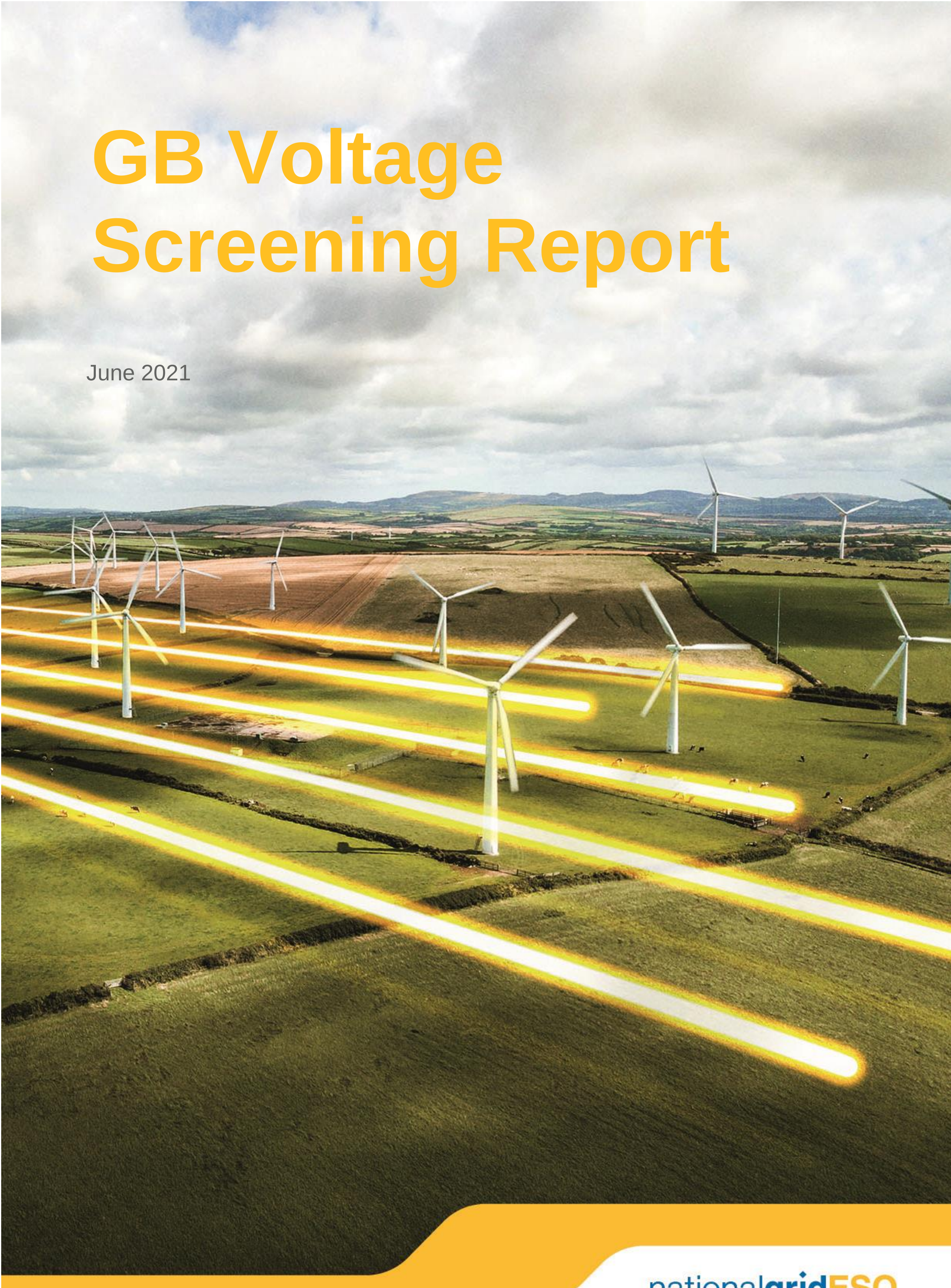
GB Voltage Screening Report

June 2021



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Executive summary

As the Electricity System Operator (ESO), we are responsible for ensuring that the voltage on the system is maintained within the compliance limits described in the Security and Quality of Service Standard (SQSS). With the changing energy landscape, it is becoming more important than ever to ensure any issues are identified and communicated to achieve timely delivery of solutions. This will allow us to operate the system in a safe, reliable and an economic manner.

