GB System Operation with increasing penetration of Power Electronic Converters

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National Grid Electricity System Operator (ESO)

- National Grid ESO runs the electricity system in Great Britain (England, Wales and Scotland) and ensures that electricity is transported **safely**, **securely** and **reliably** on the transmission network.
- In 2017, Ofgem, BEIS and National Grid plc agreed to create a legally separate business and since 1 April 2019, National Grid ESO became a separate entity within the National Grid Group.
- Separating the ESO business from National Grid Electricity Transmission provides
  - transparency in our decision-making, and
  - gives confidence that everything we do will **promote competition** and is ultimately for the **benefit of consumers** and **industry stakeholders.**

Ensure a reliable & secure system to deliver energy	**Unlocking Customer Value through Competition**	**Enable & support the drive to a sustainable whole energy future**	**Driving innovation and participation**	**Develop people and systems**

Contents

The Energy Transition

- The energy landscape is undergoing fundamental change due to decarbonisation, decentralisation and digitisation.
- In June 2019, the UK government committed to a net zero carbon target by 2050, a change from the previous target of 80% reduction from 1990 levels.
- Significant Offshore Wind Sector deal agreed.
- National Grid ESO’s ambition is to be able to operate a zero carbon electricity system by 2025
- Significant milestones from a network operation perspective observed since 2017

Coal Free Operation for >18 days

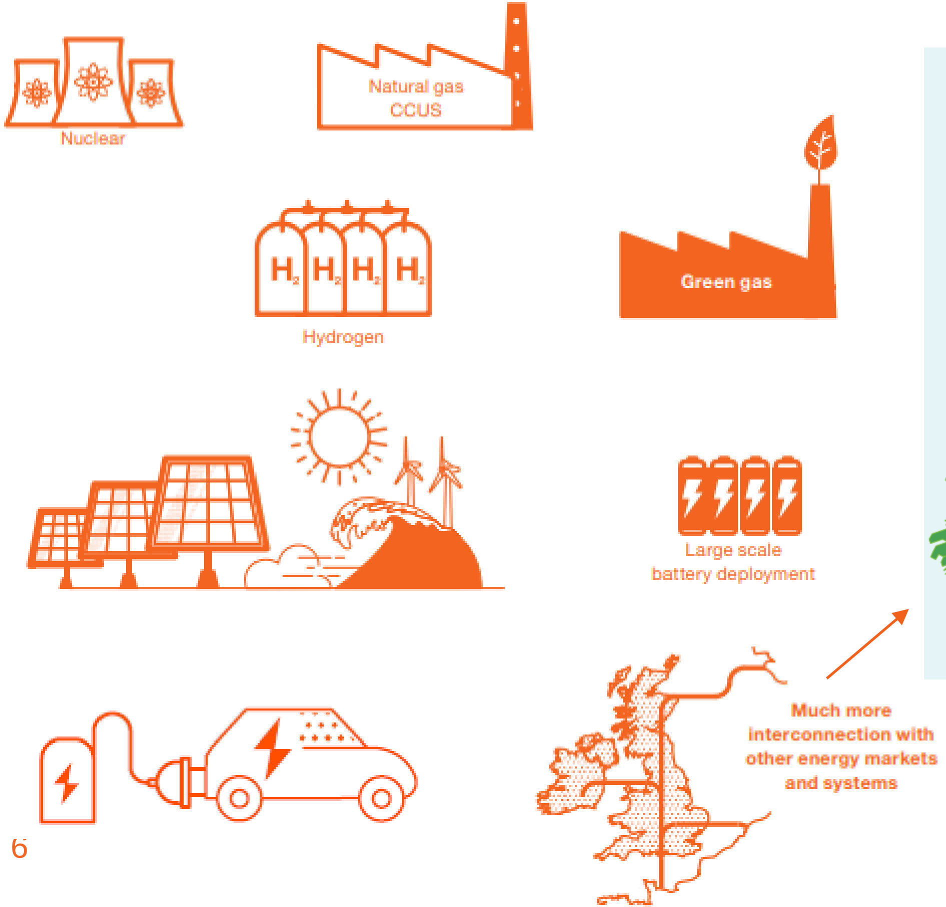
Solar generation at record high

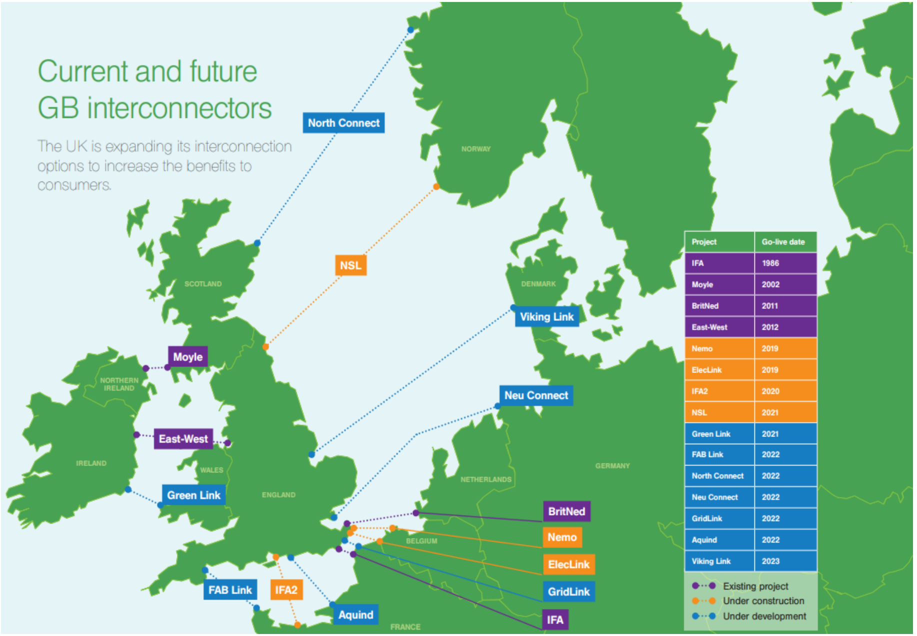
Transmission demand lowest during the day than overnight

Low carbon sources meeting ~ 60% demand

2018 saw lowest carbon intensity winter

The Energy Transition





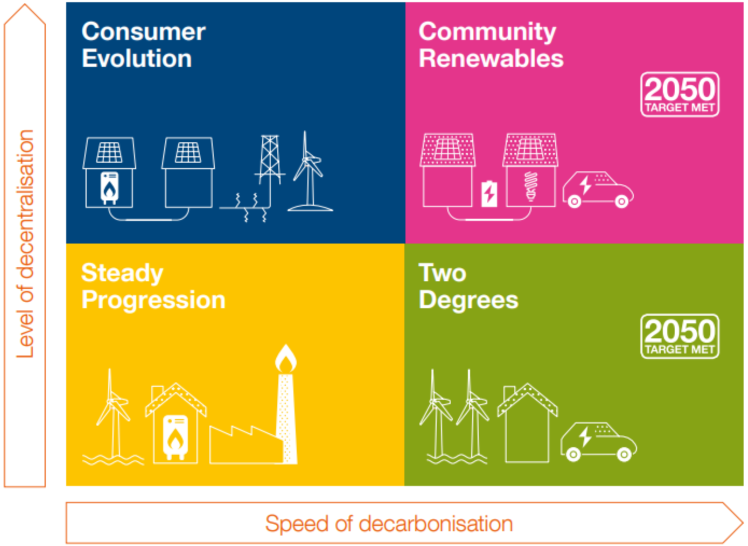
Project	Go-live date
IFA	1986
Moyle	2002
BritNed	2011
East-West	2012
Nemo	2019
ElecLink	2019
IFA2	2020
NSL	2021
Green Link	2021
FAB Link	2022
North Connect	2022
Neu Connect	2022
GridLink	2022
Aquind	2022
Viking Link	2023

