ES Cornwall Memorial Scholarship

Third Quarter Report

1st April 2023 to 1st July 2023

National Grid ESO, Warwick, United Kingdom

Author: Mitchell Tap

07/07/2023

ACKNOWLEDGEMENTS

The author of this report would like to thank the employees of National Grid and National Grid ESO who have helped make this placement possible. From what started as a simple message on LinkedIn to being fortunate enough to receive a 6-month contract with National Grid ESO there have been a number of people who have gone above and beyond. In particular, I would like to thank Philippa Templeton for taking the time and care to respond to my initial message and for starting the onboarding/opportunity process. Thanks also to Patrick Bradley for helping to organise things from an administration and new starter perspective. Finally, thank you to my manager Shurooque Baloch, firstly for meeting with me to see if this fixed length contract was possible in the first place and also for welcoming me to the Operability Product team. I have been enjoying my work so far and am appreciative of this terrific opportunity to gain experience in a team dealing with some of the biggest challenges associated with the transition of the electricity network.

I would also like to thank my managers at Energy Queensland, Alan Louis and Terese Milford, for their support in allowing me to undertake this opportunity. I am looking forward to my return to the Intelligent Grid New Technology team and using the experiences I have gained to help during what is shaping up to be an exciting time as Queensland and Australia pursues a highly renewable future.

Finally, thank you to the ES Cornwall Memorial Scholarship and its Board for this fantastic opportunity. I have no doubt that this chance to gain international experience will help me become a more well-rounded engineer and I endeavour to bring this experience back to Australia to hopefully share and contribute to the ongoing development of the Australian electricity supply industry.

DISCLAIMER

This report provides a summary of the experiences and work undertaken by the author during the period of April 2023 – July 2023 as part of an overseas ES Cornwall Memorial Scholarship placement. Statements and material contained within this report are the opinion of the author and do not reflect the opinion or positions of any other person or organisation. Reproduction or referencing of this report should also reflect this.

EXECUTIVE SUMMARY

The Australian electricity supply industry is in the midst of a rapid transition to an electricity network with a high penetration of renewable generation reliant on inverter-based resources to connect these to the grid. Many obstacles to facilitate this future have already been overcome, however there are still significant challenges associated with moving away from the traditional synchronous generation that has reliably powered the electricity industry for a number of decades.

During my time as an ES Cornwall Scholarship holder I hope to explore a number of these challenges and learn from some of the leading European organisations in this field to help grow my capabilities and understanding of how Europe intends to complete this transition. I am hoping to return to Australia with this knowledge that will not only help me in my day-to-day nominal role, but also I am hoping to share my experiences more broadly to express gratitude for this opportunity that has been afforded me.

This quarterly report is the third of four reports I will submit during my time as an ES Cornwall Scholarship holder and covers my first three months with National Grid ESO. In the three months covered by this third quarterly report, I have commenced my time as a Power System Engineer in the Product Operability team. In the early sections of this report, I will provide an introduction to the Great Britain electricity network and highlight some of the work done to date to transition to a network less reliant on synchronous generation and with greater renewable generation integration. Following this I will provide a more specific overview of the work I have been focusing on over the last three months including:

1. A study using PSCAD of how the short circuit ratio at a HVDC converter connection affects its stability,
2. Progress on deploying a real time inertia monitoring tool, and
3. An investigation of how frequency and the rate-of-change-of-frequency differs across the Great Britain network in different regions and inertia profiles.

TABLE OF CONTENTS

Acknowledgements ii
Disclaimer ii
Executive Summary iii
Table of Contents iv
Glossary v
1 Scholarship Plan / Overview 6
2 Placement 2 – National Grid ESO 8
2.1 National Grid Introduction/Background 8
2.2 The Great Britain Electricity Network 10
2.3 What Have I Been Working On? 13
2.3.1 Short Circuit Ratio Versus Stability Study 14
2.3.2 Real Time Inertia Monitoring 17
2.3.3 Regional Inertia, RoCoF and Frequency Study 18
2.3.4 Utility Week Attendance 20
3 CIGRE Working Groups 22
3.1 Working Group B5.78 22
3.2 Working Group C6.44 22
4 Plan for Next Quarter (July 2023 – October 2023): 23

GLOSSARY

Table 1: List of acronyms and terms with their meaning.

Acronym/Term	Meaning
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
DER	Distributed Energy Resource
DSO	Distribution System Operator
EV	Electric Vehicle
EMT	Electromagnetic Transient
ESO	Electricity System Operator
FSO	Future System Operator
HVDC	High Voltage Direct Current
IBR	Inverter Based Resource
MSCR	Minimum Short Circuit Ratio
NG	National Grid
NGV	National Grid Ventures
Ofgem	Office of Gas and Energy Markets
PMU	Phasor Measurement Unit
RMS	Root Mean Square
RoCoF	Rate-of-Change-of-Frequency
SCL	Short Circuit Level
SCR	Short Circuit Ratio

1 SCHOLARSHIP PLAN / OVERVIEW

The problem statement that I will be addressing during my time as an ES Cornwall Scholarship holder is:

"Maintaining Stability in an Electricity Network with a High Penetration of Distributed Energy and Inverter Based Resources"

This motivation is driven by the challenges currently being experienced in Australia regarding the energy transition. The Australian energy industry is continuing to face unprecedented growth in renewable energy technology and distributed energy resources (DERs). A result of this is that the industry of today looks very different from ten years ago, and this change will only continue to accelerate as Australia transitions to the network of the future. To ensure this transition takes place as smoothly as possible, with both consumers and industry in mind, there are several key areas of complexity that must be addressed. One of these is the need to ensure that the electricity network maintains an adequate level of network stability and resilience in the face of significant change to the fundamentals that the network was built upon – namely one-way energy flow from centralised large synchronous generators.

Network stability is a multi-faceted problem, with two of the main aspects being system strength and inertia. System strength is defined by the Australian Energy Market Commission (AEMC) as a "characteristic of an electrical power system that relates to the size of the change in voltage following a fault or disturbance on the power system[1]". The system strength at any given location is proportional to the fault level at that location. Similarly, frequency stability is linked to system inertia and the ability of the network to resist high rates of change of frequency (RoCoF) in the event of significant active power changes.