In our RIIO2 business plan, we committed to providing you with information on our high voltage screening process to indicate other regions, that could face high voltage issues in the future. Following previous screening exercises, we have successfully identified and run some high voltage pathfinder projects such as the concluded Mersey Pathfinder project and the ongoing Pennine pathfinder project.

In this report we describe the methodology used to identify regions with high voltage issues through a repeatable and a consistent approach to voltage screening. This has been done by identifying:

- Areas with a dependency or over-reliance on certain assets or generation
- Areas with historically costly real time voltage actions and locations that were not compliant with pre-fault planning voltage limits as per SQSS from historic data
- Faults on the network which could have resulted in voltages in excess of allowed planning limits

Using this methodology, we have identified 7 regions with high voltage issues. These are:

- **West Midlands** due to long transmission lines that are lightly loaded with limited local voltage support from reactors or generators
- **London** caused by the high gain from cable circuits particularly overnight when the demand is low, combined with reliance on synchronous plant.
- **South West Peninsula** flagged due to a large penetration of embedded generation offsetting demand and reliance on synchronous plant
- **North Wales** due to long lines and reliance on a limited choice of local generation.
- **South Wales** caused by local generation reduction and heavy reliance on certain local generation.
- **South Central** due to various pre and post-fault high voltage issues, and its reliance on a limited source of synchronous generation, resulting in high cost to manage the local voltage.
- **Pennines** caused by the reduction in local generation and any further reduction could lead to compliance issues. A high voltage pathfinder project is currently ongoing to procure solutions in this region.

Our report focuses on areas with high voltage issues as low voltage issues are already captured through the Electricity Ten Year Statement (ETYS) and the Network Options Assessment (NOA) processes. The next steps following the report are to further analyse the regions and understand the drivers behind the future voltage issues.

We value your thoughts and comments on this report, the methodology and the results. If you have any feedback or questions on the report, please contact us at transmission.etys@nationalgrideso.com.

Introduction

As Great Britain looks to decarbonise the electricity system National Grid Electricity System Operator (ESO) has had to think differently about how system voltage is managed. Recently we have seen a continual decrease in both minimum demand and reactive power consumption on distribution networks, resulting in an increasing need to absorb more reactive power on the transmission network.

Historically, transmission network needs have been met through solutions provided by the incumbent Transmission Owners. With the rapid decentralisation of generation and a more integrated approach across the transmission and distribution systems, the operational teams need to be able to access a wider range of potential solutions to address the emerging voltage challenges. In our latest RIIO2 business plan, we have made a commitment to communicate system needs and provide an initial view on the potential next priority region(s) for high voltage assessment. The voltage screening process is the first step in our overall High Voltage Management Process and will help us in our ambition to identify the best solutions by comparing potential distribution network, commercial and transmission network solutions. Our screening process does not currently consider stability constraints and subsequently, detailed analysis could impact the priority of some identified regions.

Changing voltage needs

The Electricity System Operator (ESO) is committed to communicating network issues to industry, so that essential action can be taken to secure the transmission system. Over the last decade, the regulation of voltage, by controlling reactive power, has become particularly demanding. This is caused by:

- **The new shape of the energy landscape:** Historic abundance of synchronous plant provided the flexibility of dispatching both active and reactive power output on the system. This allowed varying reactive power from generating plant on a dynamic basis to ensure that the requirements of the Security and Quality of Supply Standards (SQSS) were complied with. Following a decline in synchronous generation plant, reactive power delivery is increasingly relying on assets such as capacitors, shunt reactors, Static Var Compensators (SVCs), as well as non-flexible renewable generation. Depending on their physical location on the network, they can also be far away from where the voltage issues are seen and may be less effective in resolving issues.

- **Consumer consumption of energy:** Increase in embedded generation, improved efficiency in electrical goods year on year and a decrease in industrial demand have all resulted in a decreasing minimum demand (typically occurs during summer) on the transmission system. This is leading to more lightly loaded lines resulting in higher gain on the system leading to higher voltages. This is particularly challenging in regions with cable circuits or long overhead lines.

