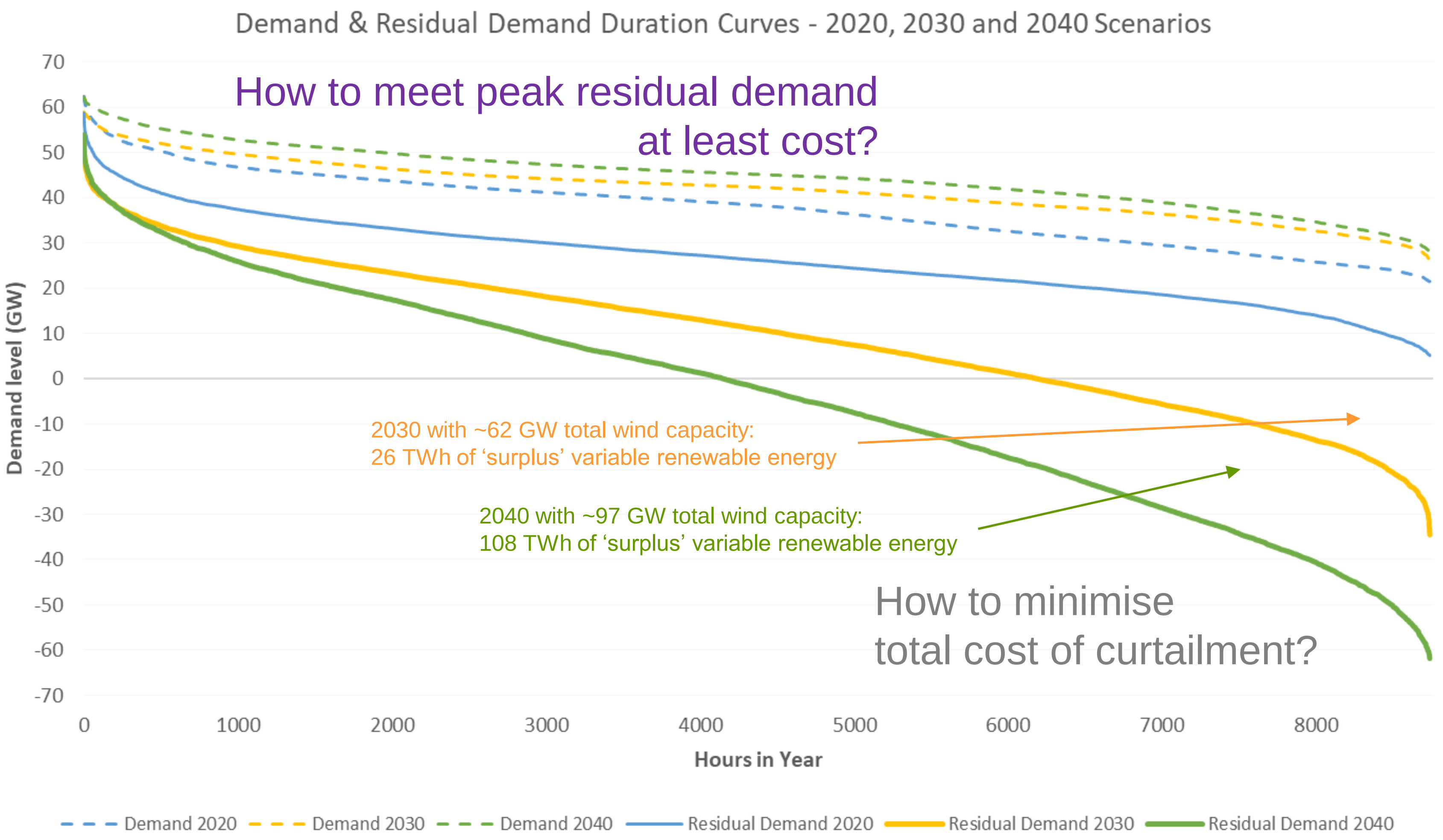
journal homepage: www.elsevier.com/locate/enpol