Networks with low system strength and low inertia are susceptible to several issues including wider area undamped voltage oscillations, prolonged voltage recovery after disturbance, instability of generator and dynamic plant voltage control systems, mal-operation of protection equipment and increased harmonic distortion[2]. In the past, synchronous machines have traditionally provided system strength. Meanwhile, inverter-based resources (IBRs) are reliant on adequate system strength to operate reliably but do not necessarily contribute positively to overall system strength. This is because the fault level contribution from synchronous generators is high, whereas system strength is inversely proportional to grid-following IBR penetration since the fault level contribution of IBRs is low[3]. With the growing penetration of IBRs causing the make-up of Australia's energy generation to swing more towards IBRs, synchronous generators are slowly being phased out. This is therefore leading to decreasing system strength which then has the flow-on effect of limiting the amount of IBRs that can be added to the network. The key question is therefore how the Australian energy industry can increase renewable energy production from IBRs whilst also ensuring an adequate level of system strength.

The challenges being brought on by increasing levels of DERs are not likely to slow down. Connected rooftop solar capacity in Queensland is already estimated to be over 3,346 MW with approximately one-

[1] AEMC. (2017). *National Electricity Amendment (Managing power system fault levels) Rule 2017*. Australian Energy Market Commission.
[2] AEMO. (2020). *System Strength in the NEM Explained*. Australian Energy Market Operator.
[3] Keller, J., & Kroposki, B. (2010). *Understanding Fault Characteristics of Inverter-Based Distributed Energy Resources*. NREL.

in-three households having rooftop solar installed[4]. The further development and cost reduction of other DER technologies, such as battery storage and electric vehicles, will also serve to increase the level of DER penetration on the distribution network. The best time to act and plan for a high DER future with significant contribution from IBRs is therefore the present and implementing effective management plans will help smoothen the transition from the grid of the past to the grid of the future.

In my role as a Technology Innovation Engineer at Energy Queensland I am fortunate enough to be able to work in an area that I am passionate about; helping to enable new technologies in the distribution network and aiding the transition to an energy network with a higher penetration of DERs. While I have had some exposure to the challenges relating to network stability in a highly inverter-based network, I would love the opportunity to gain more of an understanding about how the energy industry as a whole can tackle this problem by observing what is being done overseas. My aim would be to then bring these learnings back to Australia to help the Australian energy industry best transition to a higher DER future.

To fulfil my proposed problem statement and target the challenges outlined above, I will be looking to achieve the following key aims while undertaking work placement overseas;

- Learn from leading network operators on what they are currently doing and plan to do to help modernise their energy network and allow for a high penetration of DERs;
- Undertake work with manufacturers of products that are providing solutions to network stability problems to gain a better understanding of the technology and how it can be best integrated in a distribution network;
- Improve my overall understanding of network stability challenges and how these can be collaboratively managed by all stakeholders of the electricity supply industry;
- Learn how international countries are enabling customers to make the most of new technologies such as solar, wind, energy storage and electric vehicles; and
- Use my time overseas to attend international conferences, workshops and company site visits outside of what I have been exposed to in Australia.

Table 2 shows the schedule I have currently planned for my time as an ES Cornwall Memorial Scholarship holder.

Table 2: Planned placement and conference schedule.

Dates	Activity
28/08/2022 – 02/09/2022	2022 CIGRE Paris Session
September 2022 – April 2023	KEMA Labs – Test Engineer
April 2023 – October 2023	National Grid ESO – Power System Engineer
16/05/2023	Utility Week
October 2023	Return to Australia

[4] RenewEconomy. (2020). *Rooftop Solar's Stunning Surge to New Records, As Australia Installs Reach 2.5 Million.*

2 PLACEMENT 2 – NATIONAL GRID ESO

2.1 NATIONAL GRID INTRODUCTION/BACKGROUND

National Grid (NG) is an energy company that operates within the UK and US and delivers both electricity and gas. NG consists of the following business areas:

1. Electricity Distribution [5] : Distribution company for 8 million customers spanning across 55,300 km^2 in the Midlands, South Wales and South-West of the UK.
2. Electricity Transmission: Owns and maintains the transmission network in England and Wales.
3. Electricity System Operator (ESO): ESO for Great Britain – England, Scotland and Wales.
4. United States[6]: In the United States, National Grid is an electricity, natural gas and clean energy delivery company serving the energy needs of 20 million people in New York and Massachusetts.
5. National Grid Ventures[7] (NGV): Operating across the UK, Europe and the US, NGV develops, operates and invests in large-scale clean energy infrastructure. Separate to the regulated operations of NG, NGV has a diverse business profile including subsea electrical interconnectors, wind and solar generation, electricity transmission, battery storage and conventional generation.
6. National Grid Partners[8]: Dedicated to advancing the energy systems of tomorrow, NG Partners is involved with incubating and investing in start-ups at the intersection of energy and emerging technology. NG Partners' portfolio already includes 41 investments.

For my six-month placement I will be an employee at National Grid ESO and will therefore focus more on the operations of the ESO. While a member of the National Grid Group, the ESO is a regulated business and is therefore also subject to a regulatory framework governed by the Office of Gas and Electricity Markets (Ofgem). This regulatory framework[9], known as RIIO (Revenue = Incentives + Innovations + Outputs), is how Ofgem review the business plans of NG ESO and determines the allowed revenue and how the operations and performance will be assessed.

In 2021, Ofgem and the Department for Energy Security and Net Zero begun consultation to form a Future System Operator (FSO) which would be an expert, impartial body with responsibilities across both the electricity and gas networks[10]. This decision was to drive progress towards net zero and is a result of the need being identified to design, construct, and operate a smarter, more flexible and more integrated energy system. This proposal would see the FSO take on the current role played by NG ESO, combine this with the national gas system operator and add new and additional functions as required. The FSO is proposed to be independent from commercial entities as well as separate from the day-to-day operations of the government This proposed transition to an FSO means significant changes within NG ESO and significant transformational work is currently underway to prepare for the estimated 2024 changeover date.

[5] National Grid, (2023). *Distribution Area. https://www.nationalgrid.co.uk/our-network/distribution-area-search*
[6] National Grid, (2023). *Serving our Customers and Communities. https://www.nationalgrid.com/us*
[7] National Grid Ventures, (2022). *Who we are. https://www.nationalgrid.com/national-grid-ventures*
[8] National Grid Partners, (2023). *Investing in the Potential of Energy. https://www.nationalgrid.com/national-grid-partners*
[9] National Grid ESO, (2023). *How we're regulated. https://www.nationalgrideso.com/what-we-do/how-we-operate/how-were-regulated#How-Ofgem-regulates-ESO*
[10] National Grid ESO (2022). *The Future System Operator (FSO).* https://www.nationalgrideso.com/what-we-do/our-strategy/future-system-operator-fso

Currently, the core functions of the ESO are summarised as[11]:

- Balancing Services: The ESO is responsible for procuring services to balance demand and supply in the GB network as well as ensuring the security and quality of supply through processes such as, demand flexibility service, frequency response, reactive power services and system security services.
- Electricity Transmission System Charges: Manging charges that users of the electricity transmission system must pay. This includes Balancing Services Use of System charges (to recover the day-to-day costs of balancing the system and operating the transmission network), Transmission Network Use of System charges (to recover the cost of installing and maintaining the transmission system) and connection charges (to recover the cost of installing and maintaining connection assets which connect individual users to the transmission system).
- Industry Engagement and Reporting: As the system operator, the ESO is responsible for consulting with industry, providing several publicly available reports and making operational data available to ensure efficient and cost-effective decision making in the GB electricity industry.
- Connections: The ESO connections team is responsible for facilitating the process through which customers can connect and utilise the GB transmission network.
- Network Access Planning: The ESO's network access planners assess, coordinate and sanction the planned release of transmission system assets for maintenance and the commissioning of new equipment. This helps ensure access to the transmission system is coordinated efficiently to be cost-effective and to ensure operation of the system continues to be within the required quality of supply standards.
- Electricity System Codes Administration: The ESO administers four codes that govern the GB electricity system operation. These are, the Grid Code (technical code for the connection and development of the national transmission network), the Connection and Use of Systems Code (contractual framework for connecting to and using the national transmission network), the System Operator – Transmission Owner Code (defines the relationship between the transmission system owners and the ESO) and the Security and Quality of Supply Standard (defines the criteria and methodology for planning and operating the national transmission network).

NG ESO has multiple locations around the UK with the main two sites being in Warwick and Wokingham. For most of my time with NG I will be based in the Warwick office however I will have the occasional trip to Wokingham if required for project work or in-person meetings with colleagues located in Wokingham.

[11] National Grid ESO, (2023). *Industry Information. https://www.nationalgrideso.com/industry-information*

2.2 THE GREAT BRITAIN ELECTRICITY NETWORK

The GB network includes England, Scotland and Wales and serves over 30 million customers with a peak demand of 50 GW. In 2022, the GB network delivered 324 TWh of energy with just over 40 % of this from renewable sources[12]. In comparison, the Australian network delivered 180 TWh to over 11 million customers with a renewable penetration of 30 % in 2022[13]. The energy mix in the GB network in 2022 was approximately 1.7 % coal, 38.4 % gas, 14.7 % nuclear and 41.5 % renewables with the remaining 3.7 % coming from other sources such as biomass. Figure 1 demonstrates how this energy mix has changed since 2015 with the penetration from renewable sources increasing at a fairly steady rate year on year.

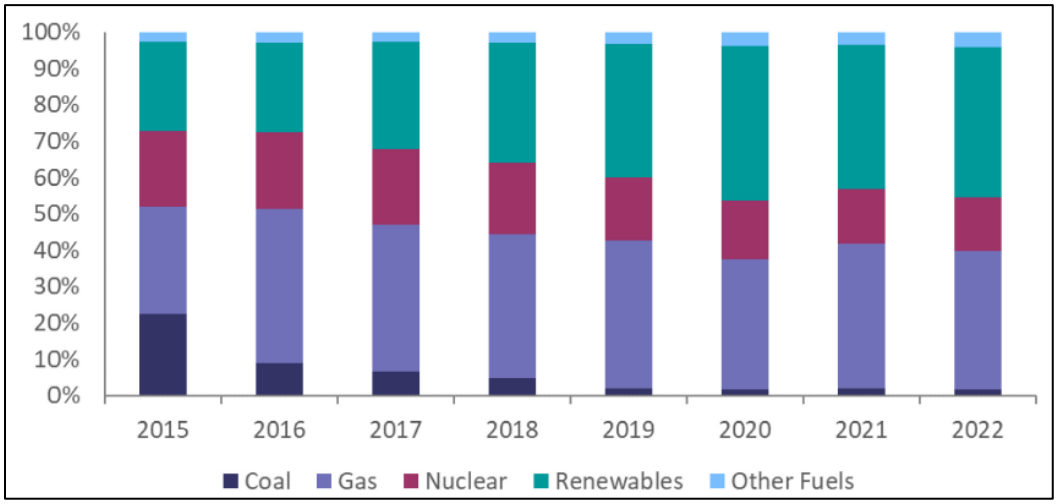

Figure 1: UK shares of electricity generation by fuel, 2015 to 2022.

The GB network has one system operator and three transmission system owners, with National Grid Electricity Transmission in England and Wales, Scottish Power Transmission in southern Scotland and Scottish Hydro-Electric Transmission in northern Scotland. There are six distribution network operators with their operating regions as presented in Figure 2.

[12] Digest of UK Energy Statistics 2023 (2023), *Chapter 5: Electricity. pp. 1-10*
[13] Australian Energy Regulator (2022). *Annual generation capacity and peak demand. https://www.aer.gov.au/wholesale-markets/wholesale-statistics/*