  It is also worth noting that the power output from renewables does not follow demand - it follows the weather - low demand nights coinciding with high wind, could result in a reduction of synchronised plant running on the system leading to limited voltage support. Also, the increase in embedded generation for the last few years has caused the trend in reactive power injection from DNO networks to increase annually, exacerbating the high voltage issue. This has changed the reactive power demand profile at the DNO level - 10 years ago, the net GSP reactive power demand was 2000MVAr of injection and is now 8000MVAr of injection leading to a major change in the way the system is operated every year.

- **Fault events:** Conversely to minimum demand, the annual peak electricity demand has been increasing. This leads to challenges ensuring that the voltage remains within limits during significant networks faults. During a fault on the network, the number of circuits that transfer power from one area to another can reduce. This increases the power flow on remaining circuits which could lead to voltage depression. Therefore, voltage support is required post fault to ensure that the voltage stays within compliance limits.

  During the summer minimum times - minimum generation scenario, faults on the system could lead to issues with high voltage step change and potentially breaching the high voltage limits. Any post-fault scenario not secured puts excessive risk on network assets.

- **Local phenomena:** Issues with voltage tend to be local rather than a whole network constraint such as frequency or inertia. The closure of power stations can cause a reduction in voltage security on the system. The screening process explores if locations have a reliance on local assets as well.

It is important to monitor these issues as part of our routine planning and operation activities, as well as to identify further issues that could emerge in the future.

Voltage issues on the transmission network

The transmission system sees various loading patterns and system characteristics at different times during the day and throughout the year. Operationally, this is particularly challenging during yearly extremes e.g. minimum demand during overnight or sometimes in the middle of the day in summer as a result of the high penetration of solar generation. While there has always been a requirement for sources of reactive power to make sure that voltage remains within compliant limits at low demands there is often not enough headroom to synchronise generators to access their reactive power.

How do voltage issues emerge?

The power flows on the system make a significant difference to the voltage characteristics. Voltage related issues seen during summer are entirely different to those seen in winter as explained below.

1. **Summer minimum periods**: On a clear sunny day, the peak solar output causes localised areas of high voltage especially in areas which have a high concentration of solar generation connecting on to the grid. This coupled with reduced synchronous generation in the baseload – other than nuclear – causes challenges and requires shunt reactors or alternative reactive compensation. There are key reactive compensation devices throughout the network which are needed to maintain voltage limits. If these are out of service due to faults or should a fault coincide with a planned outage on voltage control equipment, it can become increasingly challenging to operate the system efficiently and economically.

   Although managing the voltage profile during the day can be challenging, the overnight is even more onerous, especially in areas with a lot of underground cable networks such as London. The gain produced from the cables exacerbate the high voltage issue, requiring the ESO to take circuits out of service for voltage control. Given that the maintenance season tends to be in the summer, additional circuits could be out of service for planned outage works making it complex to switch out circuits for voltage control as this might affect demand security.

2. **Winter peak periods**: This can be challenging during periods of high flows. The SQSS requires the network to be secured for fault outages, including (though not limited to) single circuits, double circuit and busbar faults. During the winter peak, high power flows can be seen when for example high onshore and offshore wind power tries to meet electricity demand which is predominantly located in the centre of the country. This tends to further stress the transmission system to its limits in terms of capacity. The ESO needs to ensure that the network is not only secure for intact conditions but also fault conditions during these peak flows. Typically, a fault reduces the number of routes for power to flow, leading to low voltages on the network during high flows. For such secured events the ESO needs to ensure that there is an adequate level of static and dynamic reactive power to keep the voltage within the limits detailed in the SQSS.

3. **High interconnector power flows:** Since interconnector flows are dictated by the energy price differential between GB and the European continent, the flows on the interconnector can switch from importing into Great Britain to exporting. This can stress network assets and could result in a change from low to high voltage and vice versa. Voltage Source Converter (VSC) interconnectors on the system have a reactive power range which can help in such situations.