National Grid Group: Interconnectors- connecting for a smarter future booklet

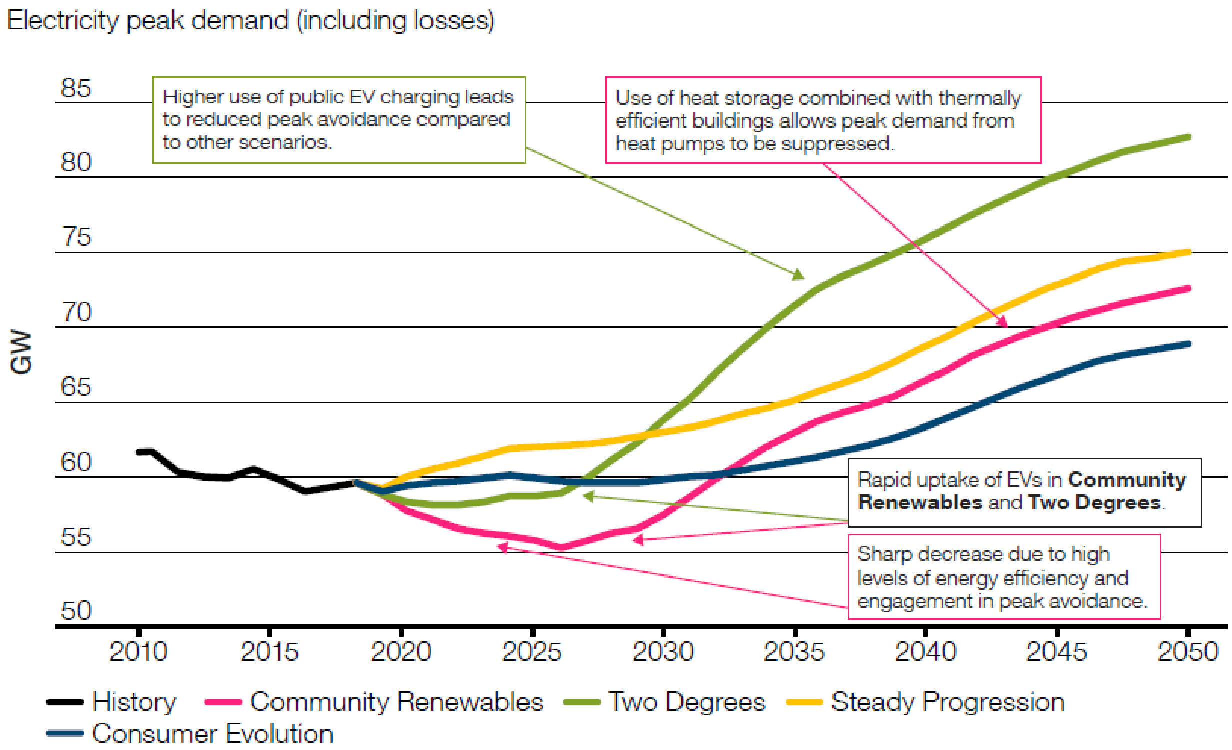
Contents

Future Energy Scenarios (FES)

- Identifies a range of credible demand and generation scenarios for the next 30 years
- Actual trajectory will depend on progress across the following external areas:
  - Policy Support
  - Consumer Engagement
  - Economic Growth
  - Technology Development
  - Energy Efficiency

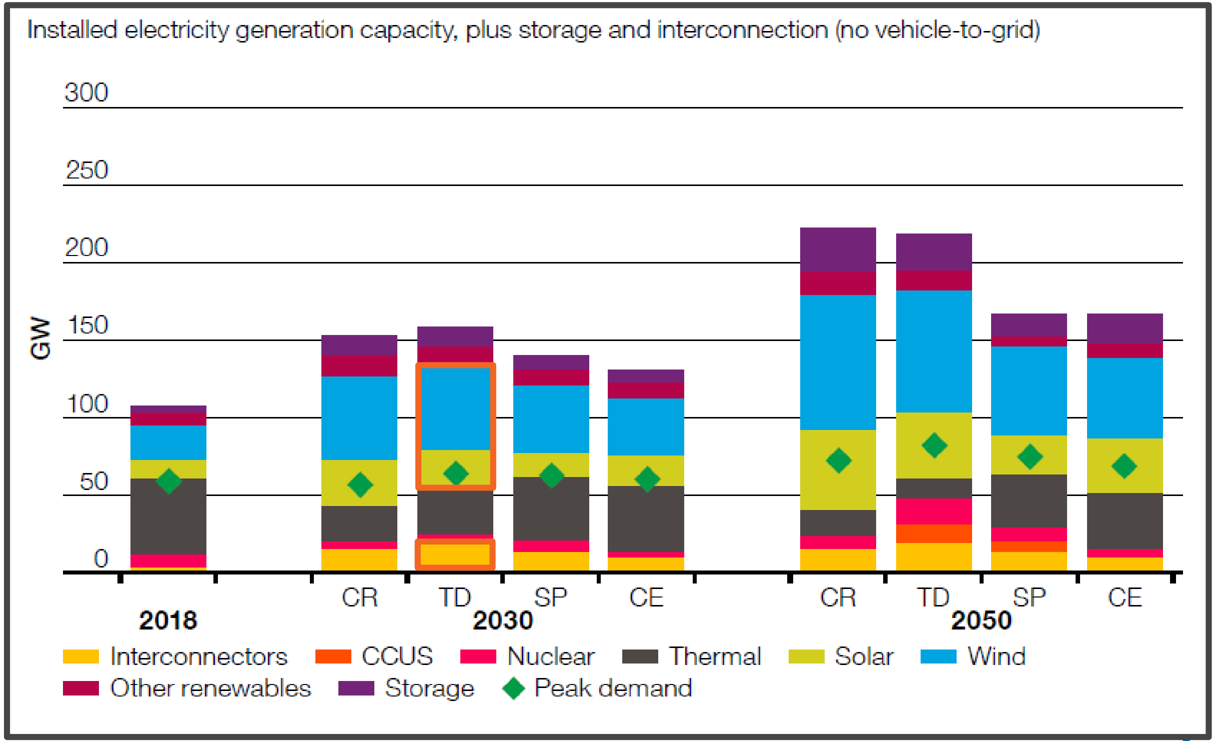


FES 2019 Peak Demand



FES 2019 Generation Capacity

In the Two Degrees Scenario for 2030, wind, interconnectors and solar generation could account for ~60% of the total generation capacity



