Operability Strategy Report

A System Operability Framework document

November 2018

nationalgridESO

How to use this document

This *Operability Strategy Report,* part of our suite of System Operability Framework documents, has been written to help put into context the current operability challenges the ESO faces and how these are likely to change in the future.

It also outlines the work that we have been doing across these challenges and what further work is required. This has been written for an audience of experienced energy industry professionals although the content in general may be of interest to a wider audience. This report is not intended to be a detailed technical analysis, however, some of the topics are quite technical in nature. More detailed analysis of many of these topics can be found in the *System Operability Framework* reports.

We have split the report into an introduction, giving a high-level context of the role of National Grid as electricity system operator, followed by five further chapters. These chapters cover the five key operability areas of frequency control, voltage control, restoration, stability and thermal.

Within each chapter, we will:
- introduce the area – a brief description of the topic and what is changing
- discuss the current and future operability gap – describing our current strategy for managing this area and explaining the need for that strategy to change
- cover progress so far and plans for future work – explaining what we are doing to move from our current strategy to our future strategy.

How to use this interactive document

To help you find the information you need quickly and easily we have published the *Operability Strategy Report* as an interactive document.

Home button
This will take you to the contents page. You can click on the titles to navigate to a section.

Arrows
Click on the arrows to move backwards or forwards a page.

Hyperlinks
Hyperlinks are highlighted in **bold text and underlined** or located in the footnotes throughout the report. You can click on them to access further information.

Contents

Executive summary

This *Operability Strategy Report* seeks to highlight the challenges we face in maintaining an operable electricity system, and summarise the work we are undertaking to ensure we meet those challenges.

As electricity system operator (ESO), we keep the power flowing. This requires us to ensure that supply meets demand, at all times. It also requires us to maintain the security of the network, ensuring that voltage levels are maintained, that the transmission system can be restored in a blackout, that the system is stable and that network assets are not overloaded.

Decentralisation and decarbonisation are leading to more generation connecting to the distribution network and generation from fossil fuels being replaced by renewable generation. These changes are impacting how we operate the system now and into the future.

Part of our role is to ensure that we can continue to economically maintain operability. Our *Operability Strategy* seeks to find the most efficient route for doing this through a combination of changes to industry codes and regulations, developing how the network is designed, and the development of our commercial and operational tools.

We have identified frequency, voltage, restoration, stability and thermal as our core security areas. This report includes a section on each security area which explains the operability gap and the solutions under development for that topic. The table on the following page outlines the key developments for each security area across the different delivery areas.

Topic	Codes and regulation	Network	Commercial and operational tools
Frequency control	• Implementation of pan-European response and reserve services • Wider access to the BM delivered through modifications for Project TERRE		• New response services • Response auction trial • Reserve review
Voltage control	• Removal of ERPS from the CUSC	• Trial comparison of network and commercial solutions in the *Network Options Assessment* through pathfinder projects	• Requests for information in South Wales and Mersey
Restoration	• Assisting in the development of a restoration standard • European code developments – Consultation on System Defence and System Restoration plans for GB	• Investigation of restoration approaches using generation in DNO networks • Review of restoration plans with TOs and DNOs	• Increasing transparency • Broadening participation in balancing services • Trialling alternative approaches for procurement
Stability	• Changes to generator protection settings in grid code and distribution code • New fault ride through requirements	• Investigation into including stability requirements in the *Network Options Assessment*	• Operational RoCoF management • Regional vector shift relay changes
Thermal	• Wider access to the balancing mechanism	• Comparison of commercial and network solutions in the 2019 *Network Options Assessment*	• Regional development programmes

Stakeholder engagement

This is the first time we have published our *Operability Strategy Report* and we are keen to understand what information stakeholders would find most useful for us to share on this topic.

We would appreciate your views on what should be included in future reports.

Please tell us what you think

You can provide feedback on the report by emailing **sof@nationalgrid.com**

Key publications relating to this report

Future Energy Scenarios

A range of plausible and credible pathways for the future of energy from today out to 2050.

Electricity Ten Year Statement

The likely future transmission requirements on the electricity system.

Network Options Assessment

The options available to meet reinforcement requirements on the electricity system.

Network Development Roadmap

Proposals on how to develop our network planning tools.

System Operability Framework

How the changing energy landscape will impact the operability of the electricity system.

System Needs and Product Strategy

Our view of future electricity system needs and potential improvements to balancing services markets.

Product Roadmap for Reactive Power

Our plan to develop reactive power products.

Product Roadmap for Restoration

Our plan to develop restoration products.

Transmission Thermal Constraints Management

Our plan for the management of thermal constraints.

Wider Access to the Balancing Mechanism Roadmap

Our plan to widen access to the balancing mechanism.

Electricity System Operator Forward Plan

This plan sets out what we will deliver over the year.

Chapter 1
Introduction

Introduction

We have written this *Operability Strategy Report* to help highlight the challenges we face in maintaining an operable electricity system, and the work we are undertaking to ensure we meet those challenges.

As Great Britain's electricity system operator (ESO) we are responsible for maintaining the continuous balance of electricity generation and demand, and operating to the National Electricity Transmission System Security and Quality of Supply Standard (SQSS).[1]

The GB electricity transmission system is a high voltage, alternating current transmission system. It has a target operating frequency of 50Hz and part of our role as ESO is to ensure that the system remains close to 50Hz and within strict limits to ensure safe and secure operation. If there is more generation than demand in any instant, then the frequency will rise above 50Hz and if there is more demand than generation the frequency will fall below 50Hz.

Frequency is not the only aspect of system operation that we need to monitor in order to ensure operability. To maintain security and quality of electricity supply there are requirements to ensure that the voltage of the network is maintained within strict limits. If there is a blackout on the system, we need to ensure that we can restore the network in a timely manner. We must ensure that the stability of the system is maintained and that sudden changes in generation, demand or voltages do not pose a threat to operation. We also need to ensure that the transmission system does not get damaged due to too much electricity flowing through circuits, this requires us to monitor the thermal capability of the network and understand where the power is flowing.

Keeping the system balanced and ensuring security and quality of supply at all times requires a combination of several linked continuous processes that take place over different time horizons and in different markets, ranging from years ahead in the wholesale electricity market or contracted services, through to real-time in the balancing mechanism (BM) and balancing services.

We are the residual energy balancer of the system; the bulk of energy balancing is carried out via the wholesale energy market. Suppliers, generators, traders and customers can all trade either bilaterally or via exchanges for contracts for electricity. This occurs from several years ahead to one hour before delivery (gate closure). If a market participant generates or consumes more or less energy than they have contracted for, they are exposed to the imbalance price for the difference. The cash-out mechanism[2] provides the incentive on the market participants to ensure consumers' demand is met. This also helps to minimise our role as residual energy balancer. The cash-out price is specific for each half hour settlement period and reflects the costs of balancing the system. There is a separate capacity mechanism[3] to ensure that there is sufficient generation capacity in the market to meet predicted peak demand.

Alongside residual balancing, we are also responsible for system operability. In the past, most of our requirements for an operable system have been met by the generation and demand mix provided by the wholesale energy market and network investment processes. In recent years, the cash-out mechanism has continued to provide the incentive on market participants to ensure an energy balance. The lack of a mechanism to enable market participants to ensure system operability has led to us having to take an increasing number of actions outside of energy balancing to enable operability.

[1] https://www.nationalgrideso.com/codes/security-and-quality-supply-standards?overview

[2] https://www.elexon.co.uk/guidance-note/beginners-guide/

[3] https://www.emrsettlement.co.uk/about-emr/capacity-market/

Whilst we hold no obligation for bulk trading in the wholesale market, we do participate in trading ahead of gate closure for economic, energy balancing and operability reasons. For residual balancing, the main tool we use is the balancing mechanism (BM). This is a market that covers the period from gate closure to the end of each half-hourly settlement period. All wholesale market participants, generators and suppliers (apart from non-physical traders) are registered as balancing mechanism units (BMUs), although not all are active participants in the BM.

To keep the system balanced and operable for a range of events we calculate a number of different requirements or constraints; frequency control, voltage control, restoration, stability, thermal. These are the amounts of flexibility, or access to changes in output or consumption, we need in various timescales to ensure we continue to meet the SQSS.[4]

These areas – frequency control, voltage control, restoration, stability and thermal – are described in individual chapters in the rest of this document.

The UK's exit from the EU in March 2019 has required us to test our planning assumptions in a broad range of scenarios, so that we are best prepared once the final details of negotiations are concluded. These scenarios fall within our normal contingency planning and we are of the view that there are no additional operability challenges presented on EU-Exit.

[4] https://www.nationalgrideso.com/codes/security-and-quality-supply-standards?overview

Chapter 2
Frequency control

Frequency control

Key messages

- Our frequency control processes have traditionally been based around the visibility and control options provided by balancing mechanism (BM) participants. More generation embedded within the distribution system, lower demand and changes in flexible generation have reduced the level of visibility and the number of control options available to us as electricity system operator (ESO).
- Increasing levels of intermittent generation will lead to more volatile and less predictable, shorter-term requirements for reserve and response. This creates an increasing need for more liquid reserve and response markets, designed to meet these shorter-term and more volatile requirements. There is also a need to access more visibility and control options from non-traditional providers.
- To address these gaps, we are redesigning response and reserve markets and improving access to both these markets and the BM.

Reserve

- Reserve is the access to a change in generation or consumption and can be both upwards and downwards. The capability to increase generation (or reduce consumption) is upwards reserve. The capability to reduce generation (or increase consumption) is downwards reserve.
- For upwards and downwards reserve the requirement is based on the largest single loss of generation or demand, the historic change in available flexibility on BMUs between time ahead and real-time, demand forecast error, wind and solar generation forecast error.

Frequency response

- Frequency response can also be thought of as a reserve, since frequency response is also access to the capability to change output but specifically in very short timescales and acting automatically in response to the system frequency.
- Frequency response requirements are calculated using the most onerous loss that needs to be contained, how quickly the frequency changes (which is a function of the system inertia), the limits frequency needs to be contained to and how fast response products act.

Introduction

What is frequency control and why is it important?