4. **Reactive power output from generation**: there is a decrease in national demand seen at the transmission level due to the penetration of renewables increasing, thus displacing synchronous generation. Demand tends to be located in central areas which help with voltage control, but the renewable generation tends to be located in remote areas. Generators play a key role in regulating voltage by dispatching reactive power at the request of the Electricity National Control Centre (ENCC). In operational timescales, the ESO continually monitor voltage and ensure it remains within limits for both pre-fault and post-fault scenarios. During generator and asset outages, the ENCC may rely on generating units to regulate voltages in an area. With various generator closures or outage periods, it

is becoming increasingly challenging to regulate the voltage across the network. This is even more challenging during summer months, when generators often conduct maintenance and are out of service. In these times the ESO relies on supplementary plant available in the region to maintain SQSS compliance.

5. **Outages which weaken the network**: The summer period is the peak season for system maintenance. During this time, it becomes particularly challenging to secure for high voltage. When circuits are on outage, switching further circuits out on voltage control becomes difficult as this compromises on other priorities such as demand security. As a result, in addition to voltage control circuits and outages, the ESO need to carefully assess outages on voltage control equipment which also tend be requested in the summer.
6. **Faults on voltage control equipment:** These faults can be temporary, long term or even permanent requiring replacement. This limits the maintenance that can be carried out on the remaining assets making it more unreliable and susceptible for a fault on them.

Ensuring SQSS compliance

The ESO's license condition requires the network to be secured to the SQSS standard. The SQSS sets out the planning and operational limits on the network and are both defined in Chapter 6 of the SQSS:

- **Planning limits:** this is the limit to which new assets are designed and commissioned. In assessing future network upgrades and connections the planning limits are used. These limits are tighter than operational limits to create a margin for future network changes and securing for any unexpected scenarios.
- **Operational limits**: the SQSS defines the steady-state voltage limits during operational conditions along with the permitted voltage step change. When the ESO is assessing the network security in operational timescales, the network must be compliant for all contingencies that the ESO is required to secure the system for as per the SQSS and any voltage excursions should be addressed within the allowed pre-fault operational timescales. In operational planning timescales, both pre and post fault actions are identified for faults. These include:
    - **Reactive Compensation Equipment**: These can be switched in either pre-fault or post-fault to manage the voltage such that faults are secured, and that the voltage is within limits
    - **Generator Dispatch:** The ESO can call on generators to dispatch reactive power. Unless the generator is already running, this can incur additional costs for the system operator to ensure a good supply and distribution of reactive power is available.
    - **Voltage Control Circuits:** The Operational Planning team and the control room prepare a voltage strategy comprising of circuits which produce the highest gain on the network to be switched out of service to bring the voltage back into acceptable limits.
    - **Automatic Reactive Switching Schemes (ARS):** These are installed at various substations to automatically switch in voltage compensation equipment when the voltage at the busbar reaches a certain value.
    - **Substation re-switch:** changing the running arrangement at substations to secure for voltage is another strategy employed to ensure compliance for busbar faults. Also, by electrically splitting sites or varying the output from quadrature boosters (QBs) and changing circuits, the loading on the circuits can be varied to ensure voltage compliance.

With these available actions, the control room can secure the transmission system for voltage excursions both pre-fault and post-fault however, this is getting increasingly difficult. The voltage screening process takes the above factors into account and if, after exhausting all available options, we still anticipate voltage issues then this is one indicator that further reactive services need to be secured to keep the network compliant. This could also be caused by regions that incur a higher cost for voltage management and studying these could result in a long-term solution which would potentially be better than repeated expensive short term actions. This screening process is discussed in more detail in the next section.

Methodology

Voltage is a localised property of the transmission system, meaning that requirements vary from one region to another. The voltage control requirements are determined by the configuration of the local network and the nature of generation and demand in that region. Since reactive power, unlike real power, has a localised effect, due to the physical properties of the transmission system, voltage control measures are most effective when applied close to the problem. Voltage issues can, therefore, be grouped into regions and assessment of each region conducted separately.

Our screening process helps identify and prioritise the region(s) which should be further explored through a detailed power system and cost-benefit analysis. This will bring consumers the best value by ensuring that the secure, economical and efficient development of the network focuses on challenging regions first.

Our high voltage management process is published within the NOA methodology Chapter 6, as shown in the figure below, the screening process is the first step in the overall process to identify and communicate high voltage requirements. This report discusses how we have undertaken the high voltage screening process to identify some regions that could face high voltage issues in the future. Our initial screening process does not, consider stability constraints. Subsequent, more detailed analysis, to identify requirements could also change the priority of some of the regions identified.