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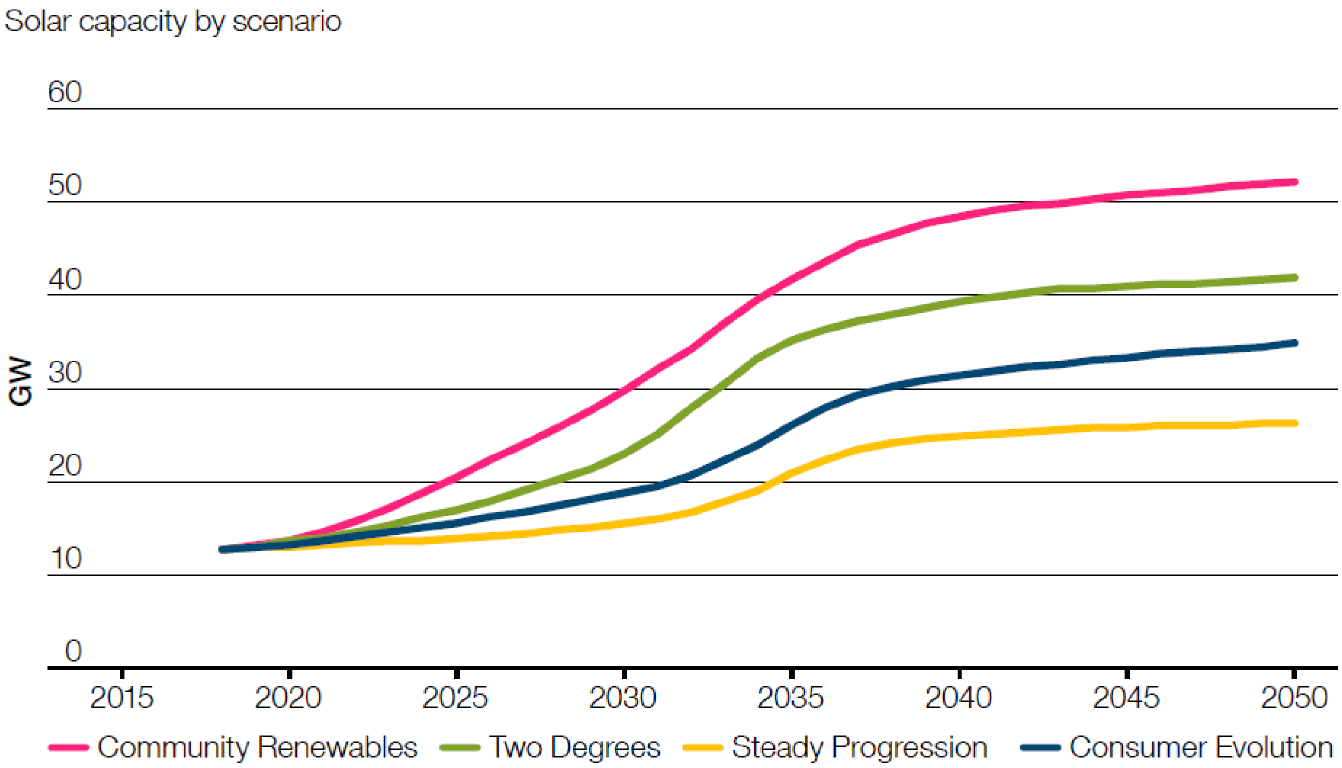
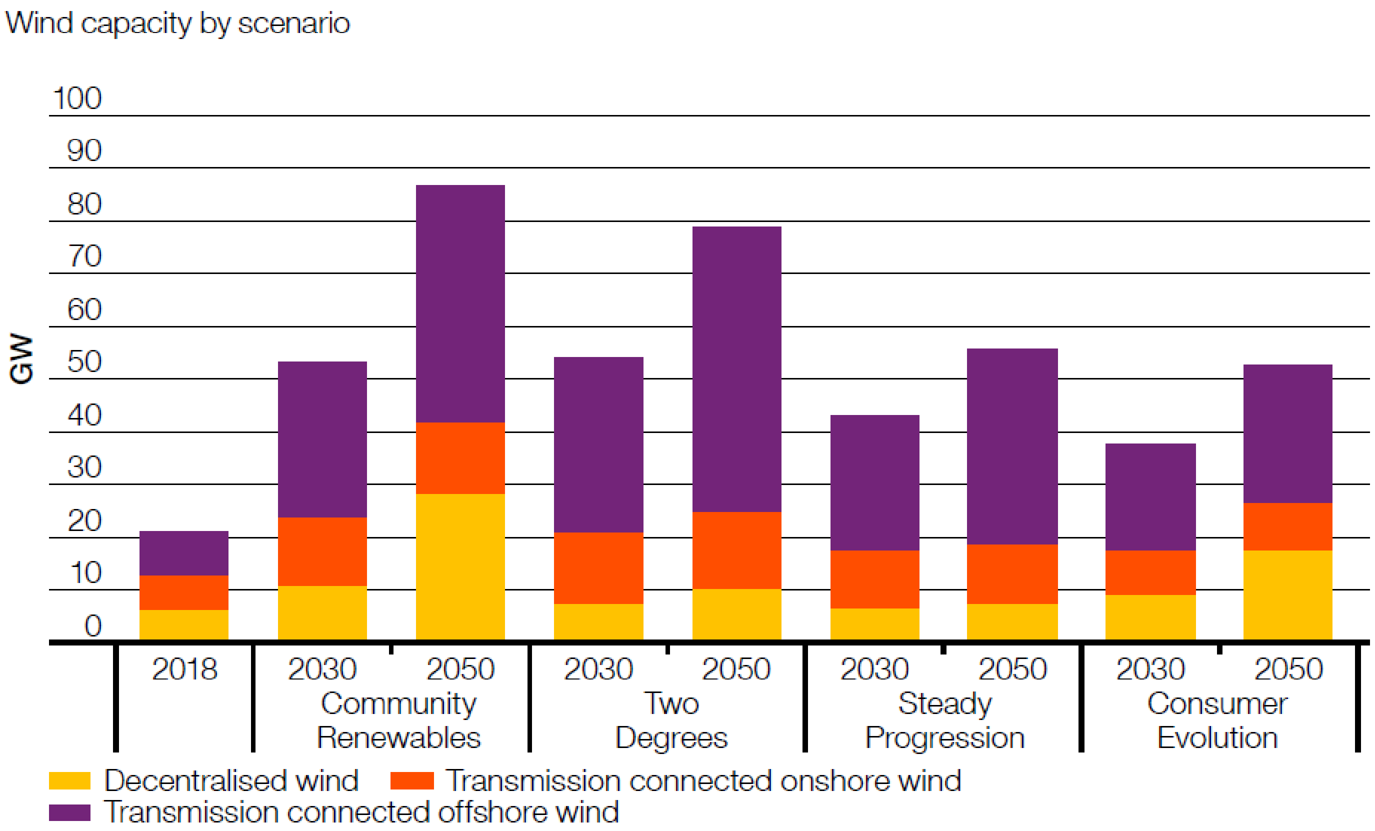
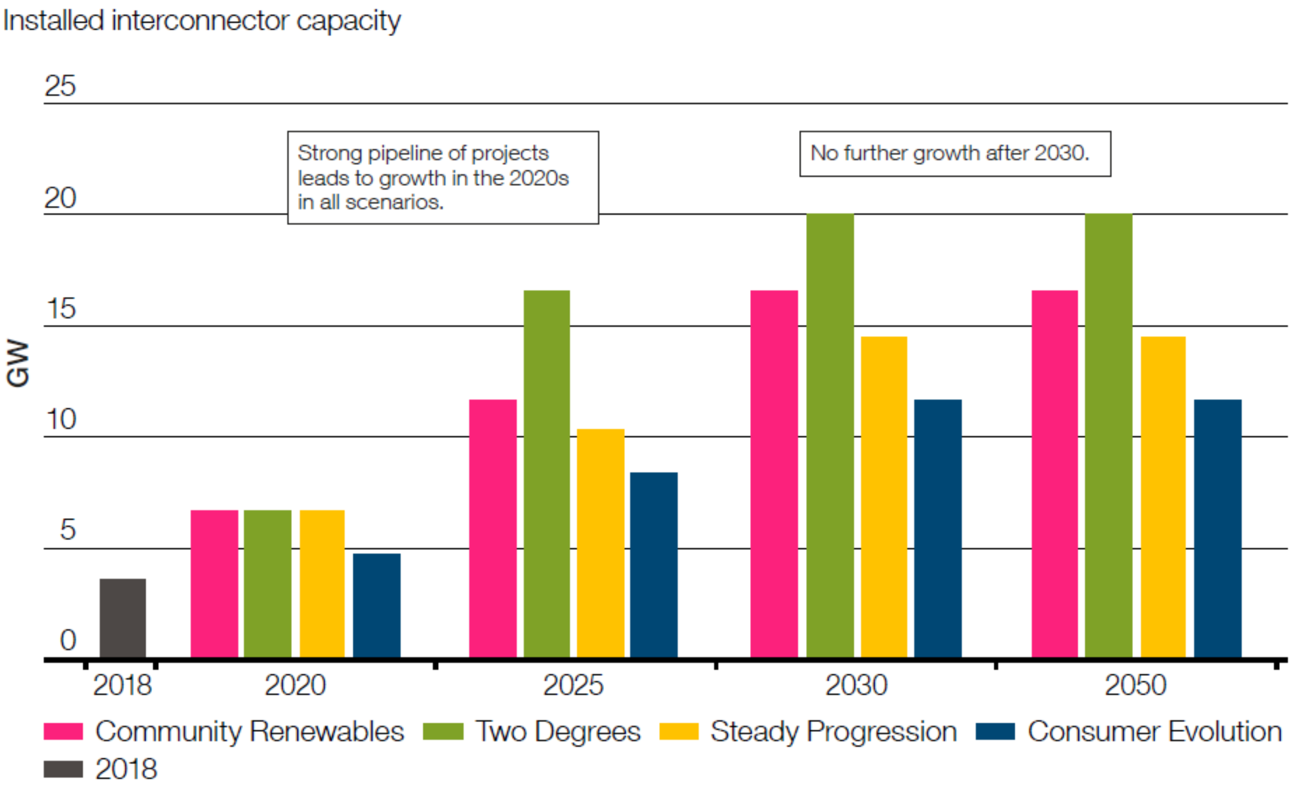
FES 2019 Solar Capacity



