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Reactive power market design – Market analysis

Report to National Grid ESO

MARCH 2022

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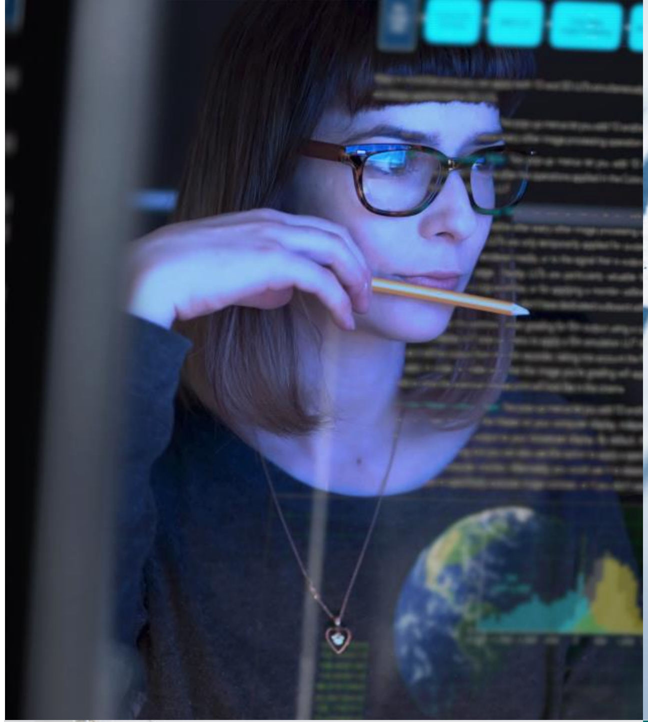
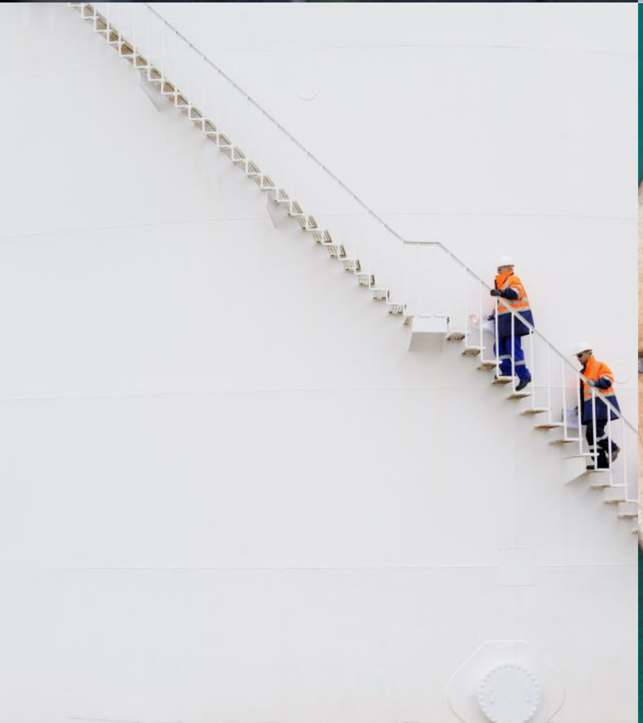
Agenda





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Key messages

Reactive power **demand and costs have increased** in recent years, whilst **legacy providers** (e.g. coal, old CCGTs) which have traditionally been used to manage voltage issues have begun to **retire** – we are expecting this **trend to continue** under existing arrangements

Current reactive arrangements are **fragmented**, with a range of procurement routes to address **specific challenges**

Reactive power is provided by both **commercial** and **regulated assets**, ESO is particularly reliant on the latter in low power flow situations – as needs are growing, new investment will be required in reactive power assets

Different technologies face different **cost structures** – there may exist significant **opportunity costs** associated with accessing increased reactive ranges for some commercial providers

Regulated assets can still offer **value for consumers**, even in the presence of a competitive market

Commercial assets and regulated solutions are inherently different – assessing on a 'like-for-like' basis is **challenging**

Key recommendations

Due to **increasing demand** for reactive power and expected future challenges, there is a need to **improve reactive arrangements** to ensure value for consumers in the long term

Consolidating arrangements in a way that all challenges can be addressed through a coherent unified mechanism would **reduce complexity** for both ESO and providers

With **legacy providers** beginning to **retire**, there will be the need for **additional investment** – making the right investment choices is especially crucial whilst the **system is in transition** towards a low-carbon future

Market arrangements will need to facilitate a wide range of providers with **diverse cost structures** to **maximise competition** – long term commitments to facilitate suitable new investment and shorter term commitments for providers with low availability certainty or volatile variable/opportunity costs of provision

Regulated assets should be assessed against commercial solutions to **maximise value for consumers**

Further work should be done with TOs and Ofgem to **align on an enduring set of principles** for assessment of regulated assets against commercial solutions

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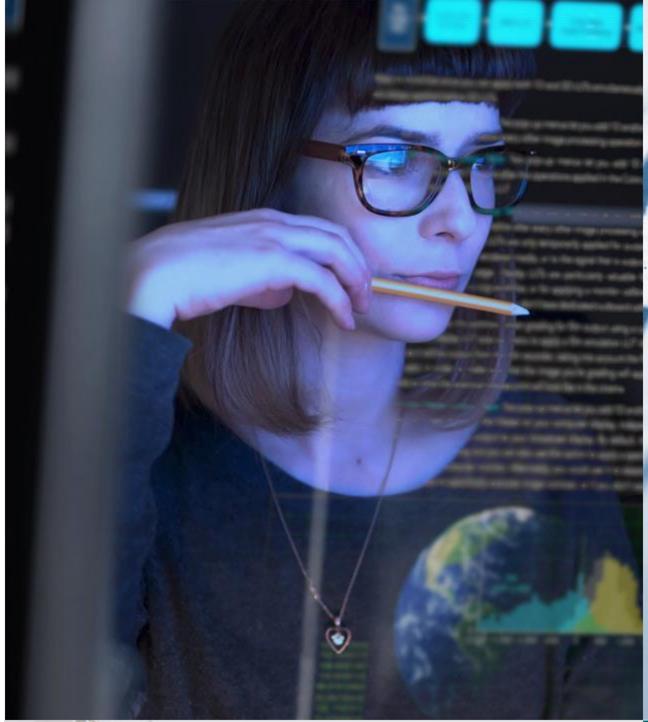

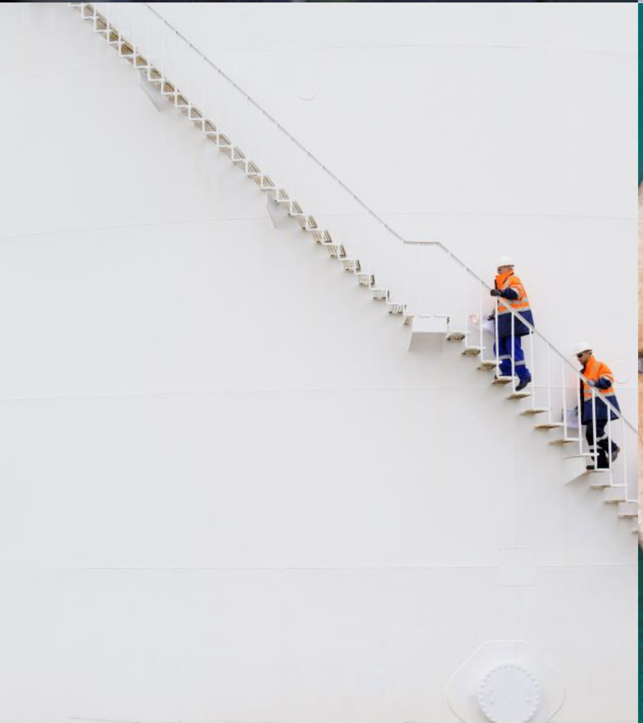


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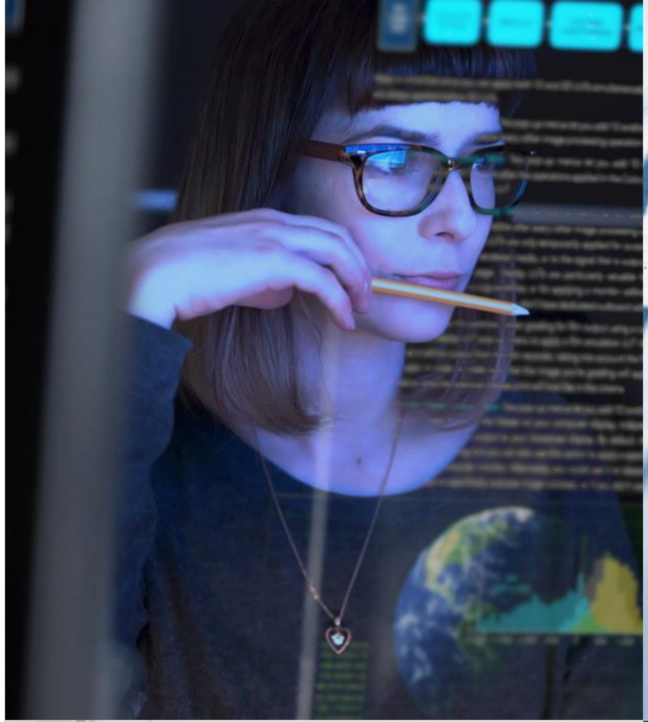

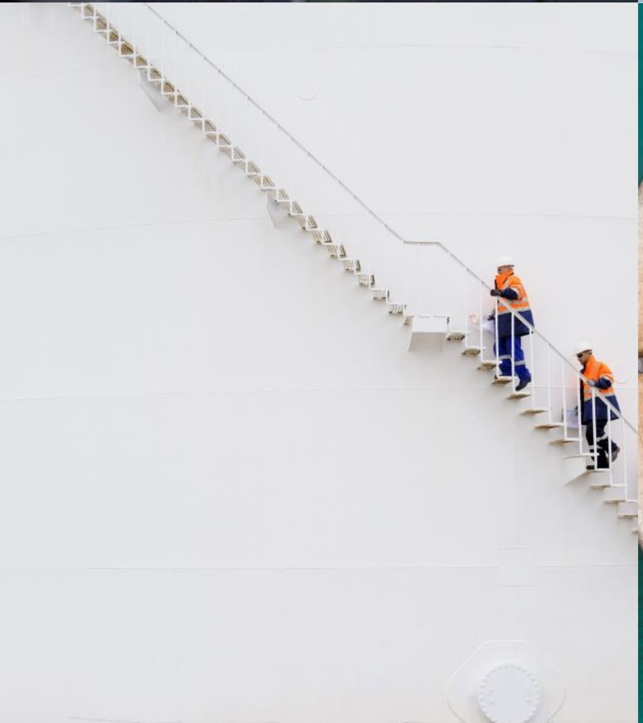


System security and uncertain future economics are driving the case for change in the provision of reactive power services

Tools obliged to provide reactive power are disappearing

Retiral of old plant providing services under the ORPS arrangements, in particular coal and in the future gas and nuclear

Shifting economics of different technologies means new generators are not replacing 'like-for-like'

Rapid increases in embedded generation and a shift towards intermittent technologies with complex characteristics and commercial arrangements potentially not bound by traditional arrangements and/or located far from system needs

Demand for reactive power services are increasing

Changes to network topology, offtake at GSP to DNO networks (due to embedded generation), and consumer behaviour

Spend on reactive power is increasing

Accessing providers is becoming increasingly expensive as traditional ORPS providers are being driven 'out of merit' by new technologies, requiring synchronisation to access

No enduring arrangements to drive technical innovation

No route to market for some solutions or insufficient economic incentives to stimulate innovation

System security could be threatened without action

New reactive power providers will need to emerge to ensure voltage performance in the future.

In practice ESO and TO arrangements are relatively robust, current arrangements can theoretically facilitate the transition (e.g. building grid assets) but there is potential to increase efficiency in service provision.

Agenda

There are a number of key routes to access for reactive power services at the ESO's disposal

Regulated price	**Network assets**	Network assets are one of the primary tools for managing system voltage, the three most widespread technologies are capacitors, reactors, and SVCs. These assets are typically instructed/used first (before ORPS providers) and costs are recovered by providers through system losses and RAB (of the Transmission Owner).
	ORPS	This is the primary route to procure services from large generators connected to the transmission network where participants are obliged to provide reactive power services within a fixed range and paid a regulated price. Importantly whilst not dispatching they are not obliged to provide the service and so may be instructed through the Balancing Mechanism or Schedule 7a trades.
Part regulated price	**Voltage contracts**	These are a derivative of ORPS, where providers are paid the ORPS rate but guarantee availability to provide the service (by contracting with a provider at a pre-agreed price to be operating at their SEL). Providers are paid ORPS rates for their reactive power and a separate payment for their availability (can be market index based or a fixed availability price).
Competitively determined price	**Pathfinder contracts**	NGESO has procured long term contracts for reactive power provision in Merseyside and in the Pennines region. Long term contracts give access to high availability solutions for reactive power that are paid an availability fee.

Key question: Do providers exist outside of these arrangements that NGESO cannot currently access?

Cost incentive to avoid provision	**Distribution arrangements**	The distribution network is not inherently a route to access reactive power but transfers across the interface between DNO region and TO assets affect the voltages on the system to some degree. Distribution connected assets are charged for reactive power outside a given power factor range, in the HV and LV networks this is explicit, within the EHV network this can be implicit in site specific charges. Furthermore a power factor closer to unity will reduce network capacity charges (levied on a p/kVA/day basis). There have been innovative projects running such as NGESO's Power Potential as well as SPENs tenders through the Piclo Flex platform to procure reactive power.

Note: Some other 'one-off' arrangements exist, ORPS = 'Obligatory Reactive Power Service', SEL = 'Stable Export Limit', ERPS excluded as not used by market participants today

Network assets

There are three core types of transmission asset owners with assets capable of providing reactive power

Transmission Owner (TO)

- TOs are the owners of the core onshore transmission system infrastructure in Great Britain.
- There are three heavily regulated TOs: NGET, SPET, SSEN-T (owned by National Grid, Scottish Power, and SSE respectively).
- Governed by the Transmission Licence.
- Transmission Owners obligation to keep system voltages within SQSS limits has resulted in the deployment of reactive compensation equipment across the network as the default option for *ensuring* compliance.

Offshore Transmission Owner (OFTO)

- OFTOs own offshore transmission infrastructure and interface between offshore assets and the core onshore transmission network (typically offshore wind farms).
- Numerous commercial players (that are subject to licence conditions) with new players eligible to enter the market.
- Governed by the Offshore Transmission Licence.
- There is a complex set of arrangements for OFTOs, however the requirement can broadly be split into two:
  - The need to maintain voltages on the offshore cable.
  - Delivery of reactive power services at the onshore connection point.

Interconnector

- Interconnector owners own the transmission infrastructure that connects Great Britain to neighbouring markets.
- Numerous commercial players (that are subject to licence conditions) with new players eligible to enter the market.
- Governed by the Interconnector Licence.
- Interconnectors to GB are all HVDC connected, and whilst reactive power doesn't flow through DC connections, most converter stations are configured to provide reactive power services.
- Whilst these are technically network assets they are remunerated via ORPS if eligible.

Notes: It should be noted that most OFTO connections today are AC, it is envisaged that DC connections will be used for some future projects

Network assets

Transmission owners must plan for deployment of reactive compensation equipment and recover the bulk of their costs through the RIIO framework

Transmission Owner (TO) obligation

- TOs are obliged under their licence conditions to plan/develop the transmission network in line with the SQSS and STC (System Operator Transmission Code), this includes keeping system voltages within limits defined in the codes.
- To ensure compliance, TOs have limited options and therefore the proliferation of reactive compensation equipment throughout the network has been necessary.

TO planning to date

- TOs will identify where there is a technical need for reactive compensation equipment and propose these developments to Ofgem via their RIIO business plan.
- TO plans are assessed against a number of scenarios, where a justified need for the asset vs. the potential cost can be assessed.

TO asset commercial arrangements

RIIO	Driver	**Capex**		**Opex**	**Other**	
	Interim	Regulated Asset Value				
	Payment type	Depreciation	Return	Fast Money	Incentives	Tax
Other		Equipment losses	*Electrical losses from reactive compensation equipment are included in the total system losses, and therefore socialised across consumers.*			

- Capex and most Opex (and returns) for reactive compensation equipment built by the TOs are recovered through the RIIO mechanism.
- Electrical losses in the equipment (small component) are included in the total system losses, and can be considered as an avoided cost for the TO.

Notes: SQSS planning obligation falls under Condition D3 of the Electricity Transmission Standard Licence Conditions, STC = 'System Operator Transmission Code'

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Transmission Owner assets in RIIO-2 business plans are included through a combination of core business plans and uncertainty mechanisms

TO reactive compensation equipment planning

- Shortfalls in reactive power requirements across the system are inherently uncertain as they are related to underlying system conditions.
- New connections or disconnections of existing assets can drive need for reactive compensation equipment up or down.
- Therefore in their RIIO-2 business plans TOs have included essential reactive compensation equipment in their RIIO-2 business plans in their 'certain' views (i.e. only equipment with a high degree of confidence to be required by the system is included).
- Other voltage management projects are included in an 'uncertainty mechanism', designed to deliver solutions only if needed.
- Potential solutions from the uncertainty mechanism can be triggered by the ESO if the need is identified.

Core RIIO-2 business plans

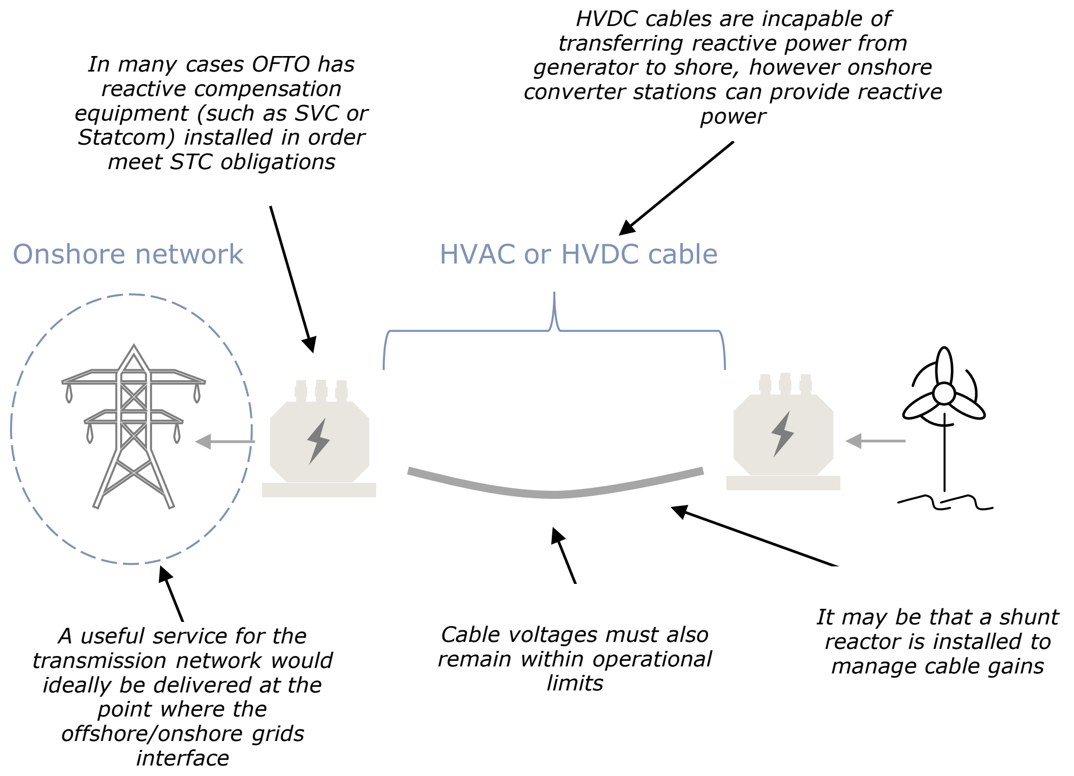
- RIIO-2 business plans from all TOs proposed a number of projects which included, or consisted wholly of, reactive compensation equipment.
- In most instances the need for equipment is generally justified by large known changes in the system (such as nuclear closure, or new circuits).

Uncertainty mechanism

- Uncertainty mechanisms are included in RIIO business plans as a way of pre-establishing potential costs and potential solutions for assets that are highly uncertain.
- In the event that the ESO identifies a need for the new investment (as covered by the mechanism) beyond that included in the core RIIO business plan, they can trigger investment through an STC planning request.
- All TOs recognised that other commercial solutions may also exist in their latest RIIO plans and have included an uncertainty mechanism on those grounds.