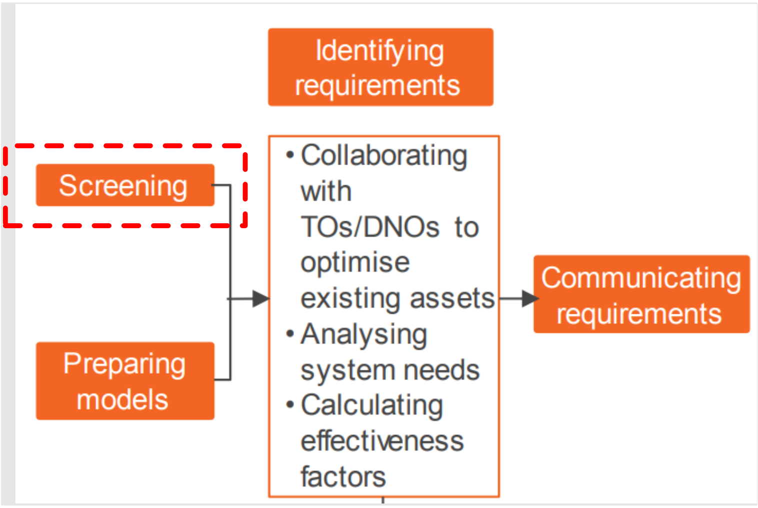
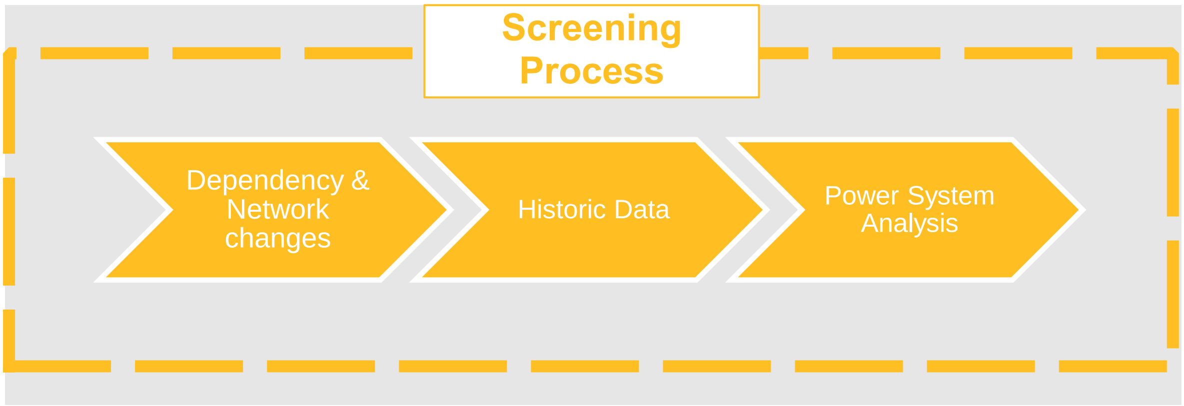


Figure 1: Extract from the High Voltage Management process, Chapter 6 NOA methodology

Voltage screening process

The voltage screening process helps identify and prioritise regions for further analysis. As part of the process, we consider several factors as described within the NOA methodology. These factors include (though are not limited to) historic voltage spend, historic voltage excursions, impacts of different network changes and identifying areas with dependency on certain equipment or generation units. Additionally, we undertake power system analysis on various snapshots to further identify if voltage issues exist. When establishing a priority for different regions, further considerations include factors like the reliance on power stations such that their closure could cause issues, the changes in network topology due to network reinforcements or new connections or even the long terms effects of generation and demand changes forecasted in the FES could lead to voltage issues. In doing so, the lead-times involved are considered to deliver a solution to solve potential issues.



Network changes and dependency identification

In some instances, with the announcement of power plant closures, we notice a voltage dependence in a region. In these cases when plant has been relied on frequently to provide voltage support, its scheduled closure may make it more difficult to keep the network voltages within SQSS limits both during standard running conditions and also following a secured event. These dependencies do not only refer to power plants, they also encompass shunt reactive compensation devices across the network with a high utilisation rate. If certain reactive compensation equipment is used nearly all the time, then it suggests an over-reliance on the asset's utilisation and potentially suggest that no further actions may be available in the region indicating a depletion in the reactive power capacity available. The screening process identifies any dependencies, as well as the potential impact of future network changes or the demand and generation variation forecasted in the FES. Additionally, the process considers various scenarios to assess the effects of the closure of plants and unavailability of shunt equipment.