FES 2019 Wind Capacity



FES 2019 Interconnector Capacity



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Trends and Impact

- Higher non-synchronous generation
- More HVDC interconnection
- Reduction in synchronous generation output
- Increase in FACTS devices
- Increase in inverter based embedded generation
- Reduction in motor demand
- Lower net transmission demand

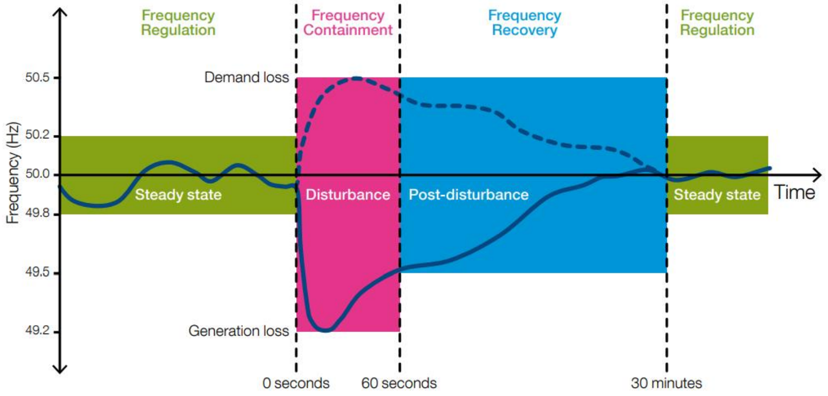
→

- Frequency Management
- Short Circuit Levels
- Voltage Management
- Control Interactions

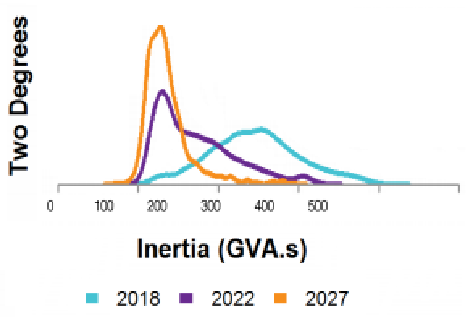
The inherent “stabilising” properties of the synchronous machines are gradually being removed from the system. Inverter based generation do not inherently have these stabilising properties e.g. inertia, fast fault current contribution etc.

Frequency Management

- The ability of a system to stabilise the frequency immediately after an imbalance is dependent on the inertia of the system.
- The increasing penetration of inverter based generation is gradually causing a reduction in system inertia.
- Frequency will move faster and can have regional variations following an imbalance, which makes frequency containment more challenging.
- The proportion of time during which the system will run at lower inertia levels will increase, so will the size of the largest loss.
- New frequency response products, faster frequency response, real-time inertia monitoring and calculation tools and measures to increase system inertia (pathfinder, Phoenix) are projects being run by the ESO to address these challenges.



Annual Distribution - National Inertia



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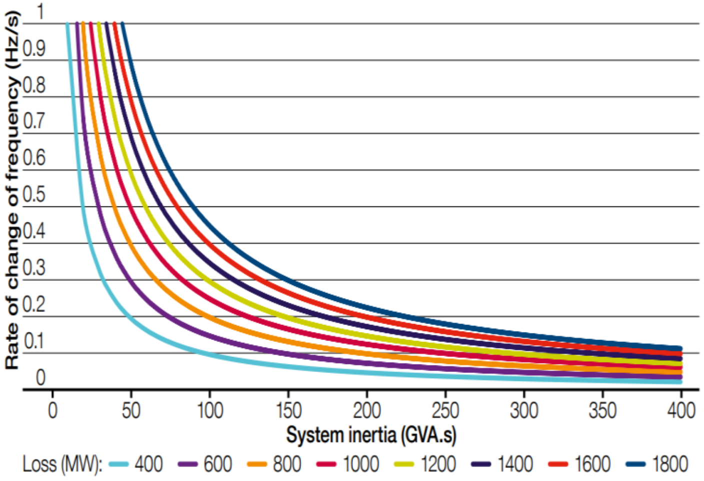
System Inertia – impact on RoCoF

- Loss of Mains protection based on measuring RoCoF could trigger the disconnection of embedded generation.
- Typically NGESO would contain the largest credible loss e.g. by repositioning interconnector flows or curtailing the output of the large generators.
- Increasing system inertia by buying on synchronous plants is in most cases not the most economic option.
- Accelerated loss of mains protection changes:
  - Removal of Vector Shift based protection
  - RoCoF setting changed to 1Hz/s measured over a 500ms window.
- Stability Pathfinder is seeking additional sources of inertia



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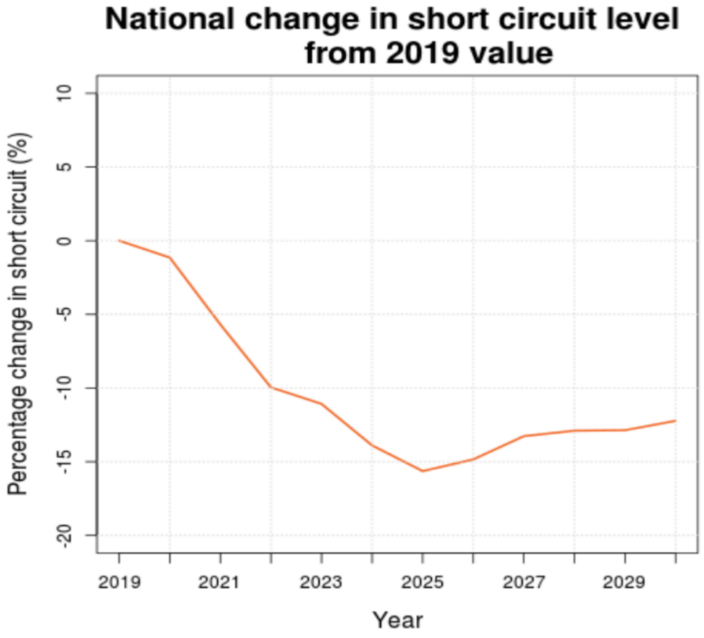
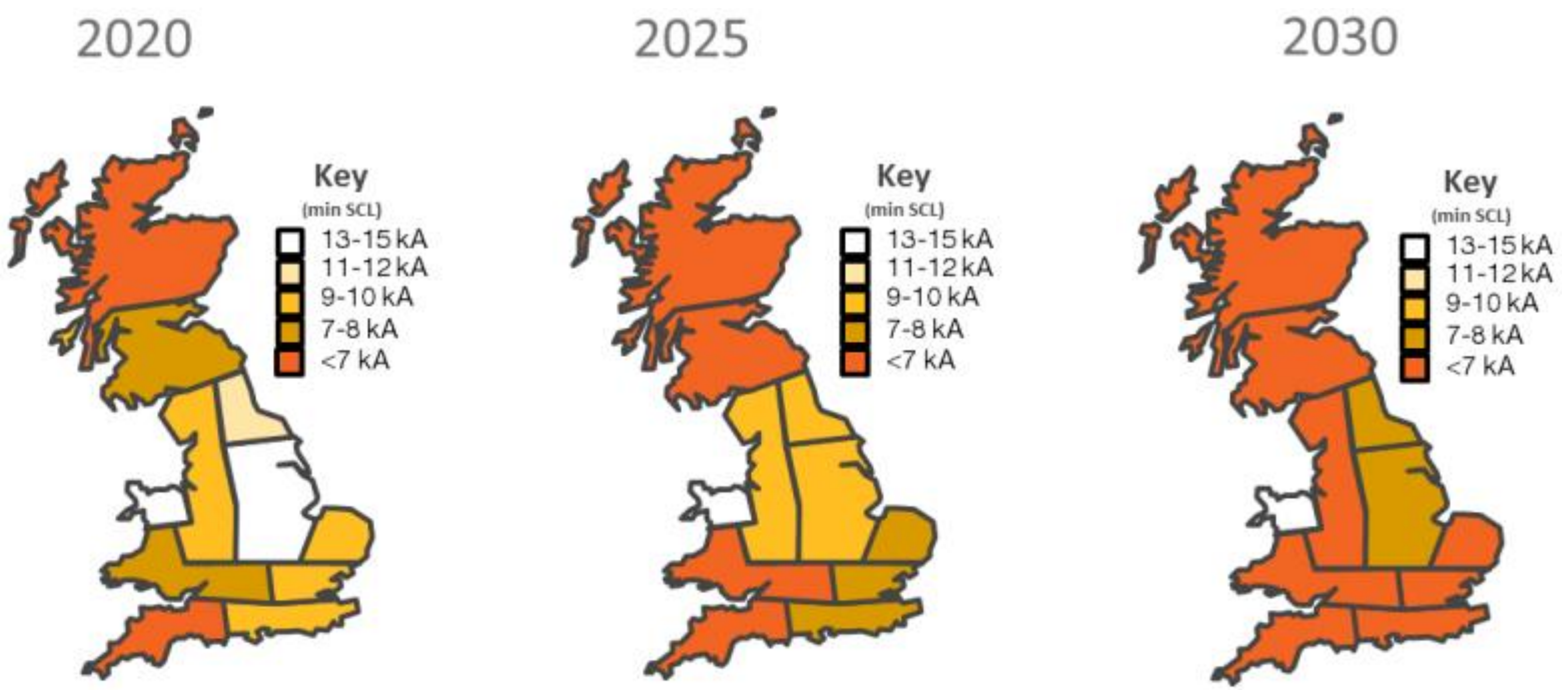
Short Circuit Levels (SCL)