Delivering a highly distributed electricity system: Technical, regulatory and policy challenges

Keith Bell, Simon Gill

- 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



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

GB Installed Wind & Solar Capacity (GW)			
	2020	2030 ST	2040 ST
Solar-PV	13.0	25.4	43.0
Wind: offshore	10.5	38.4	68.2
Wind: onshore	12.7	23.4	29.0
TOTAL	36.2	87.2	140.2
Peak residual demand	58.7	49.2	53.9
Min. residual demand	0.86	-34.4	-69.9

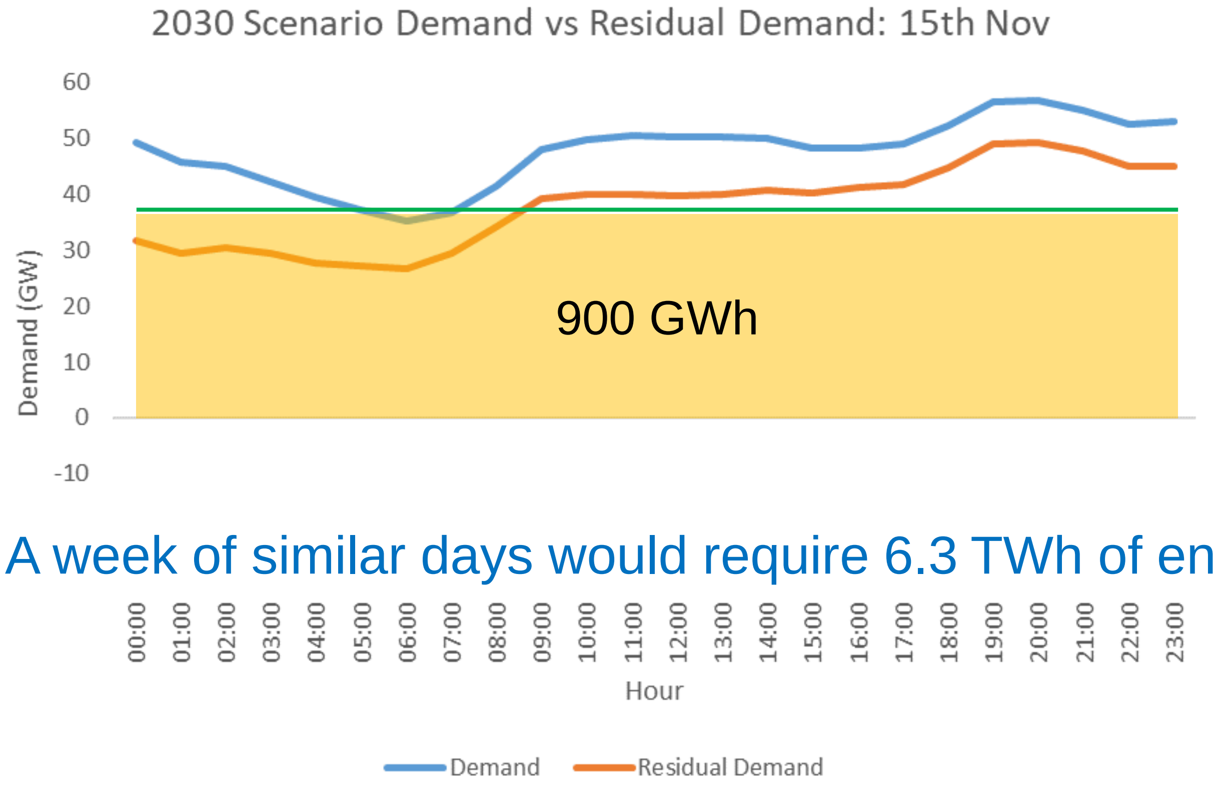
- Modelling at Strathclyde by Callum MacIver using ENTSO-E 2018 & 2020 TYNDP demand time series (2020 Best Estimate, 2030 Global Ambition, 2040 Global Ambition)
- Wind and solar output based on renewables ninja 2007 combined fleet time series scaled to FES 2021 System Transformation capacity scenarios
- 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