Frequency control is the capability to respond to sudden change in demand or generation and maintain the balance between supply and demand. Frequency control is more than just frequency response services alone and covers processes from the wholesale energy market, the balancing mechanism and balancing services. Frequency control is important to maintain secure and stable operation of the transmission system. As ESO we need access to flexibility to change generation and consumption, refining the half-hourly energy position from the market to keep supply and demand balanced and frequency stable. To ensure that we have sufficient frequency control capability available we calculate reserve and frequency response requirements and take actions to ensure there is sufficient flexibility available to meet those requirements.

What is changing in frequency control and what is driving the change?

Our frequency control processes revolve broadly around participants in the BM. The historic behaviour of BMUs, the dynamics and flexibility of those units and the inertia they provide all influence the reserve and response requirements.

Decarbonisation has produced high levels of renewable generation which has different operating characteristics, plant dynamics, data quality, flexibility and inertia contribution. This has increased reserve and response requirements and the nature of intermittent renewable generation means that the requirements are more volatile and less predictable.

Decentralisation of generation has led to an increase in electricity market participants who are not active participants in the BM. There is no obligation on some decentralised energy resources to participate in our frequency control processes. With more demand being met from these decentralised energy resources, we have periods with a smaller pool of available units within the BM to balance the system.

Demand reduction, particularly at minimum demand times, where the proportion of price inelastic supply, such as renewables and nuclear generation, is increasing, means there is little flexibility in output from the market position and we are now required to take significant volumes of actions to meet our frequency control requirements.

Operability gap

What is our current strategy?

Frequency control is not a single process but the combination of many interlinked continuous processes. The operability gap is therefore not a single requirement but can be categorised at a high level as visibility and control, or more precisely, increased liquidity in balancing markets with products that provide suitable frequency control to the ESO.

As the market has evolved, we have tried to increase the visibility and control available to us by contracting balancing services as part of the frequency control process. In addition to creating competition to help lower the cost of frequency control, these services enable participants from outside of the BM and hence increase our levels of visibility and control. Our existing approach is to contract for services at relatively long lead times and for large service periods where economic to do so. However, this approach is becoming less effective for the more volatile and shorter-term requirements.

Our requirements for reserve and response are derived from the SQSS[1] which define the standards to which the system must be operated. To ensure we remain secure and within these standards, whilst limiting cost to the end consumer, we set the requirements dynamically. The precise volume required is a function of the system conditions in real-time.

Currently the reserve requirements are met by three routes: the natural market position, firm contracting or by taking actions to turn units on or off via the BM or trading.

Currently the reserve requirements are met by four routes:

- The market position
- Firm balancing service contracts
- Forward Trading
- Taking actions to change output on BMUs in the BM.

The flexibility (amount of change in output available) provided from BMUs is key to meeting the reserve requirements. If frequency response is also being provided by BMUs, this increases the total amount of flexible output needed from the BM. The level of flexibility delivered by the market is dependent on demand and the efficiencies of available plant. Units running at full output are not providing any upwards reserve and units at their minimum are not providing any downwards reserve. Typically, during the daytime and at peak demand there is sufficient downwards reserve provided naturally from the units running, however, there may not be sufficient upwards reserve. At minimum demand times, the opposite is usually true.

Firm reserve contracts come in the form of Short Term Operating Reserve (STOR), Fast Reserve or response contracts that reduce the volume of mandatory response and hence also reduce the amount of reserve to be met by the BM[2]. With requirements influenced by levels of intermittent generation, there is a limit to the proportion of the reserve requirement that can be met by the existing contracted services and currently some reserve must be provided on running BMUs.

If there is insufficient reserve provided by the market position and our firm contracts, then actions are taken in the BM or via trading to create additional upwards or downwards reserve. To create upwards reserve additional units can be turned on and output on other units reduced such that there is then the ability to increase output when needed. To create downwards reserve units can be turned off and the output on other units increased.

We currently manage the frequency response requirement via four routes:

- Buying frequency response services via balancing service contracts
- Buying frequency response via the mandatory market
- Limiting the size of the loss to be contained
- Increasing the inertia on the system.

[1] https://www.nationalgrideso.com/codes/security-and-quality-supply-standards

[2] https://www.nationalgrideso.com/balancing-services/reserve-services

We procure the bulk of our frequency response via balancing services contracts. We aim to procure sufficient to meet a baseline requirement ahead of time with services ranging from years ahead to month ahead. These services[3] include:

- Firm Frequency Response (FFR)
- Frequency Control by Demand Management (FCDM)
- Enhanced Frequency Response (EFR)
- Legacy bi-lateral contracts.

Where we have insufficient contracted response or if the requirement is too volatile for long-term contracting we procure response from the mandatory frequency response service. This is provided by part-loaded BMUs and is armed close to real-time but planned from day ahead.

When response requirements are large and access to response is limited it may be economic to manage the frequency response requirement by reducing the size of the requirement rather than buying response. Typically, this is during periods with large single losses or during low demand or inertia periods. Most commonly we do this by reducing the size of the largest loss either by taking actions in the BM or via forward trading. We can also reduce the requirement by increasing the inertia on the system, however the relationship of inertia to response requirement means that currently this is rarely economic to do.

Why must our strategy change between now and 2030?

The *Future Energy Scenarios* (*FES*[4]) 2018 forecasts indicated an increase in levels of decentralised and intermittent generation and reduced demand across all four of the scenarios between now and 2030. The percentage of synchronous generation is also forecast to decrease and the largest generation loss is set to increase, firstly with the connection of the North Sea Link interconnector and later Hinckley Point C nuclear station. These factors together contribute to increase the reserve and response requirements. Most of these changes are gradual but the increase to largest losses will cause a step change in requirements.

Flexibility on BMUs is becoming less accessible due to lower demands, increased decentralisation and increased levels of price inelastic supply. To access the required flexibility, we increasingly have to re-dispatch the market position.

Increases to levels of intermittent generation means that the requirements are more volatile than in the past and less predictable. Our existing procurement of balancing services is becoming less effective in meeting these requirements due to the relatively long-term nature of the products.

As the inertia on the system reduces, the rate of change of frequency increases. The existing frequency response services are specified to deliver full output within a set time. When frequency moves quicker, these services become less effective due to the time it takes them to deliver and a larger volume is required.

[3] https://www.nationalgrideso.com/balancing-services/frequency-response-services

[4] https://www.nationalgrideso.com/insights/future-energy-scenarios-fes

Progress so far

In early 2017 we published the System Needs and Product Strategy document (SNaPS[5]). In SNaPS we outlined future changes and consulted on several stages of development to our suite of balancing services. Based on the consultation responses, we revised and updated our planned work and published an update of plans in the Reserve and Response Roadmap[5] in December 2017. Since then we have published several monthly newsletters on our future of balancing services website. We have also published progress via the monthly ESO Forward Plan reports available on our website under ESO performance and reporting[6].

Frequency response

We are continuing our work simplifying the frequency response markets. Since SNaPS we have:

- removed the bridging product and reduced the size of the minimum tender to 1 MW
- made several changes to the FFR tender process, changing the regularity and time horizon for tenders
- moved from being able to tender for 1 to 24 months ahead at every tender round, to now alternating between month ahead only and month ahead plus longer-term options
- implemented four hour Electricity Forward Agreement (EFA) blocks for tenders, allowing assessments to be simpler and tenders more easily compared
- begun work to retire the FCDM service and once a suitable platform is available in 2019 we will look to move the existing FCDM providers into the wider response market
- explored new ways of maximising the value of fast acting response from variable sources such as wind, solar and distributed energy resources in the Enhanced Frequency Control Capability project[7].

One of the major commitments in SNaPS, and the roadmap, was to explore using auctions for balancing service procurement. We have completed the initial design work based on the feedback received from industry and are working with an auction provider to develop the system. The auction trial will now last for 24 months to ensure that we can fully test several different parameters and approaches prior to full implementation. A webinar covering the initial design was held in September 2018 and slides are available on the future of balancing services website[5]. Initially the auction will be run weekly, for individual EFA blocks of each day in the week ahead. There will be four response products: high dynamic, low dynamic, high static and low static. The auction will optimise across dynamic and static tenders where there is a requirement. The auction will be pay-as-clear with the forward volume requirement identified and published before each auction. Due to the complexity of the desired trial we have extended the trial period and pushed back the start date to summer 2019. We are also developing a simplified platform to run a smaller-scale trial in April 2019 before the main auction trial starts.

Alongside the development of the auction platform we have been designing and modelling a new suite of frequency response services. These new services will address several issues with the existing primary, secondary and high services and enable faster acting response and unbundling. Changing these services becomes increasingly important as the inertia of the system reduces and holding sufficient conventional response to keep frequency stable becomes uneconomic. We have consulted with the industry on the design of these services with recordings of the webinars available on our website[8].

[5] https://www.nationalgrideso.com/insights/future-balancing-services

[6] https://www.nationalgrideso.com/about-us/incentives/eso-incentive-performance-and-reporting

[7] https://www.nationalgrideso.com/innovation/projects/enhanced-frequency-control-capability-efcc

[8] https://www.nationalgrideso.com/balancing-services/frequency-response-services/future-frequency-response-products

We have been working to improve transparency and timeliness of procurement data and as such have been running post-tender webinars to explain the assessment results. We have also made improvements to the cost reporting in the Monthly Balancing Services Summary (MBSS[9]). At the end of September 2018 we published an updated set of principles for the testing and monitoring of balancing services. This is the first step to rationalising and standardising our performance monitoring processes, which is a necessary precursor to streamlining our upfront testing requirements. Ultimately this will reduce barriers to entry to our services and improve liquidity in these markets. Details of the policy can be found on the future of balancing services website[10].

Reserve services

We have published outline change proposals for STOR and Fast Reserve services and will be publishing the detailed change proposals and implementing the changes following the results of this consultation. The majority of the proposed changes are to improve standardisation across the products.

The Platform for Ancillary Services (PAS) project has created an Ancillary Services Dispatch Platform (ASDP) which will provide the communication infrastructure for future non-BM and some BM ancillary services. The platform has been developed and is live for the Fast Reserve service and is currently being specified for the STOR service. This will eventually replace the outdated Standing Reserve Dispatch system which will enable new providers to be connected in shorter timescales but will also allow for more flexibility in the design of services.

Whole-system

The Energy Networks Association (ENA) Open Networks Project is a major energy industry initiative that will transform the way our energy networks work, underpinning the delivery of the smart grid. Through the Future Worlds consultation, we are working very closely with the ENA and other network companies to engage a wide stakeholder base on potential future energy system arrangements from a whole electricity system perspective. This work is a key enabler for unlocking the consumer value of the smart, flexible electricity system of the future. The consultation was published on the 1st of August and closed at the end of September.