Historic data analysis

In our role as the GB Electricity System Operator, we collect vast quantities of commercial and operational data from SCADA and other metering systems across the country. This data is collected and used in a post-operation review capacity for our operational staff and to determine network pinch points for our planning teams to investigate and propose network or commercial solutions to alleviate these constraints.

Historical voltage spend

Historic spend is reviewed in each region to procure commercial services for managing high voltages. A high historic spend for voltage security in a region suggests heavy reliance on the Balancing Mechanism (BM) to buy generation for voltage control purposes or procuring reactive support through the Trading and Obligatory Reactive Power Service (ORPS). Looking at the historic reliance on these services would suggest potential benefits of conducting an assessment to evaluate the best options to provide future reactive support in the region

Historical operational data

Some examples of the data collected, often on a second by second basis, include frequency, demand, line loading, busbar voltages, shunt energisation and utilisation, dispatch of generation, and historic spend. In a voltage screening capacity, the primary focus is on busbar voltages across all transmission substations around the country, as well as reactive compensation utilisation and historic spend of procuring reactive services.

A voltage scan takes place on a weekly basis analysing historic data for voltage excursions for both pre and post fault conditions beyond the SQSS (Security and Quality of Supply Standards) limits. If any are discovered, they are queried to determine the root cause.

This data is now being applied to pre-fault SQSS limits in areas of high historic spend to highlight areas of interest for our pathfinder projects. This involves a more in-depth analysis, to discover why planning limits may be exceeded. Most commonly this is a result of switching events, outages, or secured events on the network. It is important to filter out these events to focus solely on the pre and post fault voltage profile of a region. Once a potential region of interest has been identified it is subjected to post-fault power system analysis as described in the next section.

Power system analysis

Following the flagging of potential areas of interest; it is necessary to conduct additional analysis with power system simulation software to evaluate whether post-fault SQSS limits may be exceeded. This analysis involves taking a detailed model of the existing National Electricity Transmission System and subjecting it to various fault conditions under differing scenarios to confirm the security of the network. These scenarios will vary depending on the topology of the region. A typical case would involve a model with a lower demand profile tested against every contingency in the network, including (though not limited to) single, double circuit and reactive compensation failure. Any excursions beyond SQSS limits are flagged for further analysis in the next stage after screening called 'identifying requirements' as highlighted in Figure 1. Also, we will be working closely with the relevant Transmission and Distribution Network Operators as we prepare detailed models for the next stage in this process. For more information please refer to the High Voltage Management process, Chapter 6 NOA methodology.

Likelihood and lead time

As part of the screening process, the underlying conditions under which high-voltage issues arise are analysed and their likelihood assessed. This helps determine whether identified voltage issues are likely to persist into the future or are just driven by one-off events. For example, if the high historic spend was due to a routine maintenance outage, it will be considered more likely than spend due to a long outage caused by a fault.

To help get a sense of the level of urgency, lead time between network requirements and the typical lead time to deliver an option in the region of interest is reviewed. If, for example, a compliance concern will arise before any options can be sourced to meet the requirements, then there is an urgency to assess the region.

Regions with potential voltage issues

From the methods described above, Figure 2 shows the regions that have been flagged for voltage compliance issues in the near future. Some of these voltage regions are also published in the Operability Strategy Report. It must be noted that, at this stage, this is an indication of the regions with potential issues. Further analysis needs to be carried out to determine the drivers behind the issues and quantify the level of requirement finding solutions to resolve them. In some instances, further analysis might determine that we do not need to progress certain regions.