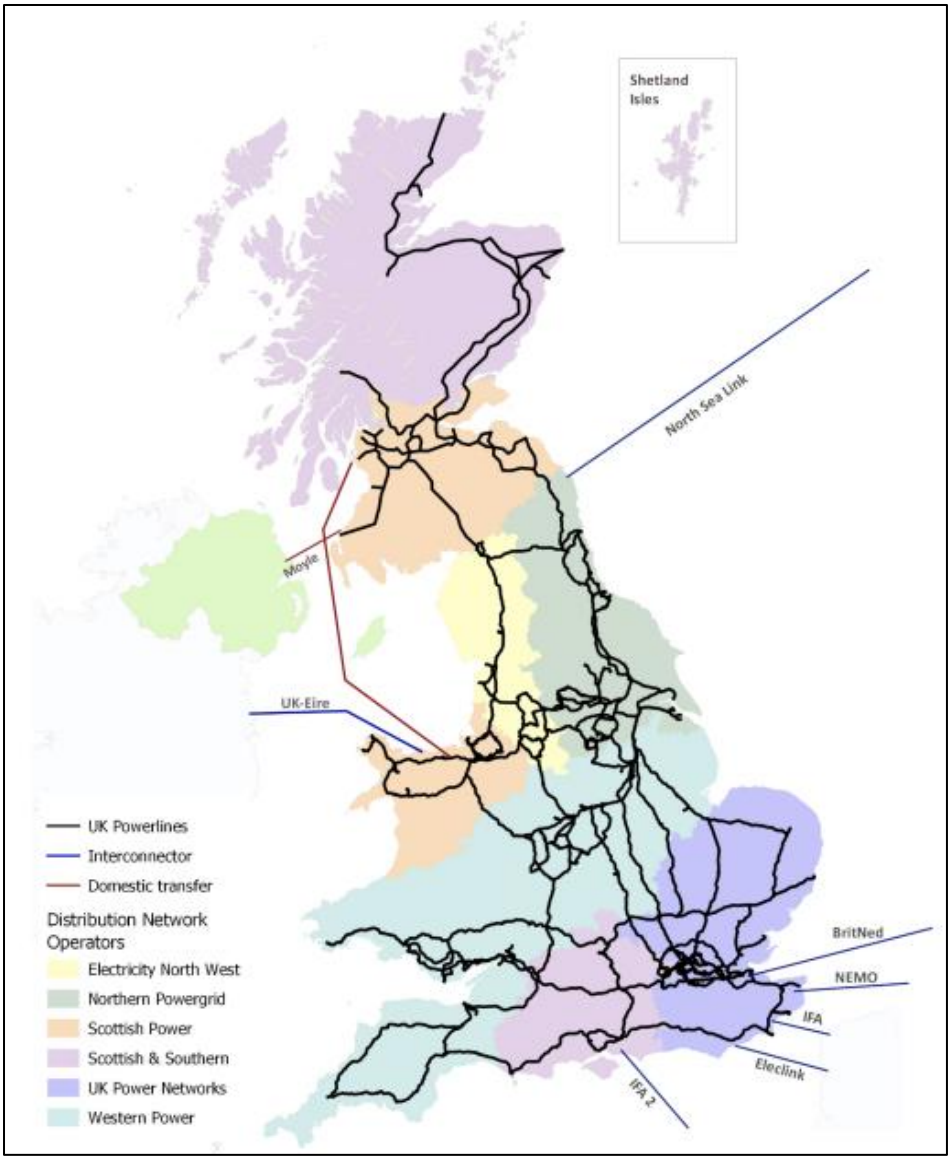

Figure 2: GB network transmission powerlines, international interconnectors and distribution regions.

The GB network has eight HVDC international interconnectors to neighbouring European countries with connections to France, Northern Ireland, the Netherlands, Ireland, Belgium and Norway. The international interconnectors facilitate buying and selling of electricity between the countries and depending on system needs and market drivers the interconnectors may be predominantly importing or exporting. The UK was a net exporter in 2022 for the first time in more than 40 years with net exports reaching 5.3 TWh[14]. The primary reason for this change was outages amongst the French nuclear fleet shifting France from being one of the UK's greatest import connections to being the largest export connection. This significant shift is evident in the imports versus exports via interconnectors graph presented in Figure 3

[14] Digest of UK Energy Statistics 2023 (2023), *Chapter 5: Electricity. pp. 1-10*

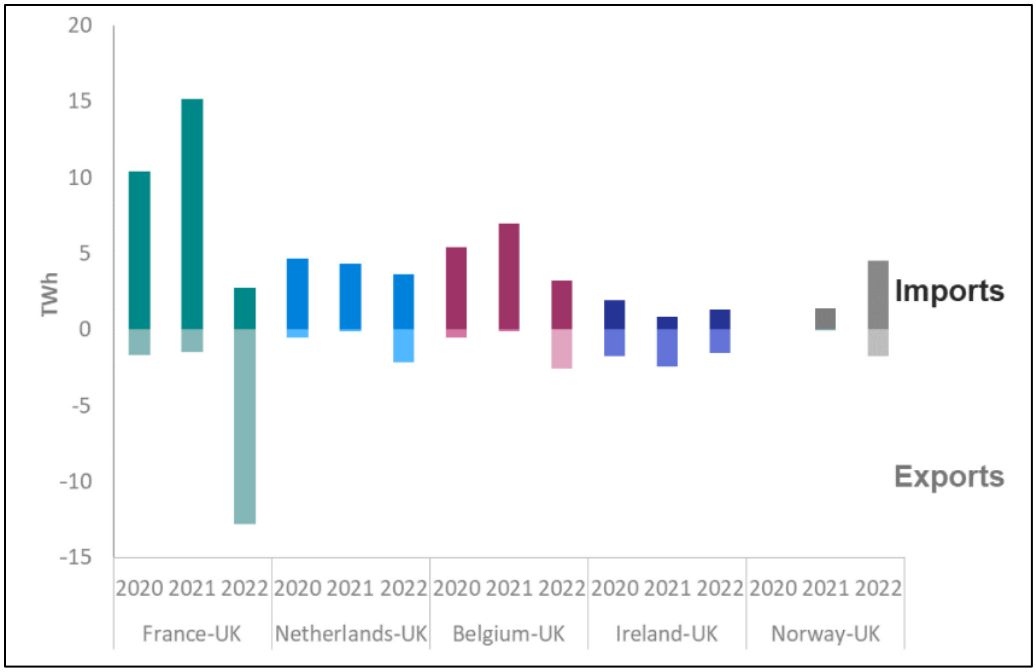

Figure 3: UK electricity imports and exports by country from 2020-2022.

Offshore wind is the largest contributor in the UK's renewable energy mix with a slight lead over onshore wind and bioenergy. Unlike Australia, solar is not as significant of a contributor with only 10 % of the UK's renewable energy generation being sourced from solar. This renewable energy mix breakdown is presented in Figure 4. The lower contribution from solar is also reflected in the slower uptake of rooftop solar with only 4 % of households estimated to have rooftop solar installed in contrast to the 33 % of households in Australia[15]. Conversely, the adoption of electric vehicles (EVs) is far more advanced than Australia with approximately 370,000 EVs being sold in the UK to date as opposed to Australia's 38,400[16]. As a percentage of new car sales in 2022, EVs made up 23 % of sales in the UK but only 4 % in Australia. These stark differences in the uptake of rooftop solar and EVs between the two countries are just a couple of examples how despite developed electricity networks having a lot of similarities, there are still significant differences that lead to a range of unique challenges.

