Sub-synchronous oscillations in GB

Current state and plans for future management

May 2024

ESO

Executive Summary

As Great Britain's electricity system approaches achieving net zero, operational paradigms change, and new technical challenges emerge. We in the Electricity System Operator (ESO), in collaboration with the industry and government departments, ensure that these technical challenges are overcome and security of supply is maintained. In the ESO, we recognise the importance of our role at the leading edge of the electricity system decarbonisation, and in addressing future challenges as they become apparent.

The purpose of this report is to share our experience and plan to tackle the emerging sub-synchronous oscillations challenge with the industry. The report first explains what sub-synchronous oscillations are, and clears some misconceptions associated with how or when these oscillations occur. The report explains how this type of events is neither a new phenomenon nor an exclusive challenge to renewable-based systems. This report also clarifies that low short circuit level is not necessarily the only cause of sub-synchronous oscillations. The report provides an overview on how we deal with these oscillations when they occur by describing a recent event from Summer 2023 and the measures we took to maintain the security of supply. Since the events of Summer 2023 we have increased our ability to see oscillation events and through improvements to our control room systems, the network has experienced further occurrences of limited oscillations in January and May 2024 albeit of a lower magnitude and with higher levels of damping than the Summer of 2023. We continue to work with industry participants on identifying the sources of oscillation and we have developed operational tools to assist us during such events.

This report describes the current challenges the industry is facing when tackling sub-synchronous oscillations by focusing on the critical issues. We share how access to electromagnetic transient (EMT) models of existing and older assets is critical to simulate the system and conduct advanced studies of the system dynamics.

We present in this report our plan to enhance the long-term resilience of the transmission system to emerging new classes of sub-synchronous oscillations. The plan is structured into five areas,

1- Real Time Monitoring and Situational Awareness: enhancement of our visibility of system damping and investment in monitoring tools.

2- The Compliance Process: incorporating lessons learnt from recent events into the connection compliance process.

3- EMT Modelling Capability: collaboration with the industry to build GB-wide EMT model and investment in building our tools and capability.

4- Research and Development: collaboration with academia and research organisations to gain better understanding of emerging challenges, adapt operational policy and build effective tools.

5- Transparency and Engagement: maintaining continuous line of communication with our customer and stakeholder on the progress of our plan and future challenges.

ESO

Contents

1. Introduction:

What is a Sub Synchronous Oscillation?

Firstly, it is important to note that sub-synchronous oscillations aren’t a new phenomenon. Sub-synchronous oscillations are power system oscillations at frequencies that are less than the power frequency of 50Hz in Great Britain. They arise from the interactions between certain transmission equipment such as generator shafts; series compensated lines; excitation controllers; power system stabilisers and controllers of power electronic converters of either high voltage direct current converters or power park modules such as wind, batteries, and solar photovoltaic plants. If left undamped, sub-synchronous oscillations can cause equipment damage, disconnection of generation and in the worst-case scenario loss of supply.

Figure 1 shows a snapshot of what sub-synchronous oscillations looks like based on an event occurred in North Scotland in August 2021. The oscillations can be seen emerging slowly, sustaining for a short period of time and then being damped.