In the Reserve and Response Roadmap we committed to publish and consult with industry on exclusivity clauses within balancing services contracts. These clauses place restrictions on what other commercial services, such as those to Distribution Network Owners (DNOs), can be provided by parties who are contracted to provide balancing services to the ESO. The consultation period has just closed and we will be reviewing the responses and looking to update the standard contract terms as necessary. This review is also an important element of the ENA Open Networks Project.

BM access

Our next steps in improving access to the BM are set out in our Wider Access to the Balancing Mechanism Roadmap[11]. This will ensure the widest possible participation in the BM, allowing access to a wide range of resources for reserve and constraint management. Our work here falls into three areas:

- improving existing routes to market
- developing new routes to market
- enhancing IT systems to improve data flows between the ESO and market participants.

The Trans-European Replacement Reserve Exchange (TERRE)

The TERRE project will establish a pan-European replacement reserve exchange. This platform will enable providers of 1 MW or greater (including aggregated units) to participate in a market for 15 minute energy blocks auctioned at one hour ahead.

[9] https://www.nationalgrideso.com/balancing-data/system-balancing-reports

[10] https://www.nationalgrideso.com/insights/future-balancing-services

[11] https://www.nationalgrideso.com/sites/eso/files/documents/Wider%20BM%20Access%20Roadmap_FINAL.pdf

Plan for future work

Commercial and operational tools

Response auction platform development and product design

Between now and the start of the auction trial we will be working with the auction provider to develop the auction platform – including auction algorithm, data requirements, process timings, user interface design – and plan for the other features to be trialled. We will keep you updated on our progress via the usual routes including via the mailing list available on the future of balancing services webpage[12].

Response auction trial

We aim to start the response auction trial in summer 2019. The trial will run for 2 years.

New frequency response product suite design

Work on the new frequency response product suite is continuing. We will be publishing an update in December with details of the products and how they are likely to be phased into the response market.

Reserve services review

We have recently launched an internal review of our current reserve services. As this progresses we will be consulting with you via our usual routes. More details including the scope of the review will be published in 2019.

ASDP development for STOR service

Development of the ASDP platform by the PAS project will continue for the STOR service. The aim is to discontinue the old Standing Reserve Dispatch (SRD) system and phase in ASDP as the replacement. The first providers are expected to go live on ASDP in January 2019. A recent webinar was held to cover the development work, more details can be found on the technical requirements tab of the STOR webpage[13].

Networks

Energy Networks Association (ENA) Open Networks Project

For more details of the work on the Open Networks Project please refer to the ENA website[14].

Codes and regulation

Wider BM access and TERRE platform development

For more details of the work on BM wider access and TERRE please refer to the BM access roadmap[15].

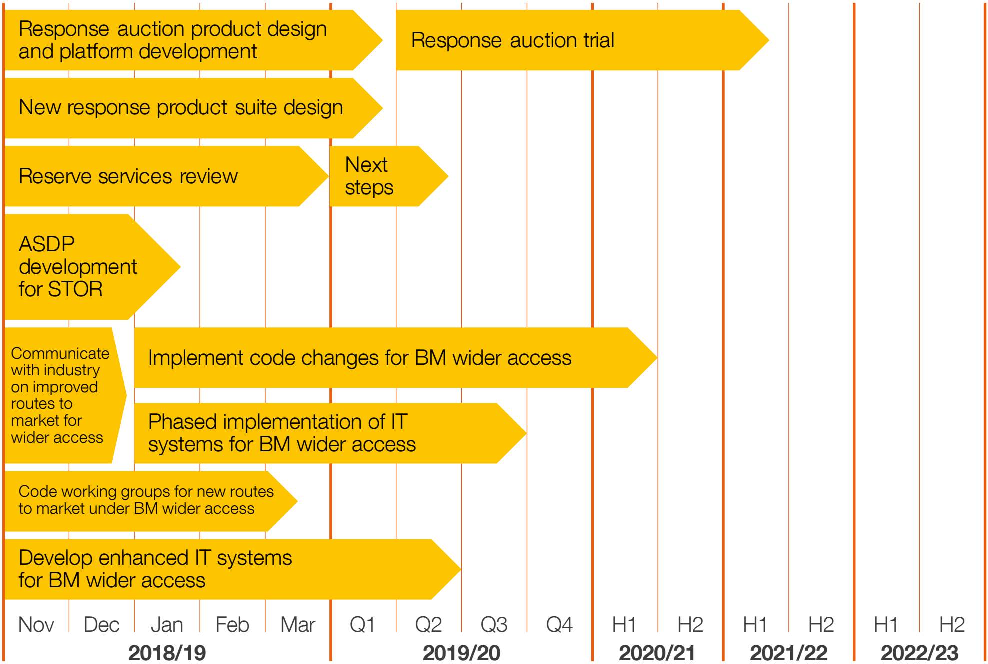
[12] https://www.nationalgrideso.com/insights/future-balancing-services

[13] https://www.nationalgrideso.com/balancing-services/reserve-services/short-term-operating-reserve-stor

[14] http://www.energynetworks.org/electricity/futures/open-networks-project/

[15] https://www.nationalgrideso.com/sites/eso/files/documents/Wider%20BM%20Access%20Roadmap_FINAL.pdf

Figure 2.1
Frequency control timeline



Chapter 3
Voltage control

Voltage control

Key messages

- Reactive power is required for voltage control. As GB transitions to a decentralised and decarbonised electricity system, we will need access to new sources of reactive power.
- The requirements for reactive power will increase as network loading becomes more volatile and many conventional generators (which provide reactive power) run less predictably and less often.
- New sources of dynamic reactive power are needed. More absorption is needed to manage pre-fault high voltages, and more injection is needed to support post-fault low voltages.
- More flexible reactive power options are needed. These can come from either regulated network assets or competitive providers in the market. We are developing new assessment and commercial procurement processes that will enable these to be assessed to deliver the most economical solution.
- The plans set out in our Network Development Roadmap[1] will deliver a new set of arrangements that facilitates cross-comparison of whole electricity network investment options with competitively procured market based solutions for long-term investment.
- The plans set out in our roadmaps will deliver a revised set of reactive power services that offer the best value for money and meet the changing needs of the system and providers.

Introduction

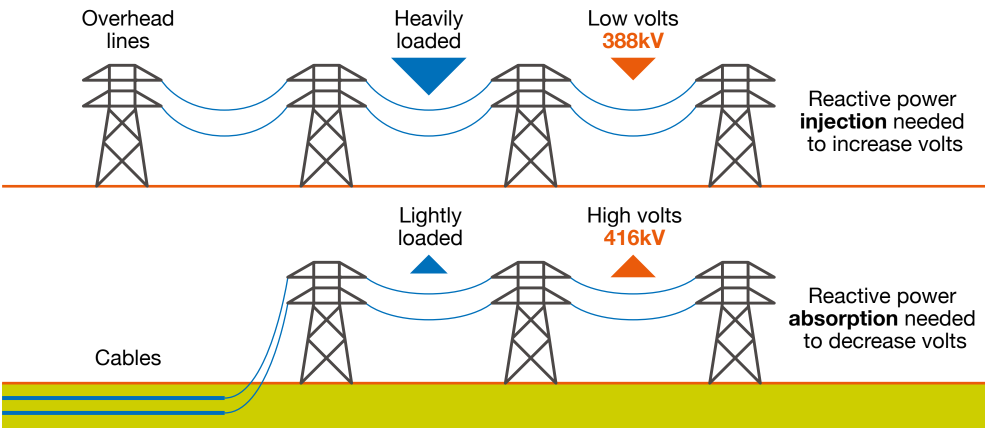
What is voltage control and why is it important?

Maintaining the electricity system at the correct voltages facilitates safe and efficient power transfer within the performance limits of the network, generation and consumer devices. This requires the right balance of reactive power injection and absorption to be maintained in real-time. Reactive power can come from network assets, generation or demand.

The amount of power flowing through the network affects voltage. Heavily loaded overhead lines absorb reactive power which lowers voltage. Cables and lightly loaded overhead lines inject reactive power which increases voltage. High voltages occur more often throughout the summer months, overnight and at weekends because demand is generally lower at these times and the network is less heavily loaded. An increasing proportion of the network is cabled, particularly within the distribution networks, which contributes to a growing need for reactive power absorption at these times.

[1] https://www.nationalgrideso.com/sites/eso/files/documents/Network%20Development%20Roadmap%20consultation.pdf

Figure 3.1
Reactive power injection and absorption



Reactive power differs from active power because it is a locational requirement. Reactive power is only effective for voltage control if it is provided close to the area where the voltage needs to change. It becomes less effective with distance.

A regional deficit of reactive power causes a voltage constraint. This means that generation or demand must be instructed to change its injection or absorption to prevent power flows through the network from causing a breach of safe voltage limits.

What is changing in voltage control and what is driving the change?

More reactive power absorption is needed across much of the network due to changing demand patterns, reactive power exports from distribution networks and more volatile flows that result in more frequent occurrences of high voltages. Dynamic reactive power will help to manage this volatility, but it is likely to be efficient for some new capability to come from static sources.

More reactive power injection is needed on a more locational basis. Dynamic reactive power injection is needed to replace the capabilities historically acquired from large conventional power stations that are now running less often or may close in the future. Presently, these generators provide a significant proportion of the reactive power capability of the system. It is again likely to be efficient for some new capability to come from static sources.

Figure 3.2
Summary of changing reactive power needs

	Injection	Absorption
Static	Lower need than historically, but some still required on a locational basis.	Higher than historically across much of the network.
Dynamic	Much higher need than historically on a locational basis where deficits emerge.	Much higher need than historically across much of the network.

Operability gap

What is our current strategy?

To operate the system safely and securely, there must always be sufficient reactive power available in each region of the network. The voltage limits for the electricity transmission system are set out in the SQSS[2] which sets out the standard to which the system must be planned and operated. The operational limits are generally set at a wider band than planning limits to account for the uncertainties of real-time operation such as volatility of flows and unplanned outages of the network or generators. To manage the volatilities of system operation, it is necessary to use a mixture of static and dynamic sources of reactive power.