REACTIVE POWER ARRANGEMENTS

Offshore Transmission (OFTO) assets have complex arrangements which can include a mixture of commercial and regulated payments



OFTO arrangements

There are a number of technical with respect to OFTOs that can be in place, these can broadly be categorised as generator only, OFTO only, or mixed solutions

- **Generator only solutions:** the offshore wind farm (or other offshore equipment) wholly provides reactive power services and is paid the ORPS rate (metered at offshore grid entry point) and is supporting the voltage on the offshore cable with some additional reactive power transferred to the onshore system.
- **OFTO only solutions:** reactive compensation equipment is installed to provide reactive power at the onshore grid connection point, and separate equipment is generally installed to compensate for cable gains. Value is realised by the OFTO through their Regulated Asset Base (RAB) and charged through TNUoS[1].
- **Mixed solutions:**
  - Can be that OFTO providers all onshore capability and generator compensates for cable gains only; or
  - Generator and OFTO share responsibility for onshore MVAr.
- In both cases generator is paid ORPS at offshore grid entry point and OFTO recovers cost through RAB.

Notes: [1]TNUoS (Transmission Network Use of System Charge) charges for this equipment is recovered via a mix of local circuit, local substation, and general TNUoS depending on the location and type of reactive equipment, not all configurations provide the same value to the ESO for maintaining onshore transmission voltages

The Obligatory Reactive Power Service (ORPS) is provided by large, transmission connected plant

Key providers

Synchronous generation

– CCGT/OCGT
– Nuclear
– Biomass
– Large hydro & Pumped Storage

Non-synchronous generation

– Mostly onshore/offshore wind
– Some small hydro can be converter connected

Commercially operated HVDC links

– Interconnectors

Characteristics

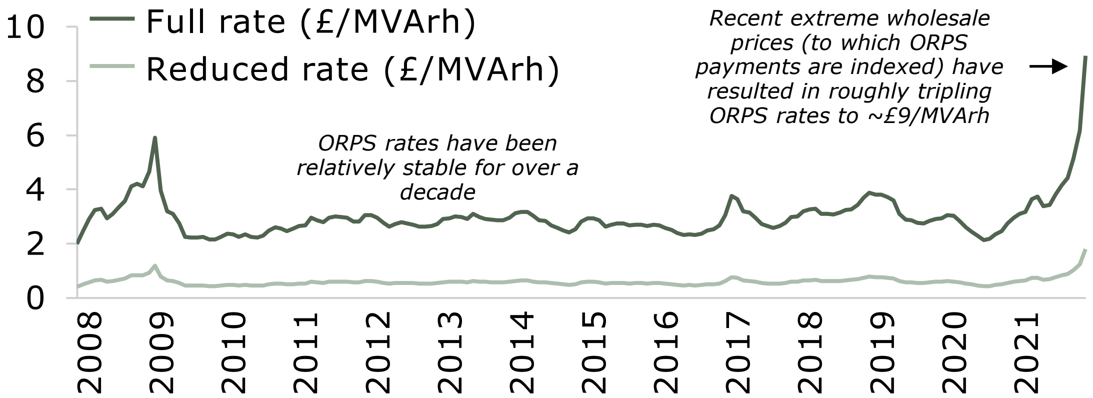
– Introduced in the early 2000s, since there have been few changes to the service design or remuneration mechanism.
  – Originally remuneration was designed to cover the cost of providing the service.
  – Evolving structure has indexed to inflation and power prices to deal with changes to underlying costs.
– ORPS is governed by Mandatory Service Agreements (MSA) with each provider.
– ORPS provision is mandatory for large transmission connected generators (though some other MSAs exist outside of the catch-all definition of the service).
– ORPS is a uniform payment across generators based on their MVArh output, this is irrespective of the utilised range.

Obligations

– Must provide reactive power ranges as set out in the Grid Code (or otherwise translated into their mandatory service agreements).
– Must make reactive power available within a specified active power output range.
  – Individual MSAs may not reflect 'generic' legacy arrangements and reactive power may be provided outside of traditional range e.g. some non-synchronous generators can provide MVAr capability at below 20% of rated capacity output and be compensated for this.
– Providers that don't fully comply with obligations may be paid a reduced rate.

The ORPS remuneration mechanism is regulated, with providers compensated on a uniformly priced delivered volume basis

Payment mechanism



- Prices indexed to an average of three month ahead price indices as well as inflation.
- Providers compliant with obligations receive full payment, those in breach receive a reduced rate (20% of full rate).
- Providers may be in breach if: they fail a Reactive Test; fail to comply with an instruction (either unable to technically deliver within the specified range or ignore instruction); or aren't capable of provide 0MVAr at the commercial boundary.

Generator cost exposure

Mechanical wear

- Increased wear on the equipment and associated maintenance costs (increases more as power factor deviates further from unity).
  - Includes parts (due to shorter equipment lifetime) and labour.

Outages

- Lost revenue from outages associated with wear on the equipment:
  - either in the form of planned outages; or
  - potentially more seriously unplanned outages due to equipment failure.

Efficiency losses

- Lower efficiency when operating at higher reactive ranges increasing costs.
- Losses in wind farms from the turbine to the subsidy metering point may also be increased at higher reactive power ranges meaning lost subsidy revenue.

Voltage contracts are used to guarantee availability of ORPS providers at a pre-agreed price

Voltage contract applications

- Contracts to secure system voltages in the event of an expected shortfall can be offered to market participants when a (potential) shortfall of reactive power provision is identified by the ESO.
- These are communicated to market through submission of a Transmission Constraint Management Requirement Notice, and can be just a few weeks before the commencement of the services.
- Generally these occur when there are outages with major transmission infrastructure or unusual supply/demand dynamics at play for reactive power in a given location (i.e. contracts are generally only offered for relatively short durations).
- Due to the highly locational nature of reactive power requirements, eligibility is typically restricted to just a handful of providers.

Voltage contract commercial arrangements

- There are two types of services generally procured by the ESO to provide availability for reactive power services, these are Firm and Optional (non-firm).
- Prices are determined on a competitive basis (pay as bid), with an economically optimal solution used to determine successful providers.
- In both cases generators are paid for their reactive output based on ORPS default payment rates.

Firm service

- Providers commit to generating at their stable export limit to guarantee availability to their reactive range.
- Remunerated on a *£/Settlement Period* basis.

Optional service

- For the Optional service this is paid out when the ESO enacts the service.
- Remunerated based on the difference between the prevailing *spark spread* and a pre-agreed *strike price*.
  - The strike price for the Optional service is tiered based on the plants PN
  - If spark spreads are high and the plant is scheduled to run anyway[1], there would be ultimately lower cost to customers

Notes: [1]Generators are notified before gate-closure to guarantee availability, therefore the ESO cannot rely on PN's as an accurate reflection of availability as commercial parties are free to change their PN up until gate closure/ Final Physical Notifications are submitted

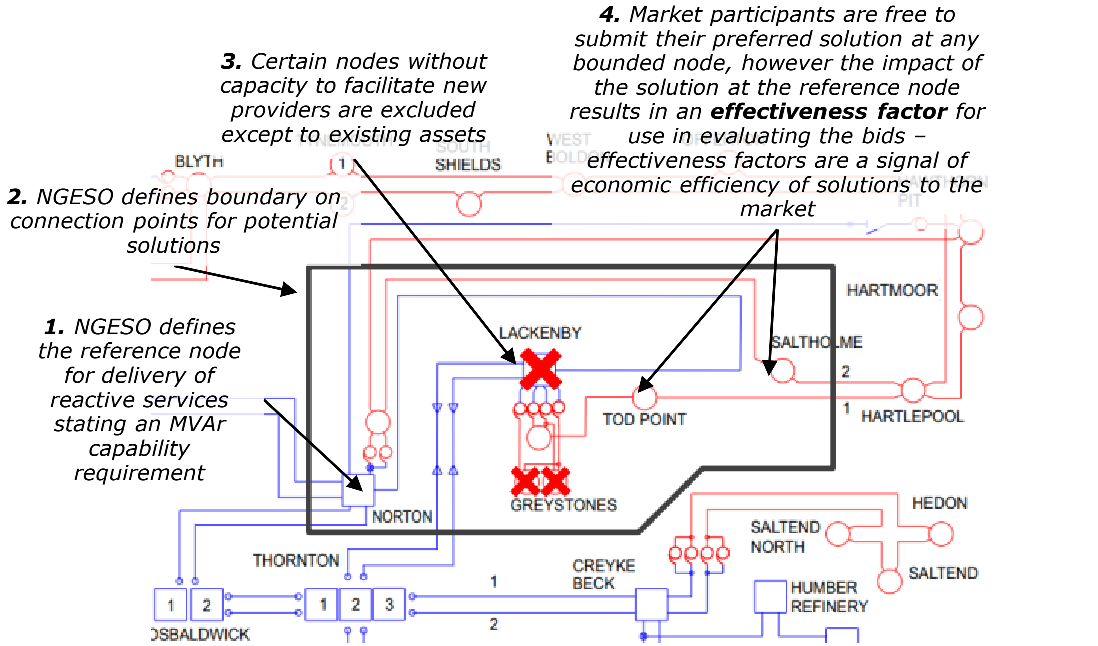
REACTIVE POWER ARRANGEMENTS

The pathfinder initiatives have laid the foundation for potential long-term contracting of reactive power

Commercial arrangements

Timeframe	10 year agreement
Product	Static reactive power absorption (single direction service)
Requirement determination	Offline-long term study
Eligibility	New providers incl. those down to 66kV, grid asset solutions also assessed in process
Obligations	Year round availability, utilisation when instructed (max utilisation 5,500h/y)
Payment mechanism	£/SP availability fee[1]
Bid evaluation	Effectiveness factor adjusted least cost solution (incl. infrastructure costs)
Penalties	Non-payment, becoming more penal below 90%[2] – termination for non-performance

Needs and solutions (West Yorkshire example)



For the West Yorkshire region, effectiveness factors are not a meaningful way of signalling requirements meaning signals to participants on where to connect are more vague, however ESO were able to signal where solutions were likely to be highly effective. A market based solution will need to overcome these issues.

Notes: [1]Grid asset costs are assessed, however they are remunerated via existing arrangements i.e. RAB cost recovery [2]Below 90% availability, participants would lose more than their £/SP fee for each SP that they are not available down to 45% availability, thereafter no payment is due to the provider.

Technical and regulatory barriers for distribution connected assets are high, with limited current routes to provision outside of direct DNO contracting

DNO security & technical barriers	The voltages within the distribution network itself must be maintained at acceptable levels in line with DNO licence conditions, this creates difficulties in transferring meaningful volumes of reactive power throughout the distribution level up to the higher voltages required at the transmission network. Actions taken by individual generators may be ‘cancelled out’ by DNO actions without a coordinated approach.
Charging arrangements	Existing charging arrangements (such as capacity charges, site specific charges, and in the case of LV/HV connected properties – explicit charges) include a cost for reactive power influences on the system. These charges have historically been designed around the additional costs associated with reactive power in the distribution network. The mechanism by which these charges are determined in the context of useful service provision would need to be evaluated.
Existing agreements	Existing connection agreements limit the power factor range which generators are allowed to operate at to ensure distribution network security, any changes to the range of power factors (*leading or lagging*) would require widespread change to connection agreements. Furthermore, flexible agreements to not guarantee availability for reactive service provision (as they may be de-energised outside of ‘firm’ windows).
Competing incentives	Higher levels of reactive power flowing across the network will lead to higher losses on the system, which is a disincentive for DNOs who are incentivised to minimise losses (albeit under the latest iteration of the RIIO framework, this is expected to move from a financial incentive to a reputational incentive, i.e. measured and reported but without direct implications for revenue under the mechanism). Additional losses will also lead to additional costs for customers within the distribution network.
Overlapping services	Based on DNO feedback some distribution networks are planning to, *or already*, actively procuring their own reactive power services from providers. The interaction between DNO and TO assets must be considered to avoid double-procurement, or avoid conflicting instructions between groups of providers in a given region (nullifying benefits).

Notes: DNO reactive arrangements considered in more depth in a separate workstream

Power Potential has established a potential framework for enabling reactive power provision from distributed energy resources through cooperation between ESO and UKPN

Key characteristics of Power Potential	
Product	Dynamic reactive power (core product)
Operational limits	An acceptable PQ[1] envelope which ensured compliance with DNO system voltage requirements was determined by UKPN, allowing safe operation without undermining existing obligations.
Effectiveness of solutions	A single static effectiveness factor was assigned to each plant, allowing economic assessment of bids adjusting for provision at the point of service delivery (rather than solution location).
Dispatch route	Dedicated platform (DERMS) for instruction, integrated with DNO and ESO existing platforms. Services instructed from ESO to DNO (commercial signal), then DNO to generator (technical signal).
Commercial arrangements	Availability by settlement period (day-ahead), submitted offer for availability price and utilisation price
Next steps	UKPN intends to work alongside ESO to develop BAU solution by 2028

Roles and responsibilities

ESO – service buyer

- Determines high level needs for transmission network and assesses effectiveness of service delivered at GSP to meet system needs
- Provides needs to DNO at the GSP
- Evaluates and accepts offers

Future costs could be recovered through existing arrangements

DNO – service facilitator

- Defines PQ envelopes to ensure voltage levels in distribution network do not exceed limits
- Defines effectiveness factors for DER delivery at GSP
- Relays availability information and offers from DER to ESO
- Relays instructions to DER

No clear route to recovering costs in the future (charge provider, charge ESO, shared, passthrough in EDCM/CDCM, or other?)

DER – service provider

- Relays availability and offer prices to DNO
- Acts on instructions as received from DNO

Future costs should be recovered through market mechanism if solution is economic

Notes: [1]PQ envelope refers to the space governing the allowable reactive & active power operating region for a provider

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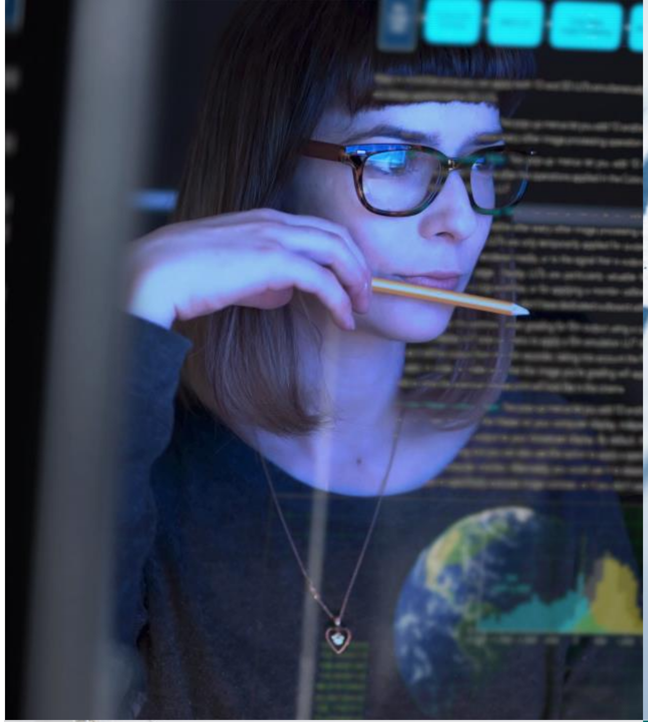
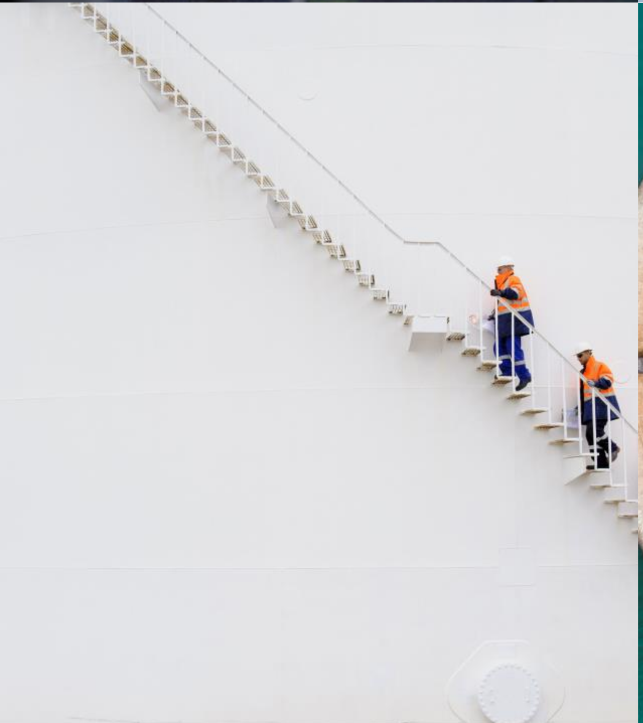




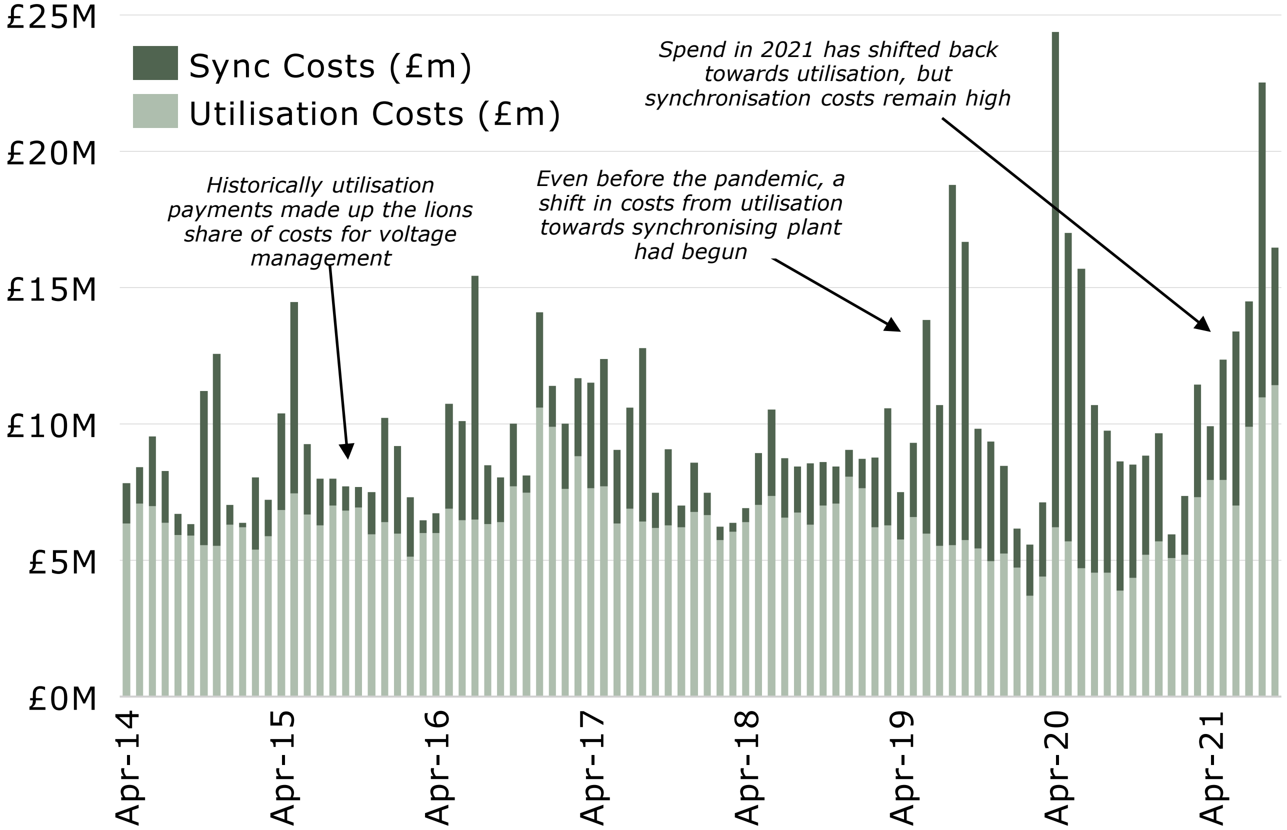
RECENT HISTORY

The balance between utilisation payments and payments to generators to position themselves to provide reactive power has shifted in recent years

VOLTAGE COSTS

- Historically utilisation payments were the largest contributing factor to voltage spend in Great Britain.
- In recent years significant additional costs are being borne by the ESO (and ultimately customers) due to fundamental changes in the system.
- Thermal plant required to provide the service are increasingly being synchronised to access their reactive range:
  - this is driven partially by the increasing volumes of low-marginal cost generation such as wind and solar; and
  - partially due to the retiral of plant in strategically important locations on the network.
- Synchronisation costs are particularly high in spring/summer when lower demand results in less 'space' for thermal generator on the system.