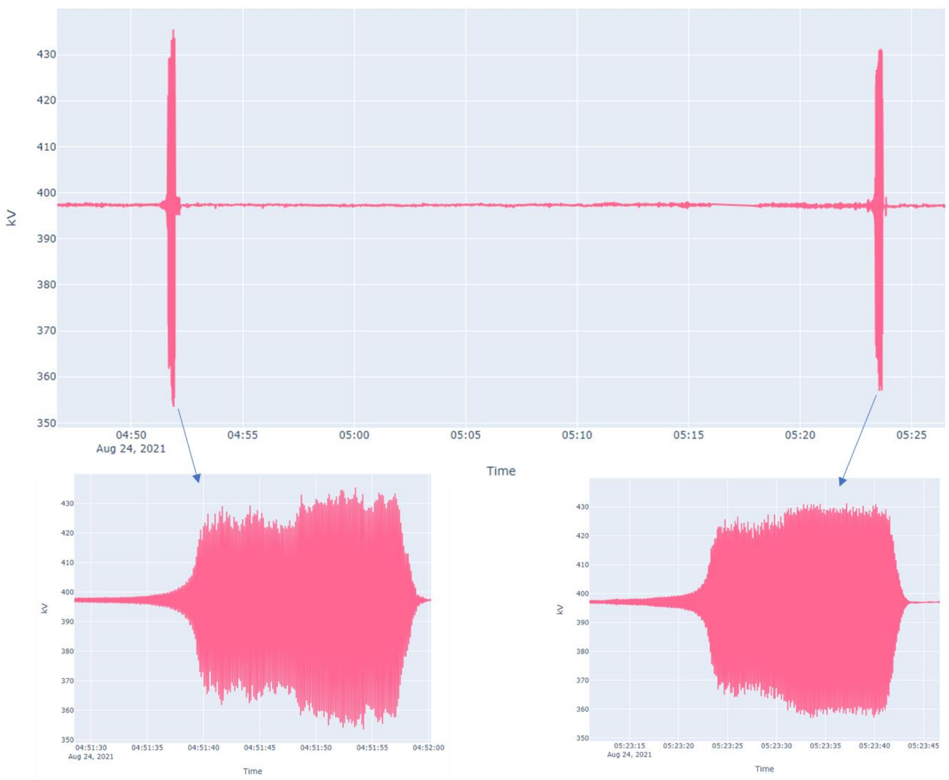

Figure 1 Sub-synchronous voltage oscillations (8Hz) recorded in GB transmission system, North Scotland, in 2021. Top figure shows an extended view of the event. Bottom figures show zoomed-in view.

Sub-Synchronous oscillations are not new nor uncommon in a power system and typically are of low magnitude and are adequately damped resulting in no system impact. As can be seen from the definition above, sub-synchronous oscillation is not a phenomenon exclusive to renewable resources–integrated-systems; It also occurs in synchronous-based systems. The oscillations related to inverter-based resource systems tend to have higher frequencies than synchronous-based systems which brings a unique set of challenges as described in Section 3.

Throughout the past decades, the classification of sub-synchronous oscillations has evolved to include new classes which developed as new technologies were integrated into the power system. Figure 2 shows the current classification of sub-synchronous oscillations. The technical details of each class of sub-synchronous oscillations are beyond the scope of this report. Interested readers can find further details in relevant literature[1].