- Static sources provide a fixed amount of reactive power. Sometimes this can be changed to a different fixed level on instruction. Generally static reactive power sources are cheaper than dynamic sources but offer less flexibility and cannot be used to secure the system exclusively.
- Dynamic sources provide variable reactive power to maintain voltage at the correct level. As voltage falls, dynamic providers inject more reactive power and as voltage rises they absorb more reactive power. Dynamic sources of reactive power are generally more expensive than static, but are more flexible and often necessary for secure system operation.

These different characteristics mean that it would not be possible to secure the system using entirely static reactive power, and it would not be efficient to secure the system using exclusively dynamic reactive power. An efficient mix of both types is required. Sufficient dynamic reactive power must be available in each region of the network to automatically respond to changes in voltage due to an unexpected trip of a generator, network or demand. It is also necessary to have an underlying level of automatic actions to ensure that we do not have to continuously switch static sources on manual instruction.

Why must our strategy change between now and 2030?

The emerging operability gap for voltage control can be expressed as an increasing reactive power requirement.

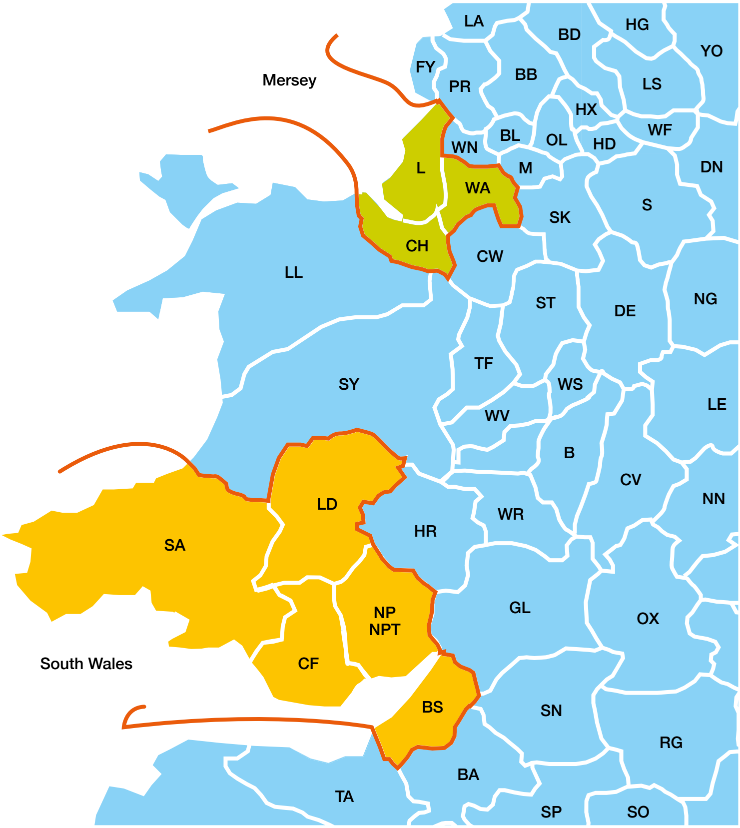
The series of actions set out in the Product Roadmap for Reactive Power[3] will stimulate new providers to ensure that the pool of potential market participants is as liquid as possible. This will help to drive providers towards regions of poor liquidity where opportunities exist. Two regions where an operability gap has been identified in the short term are South Wales and Mersey. More information on this can be found on the reactive power services section[4] of our website.

[2] https://www.nationalgrideso.com/codes/security-and-quality-supply-standards?overview

[3] https://www.nationalgrideso.com/sites/eso/files/documents/National%20Grid%20SO%20Product%20Roadmap%20for%20Reactive%20Power.pdf

[4] https://www.nationalgrideso.com/balancing-services/reactive-power-services

Figure 3.3
Location of reactive power tenders in Mersey and South Wales by UK postcode



Progress so far

When we asked you how we should be developing our plans in the *System Needs and Product Strategy* consultation[5] last year, you said that you wanted our specific needs and service opportunities to be articulated more clearly. In response to this, we published our Product Roadmap for Reactive Power[6] and our Network Development Roadmap[7]. These outline our commitments to reform our reactive power services and introduce cross-comparison of network and market-based approaches in our *Network Options Assessment*[8] process. This chapter provides an update on our progress against these commitments.

Improving data and transparency of reactive power services and spend

We have improved reactive power reporting in the Monthly Balancing Services Summary (MBSS)[9] to include more information about reactive power spend. The MBSS was revised in July 2018 versus a commitment to do so by March 2019, and we will continue to improve our reporting and level of transparency by adding more data on regional spend. The revised MBSS now includes more information about both trades and BM actions to address voltage constraints. It also includes a more detailed breakdown of spend on reactive power services.

Ensuring that industry codes are up-to-date and fit for the future

We have raised a modification for the removal of the enhanced reactive power service (ERPS)[10] from the Cconnection and Use of System Code (CUSC)[11]. The modification was raised in August 2018 versus a commitment in the Reactive Power Roadmap of December 2018. This modification will clear the path for more flexible, holistic and competitive commercial arrangements for the procurement of reactive power to be developed.

Signalling new commercial opportunities

We have issued an information pack which sought feedback on participation in a reactive power procurement exercise in South Wales and Mersey. The duration of service is two years (April 2019 to March 2021) and we have sought feedback on both contract options and structure before a determination on the tender exercise.

The full information packs for providers who are interested in tendering in to these procurement exercises are available on our Reactive Power Services web page[12].

[5] https://www.nationalgrideso.com/sites/eso/files/documents/8589940795-System%20Needs%20and%20Product%20Strategy%20-%20Final.pdf

[6] https://www.nationalgrideso.com/sites/eso/files/documents/National%20Grid%20SO%20Product%20Roadmap%20for%20Reactive%20Power.pdf

[7] https://www.nationalgrideso.com/insights/network-options-assessment-noa

[8] https://www.nationalgrideso.com/insights/network-options-assessment-noa

[9] https://www.nationalgrideso.com/balancing-data/system-balancing-reports

[10] https://www.nationalgrideso.com/balancing-services/reactive-power-services/enhanced-reactive-power-service-erps

[11] https://www.nationalgrideso.com/codes/connection-and-use-system-code-cusc

[12] https://www.nationalgrideso.com/balancing-services/reactive-power-services

Plan for future work

Commercial and operational tools

Commercial opportunities

Following our request for information on a reactive power procurement exercise in South Wales and Mersey we will publish our decision on whether to run a tender exercise or not in December 2018.

Networks

Comparison of network and market solutions

We have also committed to reviewing the relationship between regulated network assets and market-based commercial solutions for reactive power. Our pathfinders will help to inform this process and are described in more detail in our Network Development Roadmap – Confirming the direction[13] document. These pathfinders will extend our approach to include market-based commercial solutions in 2019. This could result in a signal for network development being provided or a new longer-term commercial service being procured.

Codes and regulation

Whole-system solutions

There are currently no clear rules in place to govern the efficient range of reactive power exchanges between the different transmission and distribution networks. This is an issue that we committed to look at in the Reactive Power Roadmap, and we will provide an update in the next *Operability Strategy Report*.

Obligatory reactive power service

Having raised a modification to remove ERPS from the CUSC we will work with industry to determine the future role of the obligatory reactive power service (ORPS)[14]. This may include raising further modifications to enable the design of a more competitive commercial service. We intend to have held the first of the sessions, working with industry on this challenge, by April 2019.

Innovation

Power Potential

In Power Potential[15] we have teamed up with UK Power Networks for a first in the world trial of dynamic voltage support to the transmission network from distributed energy resources (DER). This means that small generators in the distribution network will be able a to provide a fast change in reactive power output to regulate the voltage on transmission system.

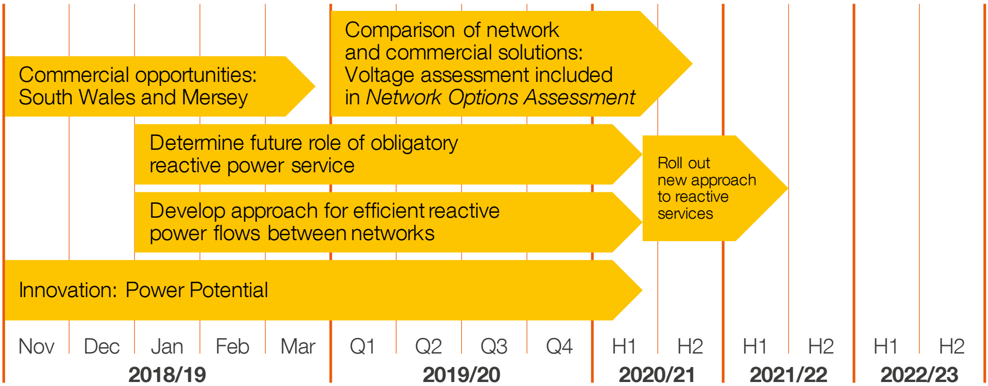
The Power Potential project looks across the whole-system landscape to identify key areas of technical and market development to unlock additional network capacity, reduce constraints and open up new revenue streams for market participants. It will create additional generation potential in the area and could generate savings of over £400m for consumers if its concepts are rolled out successfully. Trials will start in 2019. The results from this trial will feed into our Product and Network Development roadmaps.

[13] https://www.nationalgrideso.com/sites/eso/files/documents/Network%20Development%20Roadmap%20-%20Confirming%20the%20direction%20July%202018.pdf

[14] https://www.nationalgrideso.com/balancing-services/reactive-power-services/obligatory-reactive-power-service-orps

[15] https://www.nationalgrideso.com/innovation/projects/power-potential

Figure 3.4
Voltage control timeline



Chapter 4
Restoration

Restoration

Key messages

- Our current restoration approach relies on large, transmission connected synchronous generators. The future energy mix will be more diverse and generation is becoming less centralised. These changes offer an opportunity and a necessity to develop new approaches to restoration.
- We are developing new approaches to restoration through a variety of routes:
  - working with government and industry to share, understand and solve challenges
  - innovation projects reviewing the capability of different types of generation technologies and investigating restoration using generation connected to the distribution network
  - developing the restoration services we procure through the actions set out in our Restoration Product Roadmap.

Restoration

Restoration refers to the wide process of restarting, and restoring networks, following a shutdown. There are a number of ways that providers can assist in different stages of restoration.