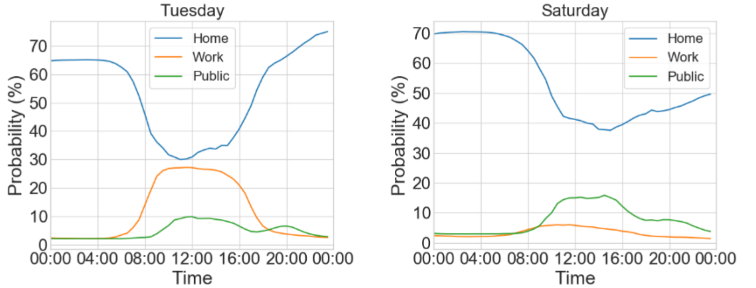
- Maximum total wind output: 16.6 GW (minimum 3.0 GW)
- Maximum residual demand: 49.2 GW



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
- 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

When and where cars are parked



Thanks to James Dixon for EV analysis

What might provide flexibility?

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Fast Frequency Containment Reserve → Frequency Containment Reserve → Frequency Restoration Reserve → Ramping → Standing reserve / capacity

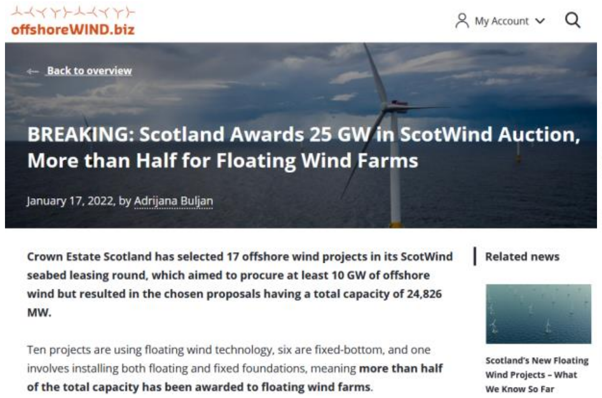
	Flexible?	Schedulable?	Persistent?
Wind	If it's windy, yes	No	Sometimes
Nuclear	No, not really	Yes, for the most part	Yes
CCGT burning blue or green H_2	Yes	Yes, for the most part	Yes, if fuel is available
CCGT burning CH_4, with CCS	Perhaps, but at a cost	Yes, for the most part	Yes, if fuel is available
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?)
- Schedulabilty: 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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BREAKING: Scotland Awards 25 GW in ScotWind Auction, More than Half for Floating Wind Farms

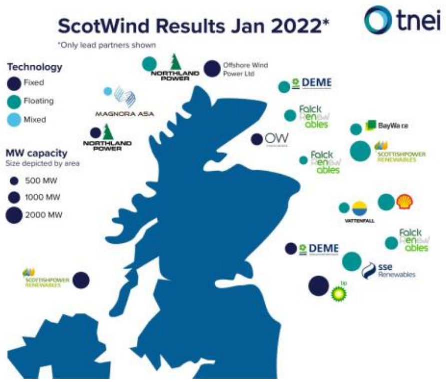
January 17, 2022, by Adrijana Buljan

Crown Estate Scotland has selected 17 offshore wind projects in its ScotWind seabed leasing round, which aimed to procure at least 10 GW of offshore wind but resulted in the chosen proposals having a total capacity of 24,826 MW.