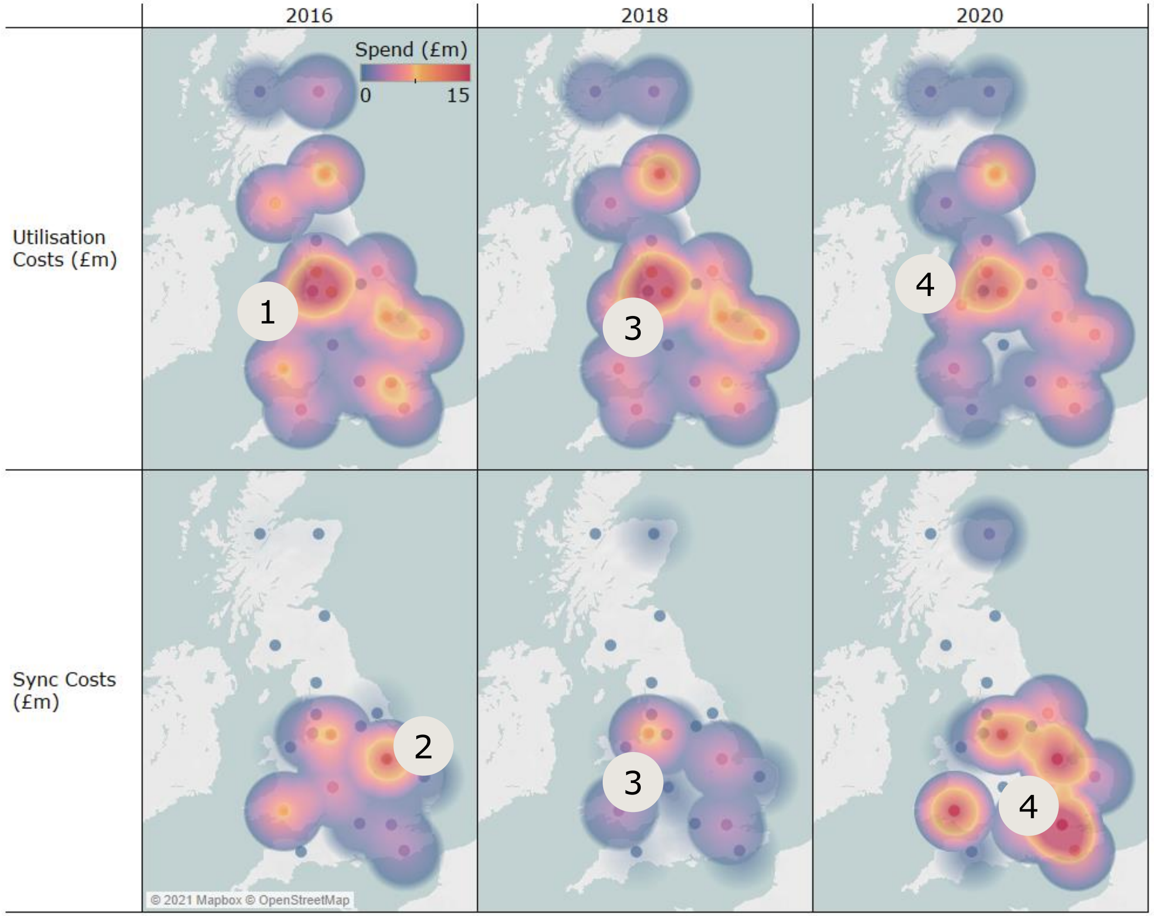
MONTHLY VOLTAGE MANAGEMENT COSTS (£M)



RECENT HISTORY

Recent spend for managing voltages commercially has shifted from utilisation of providers to payments to access their reactive range

REACTIVE SPEND BY VOLTAGE REGION (£M)



REGIONAL SPENDING

1 Historically spend was primarily driven by utilisation, much of these costs being borne around the Mersey region.

2 Some issues contributed to total spend but this was limited to the East Midlands (and to a lesser extent Mersey regions).

3 In recent years, spending in the Mersey region has been persistently high for utilisation and synchronisation of providers to access reactive power services, the pathfinder initiatives should help to alleviate some of these costs.

4 In 2020, the relativity between utilisation costs and synchronisation costs shifted for the first time. This was largely driven by demand reductions as the pandemic suppressed consumption, fewer thermal plant were synchronised to provide reactive power services and had to be accessed through the Balancing Mechanism to ensure system security

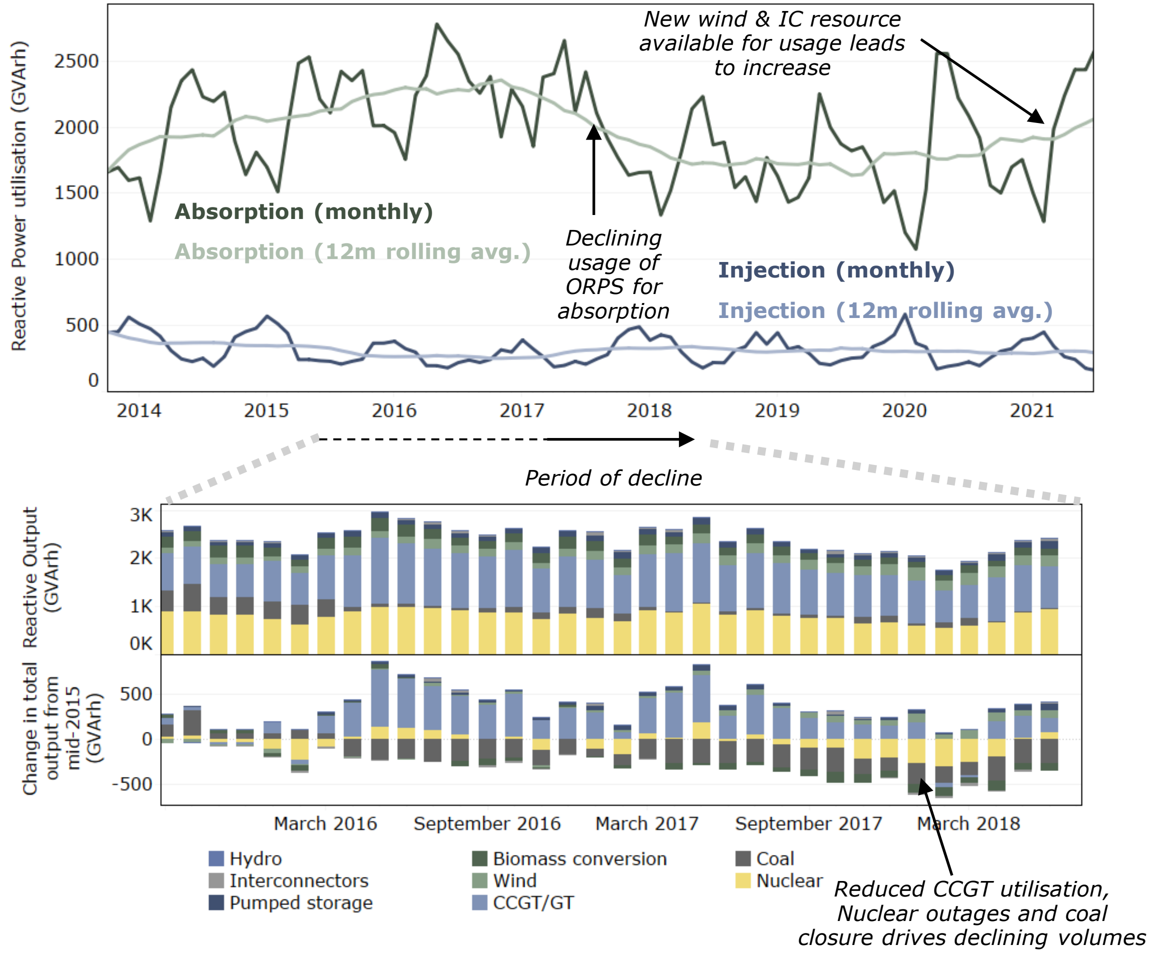
A wave of closures led to reducing ORPS availability and utilisation from end-2016

ORPS VOLUMES

- The ORPS service has historically primarily been used to lower high voltages occurring across the system (absorption).
- There is still a need for injection of reactive power in some locations across the network in certain conditions.
- There is an inverse correlation in volumes between winter and summer, where summer conditions require additional absorption and winter periods require additional voltage support (relative to 'base' needs).
- Whilst total system needs for reactive power have been growing, output from ORPS providers have remained relatively stable, this is partially due to the closure of existing assets that were previously effective at providing reactive power.
- Other sources of reactive power must compensate where there is a decline in ORPS usage

ORPS utilisation

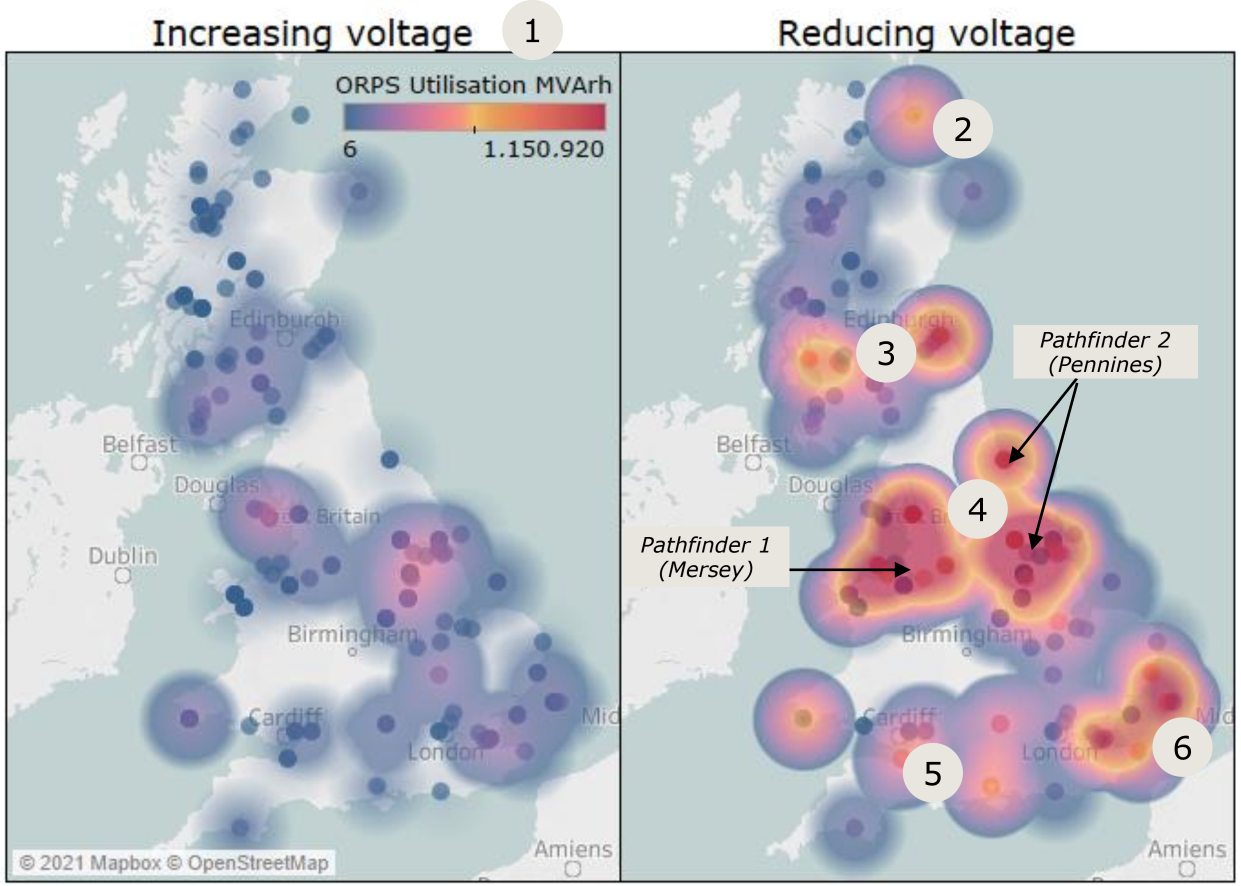
Drivers of decline



 30/03/2022 | REACTIVE POWER MARKET DESIGN – MARKET ANALYSIS

Utilisation of ORPS is uneven across the country with regional scarcities – new providers may be needed to establish effective competition

ORPS UTILISATION (MVARH, APR 2020 - JUL 2021)



1 Reactive power needs for increasing system voltage has been significantly lower than for reducing system voltage over the past year. However, for system security, peak requirements should be taken into account, not just volumes.

2 Beatrice OSW farm has a relative monopoly in the far north of Scotland, with nearby Peterhead providing some additional capability.

3 Nuclear plants including Torness and Hunterston provide much of the reactive power in this band. These plants are scheduled for decommissioning in the coming years (2030, 2022 respectively).

4 The bulk of reactive power under ORPS is procured in this region, however plant need to be synchronised to provide reactive power services. The Pathfinder initiatives should lower these costs.

5 There would be little competition in the South Coast region from current providers.

6 On the south-east coast, there are a number of providers, these are mostly solving constraints in London.

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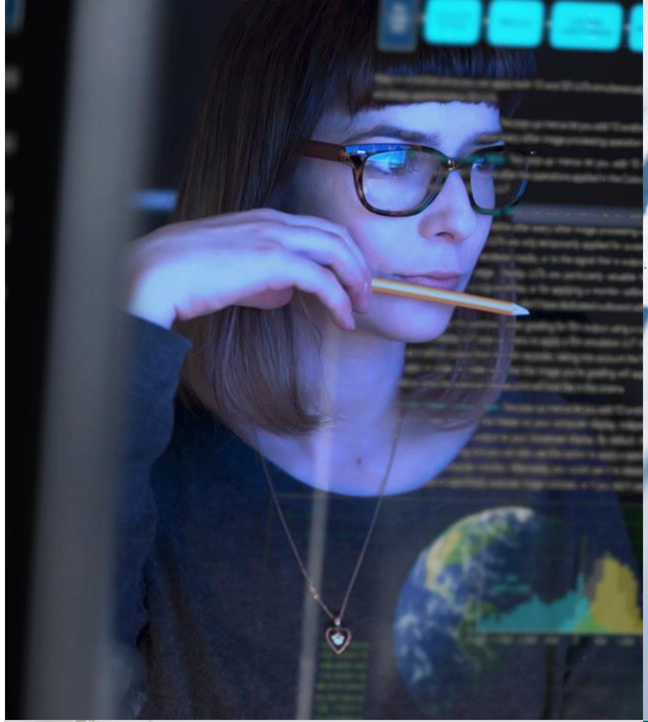
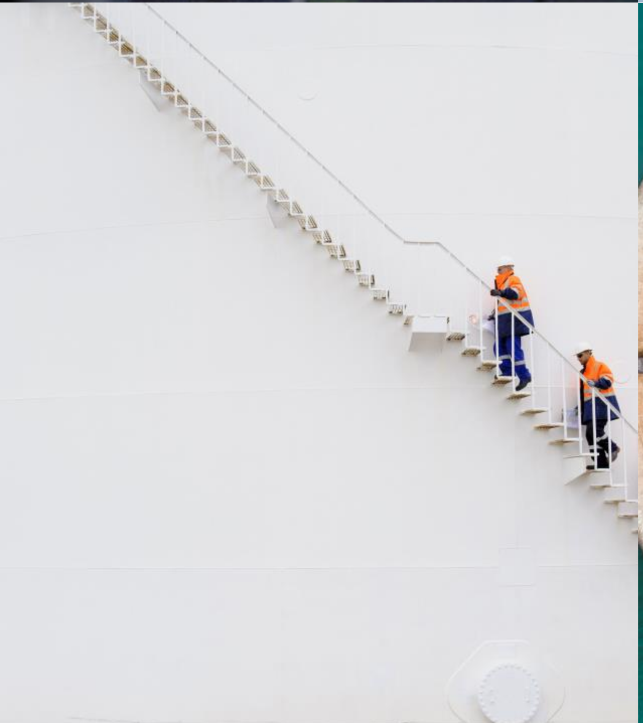


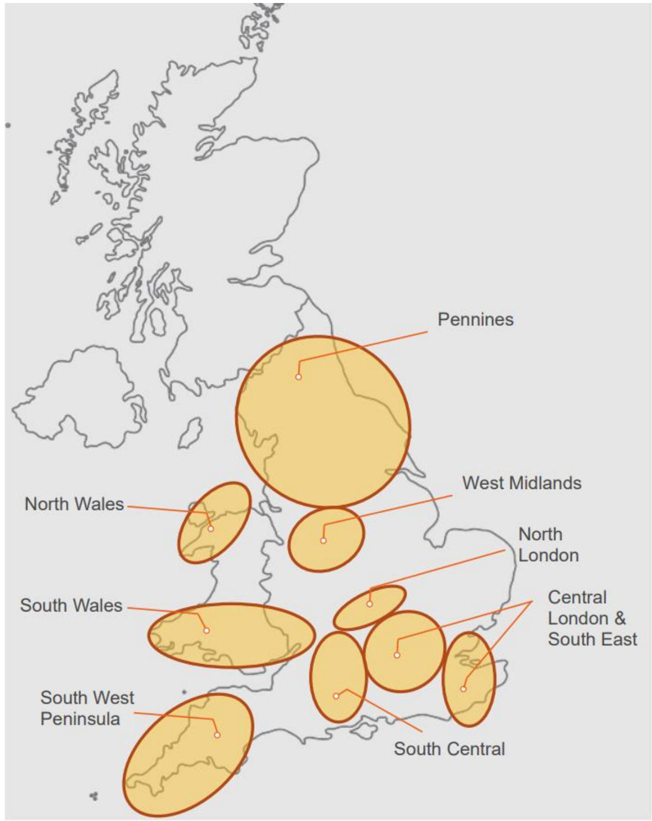


Changing network topology, generation, and consumption patterns have resulted in voltage issues arising in almost all areas of the grid in E&W

VOLTAGE REQUIREMENTS FROM NGESO

- ESO screens the local voltages on the system on a weekly basis[1] identifying where voltages are close to (or in some cases outside) of SQSS limits.
- In the majority of cases areas identified as having voltage issues can relate these issues to a few points:
  - Changing patterns in consumption of electricity (e.g. lower demand from industrial, increased energy efficiency);
  - The decommissioning of generation assets (in particular the closure of significant amounts of coal over the last 3-7 years);
  - Outages of TO assets; and
  - Increasing levels of embedded generation, changing the way in which electricity flows across the transmission system.
- Many of these issues fall outside of the ESO's control, nonetheless the ESO is required to secure the system voltage, therefore new solutions (potentially from existing providers) for reactive power must be encouraged to ensure future voltage security.

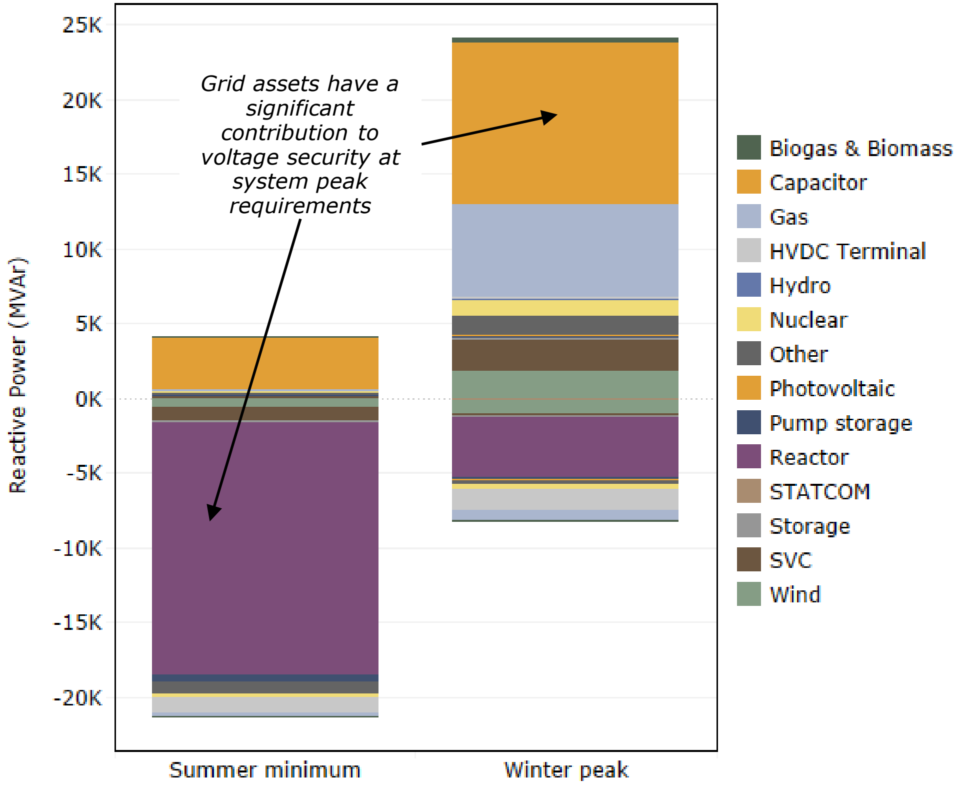
KEY AREAS IN E&W WITH SIGNIFICANT VOLTAGE ISSUES



Notes: [1]NGESO also comprehensively assess voltages on other timescales, generally from the year ahead stage right up to real time

Peak requirements for reactive power occur in opposite directions at different times of year

PEAK REQUIREMENTS BY TECHNOLOGY (MVAR, ETYS 2025/26, NATIONAL UTILISATION OF RP)



REACTIVE POWER NEEDS

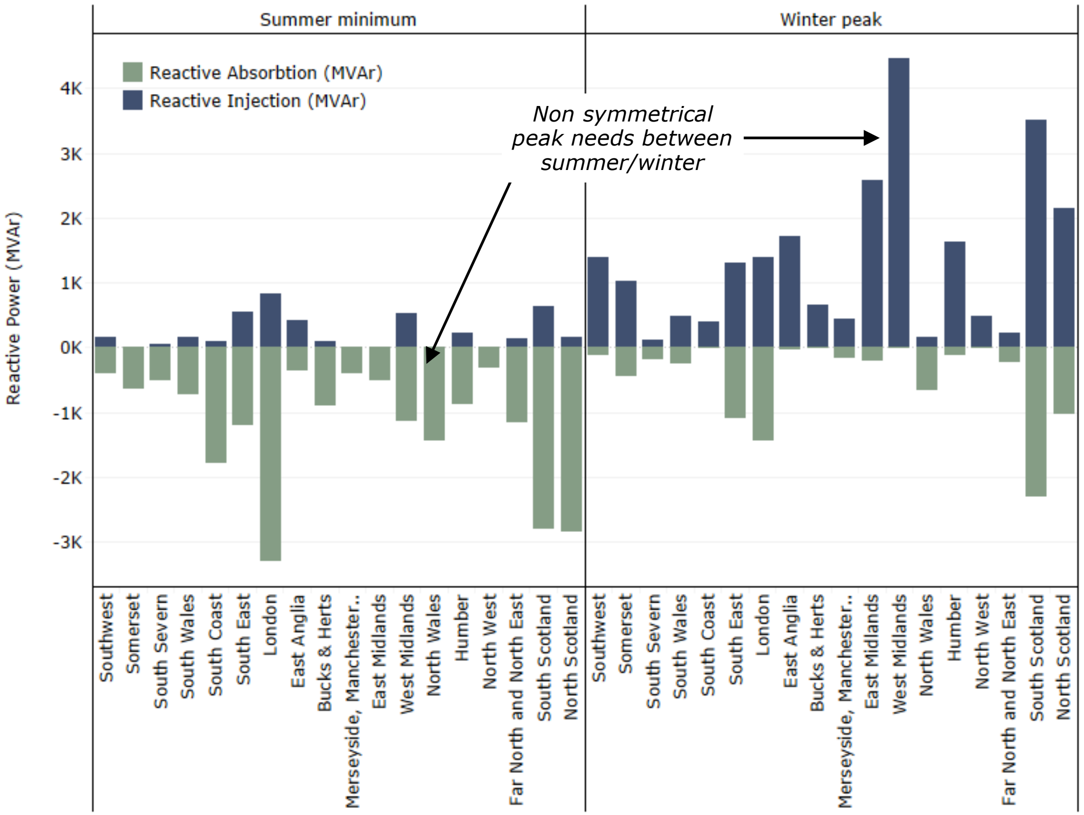
- Summer minimum conditions tend to occur overnight, when generation from renewables is limited, demand is low, and few thermal plant are synchronised.
- In summer minimum conditions, the transmission system itself is generating reactive power - the majority of reactive power needs are met by reactors, capable of absorbing reactive power with relatively low electrical losses.
- If current trends continue, additional reactors (or equivalently capable grid assets such as STATCOMs or SVCs) will be needed to ensure security at the summer minimum.
- The winter peak has the opposite trend, where reactive power must be injected into the grid to prevent voltages from falling too significantly.
- At the winter peak, more generation is available that is capable of providing voltage support than the summer minimum.