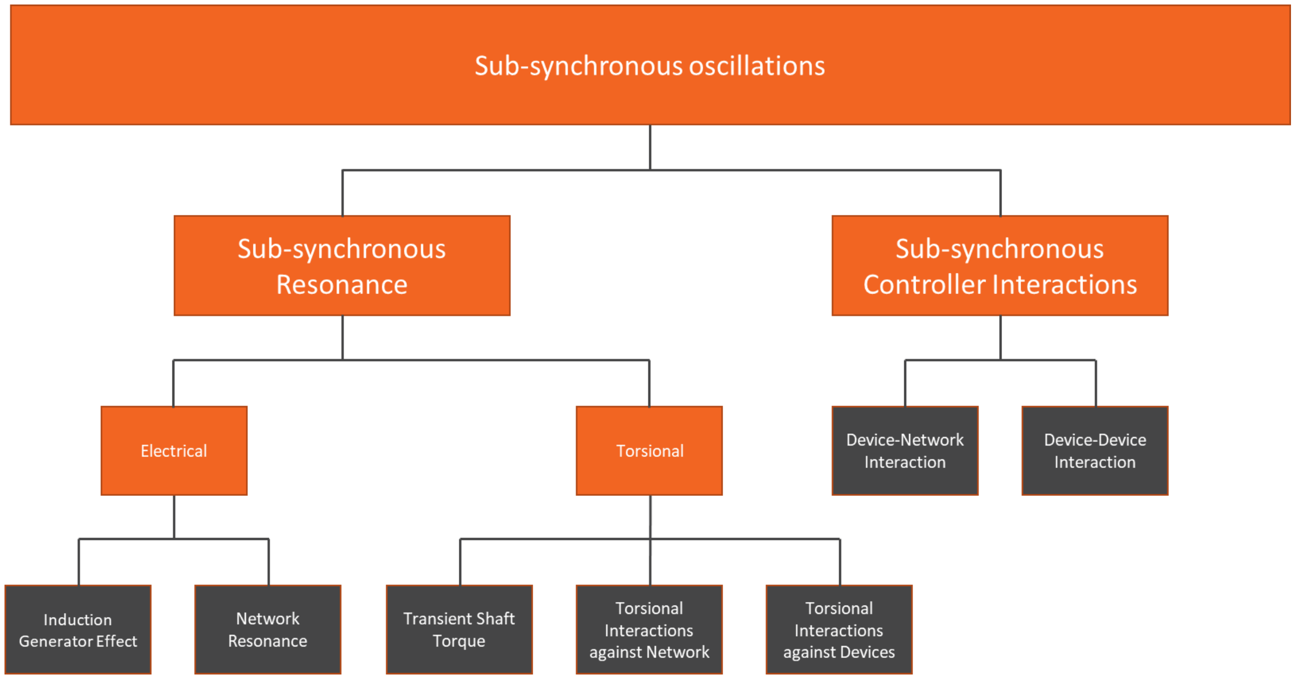

Figure 2 Classification of sub-synchronous oscillations[1].

How sub-synchronous oscillations are minimised and managed?

To minimise the occurrence, duration and impact of sub-synchronous oscillations, a robust, multi-layer process has been developed over the past decades in collaboration with the industry. In planning timeframes, The Grid Users and Owners identify the risk of sub-synchronous oscillations ahead of connecting to the network and take appropriate measures to design and tune their equipment to ensure that the plant does not cause or amplify oscillations. This is followed by a rigorous simulation and testing procedure in collaboration between the Grid Users and the ESO Engineering Compliance team to demonstrate their compliance with the Grid Code and the technical requirement specified by the Bilateral Connection Agreement (BCA).

In operational timescales, we ensure that sub-synchronous oscillations are avoided by conducting stability studies closer to real time and taking appropriate measures to mitigate the risk of sub-synchronous oscillations. The operational measures we may take include requesting the arming/disarming power system stabilisers, management of series compensation schemes, network reconfiguration, managing outages to maintain system strength, etc.

As described in the definition at the beginning of this introduction, the addition of new technologies creates unique risks of sub-synchronous oscillations that require changing how the system is planned and operated the system. The rest of the report provides further insight of the emerging challenges we are facing and our plan to tackle them.

[1] CIGRE JWG C4/B4.52 Technical Brochure Reference 909, "Guidelines for Subsynchronous Oscillation Studies in Power Electronics Dominated Power Systems", June 2023.

2. Events of Summer 2023

In the summer of 2023, limited periods of sub-synchronous oscillations, on 5 days across 4 weeks, were recorded on the GB transmission network. The recorded oscillations had higher magnitude and impact on the transmission network in Scotland compared to that recorded in England and Wales. Despite there being an impact on the operation of a few generators, interconnectors and circuits, it was contained.

On detection of the oscillations, our Electricity National Control Centre acted immediately, deploying defensive operational measures, to contain the events and maintain security of supply. These measures included holding increased levels of response, recalling outages, and reconfiguring the transmission network to maximise system strength and resilience.

While the disruption caused by these oscillations was contained and did not result in demand loss, we undertook post-event investigation to gain and share further understanding of the underlying root cause, introduce mitigation measures and look for potential changes to planning and operation policies.

We collaborated with Transmission Owners and Grid Users to collect measurement data. We mobilised teams across various departments to analyse ESO's recorded data and the data provided by Transmission Users and Owners.

The investigation found no evidence to suggest that the cause of these events is directly linked to system inertia, short circuit levels or any specific type of generation. The wider network conditions such as short circuit level and inertia were always within acceptable limits and the reductions in both values due to increasing renewable generation did not have a direct impact.

The investigation concluded that a particular asset was the major contributor to the sub-synchronous oscillations event. We instructed the asset to cease operation and engaged immediately with its technical team. Both parties worked collaboratively to understand and address the issue. After identifying the underlying issue with the asset, effective mitigation measures were proposed and demonstrated by the asset's technical team through appropriate dynamic performance tests in a simulation platform which provided sufficient assurance to allow the asset to return to service. Following implementation, we followed a cautious approach with a phased return of the asset to gain gradual confidence in the asset's performance and ensure security of supply was maintained. Following the completion of this phased return, no further performance issues were recorded from the asset and we stood down the defensive operational measures.