- A measure of system strength i.e. how resilient the system is to disturbances.
- System Strength is regional property of the system and depends on the local distribution of in-feeds.
- 2018 assessment indicates the average rate at which the minimum SCL is set to decline across the four scenarios, mainly due to the decline of synchronous generation in the early years.
- Impact on protection systems
  - mainly overcurrent protection could be at risk i.e. protection taking longer to operate or not operate as designed.
  - Stability Pathfinder is seeking additional sources of short circuit level

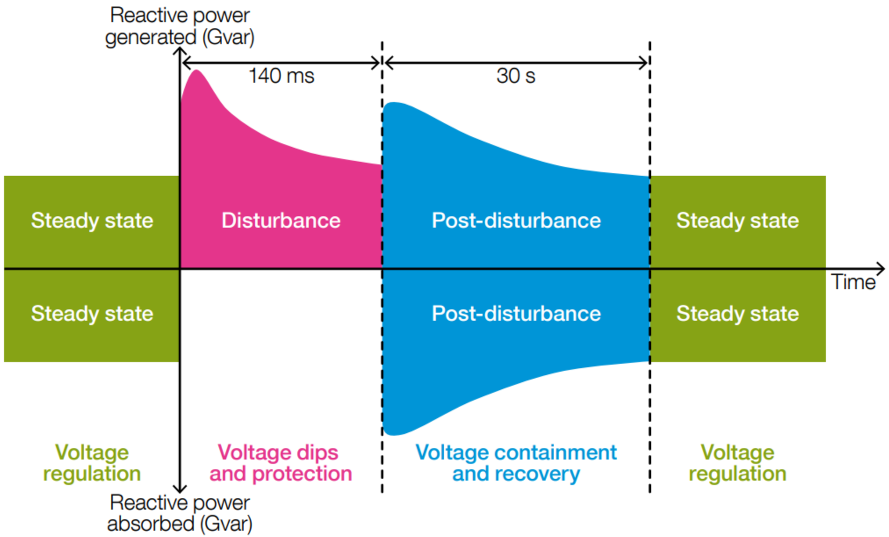


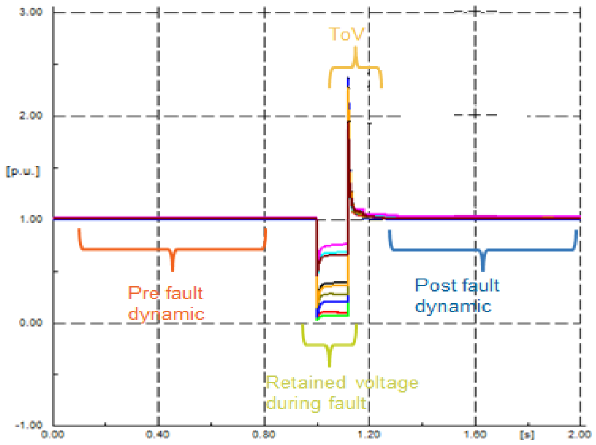
Short Circuit Levels (SCL)



Voltage Management

- Steady State and Dynamic voltage regulation
- Retained Voltage during a fault
- Voltage Recovery
- Temporary Over Voltage (ToV)





- Static and Dynamic sources of reactive power required.
- Fast reactive current injection required during and post fault

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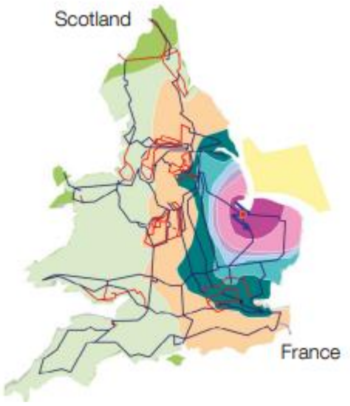
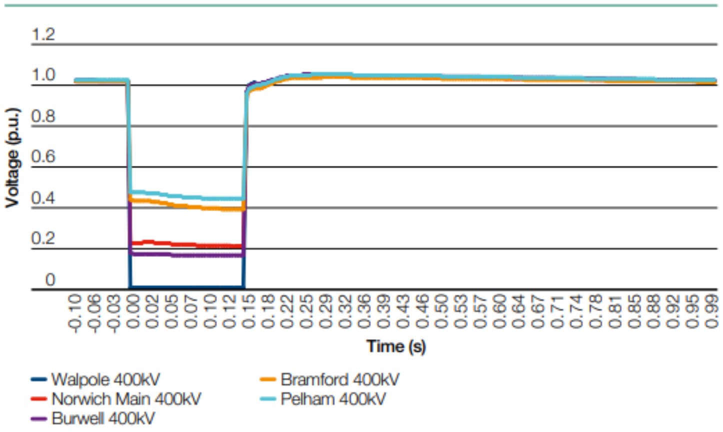
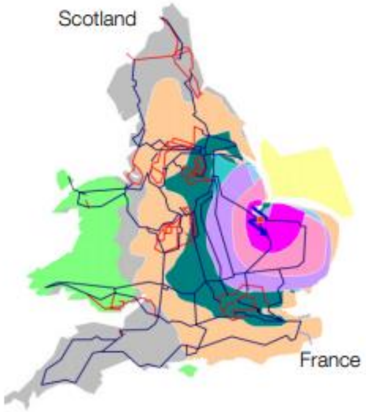
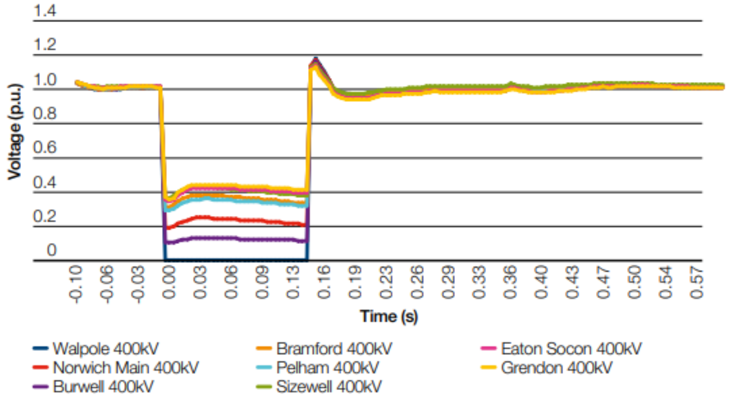
Retained Voltage