It should be noted, these are peak requirements, volume requirements will be considered later in the project

Notes: Summer minimum occurring in Aug 2025 and Winter peak occurring in Dec 2025), snapshot single point in time

Reactive power needs vary significantly by location and requirements are non-symmetrical within regions

REGIONAL REACTIVE POWER NEEDS (MVAR, ETYS 2025/26)



REGIONAL DIFFERENTIATION

- Between regions, reactive power provision for both the summer minimum and winter peak vary considerably with a strong need for reactive absorption at summer minimum and a high requirement for injection at winter peak.
- It should be noted that these requirements are also non-symmetrical (e.g. Midlands regions) – it may be that capability (MVAr) requirements are higher in one direction than in the other (e.g. significantly higher peak requirement for reactive injection than absorption in the midlands regions).
  - As a result of this it is likely that procurement volumes for upwards/downwards services will only have a certain volume of symmetrical requirements, with excess procured in a single direction.
  - This could have implications for new build technical solutions e.g. SVCs (bi-directional) vs. capacitors (single direction) which differ in cost.

Note: There are also differences in reactive power needs within individual aggregated zones listed here

Reactive power peak requirements are overwhelmingly met by reactors in the summer – in the winter, plant is synchronised and contributing

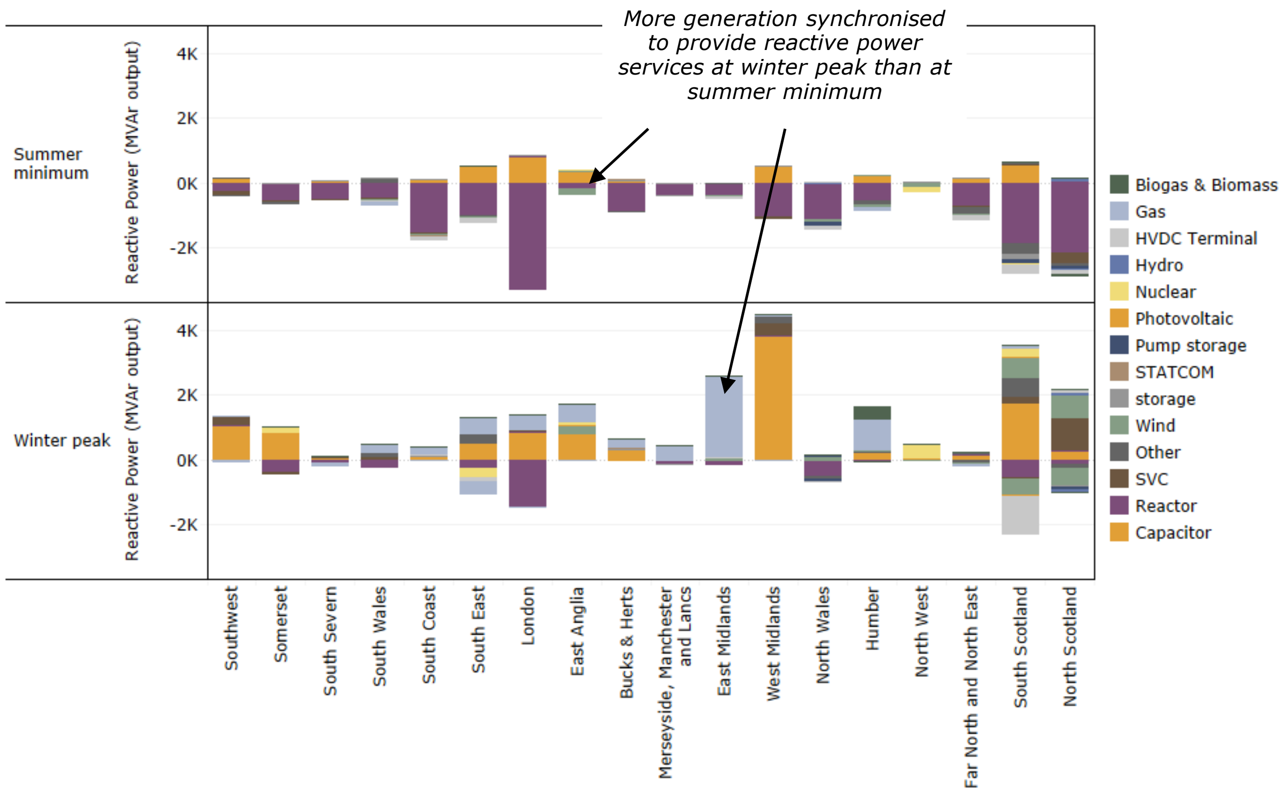
SUMMER MINIMUM

- CCGTs provide little contribution at summer minimum as they are not generating (a pre-requisite for providing support).
- Wind output is also low, providing little support for reactive power needs.
- In general, technologies which require significant MW output to provide reactive power will struggle to contribute to summer minimum requirements.

WINTER PEAK

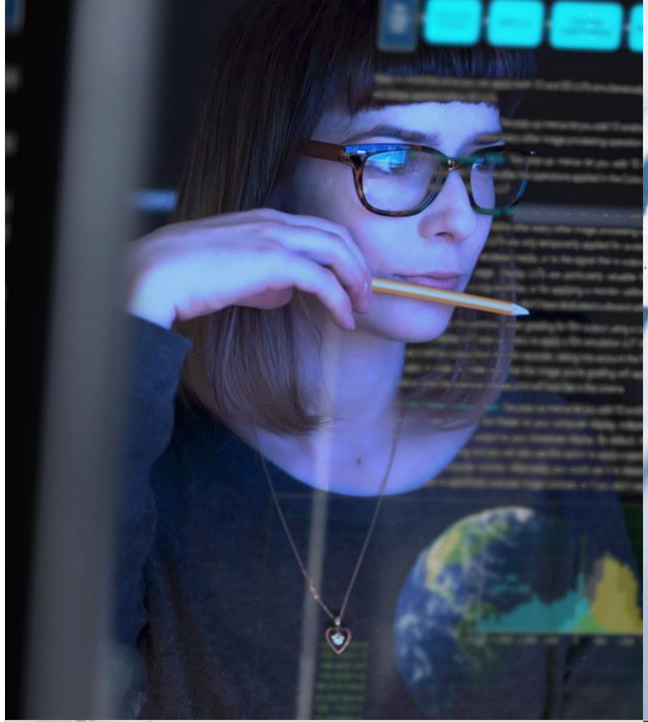
- At this point – there is significantly more plant synchronised to provide voltage support as higher demand results in more 'room' on the system.
- Capacitors and SVCs still contribute to a significant proportion of reactive power needs (more than half of the total requirement).
- As gas plant begin to retire, winter peak voltage support will become more challenging – relying on new and more innovative solutions.

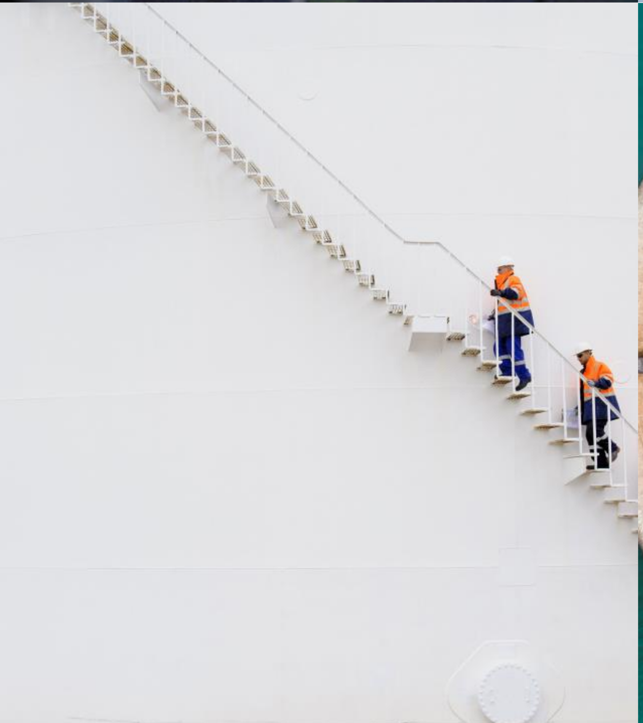
PEAK REQUIREMENTS BY TECHNOLOGY (MVAR, ETYS 2025/26)



Note: There are also differences in reactive power needs within individual aggregated zones listed here

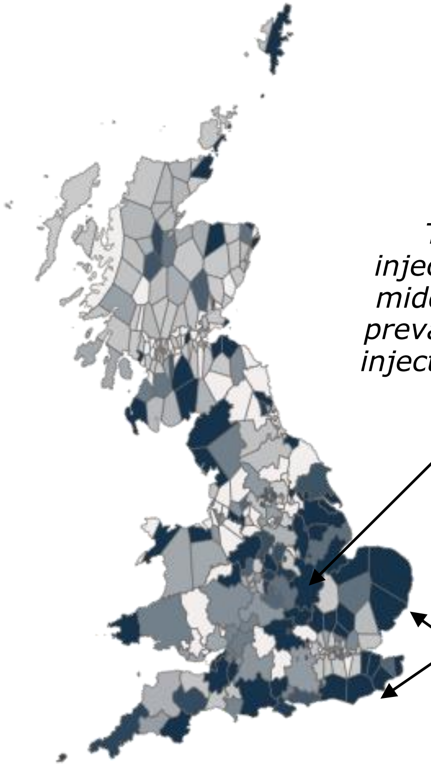
Agenda






AFRY has produced a heatmap of expected MVAr capability by GSP for ESO using ETYS data

MVAR CAPABILITY FOR INJECTION (2025/26)

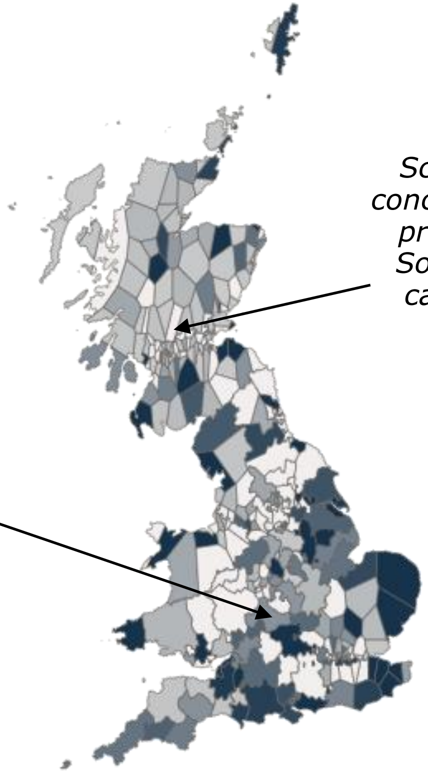


0 MVAr 1000 MVAr

There is a mismatch between injection/absorption capability in the middle of England, this is due to the prevalence of grid assets dedicated to injection, supporting voltages at times of peak demand

Large offshore windfarms (and associated OFTOs) and interconnectors increases capability in the South East, high power flows in the area means high demand for reactive injection in the winter

MVAR CAPABILITY FOR ABSORPTION (2025/26)



0 MVAr 1000 MVAr

Scotland has a lower concentration of reactive providers than in the South but substantial capability still exists

Notes: Injection contributes to increasing/supporting voltages and absorption is utilised for managing high voltages

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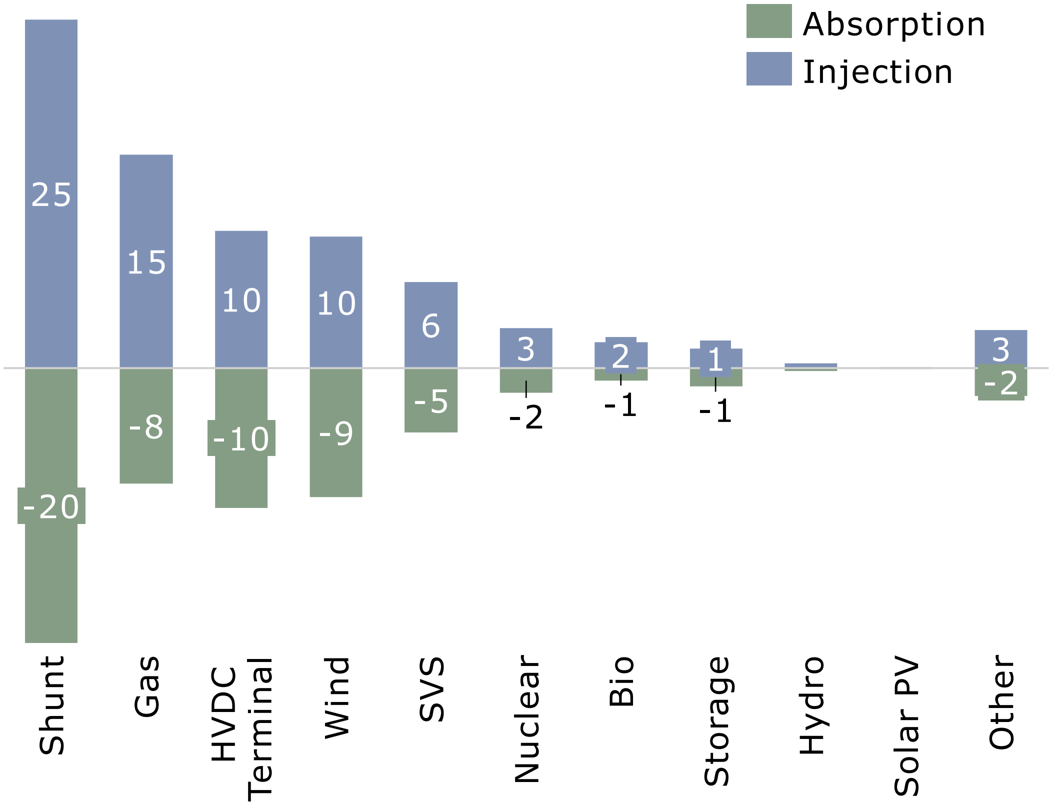
Network assets & RES play an important role, but gas-fired generators are expected to still be required to ensure overall system security in the near term

GVAR CAPABILITY IN GB (ETYS 2025/26)



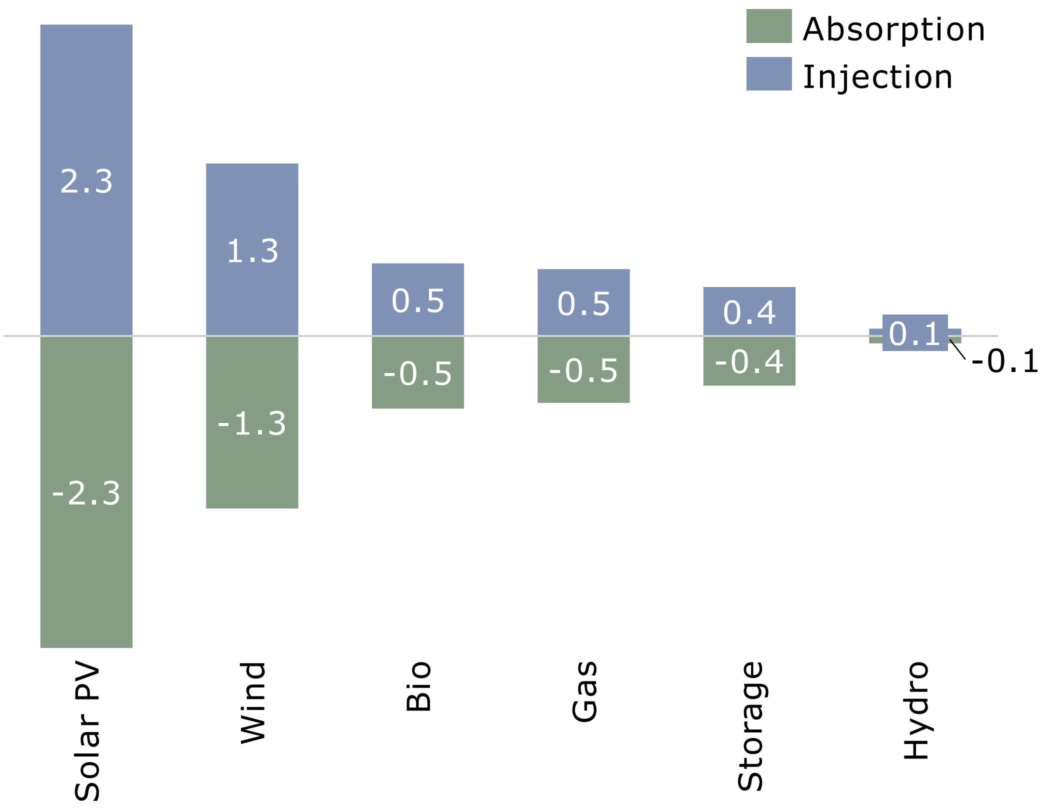
- TO network assets have high availability and are the largest source of reactive power on the network today with over 50GVAr of assets on the system (reactors + capacitors + SVCs + STATCOMs).
- CCGTs also offer substantial capability and can be instructed on to access MVArs, though other plant must be turned down to ensure demand is not exceeded – this can be extremely costly and in summer minimum conditions.
- The total capability that can be offered by wind is large, though weather dependence means availability is lower than for other asset classes.
- HVDC connections play an important role today, in the future capability will increase through a combination of interconnectors, TO HVDC connections, and OFTO assets (for HVDC connected offshore wind).
- Reactive power does not travel through DC connections, however onshore reactive compensation equipment associated with HVDC infrastructure will be accessible to ESO.
- Many providers that offer reactive services are low carbon, however the availability of low carbon reactive providers is uneven across the country (with CCGTs dominating provision in the Midlands and South East where reactive power absorption needs are highest).