Black Start provider

A Black Start provider refers to a restoration provider who can start up, energise the network and manage the supply of local demand, without using external energy supplies from the transmission system.

Introduction

What is restoration and why is it important?

In the unlikely event that the electricity system fails and the lights go out, we, as the ESO, have a robust plan to restore power to the country as quickly as possible. If you would like to know more about our strategy for restoration and our current methodology for procuring services to support restoration, you can find more information on the Black Start page[1] of our website. The role of the ESO in a restoration event is to provide coordination between generators, to energise and export power, and network owners, to ensure energy reaches homes and businesses who need their power supply restored.

What is changing in restoration and what is driving the change?

Our strategy for restoration is evolving. We have always been dependent on large, fossil fuel powered generators, connected to the transmission system, to deliver our restoration strategy. The types of technology connecting to the network are becoming more diverse and generation is becoming less centralised. These changes offer both an opportunity and a necessity to develop new approaches to the way we restore. These new approaches will require a significant shift in both technology and in how the industry works together to prepare for and implement restoration.

[1] https://www.nationalgrideso.com/balancing-services/system-security-services/black-start

Operability gap

What is our current strategy?

Our restoration plans utilise both mandatory obligations and contracted Black Start services. The Grid Code outlines how transmission connected generators will be instructed to support the restoration of the system if they do not hold Black Start contracts. Currently the Black Start contracted service requirement is equivalent to 18 large transmission connected generators, or up to three in each of the six zones. This geographical spread of providers enables restoration to occur across the country simultaneously. At this time the requirement is met by generators who can start up without needing power from the GB power system, can control frequency and voltage in a power island, and can remain stable as demand is reconnected in blocks.

Why must our strategy change between now and 2030?

As the number of large, transmission connected, fossil fuel generators reduces, we will need to change how we define our requirement. This is because, when we describe our requirement as 18 stations, it is based on the impact that a large transmission connected generator has on restoration. In the future, we will have a more diverse range of technology types with more generation connected to the distribution system, therefore the type of contribution a service will have towards restoration will be more varied.

Over the next two years we are working alongside BEIS, Ofgem and other industry stakeholders to help inform what a GB standard for restoration could look like. Development of this standard will be key to defining the requirement for both mandatory obligations and future Black Start services.

The European Network Code on Emergency Restoration introduces new requirements on system users to be resilient and on the ESO to publish a System Defence Plan and a System Restoration Plan detailing the procedures and processes in place to manage network events. Both plans have undergone consultation[2] and will be published on 18 December 2018.

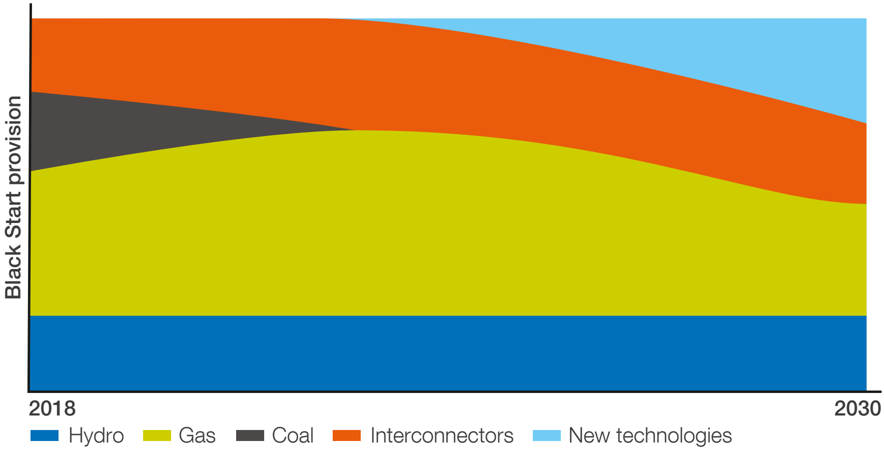
In the medium term, whilst coal stations are expected to close, there will still be a significant amount of gas and hydro generation on the system and these will remain core to our restoration strategy. Whilst contracted stations will maintain their Black Start capacity, the stations will be running less often. This means that maintaining the required warmth in the generator (required to enable a timely Black Start) between runs will be increasingly important.

The following chart gives an illustration of how the proportion of technology types providing Black Start could change over time. Initially more efficient gas stations and interconnectors can replace the services lost from coal and less efficient gas stations. Later, as gas stations run less frequently or close, this gap may partially be filled by services from interconnectors or also from Black Start services from new types of providers.

The actual proportions will depend on the technical viability and economics of different provider solutions. To find economic solutions we will need to be more innovative in the technologies and approaches we use for restoration.

[2] https://www.nationalgrideso.com/codes/european-network-codes/meetings/emergency-and-restoration-consultation

Figure 4.1
Illustration of changing Black Start provision



Progress so far

In May 2018, we published the Restoration Product Roadmap[3]. This document outlined three key areas to give new and current providers a better understanding of how the Black Start service works, and the opportunities to take part:

- Improving transparency around Black Start services.
- Opening up restoration to a broader range of participants.
- Alternative approaches for procuring Black Start services.

Improving transparency around Black Start services

Improving transparency around Black Start services will support operability by enabling potential new providers to better understand where there are opportunities to offer new services and participate in restoration. The publication and update of the Black Start Strategy[4] and the Procurement Methodology[5] is a step forward in making our processes clearer.

The total Black Start spend in 2017/18 was £57.7 million. We have published the Black Start Allowed Revenue Report[6], which provides more detail on how this was spent. You can find out more about our spending on balancing services in the Monthly Balancing Services Summary (MBSS)[7]. Earlier this year we updated the MBSS so that Black Start costs are split into different categories making it clearer how much we spend on different aspects of Black Start.

We are now more transparent about opportunities for new providers. In the Restoration Product Roadmap[3], we published a map outlining when and where we have opportunities for new services to be offered. The existing technical requirements for service provision are available in the Black Start Strategy[4] and on our website. To be able to offer a service today you will need to meet these criteria. As we develop our strategy and learn from our innovation projects we will update these requirements.

Opening up restoration to a broader range of participants

As well as helping to fulfil our requirement, opening up restoration to a broader range of participants could help us to find more economic solutions and increase our restoration resilience through increased diversity of provider types.

Alternative technologies

To better understand the capability of a broader range of technology types we have scoped out an innovation project, Black Start capabilities from emerging technologies, to work with potential providers who are currently unable to deliver our existing technical requirements.

Combined services

We have progressed our thinking on how Black Start technical obligations can be split between two parties: One party would need to be able to self-start, energise the network to their partner and manage step change in output equivalent to the loading profile of their partner. The second party will need to fulfil the normal service requirements (for example, frequency control, reactive control and block-loading to restore demand), but without requiring the capability to self-start.

We have one service of this type in place and we are working with market participants to move forward to refine and standardise the methodology and contract terms so that they can be applied more broadly. As this methodology develops we will make more information available.

[3] https://www.nationalgrid.com/sites/default/files/documents/National%20Grid%20SO%20Product%20Roadmap%20for%20Restoration.pdf

[4] https://www.nationalgrideso.com/sites/eso/files/documents/Black%20Start%20Strategy%20Version%202%20April%202018.pdf

[5] https://www.nationalgrideso.com/sites/eso/files/documents/Black%20Start%20Procurement%20Methodology%20Issue%202%20April%20 2018_0.pdf

[6] https://www.nationalgrideso.com/balancing-services/system-security-services/black-start?market-information

[7] https://www.nationalgrideso.com/balancing-data/system-balancing-reports?

Interconnectors

We have reviewed our internal process for managing the relationship with potential Black Start providers and have integrated interconnectors into our standard process. This means that we can be more consistent in our approach across several different types of provider. At the moment, standard contract terms are based on the set up for generators, and so we have been developing specific contract terms for interconnectors which will enable us to take into account the difference in approach between different technology types. The Grid Code[8] has already been modified to include Black Start provision from interconnectors.

Alternative approaches for procuring Black Start services

Since the publication of the Product Roadmap we have reviewed options and developed a high level plan for a new, competitive procurement approach. We are currently identifying the most appropriate zones to trial a market based procurement mechanism. Our aim is to learn from this trial process and, where appropriate, use this learning to roll out a market approach to other zones as we open the service to a broader range of participants. We have initially engaged with the industry on this topic at the electricity operational forum in October and, as we develop our proposals further during the next few months, will be seeking further input from industry.

[8] https://www.nationalgrideso.com/codes/grid-code

Plan for future work

A full GB restoration requires input from several parties, not only the ESO. Therefore we will continue to work with our stakeholders to share our findings from research, and collaborate to resolve restoration challenges.

Commercial and operational tools

Commercial and operational tools are being developed through our Restoration Product Roadmap actions. The next steps for these topics are described below.

Improving transparency around Black Start services

To increase the transparency of our service requirements by March 2019 we plan to simplify the format of our technical requirements and to be clear on the range of capability that can currently be considered. We will also publish more detailed requirement information; specifically on the size of demand loads a service provider would need to be able to accept during restoration. More detail on the valuation of individual characteristics will be provided ahead of any competitive procurement exercise.

Opening up restoration to a broader range of participants

Our aim is to investigate from Q1 2019/20 the capability of wind for assisting in restoration and storage from Q3 2019/20. We will use the learning from the Black Start capabilities from non-traditional technologies project to inform this approach.

Alternative approaches for procuring Black Start services

We will continue to develop our market approach for service procurement and in early 2019 will engage with the industry via the publication of an Expressions of Interest document. This will outline our initial ideas and seek views from stakeholders. The feedback from this Expressions of Interest will inform a trial of a competitive procurement exercise in the South West and Midlands zones for a service delivering in 2022.

Networks

Restoration plans

We have restoration plans in place with Transmission Owners (TOs) and DNOs to ensure all parties are prepared. These industry plans are regularly reviewed to keep them current. Over the next 6 months we will be working directly with network owners (both TOs and DNOs) on the format and content of these restoration plans to aid familiarisation of the restoration process.

Codes and regulation

European codes

During September and October we consulted on the contents of our System Defence and System Restoration Plans[9] and had constructive feedback on the content of both which will be included in the final published version in December. We now need to integrate the requirements of the European Network Code on Emergency & Restoration into our internal assurance activities. An example of this is the new requirement for the frequency of testing Black Start providers once every three years.