Ten projects are using floating wind technology, six are fixed-bottom, and one involves installing both floating and fixed foundations, meaning **more than half of the total capacity has been awarded to floating wind farms.**

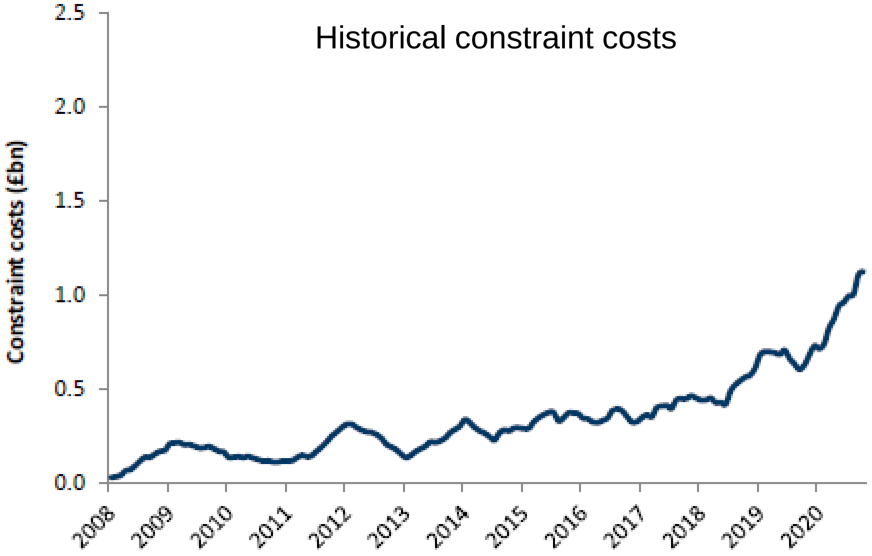
Related news

Scotland's New Floating Wind Projects – What We Know So Far

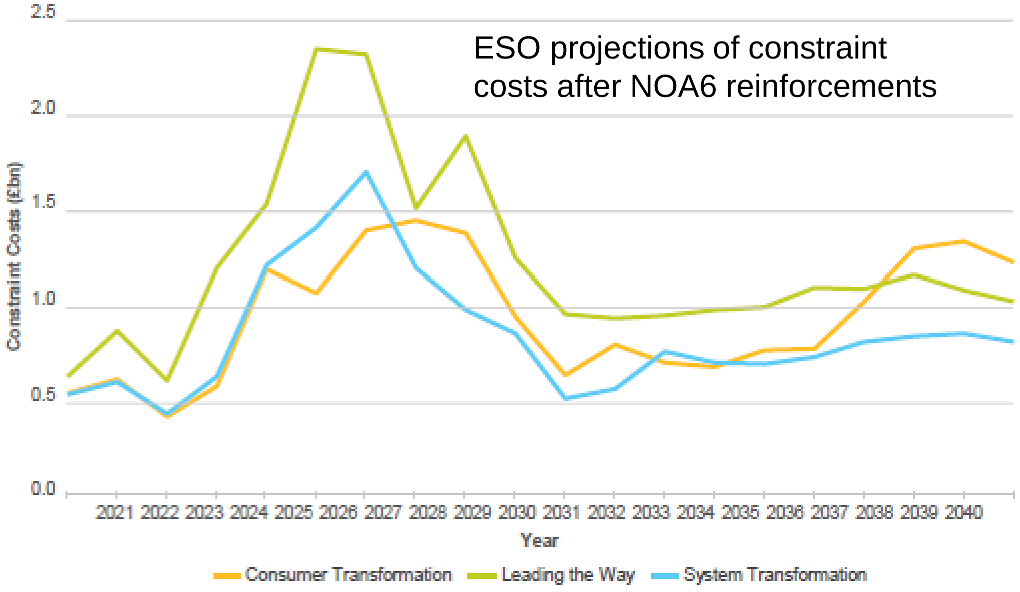


Peak Scotland-England flows could be as high as 14 GW with connection of 10 GW of new wind

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



ES MBSS data, presented by FTI, *Operation market design: Dispatch and Location*, January 17th 2022