Notes: Excludes embedded generation, Shunts=reactors/capacitors (single directional grid assets), SVS=STATCOMs + SVCs (bi-directional grid assets)

HEAT MAP

There is additional capability that can potentially be accessed from the distribution network

POTENTIAL GVAR CAPABILITY FOR SMALL DER (ETYS 2025/26)

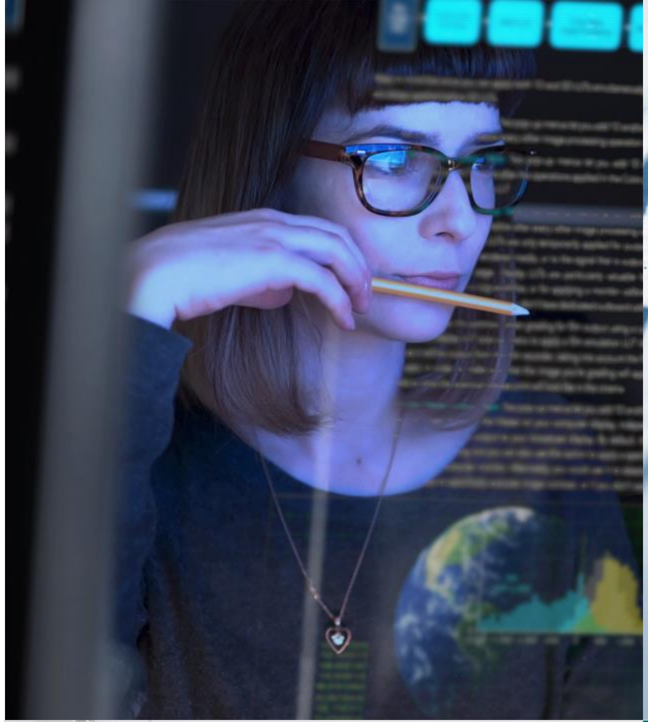


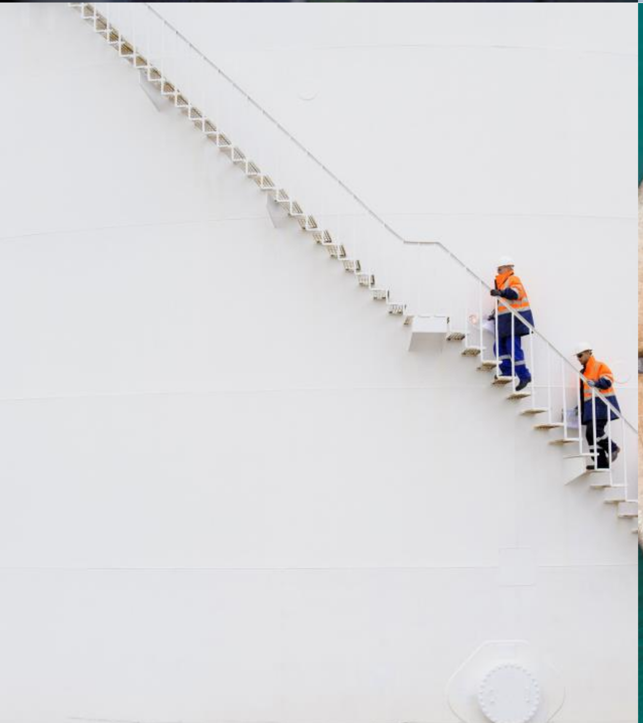
- According to ESO data, there is potentially 10GVAr of additional capability embedded within the distribution network from small DER that could be used to help resolve voltage issues.
- Most of this additional capability is from smaller scale wind or solar generators.
- Increasing exploitation of existing assets on the system could bring cost savings for consumers through increased competition.
- Much of this capability is in the south and south-east (where solar resource is strongest), an area of the network that suffers with extreme voltage challenges and high associated voltage management costs.

AFRY & ESO have run a separate workstream to look at the challenges for enabling DER to participate in a potential reactive power market.

Notes: Assumes symmetrical capability on average, potential capability based on case study information

Agenda



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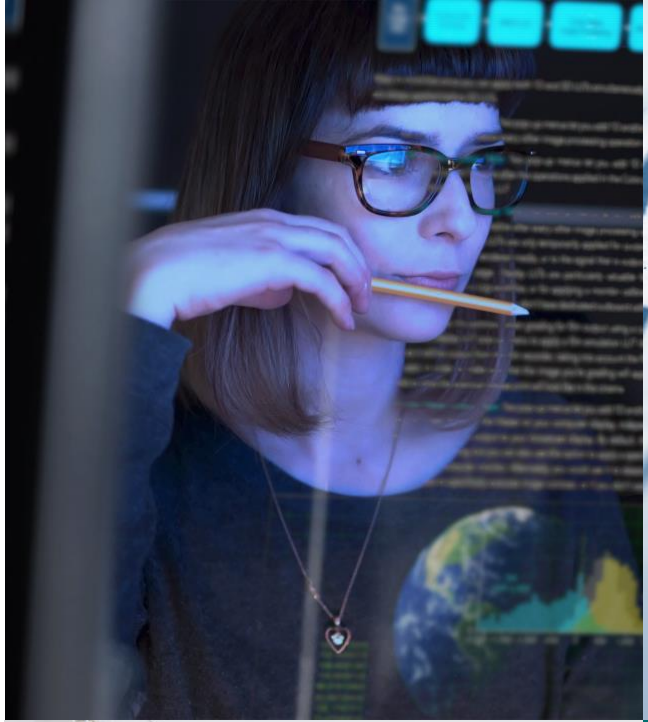
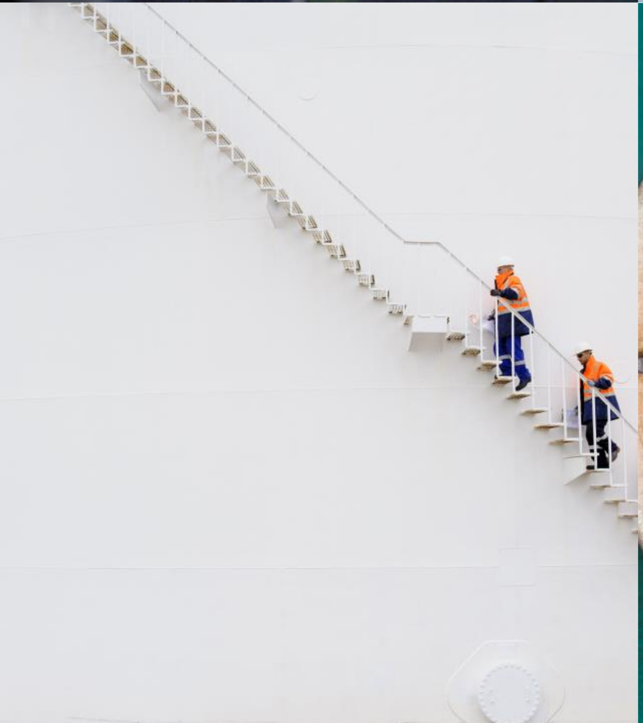
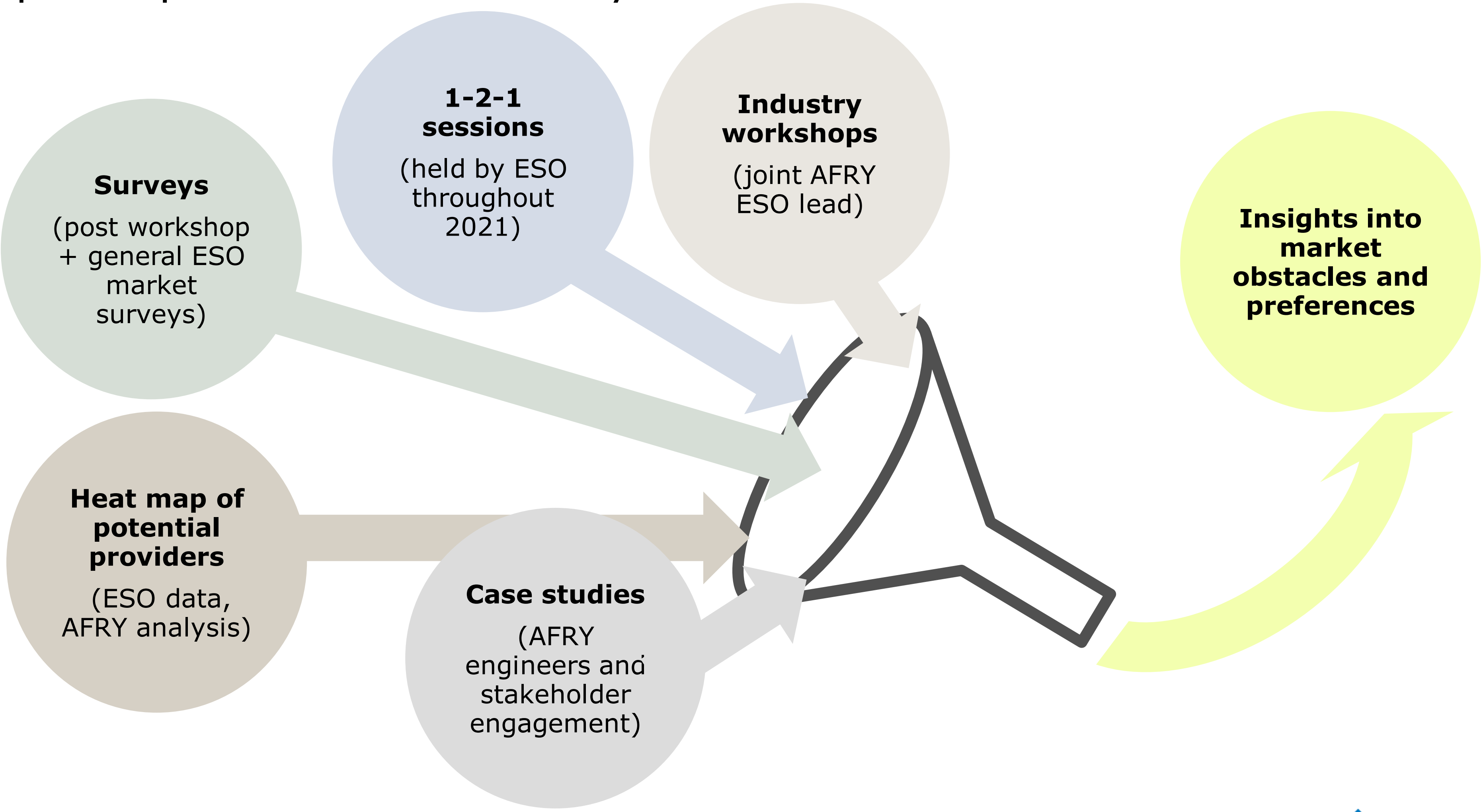





The market analysis workstream was informed by a large range of inputs from participants and own analysis



The insight revealed by market participants has informed our thinking throughout the project

Participants expressed an interest in a **hybrid** approach with long term contracts available and short term options with short term only and long term only being the least preferred options

Some providers have **additional capability** able to provide reactive power outside of ORPS ranges

Several providers quoted TO/DNO **connection agreement terms** as a barrier to utilising their full capability

Most participants either provide **ORPS**, were participating in **pathfinders**, or were DNO connected with **no route to market**

Providers felt that as the issue of reactive becomes **more salient**, **transparency** and **focus** on it should increase

Some providers felt **ORPS** didn't cover **total cost** of service provision when **heavily utilised**

Some existing ORPS providers can't understand why they are **not instructed** for their MVAr capability (transparency issues)

There was **disagreement** between providers on whether **availability payments** or **utilisation payments** were appropriate for remuneration

Providers identified **opportunity cost** outside ORPS ranges as a **key consideration** (lost subsidy payments, active energy sales, etc.)

Surveys | **1-2-1 feedback** | **Industry workshops**

Notes: Some views were expressed across multiple engagement activities

Most commercial barriers are related to uncertainty and variability

Technology affected	Key blocker	Key enabler	Preferred solution
Batteries/converter connected storage	High opportunity costs in valuable/high demand periods	Need to allow plant to participate when service is most valuable	**Short term market**
Variable converter connected technologies (e.g. wind)	Low availability certainty	Need to allow plant to participate at point where availability becomes more visible/certain	**Short term market**
Traditional thermal providers	High and uncertain fuel cost + uncertain requirement (difficult to hedge)	Need to allow plant to participate when costs are known and when requirements are highest	**Short term market**
All capacity	Additional Capex and Opex associated with higher MVA rating of equipment (if relevant)	If there is a low incremental cost, but long term commitment is inappropriate need to allow some short-term revenue to encourage deployment	**Short term market**
	Complex relationship between power factor, MW output, and heat losses (additional costs)	Need to give the opportunity for participants to bid portions of capacity to reflect non-linear cost	**ST market, availability and utilisation fee (or volume visibility)**
	Poor visibility over dispatch commitments	Dispatch risk should sit with ESO (to the extent possible), availability only fee requires participant to forecast dispatch and 'price in' dispatch costs	**Both availability and utilisation fee (or volume visibility/cap)**

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It is desirable to remove blockers to maximise participation

Technology affected	Reason for facilitation in market	Volume[1]	Reliability[2]	Cost[3]
Batteries/converter connected storage	**High opportunity cost** (when MVAr requirements are high for both absorption and injection): Potentially substantial additional capacity available in periods of system stress.	Medium	High	High
Variable converter connected technologies (e.g. wind)	**Low availability certainty:** When demand is low and output from variable renewables is also low, providers that are technically configured to do so can offer substantial additional capability for absorption that cannot currently be accessed via ORPS at relatively low cost – however, as this is unpredictable it is difficult to structure a reliable long term contract around this.	High	Low	Low
Traditional thermal providers	**High and uncertain fuel cost and requirement:** There is substantial capacity that can provide reactive power today and there is a desire to incentivise providers without having to instruct in the Balancing Mechanism.	High	High	High
All capacity	**Additional Capex/Opex for MVA capacity:** When designing new capacity, in particular new variable converter connected technologies, it is desirable to encourage maximisation of potential asset capacity at the initial design stage. A price signal can encourage this behaviour.	Unknown (future)	-	-
All capacity	**Complex relationship between MW/MVAr/Cost:** Many providers will not have visibility of their dispatch schedule in investment timeframes, so design arrangements should encourage efficient use of assets by maximising the capacity available at the time of need, not imposing arbitrary or artificial limitations.	High	-	-
All capacity	**Poor visibility of dispatch commitments:** It is impractical for most providers to forecast their dispatch of reactive power. As this is much more visible to ESO, the risk should lie with ESO to maximise participation and encourage cost reflective bidding (avoiding risk premia where possible).	High	-	-

Notes: [1]Potential system-wide MVAr capability [2]Can be reliably accessed when needed [3]Represents cost of potential solution to ESO at time of need

A two part pricing mechanism may be desirable, but only if utilisation costs are material – there are many dedicated assets for which this is not the case

Availability costs

Availability costs, are costs that are incurred for simply making an asset available to provide reactive power (before any delivery of reactive power).

As a simple example, this could be the synchronisation cost of a CCGT In this context we include the cost of existing (i.e. capacity cost which can include fixed operational costs & investment costs) however this could equally be a separate cost item

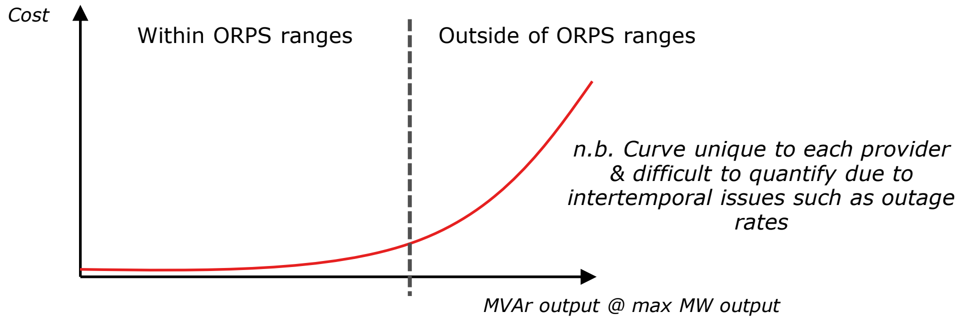
Capex/Opex	Building new assets/maintaining old assets
Synch costs	Fuel costs, start costs, variable maintenance costs & other consumables
Opportunity costs	Foregone revenue from other activities

Utilisation costs

There are two core costs of being utilised, both manifest as a result of heat: efficiency losses (additional energy costs), and wear on equipment (additional outages and Opex)

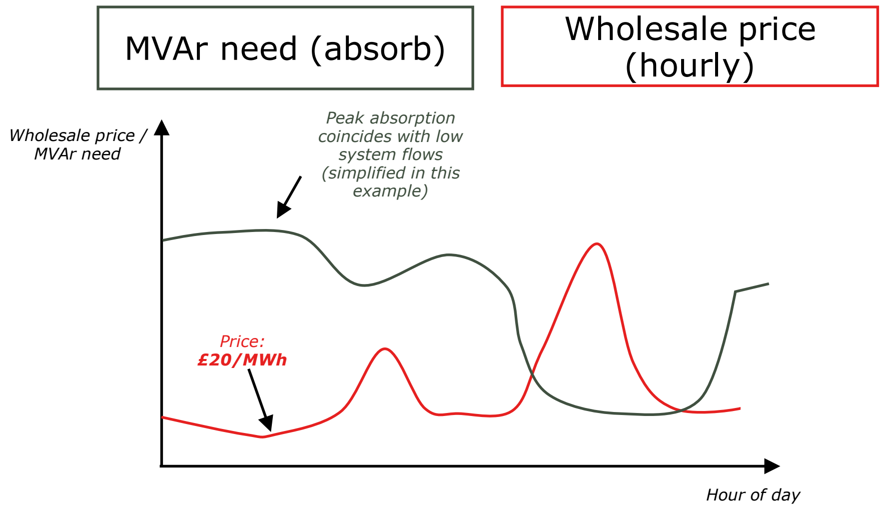
These are dependent not only on the reactive dispatch instruction, but also the MW output of the equipment making them difficult to predict and manage when power factors deviate significantly from unity.

Variable cost of component heating



Example 1: opportunity cost of a new 50MW wind farm with advanced converter technology and appropriate dimensioning for MVAr absorption (1/2)

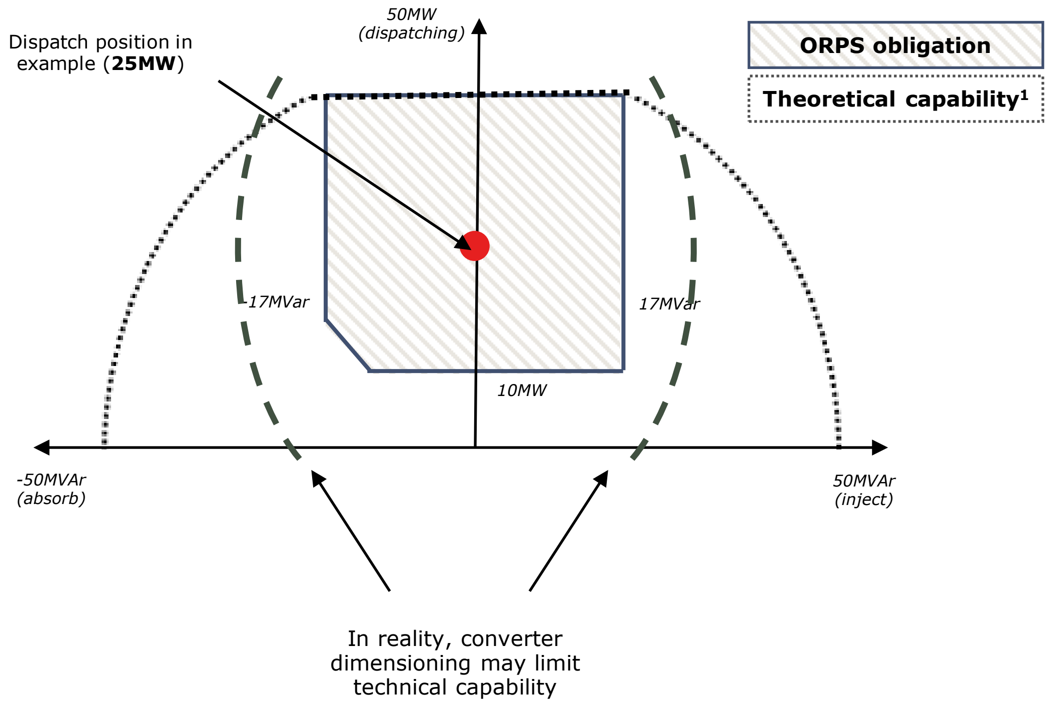
Stylised daily price shape vs. injection MVAr need in short term market



In this example we assume medium windspeed period with wind farm at 50% load factor (25MW output on a 50MW capacity wind farm)