Synchronous generation System





Inverter-based generation system

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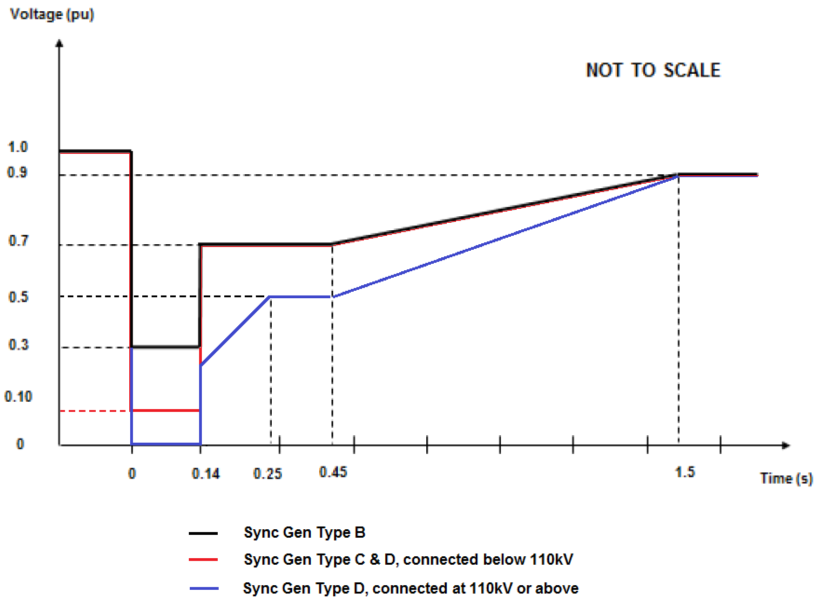
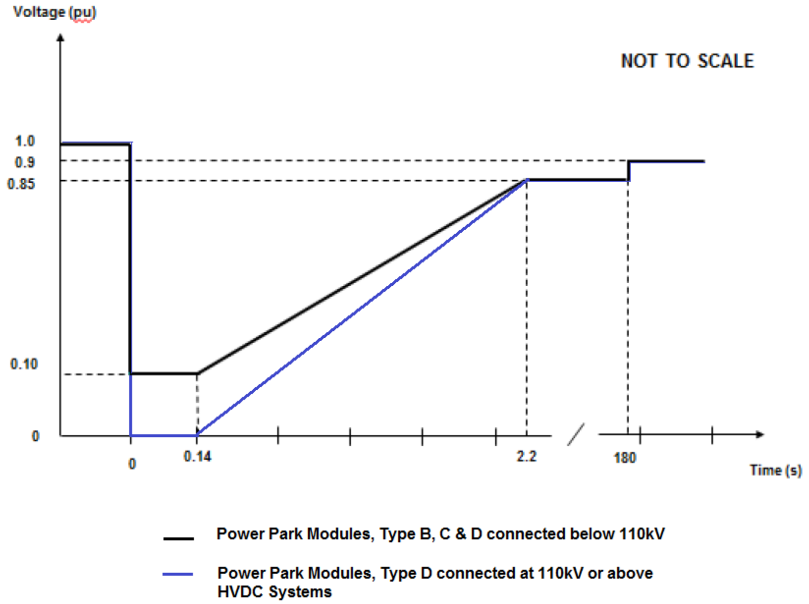
Fault Ride Through Requirements



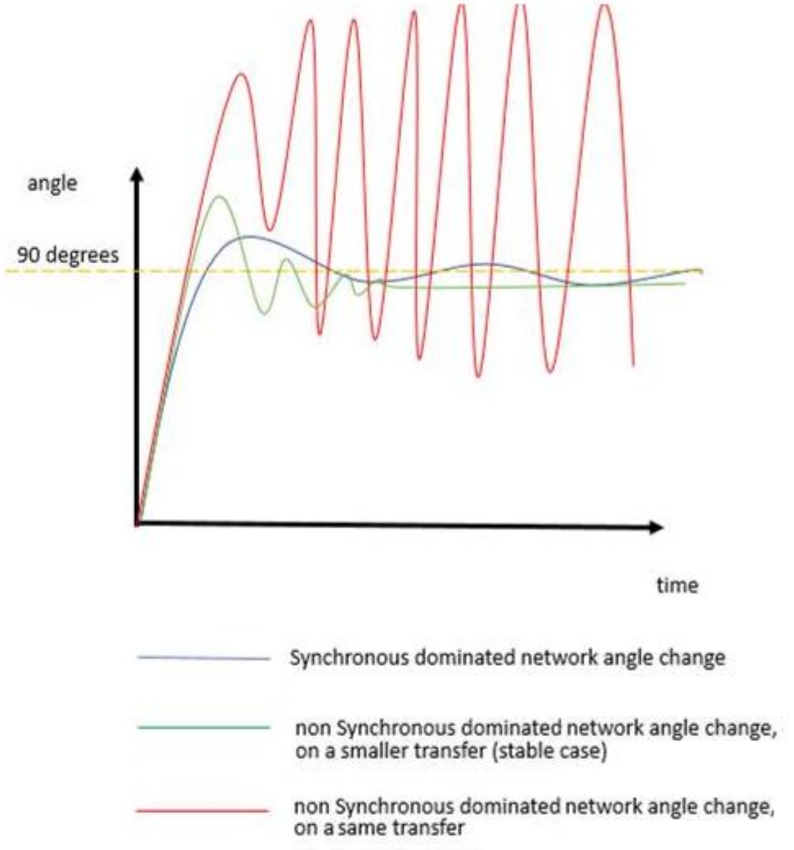


Synchronous

Inverter-based

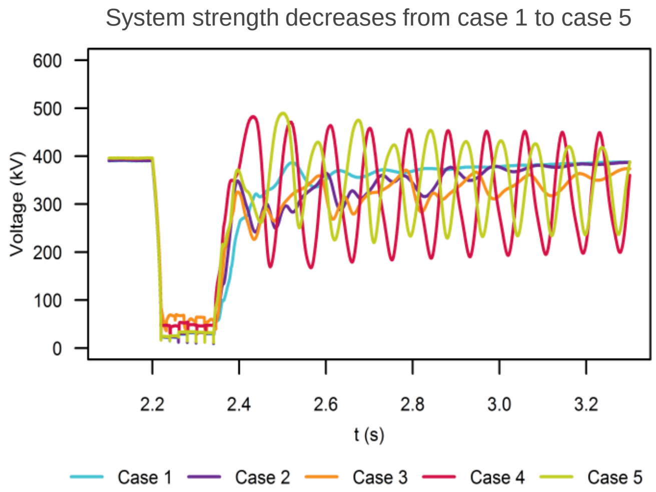
Voltage Angles

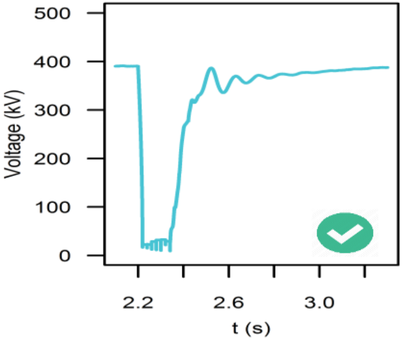
- Under low levels of synchronous generation, larger and faster voltage angle changes are observed for the same power transfer
- Increased impact on vector shift
- The transient rather than sustained angle movement impacts non-synchronous generation, leading to out of phase and latent tracking of angle.
- Critical level of **transient** angle movement appears to be around 90 degrees- this suggests stability boundaries when driven by converter lead instability can be sharper than conventional instability