During the events, a few plants did not cause or amplify the oscillations, but had unexpectedly disconnected or deloaded. ESO's post-event analysis team engaged with these plants to investigate the root cause of their adverse reaction to the oscillations and record lessons learnt. Relevant technical measures were taken to ensure that such maloperation is avoided in the future. This included retuning of voltage controllers of synchronous machines that inadvertently responded to the oscillations and changes to the protection settings of power plants that tripped unexpectedly.

Throughout the investigation we collaborated with Transmission Owners and Users. We consulted with research partners to explore novel approaches to investigate sub-synchronous oscillations. We also sought operational experience from international system operators in Ireland, USA, Australia and Finland to share experience and incorporate their knowledge into the post-event investigation. We presented our experience in public venues such as the ESO Operational Transparency Forum and The Global Power System Transformation Consortium.

3. System Stability Challenges

It is not unexpected that the changes in the operational and planning landscape will present new challenges to system stability and operability. Through the regular publication of the Operability Strategy Report, Operability Framework Report, Market Roadmap Report etc., we highlight to the industry the evolving operability challenges and the plans to tackle them. This section will focus on the challenges related to sub-synchronous oscillations in further detail.

The range of frequencies of the sub-synchronous oscillations we have recorded on the transmission network between 2021-2023 spans between 3Hz and 20Hz. A few of these events were due to control interactions, while others were due to mistuning of units' controllers or issues with units' phase locked loop function.

We learned from these events that short circuit level alone could be a misleading indicator of system resilience against sub-synchronous oscillations and system stability. While higher short circuit levels could reduce the risk of certain classes of instability, it does not eliminate all the risks associated with sub-synchronous oscillations. More advanced techniques and indicators need to be developed to cover all potential phenomena. Further details of our efforts and investments to co-develop these techniques are described in the next section. The majority of these techniques require an Electromagnetic Transient (EMT) model of the grid and generation units.

Until recently, we used Root-Mean Square (RMS) models of the transmission network to conduct stability studies. These models provided sufficient accuracy to study the stability phenomena associated with the transmission system when it was dominated by synchronous machines. EMT models provide a more accurate and granular representation of the transmission network compared to the traditional RMS models. This detailed representation enables the use of EMT models to study complex and rapid phenomena such as converter control interactions.

EMT models are highly complicated, computationally expensive, and hence require advanced computation facilities to simulate the GB transmission system or a subset of it. Building such models requires highly skilled resources and collaboration with Transmission Owners, developers and manufacturers. While we continue to invest in building an EMT model of the GB transmission system (as detailed in the next section), the current main challenge is acquiring accurate EMT models of older assets connected to the transmission system before September 2022. We have proposed a change to the Grid Code to acquire EMT models of these older assets. However, the Grid Code modification process takes time, we will continue to explore different approaches to accelerate acquiring EMT models of old plants particularly in areas where low damping issues arise.

We also learned from previous events that sub-synchronous oscillations are usually associated with low system damping for certain sub-synchronous frequency ranges. We invested in the tools and capabilities to use high-frequency measurement to monitor the system damping in real time and to take preventive actions when the system damping reaches low levels. We continue to invest in stress-testing the underlying methods of these tools and diversifying our real time monitoring portfolio.

The connection of inverter-based resources to an increasing number of substations across the transmission system means that the typical low coverage of phasor-measurement units (PMUs) is not sufficient anymore. We require increasing numbers of PMUs to be installed at more substations and circuits to capture the dynamic behaviour of plants and improve the real time situational awareness. PMU data has proved to be vital in the past sub-synchronous oscillations investigations and we foresee its increasing importance while inverter-based resources get integrated to the transmission system. Increasing the number of PMU devices requires more capable data centres to process and store PMU data and higher collaboration with Transmission Owners. As per the System Operator Transmission Owner Code (STCP27-01[2]), all Transmission Owners are required to install a PMU on all feeders and substations before 31 March 2026. While we are ramping up the investment in data capability, we continue to engage with the Transmission Owners to prioritise the order of site rollout across the transmission network.

Looking ahead, emerging technologies such as grid forming converters are expected to be integrated with the transmission system at a rapid pace. Grid forming converters can provide essential stability services such as effective short-circuit current and inertia that could enable zero-carbon operation. Studies so far have shown no additional negative impact of grid forming technology on sub-synchronous oscillations at low penetration of grid forming converters. However, we are investing in further research to uncover any potential new class of sub-synchronous oscillations at very high level of penetration of grid forming converters, as described in the next section.