Energy market opportunity	£20*25MWh = **£500**

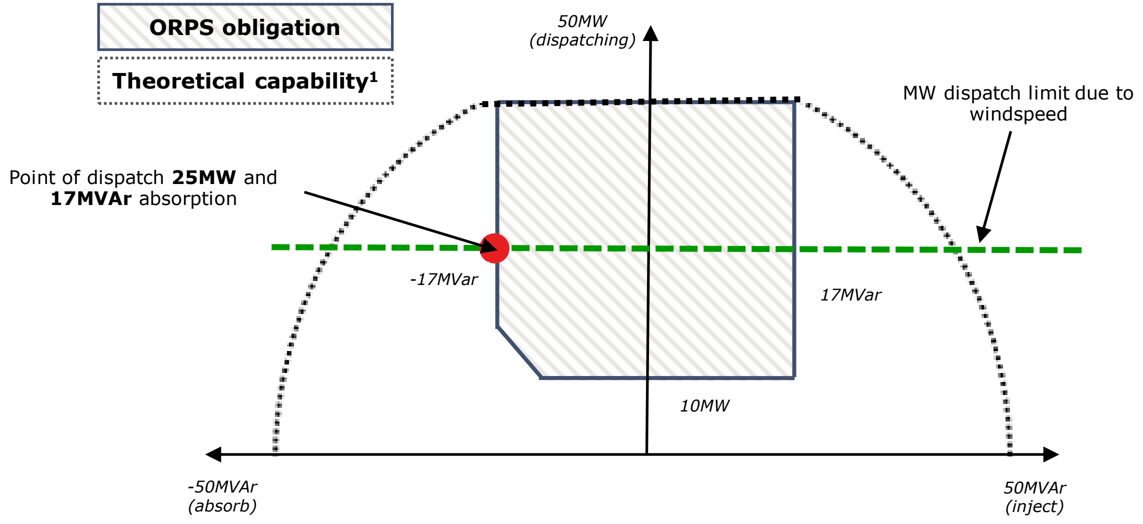
Stylised wind farm reactive capability range¹



Notes: [1]This stylised capability area has been taken from information provided by potential market participants as part of the Market Analysis workstream, many participants will not be able to access this full range due to their technical configuration

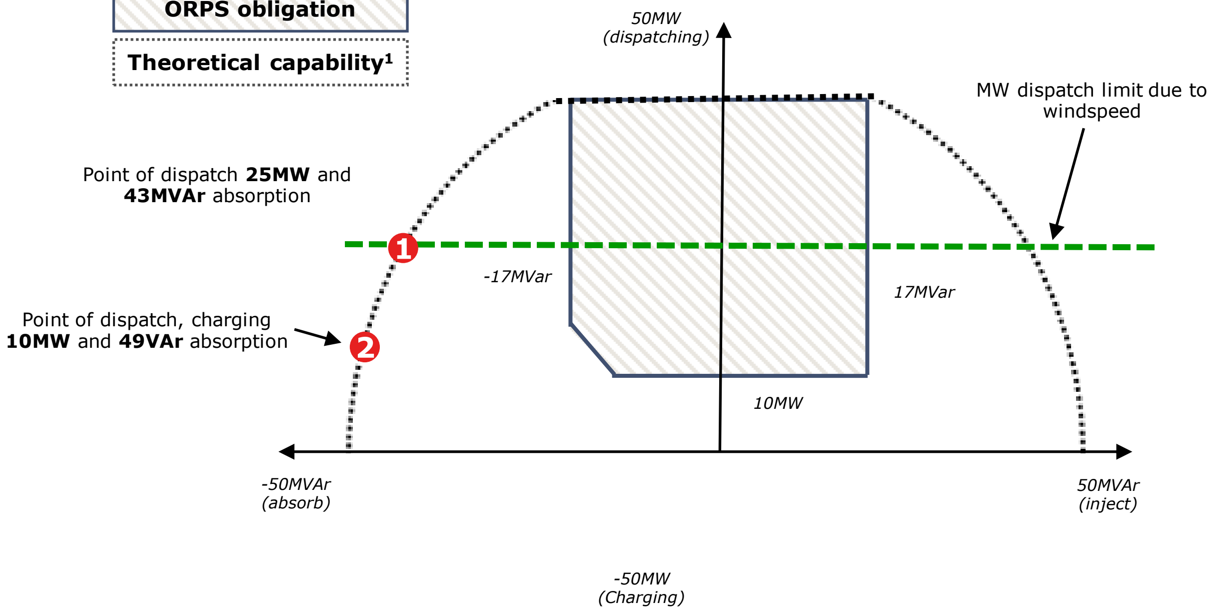
Example 1: opportunity cost of a new 50MW wind farm with advanced converter technology and appropriate dimensioning for MVAr absorption (2/2)

Dispatching within ORPS range



Opportunity cost	£20/MWh*0MWh= **17MVAr @£0/MVArh**[2]

Dispatching outside outside ORPS ranges

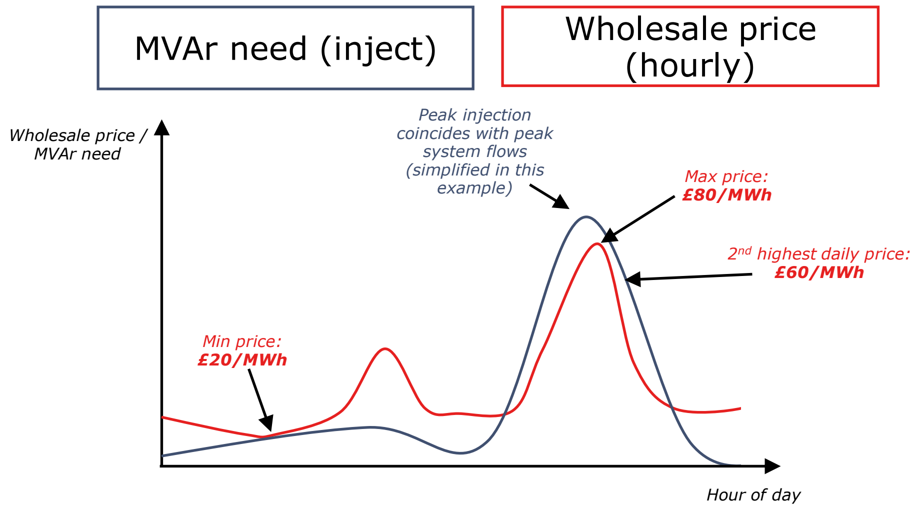


Point of dispatch 1 opportunity cost	(25MWh-0MWh)*£20/MWh=0 Extra MVAr = 43MVArh-17MVArh = **26MVAr @ £0/MVArh**[2]
Point of dispatch 2 opportunity cost	(25MWh-10MWh)*£20MWh=£300 £300/(49MVArh-43MVArh)= **6 MVAr @ £50/MVArh**[2]

Notes: [1]This stylised capability area has been taken from information provided by potential market participants as part of the Market Analysis workstream, many participants will not be able to access this full range due to their technical configuration. [2]Some additional losses due to heat may apply

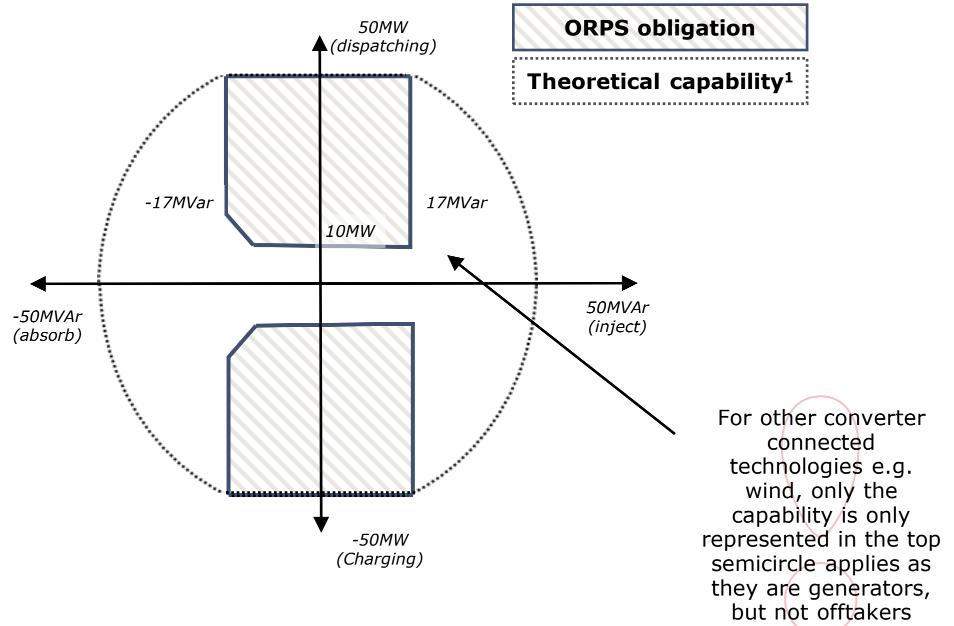
Example 2: opportunity cost of a 50MW/50MWh battery for MVAr injection (1/2)

Stylised daily price shape vs. injection MVAr need in short term market



Battery characteristics	Capacity: **50MW/50MWh** (1h duration) Round trip efficiency: **85%** ***Other costs ignored for simplicity***
Arbitrage opportunity	(£80-£20)*85%*MWh/h = **£51/MW/cycle[2] = £2550/cycle**

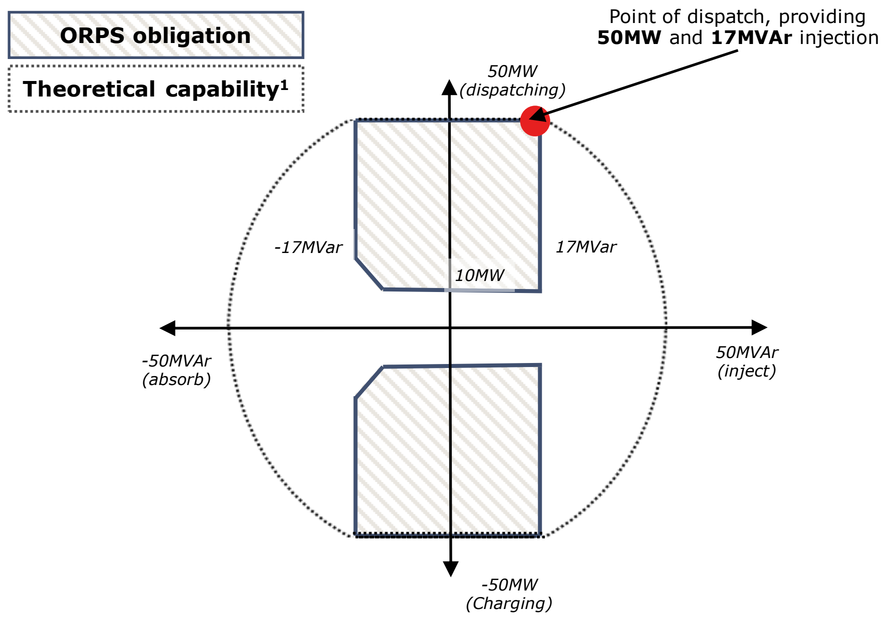
Stylised battery reactive capability range[1]



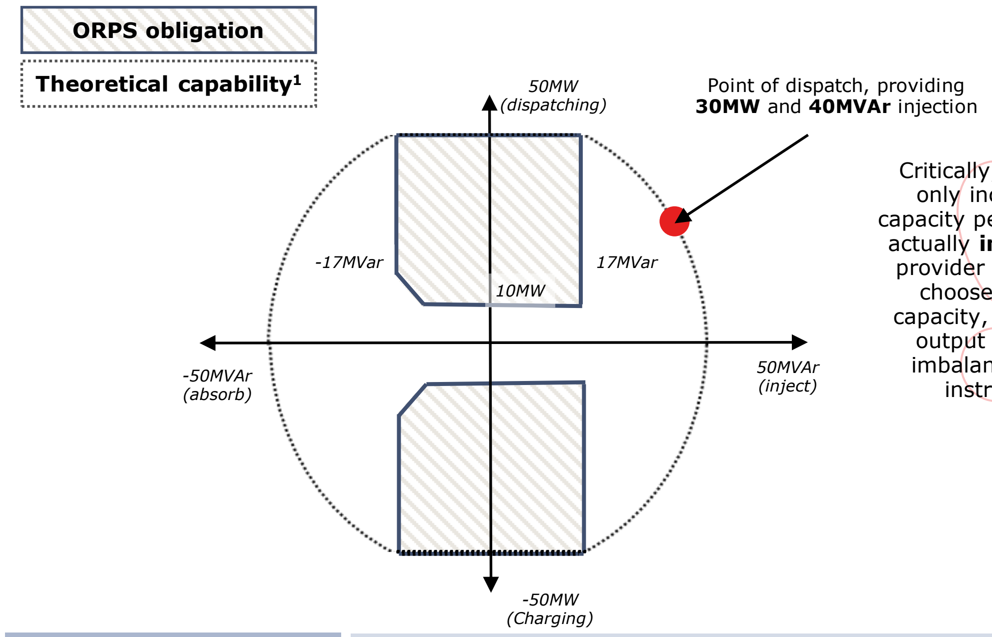
Notes: [1]This stylised capability area has been taken from information provided by potential market participants as part of the Market Analysis workstream. [2]A cycle is a full charge and full discharge of a battery between zero and maximum storage capacity. Intertemporal issues are simplified in this example for demonstration purposes

Example 2: opportunity cost of a 50MW/50MWh battery for MVAr injection (2/2)

Dispatching within ORPS ranges



Dispatching outside ORPS ranges



Critically, provider only incurs this capacity penalty when actually **instructed**, provider can either choose to hold capacity, or sell full output and risk imbalance when instructed

Arbitrage opportunity (max price)	(£80-£20)*85%*50MWh **= £2550/cycle =£51/MW/cycle**
Arbitrage opportunity (2nd highest price)	(£60-£20)*85%*50MWh **= £1700/cycle = £34/MW/cycle**

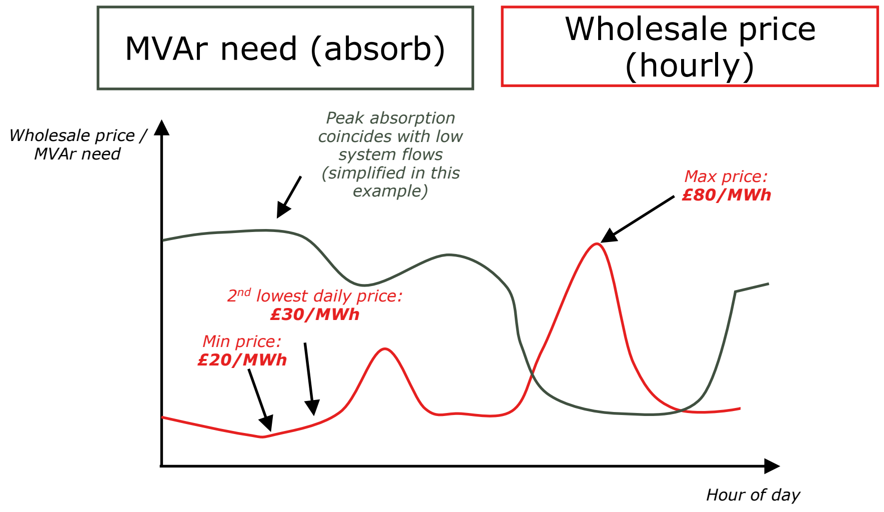
Provider is MW constrained so must sell residual energy at 2nd highest price period

Arbitrage opportunity (peak hour only)	(£80-£20)*85%*30MWh **= £1530/cycle = £51/MW/cycle**
Opportunity cost	(£51-£34)*(50MWh-30MWh)=£340/cycle £340/(40MVArh-17MVArh) = **23MVArh @ £14.8/MVArh**

Notes: [1]This stylised capability area has been taken from information provided by potential market participants as part of the Market Analysis workstream.

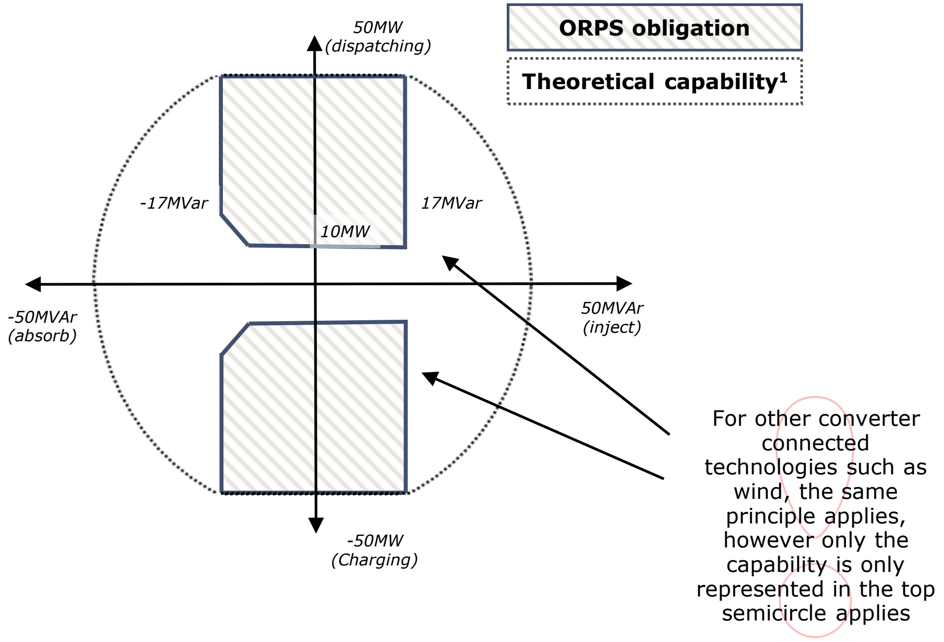
Example 3: opportunity cost of a 50MW/50MWh battery for MVAr absorption (1/2)

Stylised daily price shape vs. injection MVAr need in short term market



Battery characteristics	Capacity: **50MW/50MWh** (1h duration) Round trip efficiency: **85%** ***Other costs ignored for simplicity***
Arbitrage opportunity	(£80-£20)*85%*MWh/h = **£51/MW/cycle² = £2550/cycle**

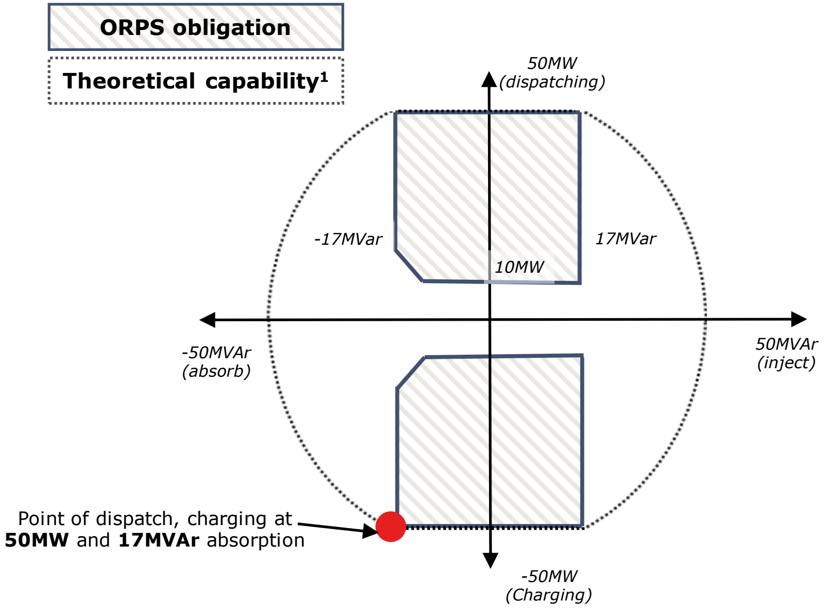
Stylised battery reactive capability range[1]



Notes: [1]This stylised capability area has been taken from information provided by potential market participants as part of the Market Analysis workstream. [2]A cycle is a full charge and full discharge of a battery between zero and maximum storage capacity. Intertemporal issues are simplified in this example for demonstration purposes

Example 3: opportunity cost of a 50MW/50MWh battery for MVAr absorption (2/2)

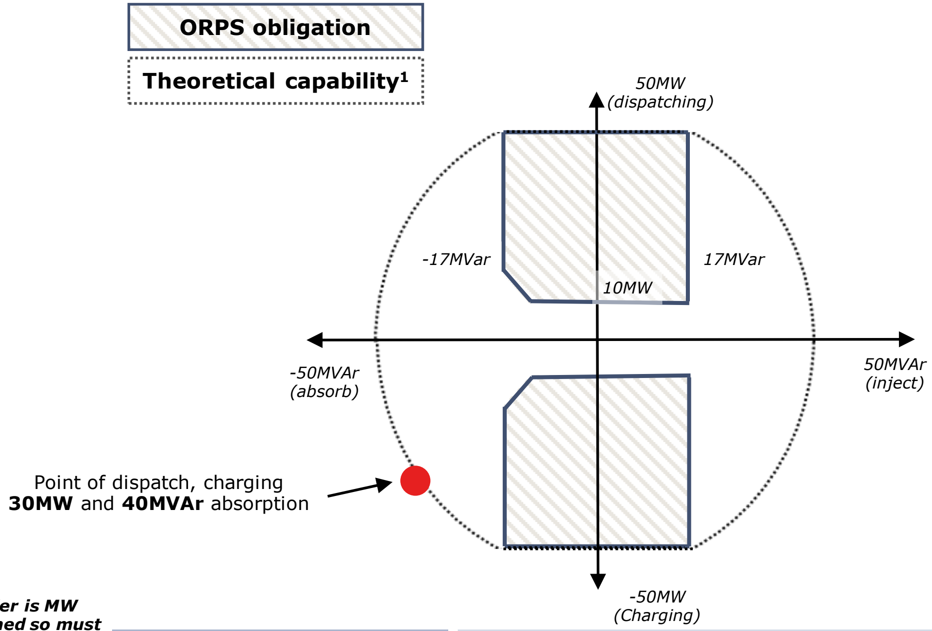
Charging within ORPS ranges



Arbitrage opportunity (min price)	(£80-£20)*85%*50MWh **= £2550/cycle =£51/MW/cycle**
Arbitrage opportunity (2nd min price)	(£80-£30)*85%*50MWh **= £2125/cycle = £42.5/MW/cycle**

Provider is MW constrained so must buy residual energy at 2nd lowest price period

Charging outside ORPS ranges



Critically, provider only incurs this capacity penalty when actually **instructed**, provider can either choose to hold capacity, or buy full input and risk imbalance when instructed

Arbitrage opportunity (peak hour only)	(£80-£20)*85%*30MWh **= £1530/cycle=£51/MW/cycle**
Opportunity cost	(£51/MWh-£42.5/MWh)*(50MWh - 30MWh) = £170/cycle £170/(40MVArh-17MVArh) = **23MVArh @ £7.4/MVArh**

Notes: ¹This stylised capability area has been taken from information provided by potential market participants as part of the Market Analysis workstream.