Included in the System Defence Plan is the creation of an assurance framework, and assurance assessment for Black Start across the industry. This assurance framework has been developed by ESO through BEIS' Black Start Task Group, and over the next 3 months this will be finalised and put in place across the industry.

Restoration standard

The introduction of a GB restoration standard will establish an expectation for restoration timescales for the industry. We have been contributing to the development of a standard through our unique probabilistic model which models potential restoration times. Over the next 12 months we will continue to work with BEIS, Ofgem and the industry to implement the standard.

As the restoration strategy changes and develops, both with new restoration methods and new providers, there may be requirements for documentation to be amended, including some code modifications. These modifications will be subject to the standard approvals and we will consult with our stakeholders on the impact of proposed changes.

[9] https://www.nationalgrideso.com/codes/european-network-codes/meetings/emergency-and-restoration-consultation

Innovation

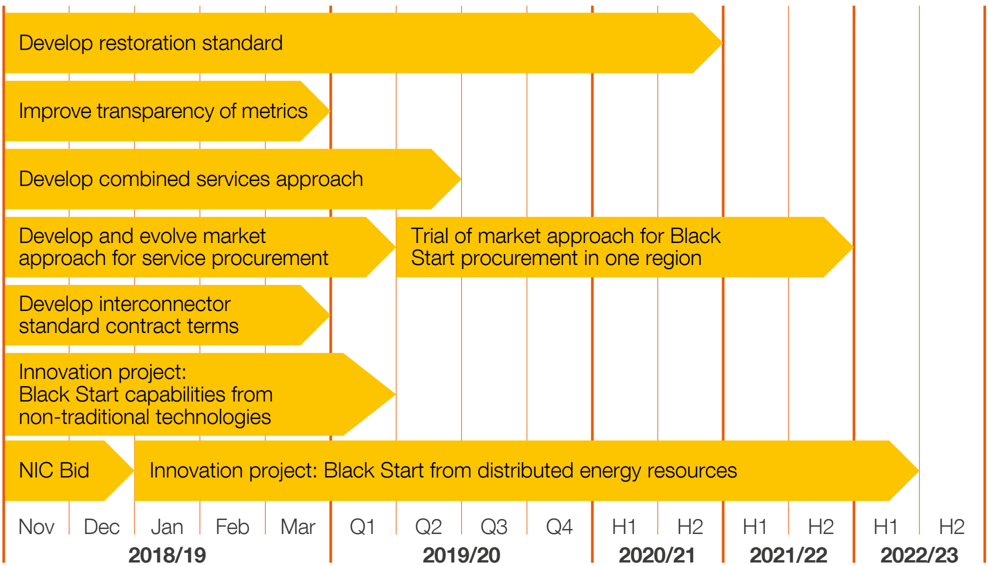
Black Start capabilities from non-traditional technologies

We are investigating how different technologies can contribute during restoration and gaining a clearer understanding on where there are gaps in our knowledge on this. With this information we will be able to include a broader range of provider types in the "business as usual" restoration process and also appreciate where our processes may need to change in order to accommodate other provider types. This topic is currently being investigated through the Black Start capabilities from non-traditional technologies project. This project, being carried out by National Grid, is expected to take six months and will inform and prioritise the next steps of our Black Start restoration strategy to utilise the changing energy mix. We will conduct focused stakeholder engagement to inform the work and engage with stakeholders on the findings through publication of a report and presentations at industry events.

Black Start from distributed energy resources

We would also like the opportunity to establish whether it is possible to coordinate distributed energy resources (DERs) to become a feasible and economic alternative. We have applied for project funding through the Network Innovation Competition[10]. If funded, this project will trial how different types of DERs can provide local restoration. The proposed project will build on existing research in GB and internationally, and investigate how to coordinate stakeholders to best manage restoration efforts. The project seeks to provide a commercial and regulatory framework for how Black Start services from DERs can be purchased and regulated.

Figure 4.2
Restoration timeline



[10] https://www.ofgem.gov.uk/network-regulation-riio-model/current-network-price-controls-riio-1/network-innovation/electricity-network-innovation-competition

Chapter 5
Stability

Stability

Key messages

- Stability is the ability of the system to quickly return to acceptable operation following a disturbance.
- Synchronous generation supports the stability of the system. Without intervention, the system will become less stable when there is less synchronous generation running. To support the transition to a low carbon energy system we need to both decrease our reliance on fossil fuel generation to stabilise the system and learn to operate with a more dynamic system.
- Due to the inherent stabilising effect of synchronous generation this subject area has previously not required the same focus as some of the other subjects covered in this report. However, as synchronous generation capacity decreases this subject is growing in importance and we have become more proactive in monitoring, understanding and maintaining system stability.
- We are developing new approaches to maintaining a stable system through a variety of routes:
  - better understanding of the issues and where and when they are likely to occur
  - innovation projects to investigate some of the potential technological solutions
  - development of code changes, commercial and operation tools, and network based solutions.

Introduction

What is stability and why is it important?

Stability is the inherent ability of the system to quickly return to acceptable operation following a disturbance. The term is used to describe a broad range of topics. If the system becomes unstable it could lead to a partial or total system shut down leading to the disconnection of consumers. If you would like to know more about stability, we have described the key topics in more detail in the *System Operability Framework* publications[1].

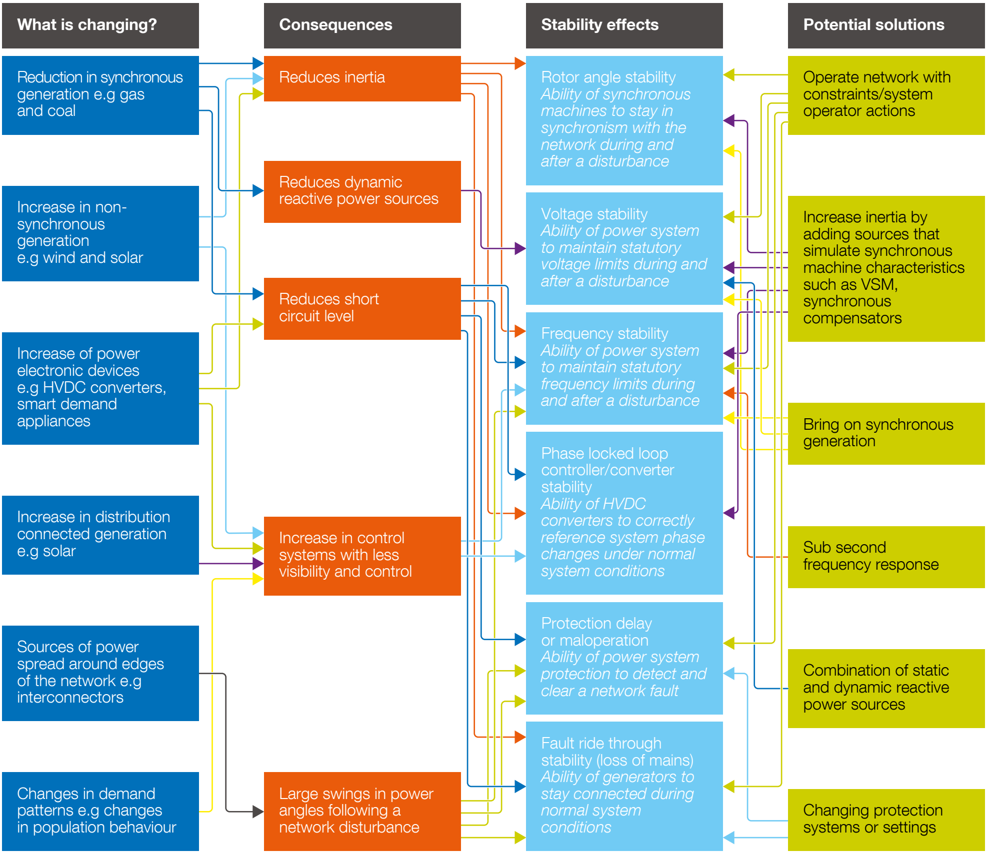
Rotating generators which produce power at the same frequency as the system frequency are called synchronous generators. Coal, gas and nuclear generators are examples of synchronous generation. Wind and solar are examples of asynchronous generation. When a synchronous generator is running it has an inherent stabilising effect on the system in most circumstances. Asynchronous generators do not have the same inherent stabilising effect.

What is changing in stability and what is driving the change?

As we move to a low carbon electricity system, more of our power is coming from renewable sources; at the same time, energy consumption is decreasing as we become more efficient. This means the amount of synchronous generation running at any time is reduced and, without intervention, the stability of the system reduces. To support the transition to a low carbon electricity system we need to both decrease our reliance on fossil fuel generation to stabilise the system and learn to operate with a more dynamic system. The diagram below outlines the key topics we are currently considering in this area and how they are interlinked. It includes topics beyond those we would have captured under a stability heading in the past. This reflects the significant change and elevation of importance of this area.

[1] https://www.nationalgrideso.com/insights/system-operability-framework-sof

Figure 5.1
Stability topics



Operability gap

What is our current strategy?

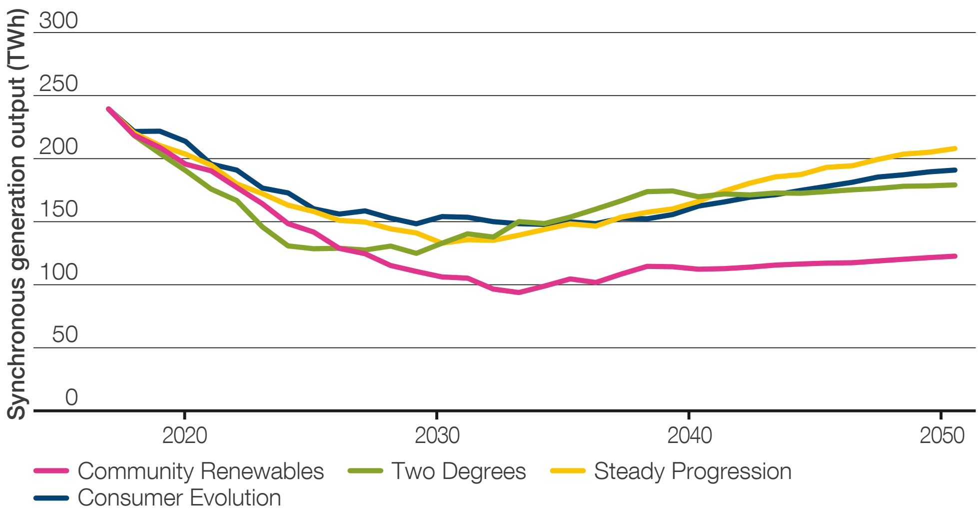
The SQSS[2] sets out how the system should be designed to meet defined stability criteria. There are also requirements on generators in the Grid Code[3] and Distribution Code[4] which govern how they should operate normally and respond to a fault.