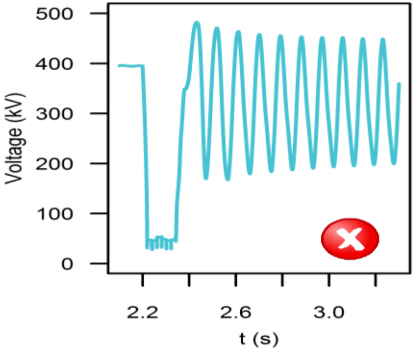


Impact on Phase-Locked Loop Stability

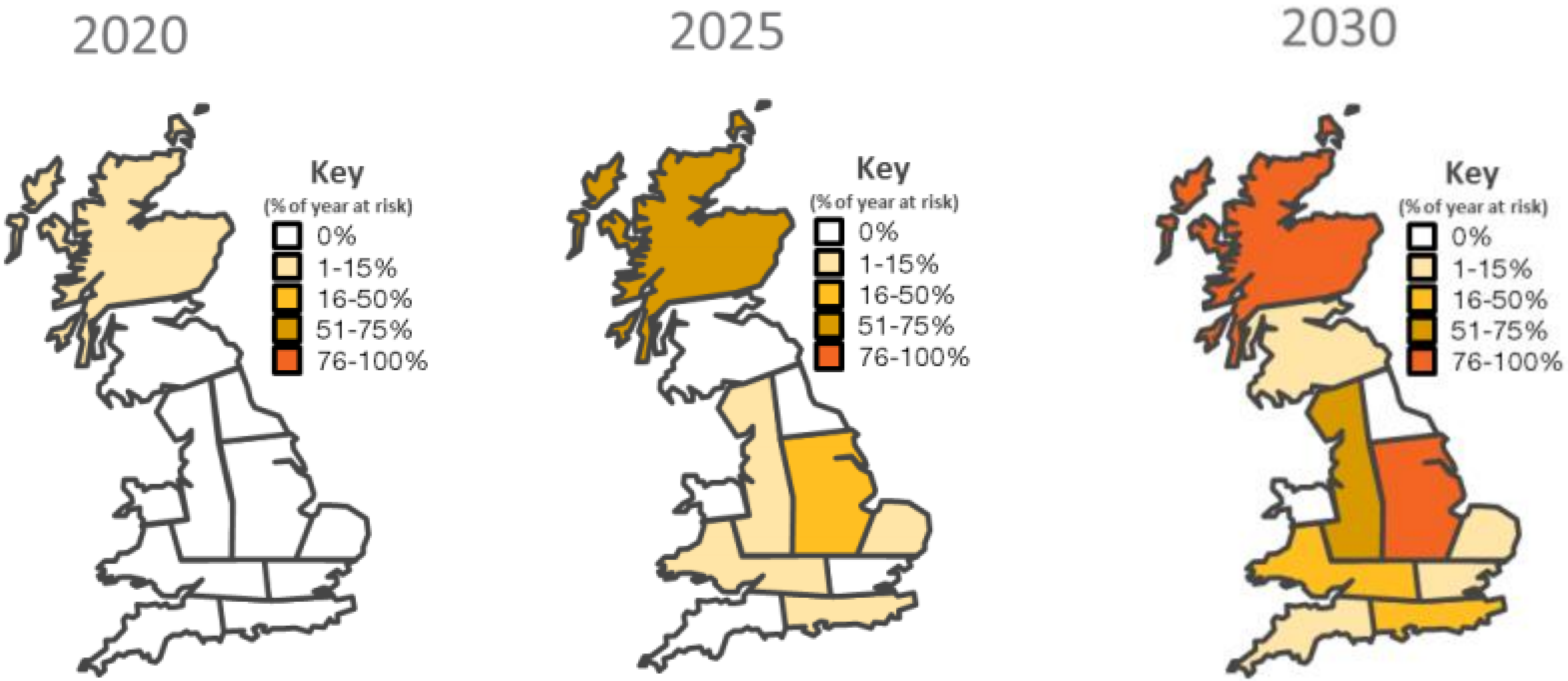
- Most Power Electronics-based generation rely on Phase-Locked Loop controllers to maintain synchronism to the network.
- They measure the voltage waveform and frequency of the network to provide a phase reference to inverters which controls its respective active and reactive power output.
- Under low system strength conditions, the voltage waveform during a fault can become more perturbed, causing PLL to lose track of the network.
- No single set of PLL gain settings (K_p and K_i) was found to guarantee converter stability under all system strength conditions.





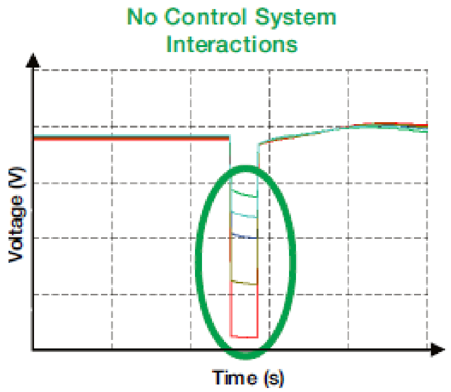


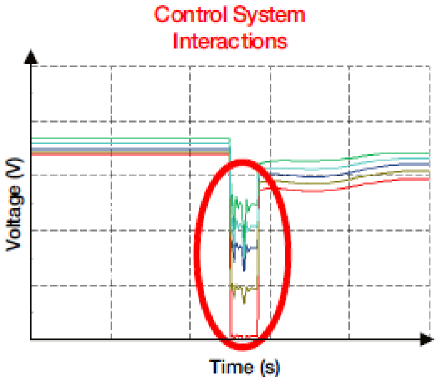
Risk of mal-operation of PLL



Control Interactions

- The possibility for the control systems of power electronic devices to interact with the network or with each other, causing voltage distortions, converter tripping or damage.
- This can be more pronounced under weak systems and where the local penetration of inverter based generation is high.
- Conventional RMS studies very often do not capture the control interaction between converters. Detailed EMT modelling and analysis is required to detect identify occurrences of control interactions.
- Interaction analysis is mostly carried out at the time of new connections on the grid but needs to be reviewed as models are updated and system conditions change.
- We are working on better understanding this risk in specific areas of the GB system where converter penetration is high.





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Pathfinders

- The pathfinders are part of the network development roadmap which is looking at how we can improve our network options assessment (NOA) methodology to consider more systems issues and a wider range of possible solutions.
- By adopting a trial-by-doing approach, the pathfinders aim to:
  - better assess and define our requirements for services required to e.g. stability, reactive power requirements etc.
  - develop an approach for requesting and comparing whole system market-based solutions with conventional network solutions.
  - assess a variety of different solutions on a technical basis and commercial basis to establish the most economic approach to meeting our network requirements.
  - Inform Ofgem of policy and regulatory changes that would be required to enable competition to happen seamlessly across the electricity industry.