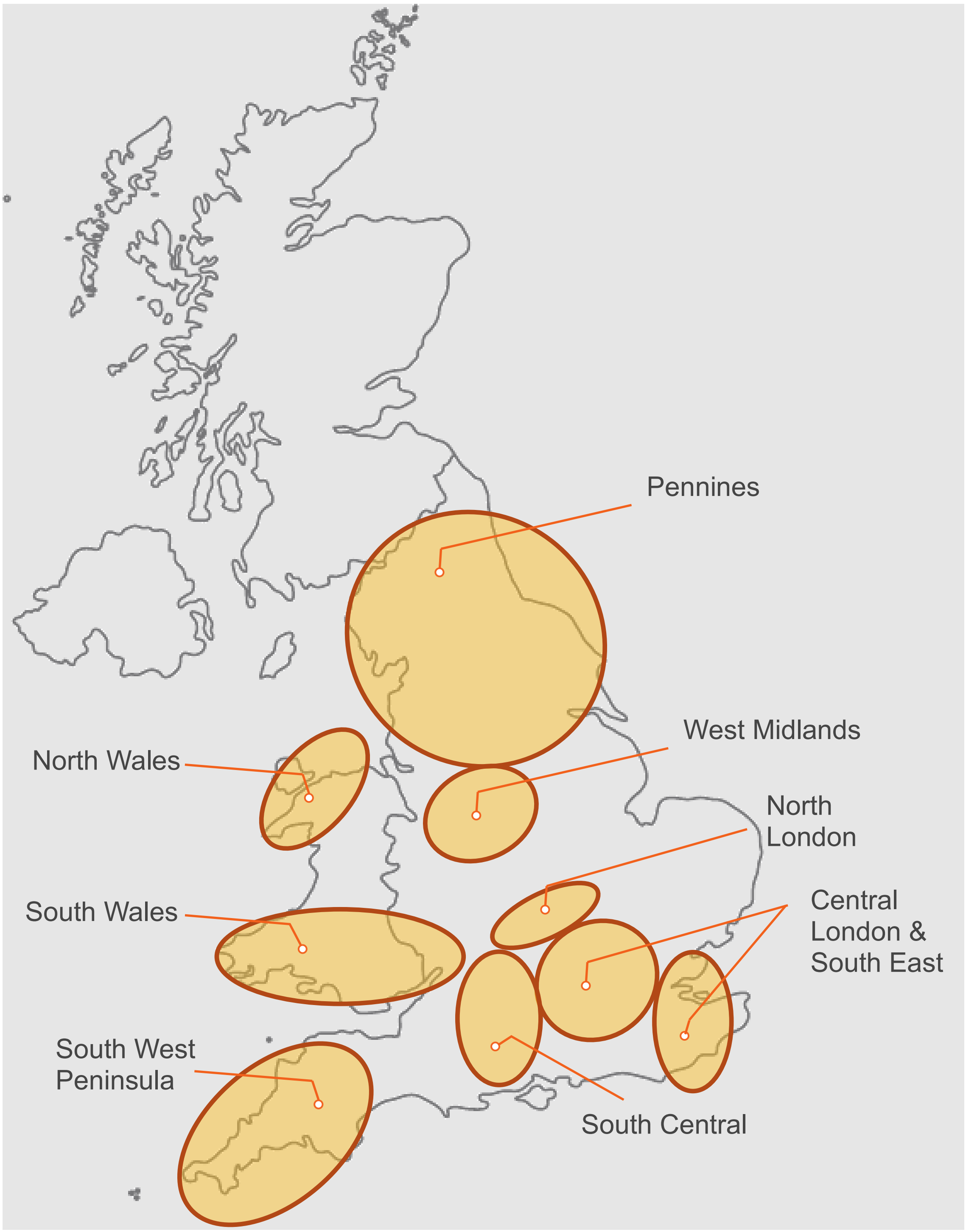


Figure 2: Regions with potential voltage compliance issues

1. West Midlands

Following the closure of power stations in this location, the areas surrounding Ironbridge, Drakelow and Rugeley have experienced diminished voltage control capability due to the overall lack of reactive compensation in the 275kV network, and the volatility of voltages to system flows. Coupling this with low electricity demand at Rugeley and a long transmission line from Ironbridge results in high voltage during summer months.

This was confirmed by the screening process reporting high voltage outside planning limits but within operational limits pre-fault. In addition to the fault case analysis, large voltage step changes can also be seen from the analysis. This is currently secured via dispatching reactive power from generation and on reactive compensation switching both of which are further away from the region and this is not very effective. Looking ahead, it is expected to become increasingly challenging to secure the region's voltage compliance limits without intervention.