[2] STCP27-01 System Performance Monitoring Requirements Issue, April 2023.

4. Our plan to tackle sub-synchronous oscillations:

We have taken a multitude of measures to ensure system stability under a continuously changing operability landscape. We have demonstrated that our agile approach is effective in tackling system stability challenges. Successful programmes such as Stability Pathfinders, Stability Market and the accelerated loss of main programme underscore the effectiveness of our approach to tackle operability and stability challenges on our journey to net-zero.

This section describes the measures have been undertaken so far and our long-term plan to mitigate the risk of sub-synchronous oscillations, with a summary provided in Figure 3.

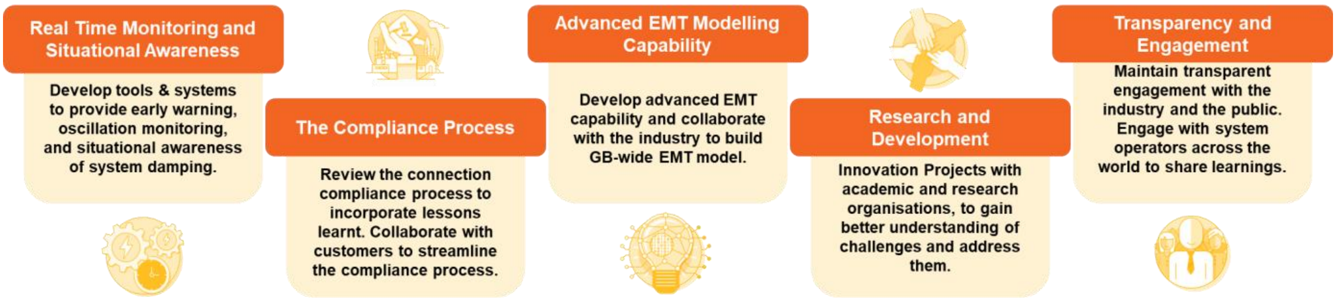

Figure 3 Summary of our plan to tackel sub-synchronous oscillations

4.1. Real Time Monitoring and Situational Awareness:

Improvements to situational awareness of the system damping and real time monitoring of the sub synchronous oscillations are essential new requirements to ensure that effective operational measures are taken to prevent or stop sub-synchronous oscillations, and consequently maintain the system security of supply.

Traditional SCADA systems cannot record the high frequency of the emerging sub-synchronous oscillations. A granular source of data and associated algorithms are required to provide with the necessary visibility to counter such fast phenomena. To do this we are building and integrating a Wide Area Monitoring System (WAMS) with oscillation monitoring functions[3]. PMU data across the transmission system will be fed to WAMS which will provide with a real time view of the system damping and sub-synchronous oscillations. We are building a data processing capability to enable these functions and coordinating with the Transmission Owners to accelerate the roll out of PMU devices.

While building WAMS capability, we tested a new monitoring system which relies on measurements on the distribution system, collecting data at a high frequency. The system proved effective and significantly improved the real time visibility of system damping and sub-synchronous oscillations. Our visibility of the system damping serves as an early warning of potential oscillation occurrence. Procedures have been adapted to deploy operational measures to keep the system damping above safe limits. We are conducting further validation of this system and looking to increase the number of measurement points to cover all GB through summer 2024.
Further, we are collaborating with SSEN-T on INSIGHT project[4], a Strategic Innovation Fund project that aims to create a virtual, real-time alert and control system that can highlight oscillatory instabilities on the network and then automatically inform control actions required to dampen/remove them.

[3] ESO RIIO-2 Business Plan 2 Digital, Data, and Technology Annex, Annex 4, ESO, August 2022.
[4] INSIGHT (Innovative Network Status Intelligence Gathered by Holistic use of Telemetry and Simulation) Project.

4.2. The Compliance Process:

The compliance process is the first line of defence against various technical risks including sub-synchronous oscillations. We recognise our central role in the energy industry. We are committed to sharing knowledge and expertise with developers and manufacturers. We have published a guidance[5] document for inverter-based plants that describes a set of small signal tests, in both time and frequency domains, to demonstrates appropriate damping performance against potential oscillations. We proposed that the tests described in this guidance should be carried out by all Users as part of the compliance process to demonstrate adequate damping and mitigate the risk of sub-synchronous oscillations. We plan to publish a similar guidance for synchronous plants.