ESO Net Zero Market Reform report

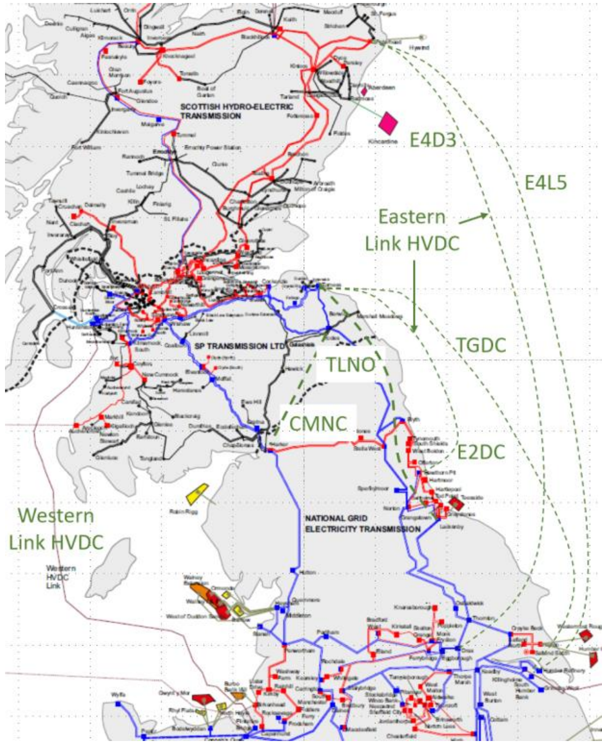


Figure: SP Transmission/NGESO

5. Getting enough network capacity

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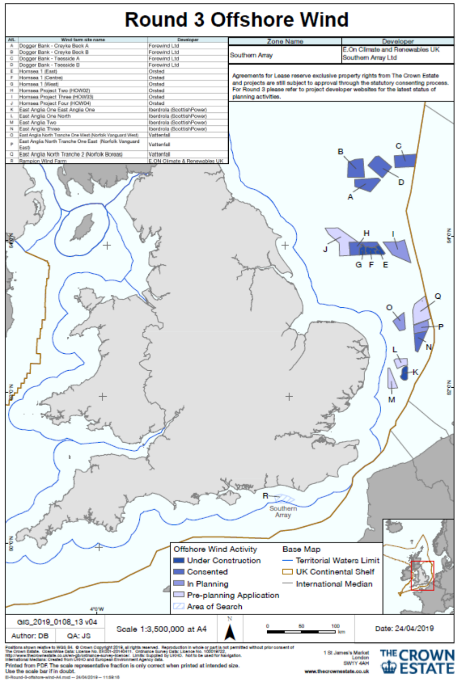
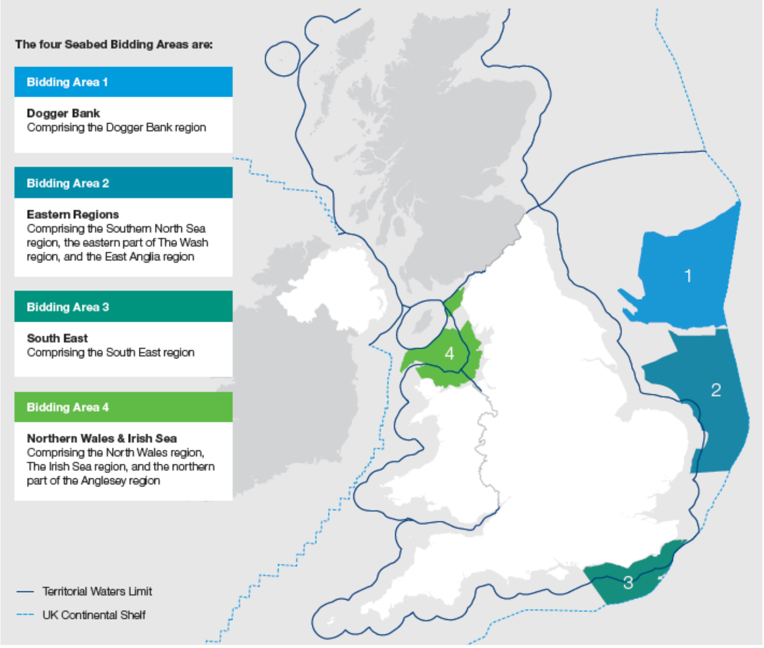
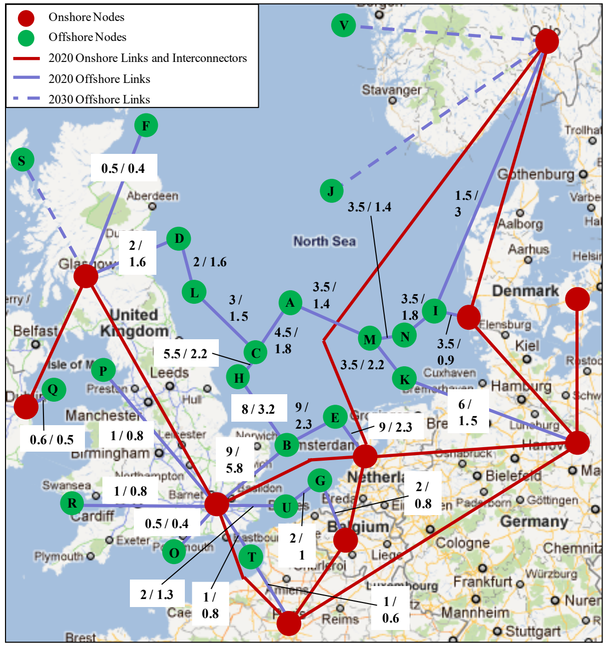
e.g. How to accommodate 40 GW of offshore wind in British waters by 2030?