[15] PowerMag, (2022). *A Global Look at Residential Solar Adoption Rates. https://www.powermag.com/a-global-look-at-residential-solar-adoption-rates/*

[16] ABC News (2023). *Electric vehicles 14 per cent of global new car sales, but less than 4 per cent in Australia:IEA. https://www.abc.net.au/news/science/2023-04-27/electric-vehicle-ev-sales-increased-globally-2022-iea-outlook/102266800*

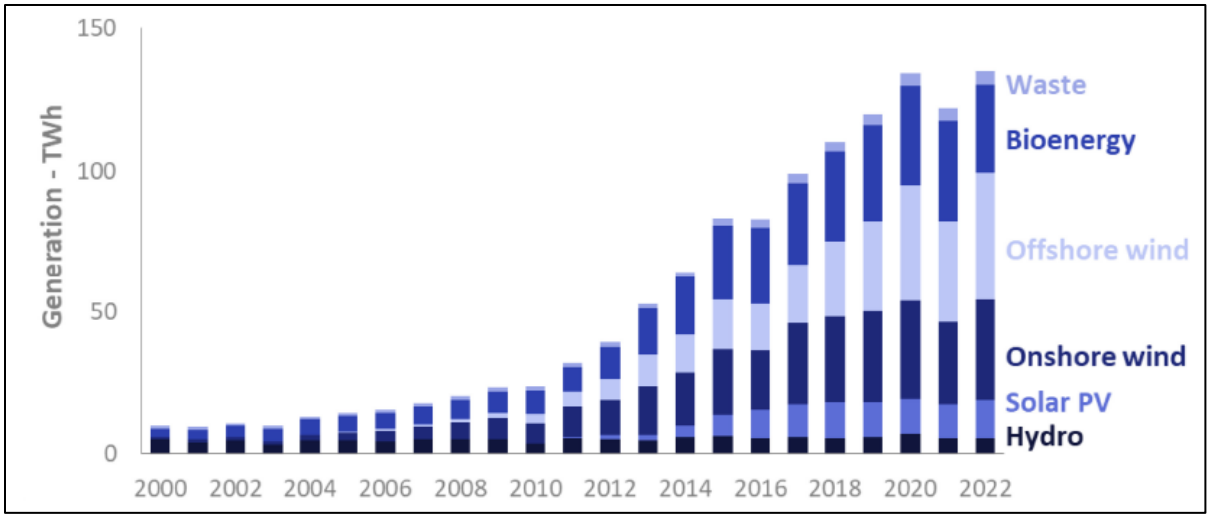

Figure 4: GB network renewable energy mix breakdown by technology, 2000-2022.

The GB network is experiencing a very similar energy transition to net zero as the Australian network with the UK goal being to generate all electricity from clean sources by 2035 (nuclear still accepted)[17]. This is ahead of the 2050 net zero target currently being employed by Australia (82 % by 2030) however AEMO has the goal of being able to operate a network with 100 % renewable penetration as early as 2025.

To help achieve the GB network's net zero by 2035 goal there have been a number of projects completed, and many more ongoing, that enable a greater penetration of renewable generation sources on the transmission system. These include industry leading innovation projects such as the stability and voltage pathfinder projects. To summarise, the goal of the stability pathfinder and the voltage pathfinder projects is to identify the most cost-effective way to operate the GB network from stability and voltage control perspectives. The stability pathfinder projects involved tendering and procuring a number of services to provide SCL and inertia to the GB network. Later iterations of the stability pathfinder project also include the installation of grid-forming inverters as inertia providing connections which is earlier than most other global developed electricity networks. Similarly, the voltage pathfinder project identified areas in the GB network requiring additional support to address forecast high voltage system issues by procuring reactive power services on the transmission system.

2.3 WHAT HAVE I BEEN WORKING ON?

As a member of the Operability Product team within the Networks department of NG ESO I have been exposed to several topics relating to the operation of the GB electricity system. The Operability Product team has a key focus on voltage and stability control and undertakes a number of projects to ensure the GB network will continue to have sufficient voltage and stability services to ensure secure, reliable and affordable operation in the future. The timescale of the Operability Product team is typically the one year ahead to five years ahead period and therefore close collaboration with both planning and operations teams is required. In addition to this, the Operability Product team also gets involved in innovation projects and

[17] BBC News (2023). *What is net zero and how are the UK and other countries doing? https://www.bbc.co.uk/news/science-environment-58874518*

tool development projects that improve the day-to-day operations of the ESO such as automation tools used by the National Electricity Control Centre.

During my first three months with the Operability Product team, I have been mostly involved with the stability side of the team and contributed to a few of the ongoing projects while also working more independently on a PSCAD stability study. Having not worked so closely with network stability before, especially at the system operator level, I have really enjoyed learning as much as I can about the phenomena of network stability and how topics including short circuit level (SCL), short circuit ratio (SCR) and inertia are all related. I have also improved my understanding of how the system operator manages stability across the network in real time and have now been involved with work that helps ensure there will be sufficient stability services in the network going forward. This is currently a particularly interesting topic due to the electricity system's transition away from synchronous generation, which provides a high SCL contribution and system inertia, to inverter-based generation.

To perform these stability tasks, I have used both PSCAD, for EMT-based simulation, and PowerFactory, for RMS-based simulation. Having not used the PSCAD modelling software before I have enjoyed the opportunity afforded to me to learn how to perform EMT studies in PSCAD. This new knowledge has supplemented my experience in EMT-based simulation using RSCAD and I am sure this will be a valuable skill going forward as the need for EMT-based simulation, especially in the inverter space, continues to grow.

Below is a quick overview of the main bodies of work I have been involved with during the April 2023 until July 2023 period at NG ESO.

2.3.1 SHORT CIRCUIT RATIO VERSUS STABILITY STUDY

The GB network is experiencing a transition from a system dominated by large synchronous generators to a system with a higher penetration of distributed and inverter-based generation. A consequence of this is that the short circuit level (SCL) normally provided by these synchronous generators is not being replaced at the same rate as new non-synchronous generation is entering the network. This is leading to an overall reduction in SCL both regionally and more broadly across the entire GB network. As SCL is directly connected to the operation of a stable electricity network, there is concern that this will lead to increased instability in the network and result in the power system being more susceptible to disturbances.

Currently, it is common within the industry for stability assessments to implement a minimum short circuit ratio (MSCR) level of 2.0 for HVDC connections and 3.0 for AC connections[18]. This is also the criteria applied by NG ESO as an indicator as per the December 2022 System Operability Strategy Report[19]. This means that the SCL at any point in the network must be maintained high enough to ensure the short circuit ratio (SCR) does not fall below these MSCR levels. This investigation performs PSCAD modelling to verify the MSCR guideline for HVDC connections. Several HVDC interconnector and wind farm PSCAD models were used to assess their stability at varying levels of SCR. In addition to this, the relationship between stability and grid X/R ratio, active power and reactive power were also investigated.

[18] CIGRE (2016). *WG B4.62 Connection of Wind Farms to Weak AC Networks.*
[19] NG ESO (2022). *December 2022 Operability Strategy Report, page. 31.*

This study found that there is a direct correlation between SCR and stability. As the SCR level of the source connected to the HVDC interconnectors was reduced, the stability of the interconnectors was also reduced. Instability was observed at low levels of SCR with stability found to correlate with SCR (i.e. stability decreased further as SCR decreased). On the other hand, there was not a direct relationship identified between stability and grid X/R ratio, active power output nor reactive power output.