Various classes of sub-synchronous oscillations are caused or amplified by mistuning units' control systems. Throughout the previous events, we learned that there is an opportunity for improvement to the current practices in quality management of plants' control systems. Issues we recorded include discrepancies between the parameters deployed in the plant model and the parameters in the physical control systems, human error and unintentional interlinks between control systems. Accordingly, we plan to engage with the industry to improve the quality management of control systems and to adapt the connection compliance processes to cover all the plant configurations. We will also explore supporting our customers by hosting a series of technical webinars and workshops to share best practices on key technical topics, including control system software management. These measures will provide significant reduction to the quality management risks and subsequently reduce emerging associated issues such as sub-synchronous oscillations.

There are several tools and procedures we rely on to manage the compliance process[6]. The Operational Notification and Compliance Checklist (ONCC) is one of these tools that is used to streamline the compliance process. ONCC lists the key milestones and activities that the customer should complete and specifies the lead party (i.e., the relevant Transmission Owner or ESO) responsible for the approval of each of the compliance activities. We recognise that new tests and guidance to de-risk emerging sub-synchronous oscillations may complicate the compliance process. We also recognise that there is room for simplification and streamlining to the growing compliance processes to avoid confusion to our customers. In light of this, we plan to engage with the relevant stakeholders soon to review the ONCC documents, clarify responsibilities, ensure better customer satisfaction and reduce potential confusion. We are investing in modern tools to help track changes in our customer's models and ensure that any model issues raised throughout the compliance and connection processes are resolved. The tools would align with the anticipated changes to the ONCC.

In addition to the above proposals to simplify and streamline compliance processes, we are taking several actions to recruit, train and organise our teams to provide transparent and prompt service to our customers throughout the connection compliance journey. We are changing our internal governance processes and forming an internal compliance steering group to be more agile in responding to our customers' needs. Our engineering compliance team is also reviewing its internal procedures to provide a transparent and clear assessment of RMS and EMT models submitted through the connection compliance process.

4.3. Advanced EMT Modelling Capability:

The studies we have proposed to be conducted by Users during the compliance process (described in the previous section) provide significant mitigation to the risk of sub-synchronous oscillations, however, it does not eliminate this risk completely. Large scale EMT studies may still be required to ensure that the collective dynamic behaviour of the plants and transmission assets does not result in sub-synchronous oscillations. We have committed to the building of this capability. The collaboration across the industry is key to making this a success.

We have initiated and supported various innovation projects to develop an EMT model of the GB transmission system. The early initiative dates to 2016, where we funded an innovation project[7] to develop an EMT model of part of the transmission network - the South Coast of England. Manufacturer-

[5] System Oscillation Assessment of Inverter Based Resources (IBRs), ESO, 2024.
[6] Compliance Process, ESO.
[7] Transient Voltage Stability of Inverter Dominated Grids and Options to Improve Stability Project.

provided models have been integrated to the South Coast model under project DETECTS[8]. The project reported further insight on associated technical challenges to validate and integrate multi-vendor EMT models. The second part of this project, DETECTS-II[9], integrates the tools and models built in the first part of the project to our IT facilities. Furthermore, we are collaborating with the Transmission Owners to build an accurate representation of GB Transmission systems in an EMT environment through the TOTEM project[10] and its extension[11]. We remain on track with our partners to build a GB transmission network EMT model, including Transmission Owners assets and some generation models, by 2025.

The accuracy of EMT models is crucial to study complicated phenomena such as sub synchronous oscillations and control interactions. Without manufacturer-provided models, the EMT model of the transmission system loses its value. Generic EMT models do not provide sufficient accuracy to represent the dynamic behaviour of plant and may provide misleading results. We have proposed through GC0141[12] a Grid Code modification to acquire manufacturer provided EMT models. The proposal has been approved, and any plant connected on or after September 2022 is required by Grid Code to share with us at the compliance stage an EMT model that accurately represents the connected plant. To support customers in sharing their models with us, we have published guidance notes[13] that outline the technical expectations of the model in terms of model efficiency, fidelity, usability, maintenance, and the minimum required documentation.