2. London

Central London experiences high voltage during periods of low demand. This is managed by switching out cable circuits to regulate the voltage. Low demand will occasionally require additional reactive support to maintain within voltage compliance limits. This region also frequently relies on generation in the south-east to manage voltage issues.

Where available, we usually manage high voltage using existing reactors, however some of these reactors are on long term fault outages and are unable to be utilised by the control room. The ESO regularly works with the TO to get the fault repaired and the reactors returned to service as soon as possible but, this indicates an over reliance on these reactors to secure the voltage in this region. Also, fault repair might require additional asset outages such as a mesh corner and the assets associated with this. If the distribution network operator (DNO) has a subsequent fault that challenges the demand security in the area, the TO might find it difficult to get the additional asset on outage to be approved by the ESO. This can cause faults on the system to remain on the system for a while until an opportunity is available.

North London region around Elstree, Watford South and Iver also experiences high pre-fault voltage and post-fault step change due to low line loading and reduced demand in the summer months. Presently, we rely on local generation for reactive power support but there are challenges managing the voltage during outage periods.

3. South Central

The South Central region covers the network from Didcot down to Marchwood, stretching to the eastern part of the Southwest region (Hinkley Point and Chickerell). Previous studies have found several potential issues, both pre and post fault. Also due to the reliance on a limited choice of synchronous generation, this area has seen very high cost each year to manage the local voltage.

4. South West Peninsula

In the south west peninsula (Indian Queens, Alverdiscott, Taunton, Bridgwater, Landulph and Exeter) there is a reliance on local synchronous generation. High voltage is evident in summer months when local demand is low, exacerbated by additional solar generation and nested generation outages. This is presently managed by dispatching reactive power from neighbouring generating plant. Soon, with the connection of additional VSC interconnector, the reactive power may make this more manageable however, if any power stations in this region closed within the next 10 years, the voltage in this region could exceed compliance limits. This over-reliance on local generation will make voltage control more challenging should this plant not be available.

5. Pennines

The Pennines region is a large region that encompasses most of the North of England stretching from the Scotland – England border, down to the Aire Valley, Humber Estuary and parts of West and East Midlands. This region has experienced the closure of coal plant and any future reduction of generation in this region could limit the options available to manage voltage during low demand scenarios. A high voltage pathfinder project is ongoing in this area and can find out more about it here.

6. North Wales

This region encompasses Dinorwig, Pentir, Trawsfynydd and Wylfa and comprises of significant offshore generation as well as local generation. Due to network topology, planned outages on circuits can be challenging as secured events could result in high voltage limit excursions.

7. South Wales

South Wales is the region surrounding the cities of Swansea and Cardiff. The local voltage under some credible fault and circuit outage conditions near Cilfynydd is currently secured by dispatching reactive power from generation further away from this region, as there is limited effective local generation. This is leading to high cost each year.

Conclusion and next steps

Our voltage screening process has highlighted several regions that could have high voltage requirements in the future. The next step is for the ESO to prioritise the regions by considering the combined factors of their cost, likelihood and lead time, for the regions that are most urgent to be addressed. Following prioritisation, more detailed power system analysis will be undertaken to understand and quantify the requirements for the prioritised region(s). Prior to determining these requirements, the ESO will be engaging and working closely with the relevant Transmission and Distribution Network Owners to prepare detailed network models for the analysis as well as ensure that existing assets in the relevant regions are optimised.

Our screening process has focussed on high-voltage regions and has not undertaken stability assessments. Stability needs will be reviewed as part of the detailed analysis phase. Any overlaps will be identified when defining the requirements for individual regions.

Once requirements have been identified, the system needs will be communicated to the market as with the previous voltage pathfinder projects. This will take the form of either a Request For Information (RFI) if appropriate or through Invitations to Tenders to allow the ESO to procure the relevant services in advance of the need.

Finally, we have a voltage pathfinder project currently ongoing in the Pennine area. You can find out more about it here. We will be taking lessons learned from this and other pathfinder projects to shape any future projects.

We welcome your feedback on how we can improve both our process and the information that we share with you. Email us your comments or feedback at transmission.etys@nationalgrideso.com.