Additionally, it would be beneficial to engage with the converter manufacturers to gain an understanding of the options available to ensure stable performance if SCL at the converter station connection point falls below design levels. This could help shape future guidelines such as whether specific services must be acquired to maintain a higher level of SCL or whether converter stations could be re-tuned to perform stably at lower SCR levels.

2.3.1.1 LESSONS LEARNED

This project was the first time I have been able to use PSCAD to conduct EMT-based simulation therefore I have greatly improved my capabilities in PSCAD. Additionally, being able to work on 'behind the scenes' models of HVDC interconnectors gave me valuable insight into how the HVDC converter stations operate.

More broadly, this study really highlighted the importance of maintaining a minimum SCL across the network and allowed me to see first hand the impact of low SCR on the stability of an inverter-based connection. This difference is demonstrated through the comparison of Figure 5 and Figure 6 which shows how a converter station responds to a three-phase to ground fault lasting 140 ms and having a retained voltage of 0 pu. The response of Figure 5 is clearly unstable as undamped oscillations are present in all of the voltage, current and frequency waveforms following the disturbance. On the other hand, increasing the SCR of the fixed AC source and applying the same fault results in a stable response as demonstrated in Figure 6.

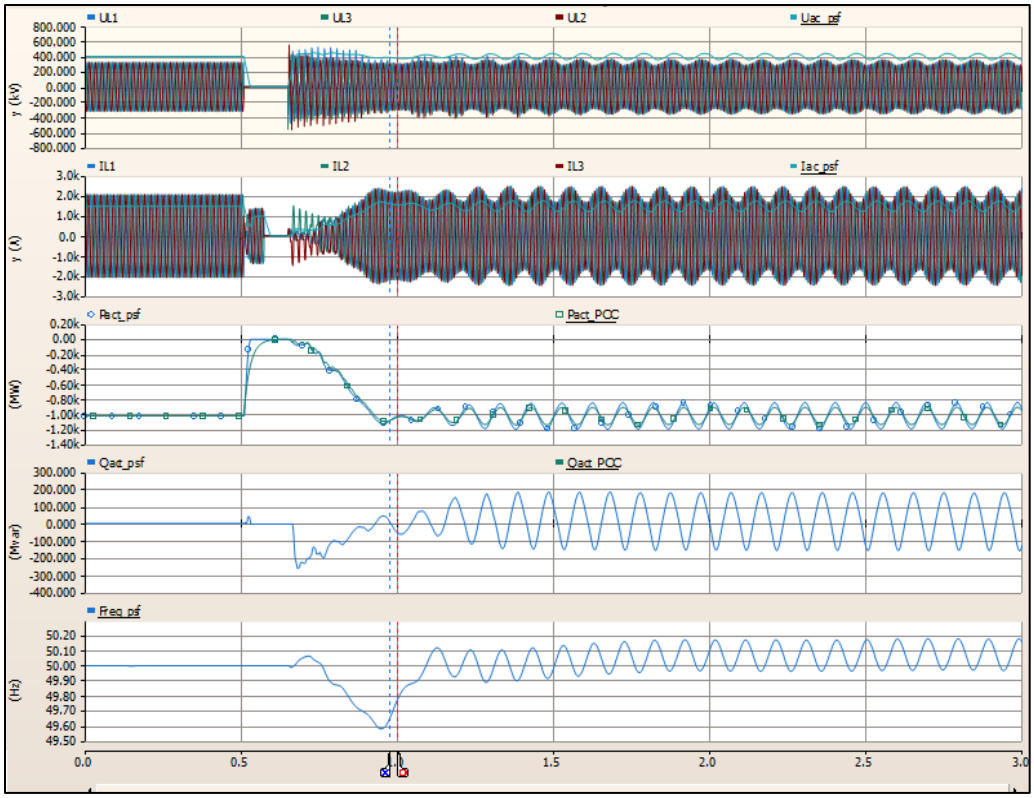

Figure 5: Example unstable response to a three-phase to ground fault.

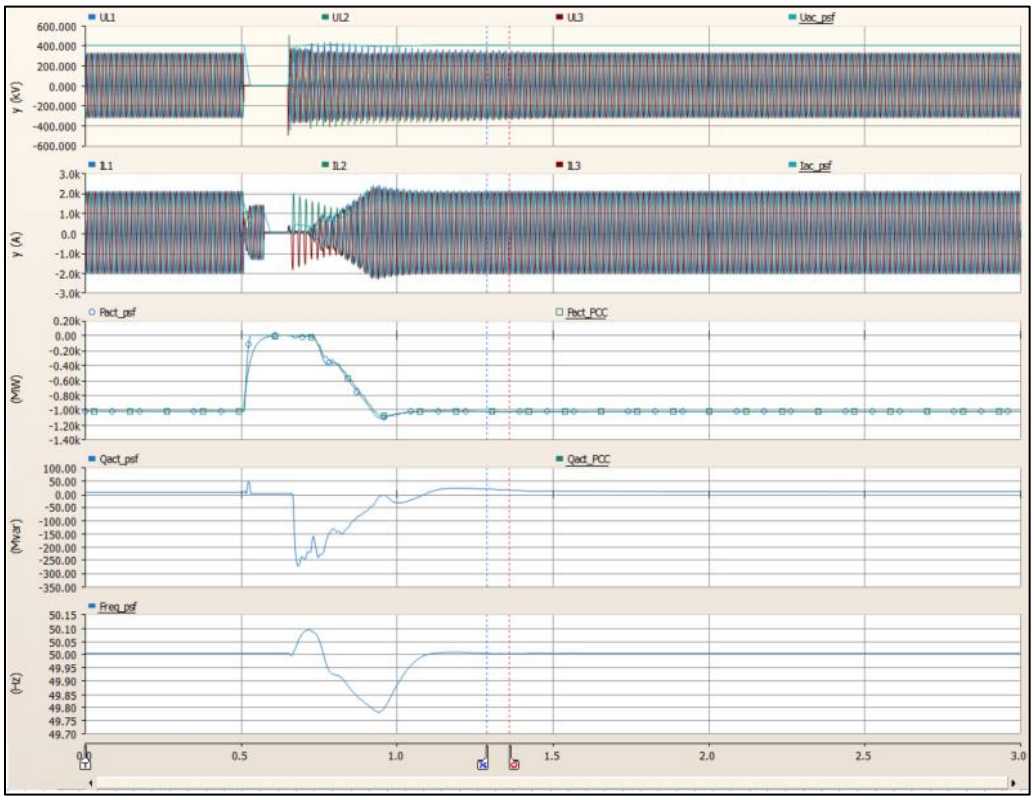

Figure 6: Example stable response to a three-phase to ground fault.