Operational decisions and appetite for risk from providers can influence how opportunity costs are incurred

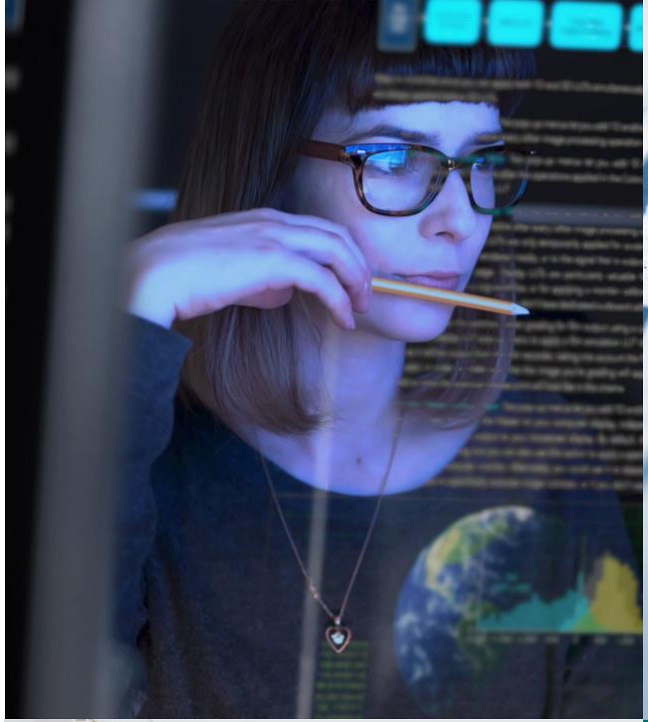
Offering MVAr outside ORPS ranges for providers

- Where providers are offering additional capability outside of ORPS required ranges, providers can either:
  - Choose to hold capacity (unutilised) it would otherwise have used to sell energy (opportunity cost) – *best option dispatch is more constant*.
  - Offer MVAr capability and simply deal with imbalance costs as they arise when instructed – *can become attractive when MVAr instructions are more variable*.
- In the latter instance, the opportunity cost would become the imbalance price multiplied by the imbalance volume resulting from the MVAr/MW trade-off:
  - In this case participants would also need to consider the risk of instruction in their offered price.

Key consideration for ESO

- It may be desirable to prevent plants from taking imbalance exposure when being instructed for a MVAr position.
- In practice we expect these volumes to be very small (at least initially).
- If large imbalance volumes were to manifest, forcing participants to hold capacity may be desirable.
- This could be enforced through testing and penalties.

Agenda




Transmission Owner assets are bound by licence obligations and are remunerated through their Regulated Asset Base

Current situation

Transmission Owner (TO) assets for reactive power services have historically been deployed out of the necessity for compliance with licence obligations. Historically, if a potential failure to secure the system is identified, TOs would apply to build assets under their RAB to compensate for expected issues forecast to arise from a deficit of reactive capability. As reactive capability was a grid code requirement with limited signals to improve capability, investment in assets was primarily an activity undertaken by the TO.

Ultimately under any market arrangement – owners and operators of regulated assets including (but not limited to) TOs will need to ensure they comply with their licence obligations.

Treatment of existing assets

Existing TO assets are remunerated outside of the reactive market, fundamentally:

- If TO assets are being remunerated sufficiently elsewhere, they should not be eligible to participate in the market (and receive windfall gains).
    - There may be concerns that increased utilisation of TO assets could increase costs for TO assets, however these costs should have been comprehensively considered by TOs when submitting costs to Ofgem for approval pre-asset commissioning.
    - An opportunity to account for utilisation forecast error should be considered at that time.
    - Some key utilisation costs (e.g. energy costs) are broadly treated as a passthrough regardless.
- We are not considering existing TO assets within their RAB period for inclusion in any markets (short or long term).

TO assets outside of their RAB period should be considered as a potential solution if economically efficient. This issue warrants further investigation.

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TO assets can offer opportunities in the interest of consumers, but direct comparison with commercial solutions will be imperfect

Reason for facilitation

TO assets costs can be competitive with commercial providers, we would therefore want to include them in a market arrangement. TO asset participation in a market could theoretically be: (a) direct, whereby they offer a competitive 'bid' into the market; or indirect, whereby the cost of the solution is independently evaluated and assessed against commercial offers.

Opportunities and challenges

Maximising tools to ESO

One of the key opportunities offered by the implementation of a market (Long Term, if not Short Term) is to evaluate alternatives to regulated TO investment, to ensure that the best interests of consumers are met in the provision of stability services.

Exposure to competition

Note that in the long term, economic theory suggests that the efficiency gains of competition (incentives for innovation and cost reduction) outweigh the inefficiencies (duplication, etc.). Therefore, the existence of a competitive alternative to a regulated investment, making a 'contestable market', is likely to be positive for consumers even if the regulated investment proves to be the winner.

Neutrality challenges

The evaluation between regulated and non-regulated assets requires a level playing field as far as is possible. There are many reasons why a perfectly level playing field may not be possible, but we should look at the potential reasons for bias to ensure that the evaluation can be as neutral as possible.

Direct participation of TO assets may undermine competition, therefore an indirect route is preferred in any potential market arrangement

Direct participation of TO assets

In the event that TO assets are forced to compete on a fully commercial basis (i.e. not remunerated through their RAB), do we expect monopolistic behaviour to emerge due to imbalance of information and the necessity for the TO facilitate its competitors?

Our working assumption is that the TO would have to surrender their rights (and obligations) under their TO licence to participate on a commercial basis (e.g. cost passthrough of energy into losses) to effectively become indistinguishable from a market participant developing a traditional grid asset as a potential solution (e.g. a commercial party building a synchronous compensator).

Key concerns with direct TO participation

Direct commercial participation for TO assets is unlikely to provide a competitive framework for providers as conflicts of interest and advantages arising from treatment of regulated assets may exist to undermine the arrangements and increase the perceived risk of market participation for other commercial providers:

- Potential market participants are reliant on the TOs to secure their connections – the facilitation of such requests is not always in the TOs' interest if competing directly.
- TOs have detailed models of their own networks, allowing them to identify and target solutions potentially before the ESO is able to signal needs to all potential participants.
    - This is particularly an issue with locational requirements where solutions must be located close to demand for services as is the case with reactive power.
    - In 'worst case' outcomes TOs could lock out commercial providers in advance (land grabbing, connection request gaming, etc.).
- TOs may have preferential access to (cheap) land close to where solutions would be required from their regulated activities giving them an advantage over commercial providers.

(1/4) Indirect competition, whilst preferable, still presents a number of key challenges

Key challenges

We expect the core route to market for TO assets would be to compare their costs to the costs of a potential commercial solution, however difficulties in comparison between different asset types exist. This is principally due to the differences in the nature of commitments (and associated preferred asset solutions), and regulatory treatment from TO assets under their RAB and commercial providers being awarded a long-term stability contract. We have explored some of the key issues in this section, however further work will be required to agree an enduring solution for regulated assets.

Asset lifetime

Under the RAB a 40 year assumed asset life is used which far exceeds that of envisaged commercial contracts.

- There are a number of unresolved questions relating to TO solutions for reactive power assets:
  - Is the 40 year period reflective of the expected life of stability-type assets? (or just other grid asset types)
  - How certain are the requirements 5 years out, 10y out, 40y out? Can we guarantee value for money in the long run from these solutions?
  - Is there potential to redeploy assets in the case they become redundant due to their location?
- *Further work to explore residual value should be undertaken to ensure comparability with commercial providers, who have the opportunity to reflect their views on residual value implicitly through bids into the market.*

(2/4) Indirect competition, whilst preferable, still presents a number of key challenges

Cost of capital and risk

There exists a comparatively low cost of capital for regulated assets due to the allocation of risk.

- This is a double-edged sword: on the one hand consumers should benefit from the lower cost of capital, but this could be used to argue that regulated assets should have even wider application. Ultimately, the lower cost of capital for regulated assets is partly because the consumer underwrites a significant portion of the TO risk.
  - If obligations, contract durations, and other key contractual elements for commercial providers were identical to TO RAB asset treatment, this advantage disappears.
  - *Whilst 40 year commercial contracts may not be practical, it may be possible to adjust the cost assessment in an attempt to make the solutions more comparable.*

Obligations & non-delivery uniformity

Obligations on availability/consequences of non-availability are not uniform between TO RAB assets and commercial solutions.

- This is another manifestation of the different allocation of risk between private and TO assets.
- Whilst TO providers may have differences in their obligations (i.e. they will not be subject to the same non-delivery consequences as commercial providers due to the regulatory framework), it may be possible to account for these differences through scaling solution costs when comparing to commercial providers.
- *This can be managed (imperfectly) by evaluating the differences in the nature of commitments (availability, late delivery, etc.) and adjusting evaluated costs based on differences in the nature of the commitment.*

(3/4) Indirect competition, whilst preferable, still presents a number of key challenges

Energy cost exposure

Treatment of energy costs associated with delivery of the service are different between TO RAB and commercial solutions.

- Some of the energy costs related to TO assets are socialised in the form of losses.
- *There must be an adjustment for this in the evaluation if commercial participants are exposed to energy costs.*

Preferential access to information

Preferential access to information by TO (or non-incumbents).

- The TO will have a strategy to comply with licence obligations and is ideally placed to understand where locational voltage issues will manifest on their network.
- If the TO is able to identify requirements before signalling of requirements to the broader market there may exist an advantage for the TO over commercial providers.
  - *Two core options: the TO auction these sites off and does not participate at all, or be forced to make them available as is the case with pathfinders for reactive power*

(4/4) Indirect competition, whilst preferable, still presents a number of key challenges

Preferential access to sites

Preferential access to sites/connections by TO (or non-incumbents).

- There is a need to allow access to sites/connections for third parties in order for competition to work effectively.
  - *Two core options: the TO auctions these sites off and does not participate at all, or be forced to make them available as is the case with pathfinders for reactive power.*
- It should be noted that incumbents also have preferential access to existing sites.

Many of these challenges are wider questions that must be answered for TO solutions to compete with commercial providers in not just the context of reactive power, but other contexts in which TO assets may be ultimately exposed to competition in the future

	Asset lifetime	Cost of capital	Obligations and penalties	Energy costs	Preferential access to sites	Preferential access to information

Relative difficulty to address comparability

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Agenda

There are a diverse range of technologies capable of providing reactive power output, but technical aspects vary widely – technical capability for converter connected equipment is evolving

Technologies investigated in depth have been rated based on their performance for each KPI

The Harvey Ball illustrate each technology’s rating for each KPI based on the following scale:

○	Poor Performance
◔	Sufficient Performance
◑	Intermediate Performance
◕	Good Performance
●	Excellent Performance

Technologies

Converter based / *Synchronous*	Technologies	Reactive power Base[4]	Reactive power High[4]	MVAr output at 0MW	CAPEX[3]	OPEX[3]
Converter based	Onshore Wind	◔	◕	Yes	◔	◔
Converter based	Offshore Wind	◔	◕	Yes	◔	○
Converter based	Solar PV	◔	◕	Yes	◑	◑
Converter based	Battery Energy Storage System	◔	◕	Yes	◑	◑
Converter based	HVDC	◔	◕	Yes	◕	●
Synchronous	Pumped Hydro Energy Storage	◑	◑	Yes[1]	◔	●
Synchronous	CCGT/OCGT	◑	◑	No[2]	◑	◔
Synchronous	Nuclear	◑	◑	No	○	○
Synchronous	Biomass steam turbines	◑	◑	No	◔	○
Synchronous	Synchronous Condenser with Flywheel	●	●	Yes	●	◕

Note: [1]Commonly operates in a mode where turbine spins in air and provide reactive power [2]Can be designed to operate in synch-comp mode [3]Capex and Opex assessed on a per MVAr basis, we recognise that for most technologies this is a secondary consideration in terms of the business case. [4]Base equals NGESO grid codes and High equals ENTSO-E definition of maximum grid code capability for non-synchronous generators. NGESO grid codes for synchronous generators.

Assumptions for the deep dive per technology – Reactive power provision

- **High, Base and Low range/case**
  - The high, base and low range/case for the typical unit size, CAPEX, OPEX and capabilities are not linked to each other but rather presented per category to give an indication of the range
- **CAPEX and OPEX**
  - 2020 cost data where the cost per kW and kWh includes everything from the generator to the point of connection to the DNO/TSO grid
- **Reactive capability**
  - Base case: NGESOs grid codes requirement for the specific technology
  - High case: Higher grid code requirements equals ENTSO-E definition of maximum grid code capability for non-synchronous generators and NGESO grid codes for synchronous generators (same as base case)
  - Low case: Lower grid code requirements from other TSOs to produce reactive power
- **Grid codes - Additional capability beyond ORPS (MVAr/MW)**
  - Differentiation between High Case and Base case
- **Is MVAr output at 0MW generation possible?**
  - If a technology can/can't produce reactive power without producing active power
- **Availability dependences to provide reactive power**
  - What determines the reactive power provision per active power

In focus

	Base case	High range	Low range
Typical unit size (MW)	100	200	50
Capex (£/kW)	500	1 000	250
Opex (£/kW/year)	40	50	30
Leading reactive capability (MVAr range per MW at full load)	0.33	0.50	0.30
Lagging reactive capability (MVAr range per MW at full load)	0.33	0.65	0.30
Grid codes - Additional capability beyond ORPS (MVAr/MW at full load)	Leading = **0.17** Lagging = **0.32**		
Is MVAr output at 0MW generation possible?	**Yes/No**		
Availability dependencies to provide reactive power	Can only provide reactive power when XXX		
Static only or dynamic? (Reactive Power)	Static and dynamic		

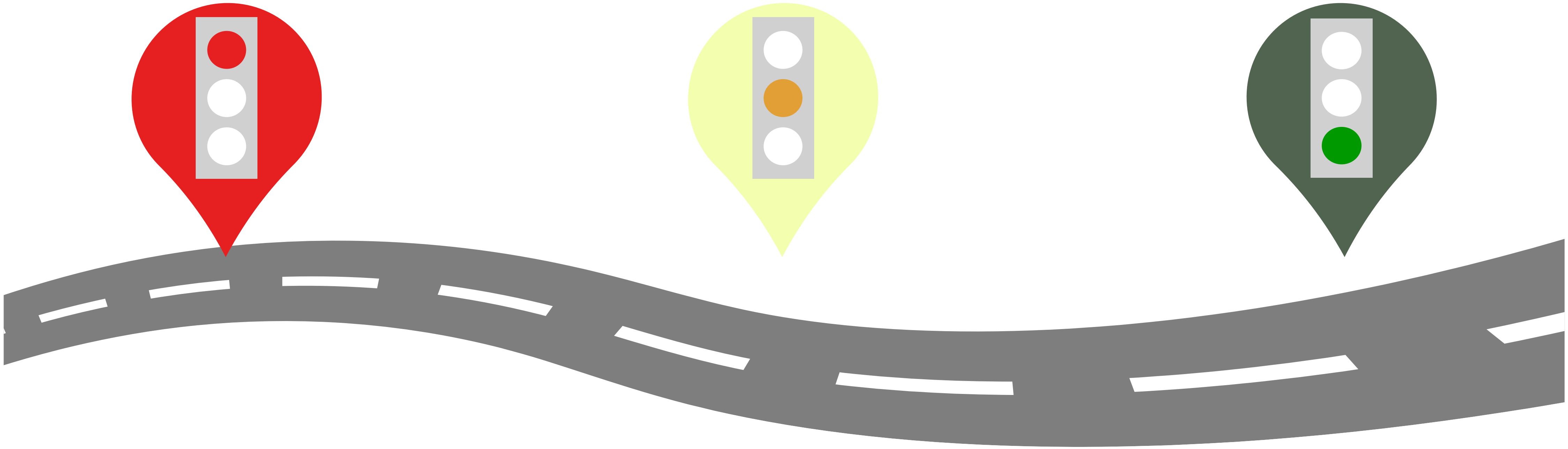
Maturity (RAG) based on maximum MVAr capability

Red, yellow and green traffic lights indicate maturity of the MVAr capability of the technology (rather than maturity of the MW capability)

- Red light indicate **low technical readiness level** and immature technology
- **Fundamental or applied research conducted** of technology. Proof of concept has been established

- Yellow light indicate **medium technical readiness level** and a maturing technology
- **Laboratory testing of components and full system conducted**. Prototype of technology deployed

- Green light indicate **high technical readiness level**
- Operational pilot system demonstrated, technology incorporated in commercial design or **full-scale deployment of technology**



There is a wide array of capabilities for converter connected technologies in the GB market today

Legacy converters without reactive compensation equipment

- For legacy converter connected technologies with no reactive compensation equipment, the reactive power range accessible to the generator is dependent on active power accessible to the installation.
- For example for a wind provider, lower wind speeds means a lower absolute MVAr value can be accessed (e.g. if this is 33MVAr for a 100MW wind farm at full load, this would be significantly less than 33MVAr as the windspeed drops off).
- If providers using this arrangement are subject to grid code obligations (such as ORPS), there would be a significant opportunity cost of compliance.
- We do not believe this technical configuration is widespread in the GB market today, however for smaller embedded plant not subject to grid code requirements, it may be that this is the configuration that is preferred due to the cost of installing reactive compensation equipment.

Reactive availability from generator: **Variable**

Legacy converters with reactive compensation equipment

- Due to the need to comply with grid code obligations, and the opportunity cost involved with the trade-off between active and reactive power, many generators have chosen to install reactive compensation throughout the network.
- Typically these are Statcoms which can be sized to meet grid code obligations, or undersized to share the burden of compliance between generator and Statcom.
- This configuration is relatively widespread in GB today, particularly at larger installations.
- As the generator and reactive compensation equipment are divorced, providers can potentially offer their reactive ranges (or a portion of their ranges) on an baseload basis (subject to maintenance windows).
- In any case, the total reactive power that can be supplied will always be limited by the MVA rating of the connection.

Reactive availability from generator : **Variable**

Reactive compensation availability: **Fixed**

New & emerging converter technologies

- Some new converter technologies and associated control algorithms are capable of using the converter itself as reactive compensation equipment (with varying degrees of freedom depending on the technology applied).
- Reactive power can be supplied independently of active power across the operating range of the generator/storage facility, but limited by the converters rating.
- This potentially offers a highly flexible source of reactive power capability, whereby providers are able to offer reactive power ranges based on the unutilised converter capacity.
- We believe this emerging technology could become commonplace in the future if the right incentives/obligations are placed on parties to include the equipment at installation.

Reactive availability from generator: partially **Variable** with a **Fixed** minimum capability[1]

limited by converter rating

[1]Converter is typically sized to facilitate compliance with grid code obligations, but there is a cost/benefit trade-off to be considered.

CASE STUDIES

Onshore Wind

Characteristics

- Reactive capability for onshore wind has the potential to be much higher than the Base case and High range which is reflected by capability to produce at 0MW.
- Wind power generators (WPG) can be classified into two main types: fixed speed and variable speed where variable speed configurations are the most common today. Variable speed turbines are fully or partly connected via a converter between the grid and the generator and has the potential to regulate the voltage.
- The data for onshore wind are focussed on variable speed turbines and especially type 3 (DFIG) and type 4 (full power converter).
- Each wind farm consists of multiple individual wind turbines with a power ranging between generally 1 MW to 5-6 MW per turbine. Each wind turbine is then connected by a cable which forms the internal grid of the wind farm which is connected to the main substation of the grid.