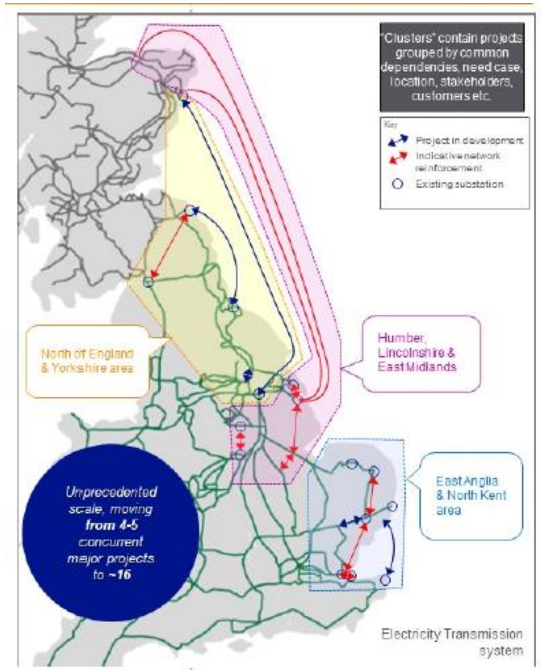




https://www.thecrownestate.co.uk/en-gb/what-we-do/on-the-seabed/offshore-wind-leasing-round-4/



TWENTIES project, 2012



NGET, 2021

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

- How will power get across the onshore network?