2.3.1.2 RELEVANCE TO THE AUSTRALIAN NETWORK

As the electricity supply network in Australia is going through a very similar transition, it is also expected that the SCL and consequently the SCR levels across the network are beginning to decrease. As this level drops further and there is increased inverter-based generation on the network, the findings from this study will become important as the network will likely need to maintain a similar MSCR to what will be required in the GB network to ensure stable operation of the Australian network.

I am not aware of AEMO yet forming a stability market or undertaking projects similar to the stability pathfinder undertaken by NG ESO to procure inertia and/or SCL boosting services. However, as the network wide SCL and inertia levels continue to drop it is possible that this might be required in the future if it is not already.

2.3.2 REAL TIME INERTIA MONITORING

I was tasked with learning about a real time inertia monitoring project currently being undertaken within NG ESO to understand the relevance this would have to the Operability Product team in the future. As the name suggests, the real time inertia monitoring project aims to implement a method of measuring (using physical devices spread across the network and data analytics) the real time inertia in the GB system. Currently, inertia is considered as a network-wide value (i.e. inertia is the same at all points of the network) and is estimated using a combination of known inertia from synchronous generation and an approximated contribution from demand-side inertia. As the need to maintain a minimum level of inertia in the electricity system is becoming a growing concern, due to the decrease in synchronous generation providing this inertia, there is increased focus being placed on determining the inertia value more accurately and understanding how the inertia varies across different parts of the network (for example, is inertia equal at a location in south-England versus a location in Scotland).

Having an accurate measurement of real time inertia in the GB network would lead to the following benefits:

- Better visibility of residual (demand-side) inertia contribution.
- Provide real time measurements to improve system knowledge and inform operational and planning decisions.
- Accurate measurements will minimise the risk of running the system insecurely and reduce the overall cost to manage RoCoF across the GB network.

2.3.2.1 LESSONS LEARNED

This project has produced a method to monitor inertia in real time across the GB network. Additionally, regional differences in inertia across the GB network were identified using the monitoring devices. An example of what this difference looks like is shown in Figure 7, which has been taken from a simulated 36-bus model of the GB network[20]. It is clear here that a disturbance in the south-east coast of the GB network causes unequal levels of RoCoF across the network with RoCoF decreasing in correlation with distance

[20] Hong et al, (2019). *Design of an Open Platform for Real-Time Power Grid Monitoring, IEEE, 2019, pp. 735-739*

from the fault. This also shows regional inertia having some effect with areas of Scotland seeing less of a RoCoF change than others due to the different local inertia providing services.

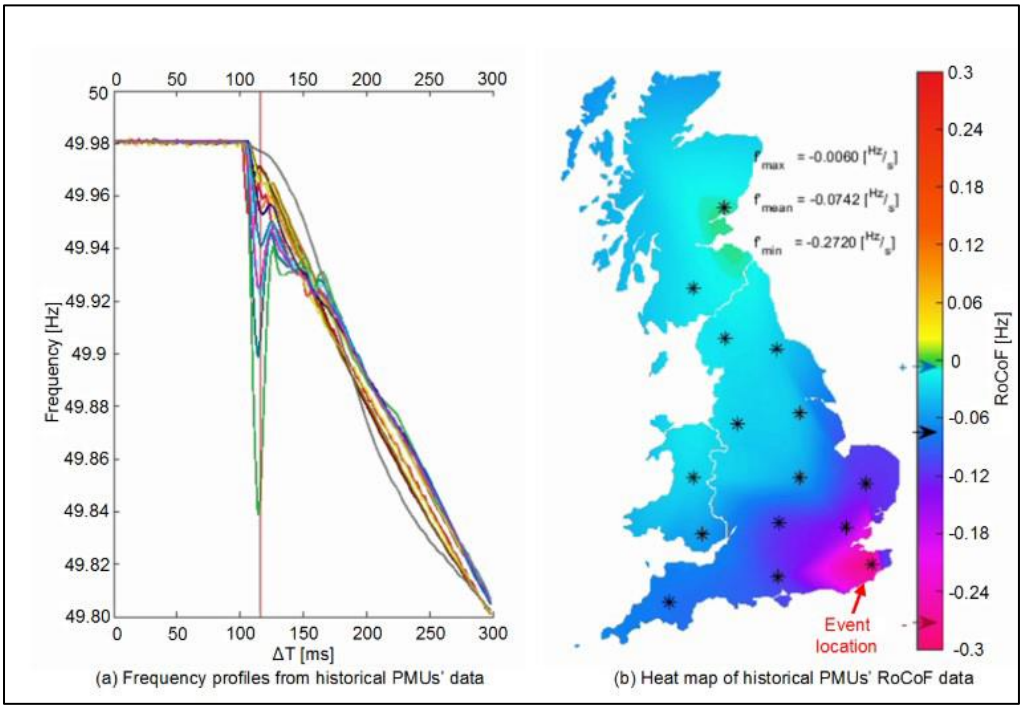

Figure 7: Frequency and RoCoF response at locations across the GB network in response to a fault on the south-east coast.

2.3.2.2 RELEVANCE TO THE AUSTRALIAN NETWORK

Due to the similarities in the energy transitions both the GB network and the Australian electricity network are currently experiencing, this concern of decreasing inertia levels is also relevant to Australia. As such a tool such as this real time inertia measurement tool will also be beneficial in Australia and is likely already being developed if it hasn't already been implemented. This project supported the need to develop a comprehensive phasor measurement unit (PMU) array across the network and it is my understanding that this work is already being undertaken in Australia through collaboration between AEMO and the transmission and distribution network operators.

2.3.3 REGIONAL INERTIA, ROCOF AND FREQUENCY STUDY

With inertia levels decreasing across the GB network as the generation mix shifts more away from synchronous generation, there is concern that the resulting increase in RoCoF following a disturbance may start to exceed the maximum levels currently secured against. This overall lowering of network wide inertia may also cause localised inertia shortfalls in regions with a lack of local inertia providing services. Consequently, National Grid ESO, in collaboration with academic and industry partners, commenced the Enhanced Frequency Control Capability project[21] in 2014 with the aim to develop a wide area monitoring

[21] NG ESO (2019), *The Enhanced Frequency Control Capability Project Closing Down Report*

and control scheme capable of enhancing the technical capability of fast frequency response and facilitating a new RoCoF-based frequency response balancing service.