In operational timescales, we monitor stability limits across the network and on a regional basis. This may lead us to instruct connectees to change their output so that we can either prevent a local stability concern or increase the stability of the network as a whole. The options we currently use in operational timescales will become more limited and more expensive as synchronous generation running declines.

Why must our strategy change between now and 2030?

The network and the assets connected to it need to be designed to support the stability of the system. Much of the network and the connectees have been designed assuming high levels of synchronous generation will be running. In all future energy scenarios we see a significant decline in the volume of synchronous generation running during the 2020s. This will mean networks and connectees will need to adapt to ensure the system is appropriately stable.

Figure 5.2
Annual synchronous generation output



[2] https://www.nationalgrideso.com/codes/security-and-quality-supply-standards
[3] https://www.nationalgrideso.com/codes/grid-code
[4] http://www.dcode.org.uk/

In some cases, it may be that the system can be operated at lower levels of stability, but the design of the network and connections needs to change to allow this. In other cases, we will need to find ways to maintain the stability of the system. Technical and economic assessment will be required to determine the appropriate approach.

There is a variety of potential options to manage future stability issues. It is likely that a combination of different options across code modifications, network changes and commercial services will be required to ensure the most efficient solution. As the requirements are regional, the solutions may also vary between locations.

New technology requiring capital investment is likely to form a significant part of the solution. To clarify this requirement to the industry and enable developers to invest we will need to be better able to articulate where and when we have requirements and consider where and when it is appropriate to make longer-term commitments.

The next two sections outline progress which has already been made to develop solutions and our plan for future work.

Progress so far

Much of our work so far on stability has been trying to better understand the impact of operating a more dynamic system. We have investigated a range of stability topics through the *System Operability Framework*. This work is helping to explain where and when changes will be needed based on the future energy scenarios.

Solutions might take years to develop, enact and build. Although our requirement is currently low we need to start exploring options now for the future, especially in view of the rapidly falling level of synchronous generation by the early to mid-2020s. There are already a variety of areas where action is being taken to resolve stability challenges. The key areas are described below.

Codes and regulation

Rate of change of frequency

In a less stable network, the system frequency changes more quickly following an event. A significant amount of distributed generation uses the rate of change of frequency as a measurement to detect if part of the network loses connection from the rest of the system. Under such a scenario the distributed generators are required to be disconnected to prevent a safety hazard. Initially through Grid Code working groups and now through the Distribution Code, it has been identified that making the generator protection settings less sensitive is more economic than maintaining the rate of change of frequency.

New generators are now obliged to be less sensitive to a change in frequency and we will initiate a change programme over the next three years to reduce the sensitivity of existing distribution connected generators. These changes will allow us to operate the system with significantly higher levels of renewable generation at lower cost to the consumer.

Fault ride through

The term fault ride through is used to describe the ability of a generator to remain connected and stable to a healthy circuit during a fault on the transmission system. As a greater volume of the generation on the network is made up of small generators, new requirements to ensure generation can ride through a fault have been introduced which now apply to all new generators above 1 MW. Any generators who either; had not ordered their equipment before 17 May 2018 or connected to the network after 27 April 2019 must now follow these new requirements.

Commercial and operational tools

Rate of change of frequency

Whilst generator protection is being made less sensitive we are monitoring system inertia and the largest potential loss to ensure the rate of change of frequency does not exceed the current sensitivity following an event. When necessary we take actions to either curtail the largest loss or raise the system inertia.

Vector shift

Some generators use a protection method called vector shift to detect if part of the network loses connection with the rest of the system and therefore should be disconnected. We identified that for some faults on the network, the amount of generation that could disconnect due to operation of vector shift protection was larger than the largest loss we normally secure. This issue was localised to networks in the south of England due to the large volumes of generation using this type of protection.

Working with Scottish and Southern Energy Networks, UK Power Networks and Western Power Distribution, we invited generators in the area to offer to make a change to their settings and then selected the most economic combination of offers to move forward to changing the settings. Resolving this problem ahead of operational timescales saved approximately £30 million in one year.

Plan for future work

We will continue to improve our understanding of where and when stability challenges will occur. In parallel we will investigate the potential solutions and develop a route to compare the costs and benefits of different approaches. Meanwhile in operational timescales, we will implement improvements to our existing processes. Specific actions are outlined below.

Commercial and operational tools

Rate of change of frequency

Changing the sensitivity of existing generation protection is expected to take place over three years. We will work with DNOs to prioritise the order that settings are changed to ensure benefits can be realised as soon as possible. Once a significant proportion has changed we will be able to update the operational limits that we are working to. This will reduce cost to the end consumer as we will need to take fewer actions to curtail the largest loss or raise the system inertia.

Demand inertia

We have used data from events on the system to develop a better way to calculate the contribution that demand has towards our system inertia. Over the next six months we will be integrating this approach into our control processes. This will mean that we are operating the system more securely and economically. We continue to work on ways of measuring inertia in real-time. If successful, this will give us world leading information on the dynamic characteristics of the system and further increase confidence that we are operating the system with the right balance of costs and risk.

Networks

Fault current report

Fault current is measured by network and generator assets to identify if there has been a fault on the system. If they measure a high fault current the assets will disconnect to prevent them being damaged by the fault. With a reduction in synchronous generation connected to the transmission system we expect fault current to reduce which may mean that the assets which use this measurement to protect themselves would not detect a fault on the network and would be damaged.

In Q4 2018/19 we will be publishing a *System Operability Framework* report to explain our latest finding on this topic following work we have undertaken with the network owners.

Comparison of network and market solutions

As part of the Network Development Roadmap[5] we are investigating whether stability should be included in the *Network Options Assessment*[6] methodology in future years. We are also looking at whether this is an opportunity to compare network solutions with commercial solutions to better understand the most economical solution for the end consumer.

Our future requirement is regional and broader than just inertia. We are working on how we can better define this requirement as well as making it clearer where and when we have a need. Our ambition is to be able to assess a range of solutions together over multiple years to establish which of those will be the most efficient way to resolve our challenges. This could result in a signal for network development being provided or a new commercial service being procured.

We are currently developing a pathfinder to trial this approach in Scotland and will be publishing more information on this in Q4 2018/19.

Codes and regulation

Low frequency demand disconnection

If the frequency drops very low it may be necessary to disconnect some demand to ensure the integrity of the rest of the network. In the *System Operability Framework* we indicated that this may not work effectively in the future. We are working with DNOs to explore if an improvement should be made to this capability.

[5] https://www.nationalgrideso.com/sites/eso/files/documents/Network%20Development%20Roadmap%20-%20Confirming%20the%20direction%20July%202018.pdf

[6] https://www.nationalgrideso.com/insights/network-options-assessment-noa

Innovation

We are leading and participating in innovation projects to help investigate some of the potential solutions to enable us to maintain system stability without having to rely on synchronous generation.

Enhanced Frequency Control Capability (EFCC)[7]

The findings of the EFCC innovation project will be published in Q4 2018/19. The improved system monitoring and control that this approach demonstrates could better enable us to understand and manage stability issues.

Phoenix[8]

We are partners in Scottish Power Energy Networks' innovation project which is looking to investigate a hybrid synchronous compensator. This type of asset could provide some of the stabilising qualities of synchronous generation without needing to generate power. This would mean that unlike synchronous generation it would not be displaced during periods of high renewable generation running.

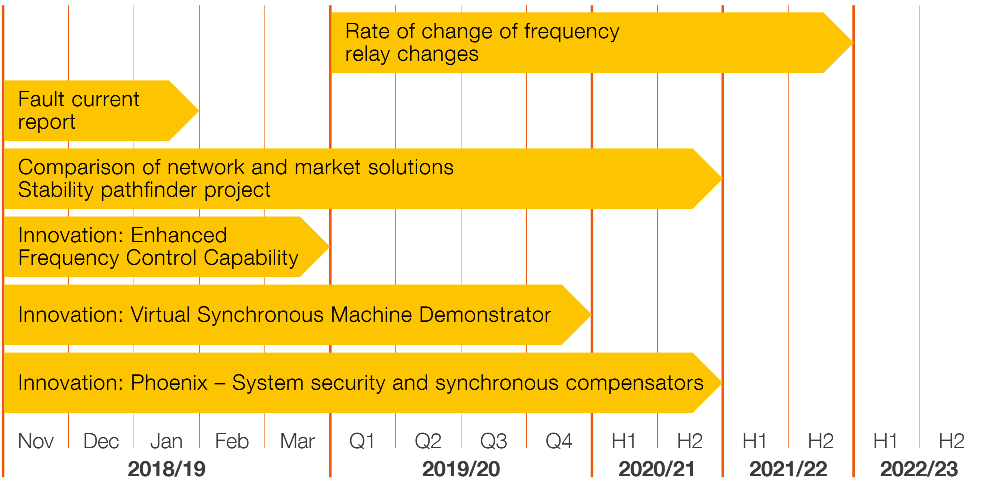
Project Phoenix continues until March 2021. The next steps for National Grid are to develop a performance requirement document to enable this type of asset to be connected to the network and to complete a cost benefit analysis based on the modelled capability. We are about to commence work on a system-wide assessment and will be ensuring that this integrates with the development of our stability pathfinder.

Virtual Synchronous Machine Demonstrator[9]

A virtual synchronous machine describes an asynchronous generator which has a control system which mimics some of the stabilising qualities of a synchronous generator. We have established a Grid Code expert group[10] exploring the technical requirements.

To support the Grid Code expert group, this project will trial a physical virtual synchronous machine which will help us to better understand the capability of this potential solution and demonstrate the system benefit in the laboratory environment.