The bottleneck in developing an accurate GB-wide EMT model remains acquiring EMT models of existing plants connected before September 2022. We have recently proposed a Grid Code modification[14] to require existing generators connected before September 2022 to share with us their manufacturer provided EMT model. Similarly, we have engaged with the Transmission Owners to codify sharing EMT models of their assets. We will follow this up by submitting a System Operator Transmission Owner Code modification proposal. We have also created EMT Modelling subgroup, as part of Joint Planning Committee Modelling Group (JPCMG), to engage with Transmission Owners on the development of GB-wide EMT model.

Internally, we have made significant investments in building EMT modelling capabilities. We have recruited subject-matter experts in EMT modelling who integrate, validate and test User's and Transmission Owner's models. We have invested in our computing capabilities to enable running EMT simulations of parts or all of the GB network model. We are exploring options, such as cloud computing, for the ever-demanding computational power of the growing EMT model. We are funding an innovation project[15] to enhance the computational efficiency of our large-scale EMT models. We are also funding an innovation project[16] to explore advanced techniques, such as real-time hybrid RMS-EMT simulations to take advantage of the growing EMT capability and explore the possibility of running stability studies for certain parts of the network closer to real time operation.

4.4. Research and Development

The fast pace of decarbonisation of GB electricity system, its islanded nature, the concentration of inverter-based resources in certain areas, are all among the many factors that makes GB transmission system unique. This uniqueness provides a set of distinct operability challenges. We rely on innovation projects to understand these challenges in a detailed and holistic way. Through these innovation projects we collaborate with academia and research organisations to get purpose-built solutions to these operability challenges including sub-synchronous oscillations.

System operators around the world rely on certain metrics to measure system strength and to ensure that stability issues are avoided in inverter-based resources system, including sub-synchronous oscillations. One of these metrics is short circuit level. Maintaining short circuit levels above a certain value reduces the potential of certain technical issues but as described earlier in the report, short circuit level may be no

[8] DETECTS - Developing Enhanced Techniques to Evaluate Converter-dominated Transmission System Operability Project.
[9] DETECTS II Project.
[10] TOTEM (Transmission Owner Tools for EMT Modelling) Project.
[11] TOTEM Extension Project.
[12] GC0141: Compliance Processes and Modelling amendments following 9th August Power Disruption.
[13] Guidance Notes for EMT models, ESO, 2023.
[14] GC0168: Submission of Electro Magnetic Transient (EMT) Models.
[15] Practical Transition into wider EMT GB Modelling Project.
[16] RealSim: Real-Time Phasor-EMT Simulations Project.

longer a good all-purpose indicator of the system strength. To gain a better understanding of system strength indicators under high penetration of inverter-based resources, we have launched Strength to Connect innovation project [17]. The project will examine what measures best indicate stable and secure system operation. It will test the measures analytically by simulation of an example network with varying levels of inverter-based resources. The outcome of this project will inform our planning and operation policy.

As highlighted in the previous section, the growing EMT capability will enable us to conduct further studies to screen the network for the potential of sub-synchronous oscillation issues. While we are building analysis tools portfolio, we have launched "Automated Identification of Sub-Synchronous Oscillations Events" innovation project[18]. The project will develop and test frequency scanning tools that can be used in EMT environment. The tools will undercover any potential control interaction issues to resolve them accordingly.

In parallel of developing EMT capability, we are investing in data-driven approaches. We have launched "Data-Driven Online Monitoring and Early Warning for GB System Stability (DOME)" project [19]. The project will examine whether measuring on-line impedance spectra of a grid can give early warning of emerging oscillations, and beyond that, whether it is possible to identify which aspects of equipment should be re-tuned to damp those oscillations. We are also launching an innovation project with Durham University to develop and test new methods of oscillations source location using PMU data.

Throughout the past events, we have used various tools and methods to conduct post-events analysis utilising PMU data collected during the event. One of these methods is "dissipating energy flow[20]", which is a measurement-based method to identify the source of sub-synchronous oscillations. The method was tested on real life events in the past and proved efficacy in synchronous machine dominated systems. However, in inverter-dominated network like GB's, the dissipating energy flow algorithm may require modifications to allocate the source of oscillations. To do this, we are soon launching an innovation project with Imperial College London. The project will assess the suitability of existing data driven algorithms to trace the source of oscillations in inverter dominated systems, including the dissipating energy flow method. The project will build on existing algorithms and develop new data-driven techniques to assist us in post-event analysis.