Pathfinders

Criteria	Stability	Voltage
Location	National (Phase 1) Scotland (Phase 2)	Mersey Ring
Service	Inertia Fast Dynamic Voltage Short circuit level	Static reactive power
Timescales	Phase 1: Start Apr 20 – Apr 21 End Mar 23 or Mar 26	Short Term Apr 20- Apr 21 Long Term Apr 22 – Apr 31
Requirement	25 GVA second	Short Term 200MVAr Long Term 230MVAr
Connection	132 kV and above	33kV and above
Availability	24/7	Short Term: Overnight Long Term: 24/7
Providers	TO, DNO and Commercial	TO, DNO and Commercial

Key Considerations for Pathfinders

- Requirement Definition – Where, when and how much?
- Specification of minimum technical criteria

- Economic Assessment
- Effectiveness Assessment
- Feasibility Assessment

- Whole System solutions
- Technology Neutral
- Technology Readiness Level

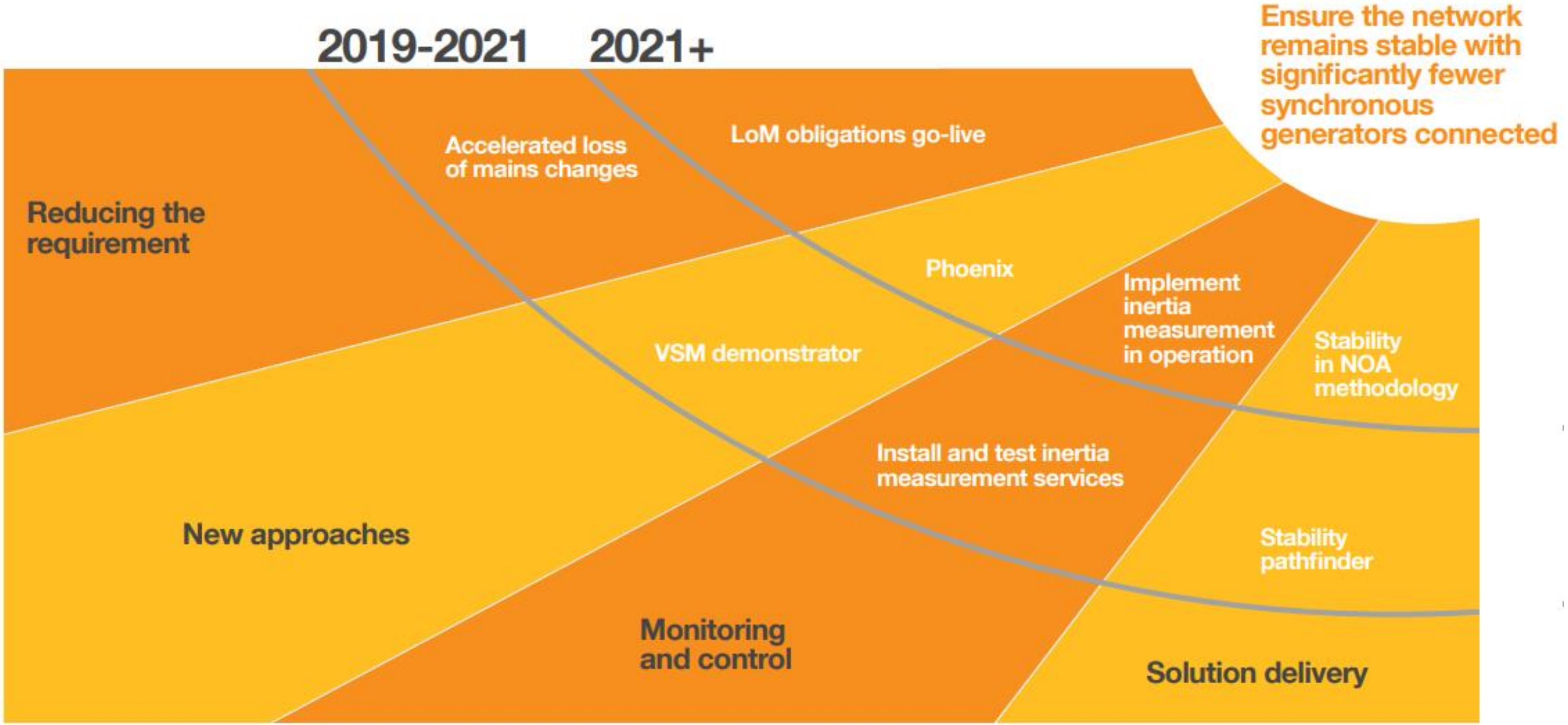
- Penalty terms for not delivering the service
- Metering and Settlement
- Contract Structures
- Testing Requirements

- Transparency
- Ensure level playing field
- Promote Competition
- Whole system Collaboration

Stability Pathfinder- Technical Requirements

Static & dynamic voltage requirements	Able to withstand voltage within SQSS limits Voltage Droop response of 4% or better ToV withstand and absorption
Short circuit level requirements	Short circuit level contribution (MVA) ≥ 1.5 p.u. of MVA available in steady state operation Fast reactive current injection of at least 1p.u within 5ms of disturbance Guarantee performance across a range of min short circuit level
Frequency & Inertia	Inertia (MVA.s) ≥ 1.5 p.u. of MVA available in steady state operation Able to operate within the frequency range of 47-52 Hz Robust to RoCoF ≤ 1 Hz/s averaged within 500ms window
Other	Active and Reactive Power Oscillation Damping Capability Prioritisation of reactive power over active power to help voltage during fault Meet Fault Ride through requirements Ride through voltage angle deviations during and post fault and resist angle deviations during a fault Details of multiple fault ride through capability

Roadmap- Key activities



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Virtual Synchronous Machines/ Grid Forming Converters

- Essentially a voltage source behind an impedance.
- Innovative converter control strategy allowing inverters to mimic certain behaviours of synchronous generators.
- Provides stabilising properties such as inertia, short circuit contribution and fast acting dynamic voltage support.
- Stability service can be provided by either by de-loading equipment or fitting storage to the converters. Current limiters are used to protect the converter within its rating.
- Control strategy can be deployed to a range of inverter based generation (Wind, Solar, batteries, HVDC etc.)
- VSM can be a very useful tool as part of the suite of solutions that can help to enhance the stability of the system

Innovation Projects

Power Nova "invertor-led instability" work
This project completed in 2018, and demonstrated the risk of an "invertor-led" form of voltage instability, requiring EMT level modelling to define accurately. The work demonstrated that presence of sufficient synchronous compensation or equivalent support removes this risk

University of Manchester EFCC work.
Within the Work Package 3 of EFCC completed in March 2019, Virtual Synchronous Machine controls were introduced into a 36 bus GB network model to illustrate how VSM could successfully contribute to overall faster co-ordinated frequency control.

University of Nottingham VSM Demonstrator
To support the Grid Code expert workgroup, this project has constructed a "lab scale" physical virtual synchronous machine which will help us to better understand the considerations associated with defining the capability of this potential solution in practice

UoS Hybrid Grid Forming Convertor
The project aims to understand the behaviour of grid forming convertors when applied across a wind farm as a whole rather than at each individual turbine. The results of the project will also inform the development of balancing services or mandatory requirements, particularly related to power quality.

UoS Battery VSM practical demonstration work.
This project will test a specific manufacturer and developer VSM proposal, using an actual physical solution of battery and convertor within the Power Networks Demonstration Centre; complemented by modelling which is validated against physical tests and offers an opportunity for compliance test conditions to be developed together with certainty of models and performance.

Phoenix Project
This project is looking at the technical and economical benefits of installing a hybrid synchronous compensator in Scotland. The project will also look at the benefits of deploying the solution in key areas of England and Wales.

VSM Implementation

- We understand in principle what VSM technology could do- facilitating its implementation is the next step.
- A VSM expert workgroup has been set in 2018 up to define a minimum specification for VSM/Grid forming capability.
- A draft VSM specification has been created which provides a good starting point for discussions within a Grid Code Workgroup.
- The next step will be to set up such a Workgroup and raise a modification proposal to include an agreed minimum VSM specification in the Grid Code.
- Having a minimum specification ensures that providers wishing to provide this service can design their equipment to meet a minimum standard which will give the confidence to the ESO that the stabilising properties will be delivered in a way that will benefit the system.
- VSM is not the only solution. National Grid ESO is committed to identifying the most cost effective set of solutions that will enable the transition to a zero carbon system.

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Conclusion – Key Takeaways

- The drive towards a low carbon future will change how the GB system is operated.
- We will continue to plan for the future by analysing the range of future scenarios and what they mean for the operation of the GB system.
- We are adopting a learning-by- doing approach through the various pathfinders to develop and test the processes from defining the system requirement all the way to procuring the most cost effective set of whole system solutions through competition.
- The learnings from the pathfinders will feed into the NOA process.
- This will ensure that we have the right solutions in place at the right time, at the right location and at the right cost to keep the GB system secure, reliable and economic for all our consumers.
- Industry collaboration is key to make our collective journey towards zero carbon a success, so if you have any ideas or insights on future challenges, solutions or our forward plans, please do come speak to us.

Thank you for listening

Email us your questions, feedback or suggestions on

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