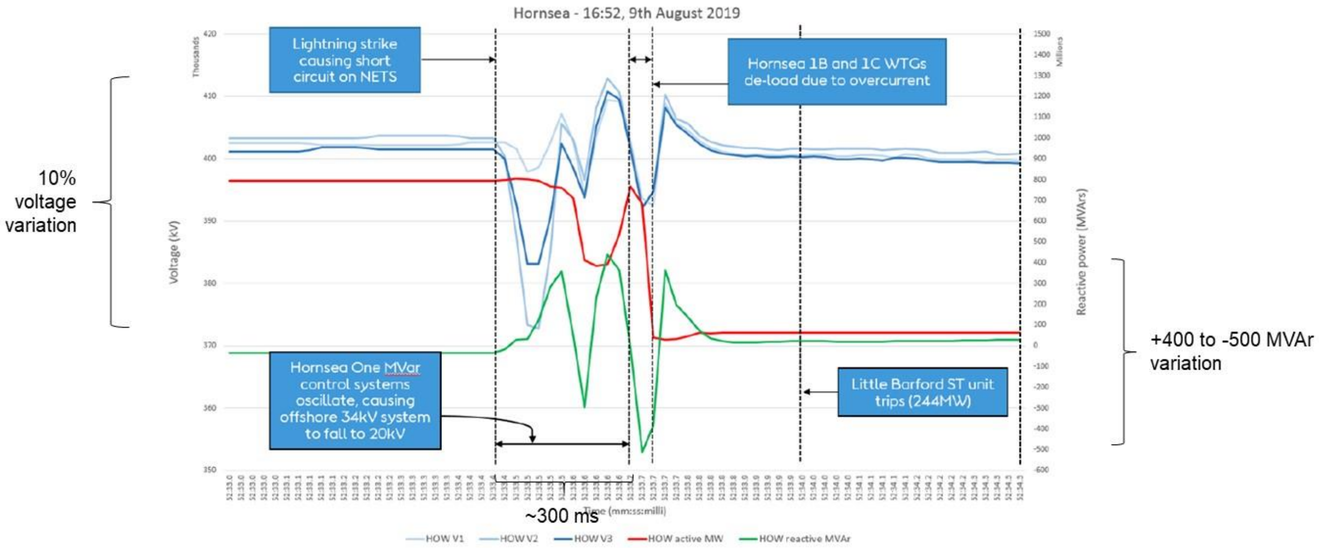
Resilience of the network to extreme weather? (What else is needed to preserve essential services?)

Coordinated offshore and onshore network design and 'anticipatory' investment?

6. Managing control interactions

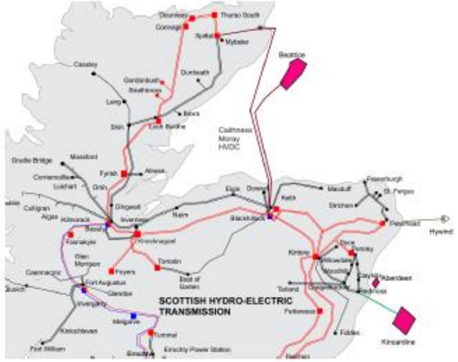
August 9th, 2019

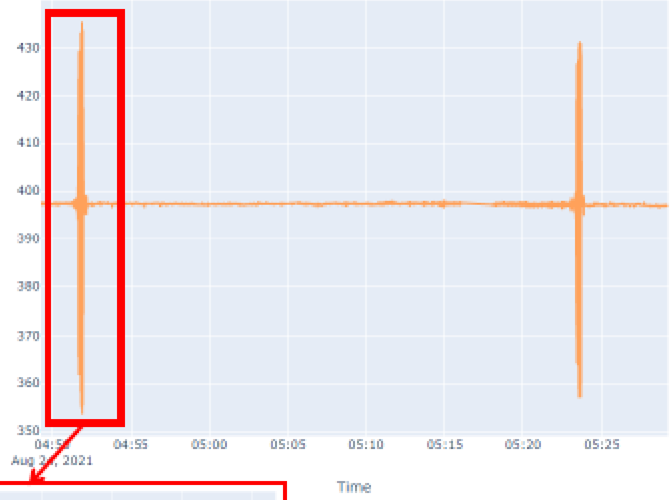
Voltages and reactive power at Hornsea 1 wind farm oscillated after the voltage dip had been cleared