Through innovation we explore potential future challenges to de-risk them in advance. One of these potential challenges is control interactions between grid forming converters when the penetration of this technology is very high. We are launching soon an innovation project with the University of Birmingham to investigate any potential new classes of sub-synchronous oscillations at high penetration level of grid forming technology. We will build on the outcome of this project and continue to adapt operational policy and codes if further risk is uncovered.

4.5. Transparency and Engagement

We follow a transparent and collaborative approach. Sharing lessons learned will not only enable us to collaborate to minimise these technical barriers but also enable system operators across the world to learn from our experience while we push forward the world's decarbonisation efforts.

Throughout the past events, we engaged with the industry and the public through the Operational Transparency Forum[21] to share the progress of the post-event investigations, the learnings gained and measures taken to secure the transmission system. We will continue to use this forum to keep the public and the industry informed of operational challenges. We also maintain a continuous line of communication

[17] Strength to Connect Project.
[18] Automated Identification of Sub-Synchronous Oscillations (SSO) Events Project.
[19] Data-Driven Online Monitoring and Early Warning for GB System Stability (DOME) Project.
[20] S. Maslennikov, B Wang, E Litvinov, "Dissipating energy flow method for locating the source of sustained oscillations" Int. J. of Elec. Power & Energy Sys., Volume 88, 2017, Pages 55-62.
[21] ESO Operational Transparency Forum, 03 Nov 2021. Slides.
ESO Operational Transparency Forum, 08 Nov 2023. Webinar. Slides.

with Ofgem and relevant government departments to inform them of the technical challenges that we are facing and our vision to overcome these challenges.

Over the past few years, we have established various forums and technical working groups with the Transmission Owners. These channels provide us with an essential regular and robust line of communication with the Transmission Owners and facilitate sharing learning and best practices. We will continue to rely on these forums and channels to overcome this and future challenges.

As laid out in this report, we strategically rely on innovation projects to engage with academic and research organisations to get a better understanding of emerging complex phenomena and explore novel methods to tackle operational challenges. We will maintain our engagement with academic organisations to strengthen our agility to manage emerging challenges.

We continuously engage with electricity systems operators across the world to share experience on various technical challenges, including sub-synchronous oscillations, and to learn from the challenges faced in other parts of the world[22]. For example, we are working closely with AEMO (Australian Electricity Market Operator) to exchange knowledge on building and maintaining large scale EMT models. We are also engaging with New England Independent System Operator to learn from their experience on detection of sub-synchronous oscillations. Furthermore, we have partnered, through the Global Power System Transformation Consortium, with other system operators to exchange knowledge, experience, and best practices. Through this consortium we support system operators in developing countries in their decarbonisation journey.

5. Conclusion

Sub-synchronous oscillation is not a new phenomenon and not a unique issue associated with a certain technology. The change in operational landscape while we approach net zero operation means we require advanced modelling techniques and monitoring tools to ensure that the risk of sub-synchronous oscillations is mitigated and managed.

The investigation of summer 2023 oscillations showed that an asset was the major contributor to the oscillations. The relevant asset owner made changes to its controller settings and the assets were brought back into service in a controlled process. The investigation found no evidence to suggest that the cause of these events is directly linked to system inertia, short circuit levels or any specific type of generation.

We have set a plan to mitigate the risk of emerging oscillations. In operation timeframes, we are investing in real time situational awareness tools to detect and monitor sub-synchronous oscillations. In planning timeframes, we are collaborating with the industry to build a GB-wide EMT model that's essential to study system dynamic and assessing the risk of oscillations. We are also working with the industry to adapt the connection compliance process to ensure that lessons learnt from previous events are incorporated in the process.

Our investment in research and development is important part of our plan to adapt our tools and understanding of emerging challenges including sub-synchronous oscillations. We will keep our customers and stakeholders informed of the progress of this plan, the future obstacles, and any other operational challenges encountered in the future.

---

[22] Modi, Nilesh, et al. "High Inverter-Based Resource Integration: The Experience of Five System Operators." *IEEE Power and Energy Magazine* 22.2 (2024): 78-88.