	Base case	High range	Low range
Typical unit size (MW)[1]	150	450	~1-5
Capex (£/kW)[2]	1 113	1 260	966
Opex (£/kW/year)	44	50	38
Leading reactive capability (MVAr range per MW at full load)	0.33	0.50[3]	0.33
Lagging reactive capability (MVAr range per MW at full load)	0.33	0.65[3]	0.33
Grid codes - Additional capability beyond ORPS (MVAr/MW at full load)	Leading = **0.17** Lagging = **0.32**		
Is MVAr output at 0MW generation possible?	**Yes**		
Availability dependencies to provide reactive power	See slide 7		
Static only or dynamic? (Reactive Power)	Static and dynamic, converter-based		
Maturity (RAG) based on maximum MVAr capability			

[1]Per wind farm. [2]Include cost of turbines, grid asset and grid connection cost. [3]ENTSO-E definition of maximum grid code capability for non-synchronous generators

CASE STUDIES

Barriers & Enablers for Onshore Wind

	Barriers		Enablers	
Reactive power	– Existing grid code requirements limit capabilities	– Manufacturers follow existing arrangements for converters and control loops, which may limit functionality	– Not fully utilised reactive power capability	– The reactive capability of the WTG has been determined by the grid codes rather than the WTG capability
	– Converters are not dimensioned to provide high reactive power per active power unit	– Higher reactive power per active power could limit the life time of the converters	– Generate or consume reactive power (leading/lagging)	– Potential to be a very flexible source for reactive power
	– Reactive power provision generally linked to available active power	– Low wind periods could lead to low production of reactive power	– Advantageous to combine with storage solutions	– In order to offer higher reactive quantities wind can easily be combined with e.g. batteries to provide services more consistently
	– Higher losses when producing reactive power	– Higher losses when operating at power factors deviating significantly from a power factor close to 1	– Reactive power provision when no wind possible	– Possible to provide reactive power by drawing power from other sources (such as the grid[1])

[1]Cost of energy draw must be considered

CASE STUDIES

Offshore Wind

Characteristics

- Reactive capability for offshore wind has the potential to be much higher than the Base case and High range which is reflected by capability to produce at 0MW.
- Wind power generators (WPG) can be classified into two main types: fixed speed and variable speed where variable speed configurations are the most common today. Variable speed turbines are fully or partly connected via a converter between the grid and the generator and has the potential to regulate the voltage.
- Offshore wind connected by HVAC theoretically has the same characteristics as onshore wind with the differences that the connection to the main grid are generally longer than for onshore wind and that that electricity needs to be transformed more than one time from the turbine to the main grid.
  - It should be noted that whilst technical characteristics are similar, GB arrangements mean a wide array of solutions are employed to meet connection requirements.

	Base case	High range	Low range
Typical unit size (MW)[1]	750	1 000	500
Capex (£/kW)[2]	1 900	2 117	1 680
Opex (£/kW/year)	91	105	76
Leading reactive capability (MVAr range per MW)	0.33	0.50[3]	0.33
Lagging reactive capability (MVAr range per MW)	0.33	0.65[3]	0.33
Grid codes - Additional capability beyond ORPS (MVAr/MW at full load)	Leading = **0.17** Lagging = **0.32**		
Is MVAr output at 0MW generation possible?	**Yes**		
Availability dependencies to provide reactive power	See slide 7		
Static only or dynamic? (Reactive Power)	Static and dynamic, converter-based		
Maturity (RAG) based on maximum MVAr capability			

[1]Per wind farm. [2]Include cost of turbines, grid asset and grid connection cost. [3]ENTSO-E definition of maximum grid code capability for non-synchronous generators.

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Barriers & Enablers for Offshore Wind

Reactive power

Barriers		Enablers	
– Existing grid code requirements limit capabilities	– Manufacturers follow existing arrangements for converters and control loops, which may limit functionality	– Not fully utilised reactive power capability	– The reactive capability of the WTG has been determined by the grid codes rather than the WTG capability
– Converters are not dimensioned to provide high reactive power per active power unit	– Higher reactive power per active power could limit the life time of the converters	– Generate or consume reactive power (leading/lagging)	– Potential to be a very flexible source for reactive power
– Reactive power provision generally linked to available active power	– Low wind periods could lead to low production of reactive power	– Advantageous to combine with storage solutions	– In order to capture more value wind can easily be combined with e.g. batteries to provide services during more hours of the day
– Long distance to the point of interconnection (POI) to the main grid	– Uncertain of how the reactive capability of the converters will affect at the POI as cables and several voltage transformations is in between	– Reactive power provision when no wind possible	– Possible to provide reactive power by drawing power from other sources (such as the grid[1])
– Higher losses when producing reactive power	– Higher losses when operating at power factors deviating significantly from a power factor close to 1		

[1]Cost of energy draw must be considered Note: Where HVDC connection exists no reactive power can be transferred across the link, all capability is at the onshore point of connection

CASE STUDIES

Solar PV

Characteristics

- Reactive capability for solar PV has the potential to be much higher than the Base case and High range which is reflected in if MVAr can be produced at 0MW.
- Solar PV generation utilises solar power to convert to electricity using photovoltaics. The direct current produced is converted to alternating current via a converter which can be further used for control of active and reactive power flow.
- Rapidly decreasing prices and matured technology over the past few years, enabling both small- and large-scale PV installations.
- Reactive power provision usually requires availability of active power → no reactive power provision during night; new technologies enable operation in VAR compensation mode in which power is drawn from the grid, regulate the DC bus, and inject the desired level of reactive power (e.g., Q at Night, SMA).

	Base case	High range	Low range
Typical unit size (MW)	10-30	70	1
Capex (£/kW)[1]	535	588	483
Opex (£/kW/year)	26	30	22
Leading reactive capability (MVAr range per MW)	0.33	0.50[2]	0.33
Lagging reactive capability (MVAr range per MW)	0.33	0.65[2]	0.33
Grid codes - Additional capability beyond ORPS (MVAr/MW at full load)	Leading = **0.17** Lagging = **0.32**		
Is MVAr output at 0MW generation possible?	**Yes**		
Availability dependencies to provide reactive power	See slide 7		
Static only or dynamic? (Reactive Power)	Static and dynamic, converter-based		
Maturity (RAG) based on maximum MVAr capability			

[1]Include cost of PV-cells, converter, grid asset and grid connection cost [2]ENTSO-E definition of maximum grid code capability for non-synchronous generators

Barriers & Enablers for Solar PV

Reactive power

Barriers

– Low capacity installations	❯	– Lower scalability than other technologies, often quite small installations
– Existing grid code requirements limit capabilities	❯	– Manufacturers follow existing arrangements for converters and control loops, which may limit reactive power provision
– Generally connected to the distribution grid instead of the transmission grid	❯	– The service will provided to the DNO grid, an intermediate step to reach the Transmission network
– Reactive power provision linked to available active power	❯	– Periods without sun could lead to low production of reactive power
– Converters are not dimensioned to provide high reactive power per active power	❯	– Higher reactive power per active power could limit the life time of the converters

Enablers

– Implementation of VAR compensation mode possible	❯	– Increases suitability for reactive power provision, enabling provision during the night time
– Generate or consume reactive power (leading/lagging)	❯	– Potential to be a very flexible source for reactive power
– Advantageous to combine with storage solutions	❯	– In order to capture more value solar PV can easily be combined with e.g. batteries to provide services during more hours of the day
– Not fully utilised reactive power capability	❯	– The reactive capability of the PV has been determined by the grid codes rather than the PV converter capability

CASE STUDIES

Battery Energy Storage System (BESS)

Characteristics

- Reactive capability for BESS has the potential to be much higher than the Base case and High range which is reflected in if MVAr can be produced at 0MW and the flexible and potential high availability.
- Battery Energy Storage System (BESS) is a flexible technology with good reactive capability.
- BESS could be dimensioned in a modular setting, where many battery cells could be compiled to meet unit size request.

	Base case	High range	Low range
Typical unit size (MW)[1]	50	200	10
Capex (£/kW)[2]	572	622	521
Opex (£/kW/year)[2]	25	29	21
Leading reactive capability (MVAr range per MW)	0.33	0.50[3]	0.33
Lagging reactive capability (MVAr range per MW)	0.33	0.65[3]	0.33
Grid codes - Additional capability beyond ORPS (MVAr/MW)	Leading = **0.17** Lagging = **0.32**		
Is MVAr output at 0MW generation possible?	**Yes**		
Availability dependencies to provide reactive power	See slide 7		
Static only or dynamic? (Reactive Power)	Static and dynamic, converter-based		

Maturity (RAG) based on maximum MVAr capability

[1] Refers to the size of the converter and not storage potential (MWh). [2] 2hr Li-ion battery, 100 MWh, Includes cost of battery, inverters, various electronic control systems, grid connection, EPC, land, permitting; [3]ENTSO-E definition of maximum grid code capability for non-synchronous generators

CASE STUDIES

Barriers & Enablers for Battery Energy Storage System (BESS)

Reactive power

Barriers

- Existing grid code requirements limit capabilities ❯ Manufacturers follow existing arrangements for converters and control loops, which may limit functionality
- Generally connected to the distribution grid instead of the transmission grid ❯ The service will provided to the DNO grid, an intermediate step to reach the Transmission network
- Converters are not dimensioned to provide high reactive power per active power ❯ Higher reactive power per active power could limit the life time of the converters

Enablers

- Excellent reactive power provision ❯ Can balance grids with drain/supply of active and reactive power
- Plannable provider of reactive power ❯ BESS could provide reactive power fast and when the demand for reactive power services is high
- Reactive power provision independent from active power ❯ Could deliver reactive power without producing any active power
- Provide reactive power while charging ❯ BESS can provide reactive power to the grid when charging resulting in high availability
- Not fully utilised reactive power capability ❯ The reactive capability of the BESS has been determined by the grid codes rather than the BESS capability

CASE STUDIES

HVDC Voltage Source Converter

Characteristics

- Reactive capability for HVDC VSC has the potential to be much higher than the Base case and High range which is reflected in if MVAr can be produced at 0MW.
- Multi-terminal system ability, can also be used with LCC links (Hybrid) but mainly focus on HVDC VSC for this case study.
- High Voltage Direct Current (HVDC) Voltage Source Converter (VSC) is suited for long-distance interconnection, e.g., offshore wind or country interconnections.
- Costs: Capex/MW declines non-linearly for larger units, opex/MW declines almost linearly for larger units.
- Not economical for short cable lengths.

	Base case	High range	Low range
Typical unit size (MW)	1 000	2 000	500
Capex (£/kW)[1]	252	210	294
Opex (£/kW/year)	1.4	1.7	1.2
Leading reactive capability (MVAr range per MW)	0.33	0.50[2]	0.33
Lagging reactive capability (MVAr range per MW)	0.33	0.65[2]	0.33
Grid codes - Additional capability beyond ORPS (MVAr/MW)	Leading = **0.17** Lagging = **0.32**		
Is MVAr output at 0MW generation possible?	**Yes**		
Availability dependencies to provide reactive power	Can only provide reactive power when the HVDC link is in operation, otherwise disconnected from the grid		
Static only or dynamic? (Reactive Power)	Static and dynamic, converter-based		
Maturity (RAG) based on maximum MVAr capability			

[1]Include cost of the complete system with inverter, grid assets and transformers (excl. cable). [2]ENTSO-E definition of maximum grid code capability for HVDC converter stations

Barriers & Enablers for HVDC

Reactive power

Barriers		Enablers	
– Existing grid code requirements limit capabilities	– Manufacturers follow existing arrangements for converters and control loops, which may limit functionality	– Generate or consume reactive power (leading/lagging)	– Potential to be a very flexible source for reactive power
– Reactive power provision	– Can only provide reactive power when the HVDC link is in operation, otherwise disconnected from the grid	– Reactive power capability can be independent to active power	– Could deliver reactive power without producing any active power
– Converters are not dimensioned to provide high reactive power per active power	– Higher reactive power per active power could limit the life time of the converters	– Not fully utilised reactive power capability	– The reactive capability of the HVDC VSC has been determined by the grid codes rather than the HVDC VSC capability

Pumped Hydro Energy Storage

Characteristics

- Pumped Hydro Energy Storage (PHES) is a flexible energy technology able to provide system services. PHES is utilising water reservoirs at different altitudes and a pump/turbine.
- Pumped hydro is a relatively established technology, however no new projects have become operational in recent years (albeit a reasonable pipeline currently exists in GB).
- The location of Pumped Hydro Energy Storage is highly restricted by geography which in many cases will not correspond with areas of the system where the need for additional reactive power service provision is acute.

	Base case	High range	Low range
Typical unit size (MW)	335	3 000	10
Capex (£/kW)	1 007	1 854	400
Opex (£/kW/year)	5	9	2
Leading reactive capability (MVAr range per MW)	0.33	0.33	0.33
Lagging reactive capability (MVAr range per MW)	0.62	0.62	0.62
Grid codes - Additional capability beyond ORPS (MVAr/MW at full load)	-		
Is MVAr output at 0MW generation possible?	**Yes**		
Availability dependencies to provide reactive power	Can provide reactive power whilst operating in any mode		
Static only or dynamic? (Reactive Power)	Static and dynamic		
Maturity (RAG) based on maximum MVAr capability			

Barriers & Enablers for Pumped Hydro Energy Storage

Reactive power

Barriers		Enablers	
– Geographical constraints	– Geological formations as old mines, caves or mountainous areas restricts the locations of pumped hydro	– Plannable provider of reactive power with high availability	– Pumped hydro could provide reactive power fast and when the demand for reactive power is high
		– Reactive power provision independent from active power	– Could deliver reactive power without producing any active power by spinning the turbine in air

CASE STUDIES

CCGT

Characteristics

- Thermal generation technology, utilising energy from combustion and steam/gas turbines to produce electrical energy to the power grid at synchronous speed.
- Widespread today in GB, but number/capacity of installations are in decline.

	Base case	High range	Low range
Typical unit size (MW)	450	500	400
Capex (£/kW)	683	714	651
Opex (£/kW/year)	29-64	64	29
Leading reactive capability (MVAr range per MW)	0.33	0.33	0.33
Lagging reactive capability (MVAr range per MW)	0.62	0.62	0.62
Grid codes - Additional capability beyond ORPS (MVAr/MW at full load)	-		
Is MVAr output at 0MW generation possible?	**No[1]**		
Availability dependencies to provide reactive power	Generators need to be spinning to provide services, ramping affects how fast it can respond to changes in demand		
Static only or dynamic? (Reactive Power)	Static and dynamic		

Maturity (RAG) based on maximum MVAr capability

[1]Can be designed to operate in synch-comp mode

CASE STUDIES

Barriers & Enablers for CCGT

Reactive power

Barriers		Enablers	
– Slow ramp up/down	– Ramping makes CCGT less dynamic for bigger changes in reactive power stabilization	– Technically configured to provide reactive power today	– CCGT is a well established source of reactive power provision today
– Reactive power capability linked to active power	– Need to produce active power to provide reactive power	– Flexible thermal generator	– CCGT are one of the most dynamic and flexible thermal generators to provide reactive power
– Wear on the equipment operating at power factors far from unity	– Wear on equipment and losses increase as power factor deviates from unity		

CASE STUDIES

Nuclear

Characteristics

- Nuclear power utilise fission to drive steam turbines for the production of electrical energy and its injection into the power grid at synchronous speed.
- There are still a large number of nuclear installations in Great Britain, however the vast majority of these are scheduled to close in the coming years with limited new entrant pipeline to replace existing facilities.

	Base case	High range	Low range
Typical unit size (MW)	1 600	1 600	600
Capex (£/kW)	4 340	10 000	3 431
Opex (£/kW/year)	73	109	66
Leading reactive capability (MVAr range per MW)	0.33	0.33	0.33
Lagging reactive capability (MVAr range per MW)	0.62	0.62	0.62
Grid codes - Additional capability beyond ORPS (MVAr/MW at full load)	-		
Is MVAr output at 0MW generation possible?	**No**		
Availability dependencies to provide reactive power	Generator needs to be spinning to provide reactive power		
Static only or dynamic? (Reactive Power)	Static but potential to be dynamic depending on operation mode		
Maturity (RAG) based on maximum MVAr capability			

CASE STUDIES

Barriers & Enablers for Nuclear

Reactive power

Barriers		Enablers	
– Slow ramp up/down	– Static behaviour rather than dynamic why not ideal for reactive power market as for today	– Stable reactive power provision	– Potential to be dynamic and deliver stable reactive power, high load factors result in availability
– Reactive power capability linked to active power	– Need to produce active power to provide reactive power	– Large source of reactive power provision	– Large generators with a capability to provide bulk source of reactive power to the transmission grid in areas

CASE STUDIES

Biomass steam turbine

Characteristics

- Biomass-fuelled steam turbines burn biomass to produce high-pressure steam, driving turbine blades to spin a generator. The steam turbine operation is similar as if fired with coal instead, but is significantly better from an environmental perspective when fuelled with biomass.
  - Coal-fired steam turbines can be converted to operate with biomass either fully or partially, reducing the reliance on fossil fuels
- Can be built as stand-alone power plants, but are often utilized in combined heat and power (CHP) plants to further increase efficiency
- Mature technology with highly plannable and flexible operation
- Operates at synchronous speed and is a good provider of reactive power

	Base case	High range	Low range
Typical unit size (MW)	50	600[1]	5
Capex (£/kW)[2]	2 000	3 200	1 400
Opex (£/kW/year)[2]	50	80	21
Leading reactive capability (MVAr range per MW)	0.33	0.33	0.33
Lagging reactive capability (MVAr range per MW)	0.62	0.62	0.62
Grid codes - Additional capability beyond ORPS (MVAr/MW at full load)	-		
Is MVAr output at 0MW generation possible?	**No**		
Availability dependencies to provide reactive power	Generators need to be spinning to provide services		
Static only or dynamic? (Reactive Power)	Static and dynamic		
Maturity (RAG) based on maximum MVAr capability			

[1]:Refers to refurbished coal power plants. New-built biomass power plant usually smaller.
[2]:All capex and opex figures refers to biomass power plant new-builds. Typically capex decreases with increasing capacity.

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Barriers & Enablers for Biomass steam turbines

Reactive power

Barriers		Enablers	
– Slow ramp up/down	– Ramping makes Biomass steam turbines less dynamic for bigger changes in reactive power stabilization	– Technically configured to provide reactive power today	– Steam turbines are a well established source of reactive power provision today
– Reactive power capability linked to active power	– Need to produce active power to provide reactive power		
– Wear on the equipment operating at power factors far from unity	– Wear on equipment and losses increase as power factor deviates		

CASE STUDIES

Synchronous Condenser with Flywheel

Characteristics

- A synchronous condenser (SC) is an AC-driven synchronous motor able to spin freely without load, and can provide system-critical services including reactive power (and other) services.
- A well established technology that has been applied to many other grids across the world to provide critical services.

	Base case	High range	Low range
Typical unit size (MVAr)	125	200	50
Capex (£/kVAr)	208	269	147
Opex (£/kVAr/year)	12	18	6
Leading reactive capability (MVAr range per MW)	Only MVAr	Only MVAr	Only MVAr
Lagging reactive capability (MVAr range per MW)	Only MVAr	Only MVAr	Only MVAr
Grid codes - Additional capability beyond ORPS (MVAr/MW)	-		
Is MVAr output at 0MW generation possible?	**Yes**		
Availability dependencies to provide reactive power	Needs to draw power to provide reactive power services		
Static only or dynamic? (Reactive Power)	Static and dynamic		
Maturity (RAG) based on maximum MVAr capability			

Barriers & Enablers for Synchronous Condenser with Flywheel

Reactive power

Barriers		Enablers	
– Losses and mechanical wear, occupies large space	– Relatively high losses and mechanical wear, and facilities require quite large space	– Mature technology	– Tried and tested technology for providing reactive power
– Occupies large space close to grid infrastructure	– Can be difficult to site where required due to land rights/ownership	– Dynamically controlled reactive power provision	– Manufactured in considerable sizes with the ability to continuously adjust reactive power output
		– No active power	– Shaft spinning freely so SC’s can provide reactive power without active power
		– Easy to deploy	– Easy to deploy in relation to a substation where the reactive demand is high

Appendix

Glossary

Acronym	Term	Meaning
ESO	Electricity System Operator	National Grid ESO – the system operator in Great Britain
TO	Transmission Owner	Collective for the companies which own the transmission network in GB
DNO	Distribution Network Owner	Collective for the companies which own and operate the distribution networks in GB
OFTO	Offshore Transmission Owner	Collective for the companies which own offshore transmission infrastructure in Great Britain
GSP	Grid Supply Point	Connection Point at which the Transmission System is connected to a Distribution System
ORPS	Obligatory Reactive Power Service	Obligatory service to provide reactive power services as specified by the grid code
RIIO	Revenue=Incentives+Innovation+Output	Framework for network company remuneration in Great Britain
SP	Settlement Period	A period of 30 minutes beginning on the hour or the half-hour
SQSS	The Security and Quality of Supply Standards	Obligations on licensees to provide
STC	The System Operator-Transmission Owner Code	Defines the relationship between the transmission owners and the system operator incl. roles and responsibilities
MVAr	Mega Volt Ampere Reactive (Capacity)	Measure of capacity for reactive power
MVArh	Mega Volt Ampere Reactive hours (Volume)	Measure of volume for reactive power
DER	Distributed Energy Resources	Energy resources including generation, demand and storage connected to the distribution network


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