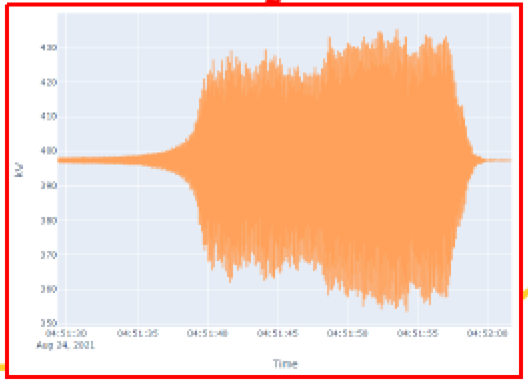


NG ESO Technical Report on the August 9 incident, Appendix D, Sept. 6, 2019

August 24th, 2021



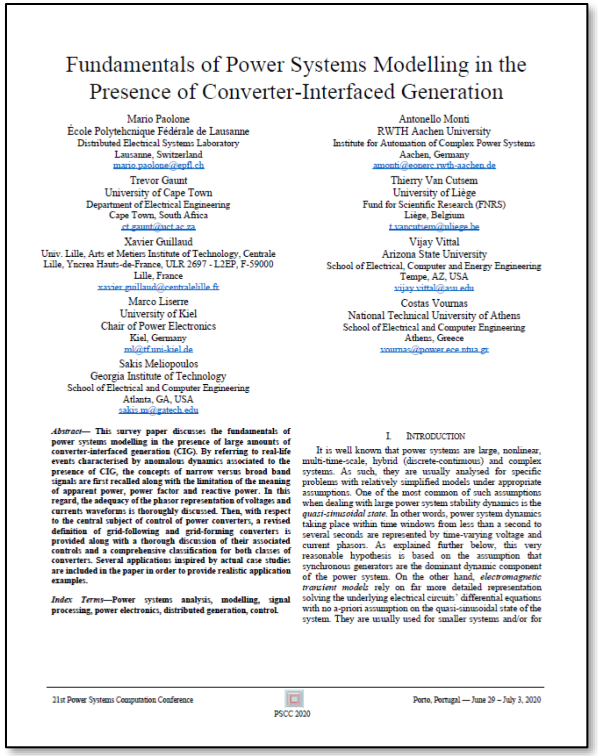




Julian Leslie, “Managing Declining Inertia and Short Circuit Levels”, *G-PST/ESIG Webinar Series: Managing Grid Stability in a High IBR Network*, January 2022

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



Fundamentals of Power Systems Modelling in the Presence of Converter-Interfaced Generation

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Abstract— **This survey paper discusses the fundamentals of power systems modelling in the presence of large amounts of converter-interfaced generation (CIG). By referring to real-life events characterised by anomalous dynamics associated to the presence of CIG, the concepts of narrow versus broad band signals are first recalled along with the limitation of the meaning of apparent power, power factor and reactive power. In this regard, the adequacy of the phasor representation of voltages and currents waveforms is thoroughly discussed. Then, with respect to the central subject of control of power converters, a revised definition of grid-following and grid-forming converters is provided along with a thorough discussion of their associated controls and a comprehensive classification for both classes of converters. Several applications inspired by actual case studies are included in the paper in order to provide realistic application examples.**

Index Terms—**Power systems analysis, modelling, signal processing, power electronics, distributed generation, control.**

I. INTRODUCTION

It is well known that power systems are large, nonlinear, multi-time-scale, hybrid (discrete-continuous) and complex systems. As such, they are usually analysed for specific problems with relatively simplified models under appropriate assumptions. One of the most common of such assumptions when dealing with large power system stability dynamics is the *quasi-sinusoidal state*. In other words, power system dynamics taking place within time windows from less than a second to several seconds are represented by time-varying voltage and current phasors. As explained further below, this very reasonable hypothesis is based on the assumption that synchronous generators are the dominant dynamic component of the power system. On the other hand, *electromagnetic transient models* rely on far more detailed representation solving the underlying electrical circuits' differential equations with no a-priori assumption on the quasi-sinusoidal state of the system. They are usually used for smaller systems and/or for

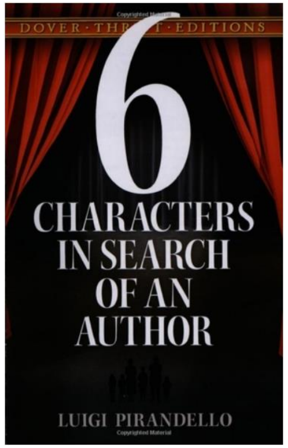
What I've not talked about

- 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