Figure 5.3
Stability timeline



[7] https://www.nationalgrideso.com/innovation/projects/enhanced-frequency-control-capability-efcc
[8] http://www.smarternetworks.org/project/spten03
[9] http://www.smarternetworks.org/project/nia_ngso0004
[10] https://www.nationalgrideso.com/codes/grid-code/meetings/vsm-expert-workshop

Chapter 6
Thermal

Thermal

Key messages

- Historically, providers in the balancing mechanism (BM) were utilised for thermal constraint management services, either through direct BM instruction or via Constraint Management Contracts.
- An increase in the number of providers in different locations on the network has led to constraints appearing in new areas.
- Many of these providers are not accessible via the BM, reducing the options available to us to manage constraints.
- We are developing new approaches to thermal constraint management through a variety of routes:
  - broadening the scope of our thermal constraint management services to allow distributed energy resources (DER) to take part
  - utilising the implementation of wider BM access[1] to increase the pool of potential providers
  - improving the detail of what we publish and working to deliver more granular data on both our spending and our requirements in this area
  - using regional development programmes (RDP)[2] to trial new ways of working across transmission and distribution; and new technologies in specific areas
  - using the *NOA*[3] to allow the comparison of network and non-network solutions across the transmission and distribution network.

Introduction

What is thermal constraint management and why is it important?

There is a physical limit to the amount of power which can be transmitted through any piece of equipment on the network and often that limit is set to ensure that equipment does not become overloaded and overheat. Whilst every piece of equipment on the network has this limit, we only have to take action if the generation and demand pattern mean that this limit would otherwise be exceeded. This is explained in further detail in our transmission thermal constraints information note[4].

What is changing in thermal constraints and what is driving the change?

New forms of generation, at different locations on the network, are causing flows on the network to change. We also do not always have the same level of visibility of, or commercial agreements with, these new forms of generation. As a result, we are seeing more occasions when our options to manage transmission constraints are limited. We also need to work with DNOs to take a whole electricity system approach to managing network constraints across transmission and distribution to ensure efficient outcomes are realised for the end consumer and so that system security is maintained.

[1] https://www.nationalgrideso.com/sites/eso/files/documents/Wider%20BM%20Access%20Roadmap_FINAL.pdf

[2] https://www.nationalgrideso.com/about-us/whole-electricity-system/regional-development-programmes

[3] https://www.nationalgrid.com/uk/publications/network-options-assessment-noa

[4] https://www.nationalgrideso.com/sites/eso/files/documents/National%20Grid%20Transmission%20Thermal%20Constraint%20Management%20information%20note_July%202018.pdf

Operability gap

What is our current strategy?

Today we work with the TOs on network optimisation to:

- optimise the use of the network and minimise constraints
- reconfigure the network, redirecting flows to parts of the network with capacity
- use short-term circuit enhancements, temporarily increasing the capacity of the network.

However, network optimisation alone will not fix all constraints. We also rely on providers to change their output so that we can redirect flows. We do this using constraint management services. These are discussed in greater detail in our recently published transmission thermal constraints information note[5].

Why must our strategy change between now and 2030?

The changing generation mix in Great Britain, new forms of generation, connected at different locations, and voltage levels are causing flows on networks to change. This has led to a change in the thermal constraints we see on the transmission system and a change in our requirements for managing them. In the past, our ability to instruct the output of a large number of transmission connected generators met almost all our constraint management needs. However, the number of transmission connected generators has reduced, and the locations of our thermal constraints are continuing to change.

We are now seeing more occasions when our options to manage transmission constraints are limited. We need to encourage new providers to participate in our constraint management services to ensure that we have adequate options to manage these constraints. We need to work with DNOs to take a whole electricity system approach in managing network constraints across transmission and distribution to ensure efficient outcomes are realised for the end consumer and so that system security is maintained.

[5] https://www.nationalgrideso.com/sites/eso/files/documents/National%20Grid%20Transmission%20Thermal%20Constraint%20Management%20information%20note_July%202018.pdf

Progress so far

Our work on thermal constraint management has focused on three core areas so far:

- Evolving our network development processes so in the future we will be able to perform direct comparisons between a wide variety of solutions across the transmission and distribution networks.
- Improving both our ability to access a wider variety of potential providers and their ability to provide services to us through our wider BM access program, which includes working closely with DNOs to understand how their networks interact with our requirements.
- Developing new systems and processes, along with our partners, through the regional development programmes, which will allow us to better maximise the use of the existing network capacity.

Network development

We have recently published our Network Development Roadmap consultation[6] and confirming the direction[7] documents. These set out how we, as ESO, could develop our network planning tools – primarily the *Electricity Ten Year Statement (ETYS)*[8] and *Network Options Assessment (NOA)* – to drive greater value for consumers.

Wider BM access

We have published our Wider Access to the Balancing Mechanism Roadmap[9] which sets out our commitments and actions to improve existing BM entry routes and create a new route to market.

Regional development programmes

RDPs[10] look across the whole-system landscape to identify key areas of development to unlock additional network capacity, reduce constraints, and open up new revenue streams for market participants. They seek to introduce new ways of working that significantly enhance the coordination and control of the transmission and distribution systems, creating whole-system efficiencies and providing new tools and resources to manage system constraints – ultimately reducing costs for customers. We currently have three RDPs in progress:

- **UK Power Networks RDP** – We are collaborating with UK Power Networks through a regional development programme for the South East Coast area of England. The aim of the programme is to maximise the opportunities for further efficient deployment of distributed resources and reduce overall system costs for energy consumers.
- **Western Power Distribution RDP** – We are collaborating with Western Power Distribution through a regional development programme for the South West area of England. The exposed position of South West England has enabled it to become a favoured location for renewable generation. It is also an area where modelling indicates the network's ability to absorb that energy may be an issue after 2020.
- **South West Scotland RDP** – We are collaborating with both SP Transmission and SP Distribution through a regional development programme for the South West area of Scotland. There is great potential for renewable electricity generation in this region, but that requires extensive and costly network reinforcements to get the energy to where it is needed by conventional means; so, we are looking at new ways to use technology and operational methods to provide cost efficient outcomes for the renewable developments in the region.

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[6] https://www.nationalgrideso.com/sites/eso/files/documents/Network%20Development%20Roadmap%20consultation.pdf

[7] https://www.nationalgrideso.com/sites/eso/files/documents/Network%20Development%20Roadmap%20-%20Confirming%20the%20direction%20July%202018.pdf

[8] https://www.nationalgrideso.com/insights/electricity-ten-year-statement-etys

[9] https://www.nationalgrideso.com/sites/eso/files/documents/Wider%20BM%20Access%20Roadmap_FINAL.pdf

[10] https://www.nationalgrideso.com/insights/whole-electricity-system/regional-development-programmes

Plan for future work

We will continue to work to open up our current services to a greater number of potential providers. Ensuring we have access to the widest group of resources will, in turn, ensure that we can continue to manage thermal constraints into the future. We will also work with network owners to develop innovative ways to maximise the utilisation of the network and find innovative alternatives to network solutions when they are in the interest of the end consumer.

Commercial and operational tools

Regional development programmes

The RDPs are trialling different innovative approaches, providing new tools to manage thermal constraints on a whole-system basis. The RDP section of our website[11] includes more detailed information on each of these and the opportunities they offer.

Codes and regulation

BM wider access

Our next steps in improving access to the BM are set out in our Wider Access to the Balancing Mechanism Roadmap[12]. This will ensure the widest possible participation in the BM, allowing us to have access to a wide range of resources for constraint management. Our work here falls into three areas:

- improving existing routes to market
- developing new routes to market
- enhancing IT systems to improve data flows between the ESO and market participants.

Networks

Comparison of network and market solutions

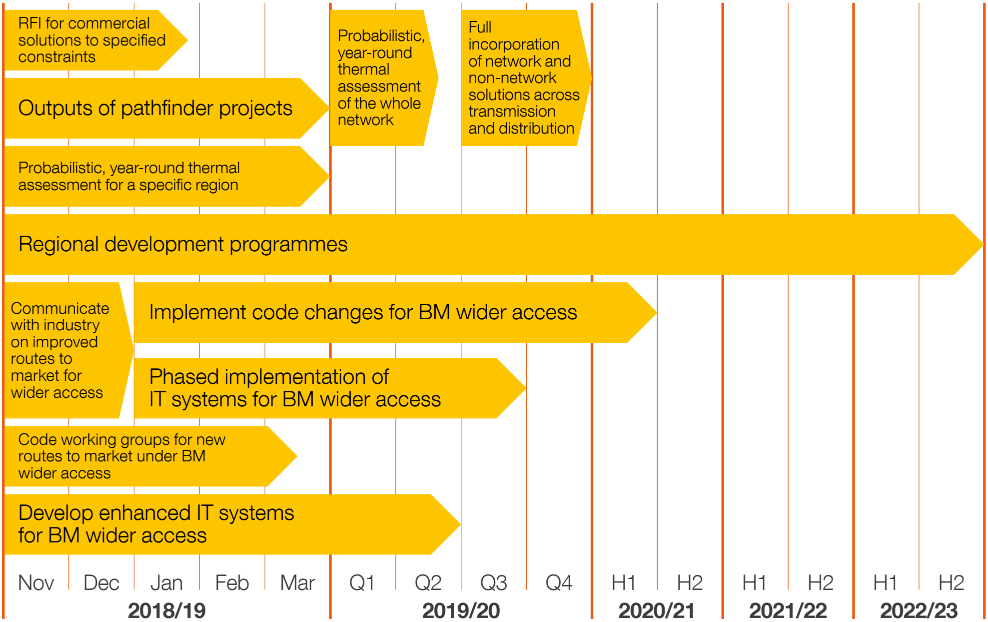
We have committed to reviewing the relationship between regulated network assets and market-based commercial solutions for thermal constraints. We are for the first time planning to request information on commercial options that could help increase boundary capability for the northern boundaries following the 2019 *NOA*[13]. This will also help us develop the required modelling tools and processes to carry out these activities in the longer term.

[11] https://www.nationalgrideso.com/insights/whole-electricity-system/regional-development-programmes

[12] https://www.nationalgrideso.com/sites/eso/files/documents/Wider%20BM%20Access%20Roadmap_FINAL.pdf

[13] https://www.nationalgrideso.com/insights/network-options-assessment-noa

Figure 6.1
Thermal constraint timeline



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For the purpose of this statement, National Grid Gas plc and National Grid Electricity Transmission plc will be together referred to as National Grid.

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