To further the work from this study, and also to build on the real time inertia monitoring project discussed in Section 2.3.2, I was asked to commence a regional inertia, RoCoF and frequency study using PowerFactory. This project will use the PowerFactory model of the GB network to investigate regional differences in response to different 'largest loss' (e.g. large synchronous generation losses) spread across the network. Different inertia profiles and generation profiles will be used to help identify how location, in terms of how far a node is from the outage, and inertia affect the RoCoF and frequency deviation measured at the node.

The project will aim to:

1. Investigate how much inertia differs regionally across the GB network by observing the difference in RoCoF measurements taken following an outage.
2. Determine how much frequency at different regions of the network differs to the central frequency of the GB network.
3. Identify whether regional differences in inertia, RoCoF and frequency are large enough to cause enough concern that would support procuring inertia providing services on a more locational basis.

2.3.3.1 LESSONS LEARNED

I am still in the early stages of this project and therefore additional learnings will be saved until my fourth quarterly report. An example of the RoCoF maps that will be produced as part of this project is provided in Figure 8 which shows how the instantaneous RoCoF varies in response to an outage in the south-west of England. In this case, a darker green colour indicates a small RoCoF with the shading increasing from green-yellow-red as the instantaneous RoCoF increases.

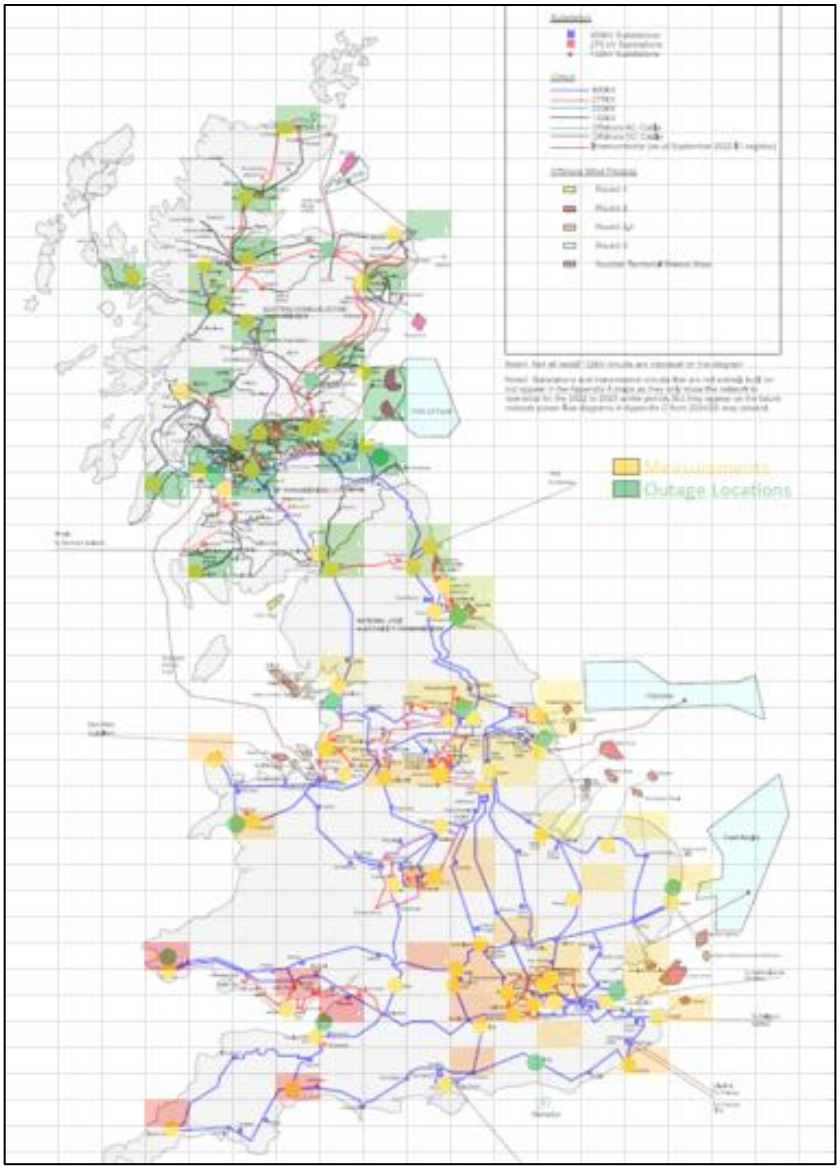

Figure 8: Example instantaneous RoCoF map of the GB network in response to an outage in the south-west of England.

2.3.4 UTILITY WEEK ATTENDANCE

I was lucky enough to attend one day of the Utility Week conference being held at the National Exhibition Centre in Birmingham on the 16th of May. The Utility Week conference brings together the energy (electricity + gas) and water industries to discuss pressing topics in the industries both shared and more specific. With over 200 exhibitors and three concurrent speaker stages, the conference covers a wide range of topics relevant to the utility sector and attracts attendees from different backgrounds including government members, network operators, equipment manufacturers and interested consumers.

The key focuses of the 2023 conference were asset management, decarbonisation and delivering net zero, optimising the workforce, data and digitalisation and building smart networks. While at the conference I was able to attend several of the speaker sessions and have provided the main takeaways below.

Climate Crisis: Adapt and Overcome (The Climate Change Committee):

- Energy assets are highly vulnerable to weather events (e.g. high temperatures, flooding) and it is predicted that these weather events could become more frequent and severe over the next 50 years.
- There is a need to design energy assets to be climate resilient to ensure they will be able to operate efficiently throughout their full design lifetime and be able to withstand some potentially harsher operating conditions than we expect today.

DSO Function (National Grid Energy Distribution):

- Compared to a traditional distribution network operator or distribution network service provider, the distribution system operator (DSO) has the added role of operating a 'smart' system.
- Operating a smart electricity system means developing energy markets and flexibility products that enable better utilisation of the capabilities of new technologies. This also means greater integration to third party products to make the most of available technology advancements.
- The DSO will need to have better data visibility and will need to make this operational data available to third parties to use. Additionally, the DSO will need to be able to manage and curtail flexible connections.
- Standardisation is vital (i.e. how would a third party product integrate with the DSO's communication system) however need to be careful not to let standardisation limit innovation.
- The future energy system will have a lot more participants and a lot more data therefore managing this data efficiently will be key. Tools such as machine learning and artificial intelligence will need to be integrated into the DSO's day-to-day toolkit to facilitate the transition to a DSO.

Delivering the Energy Transition at Pace:

- Challenges are already present in terms of resource availability (both materials and people to perform the work) and this is leading to delays in construction and commissioning. Need to make sure that the connection process is streamlined and slow projects are not stalling other projects by blocking the connection queue.
- The industry needs to listen and bring consumers and communities along on the journey. A full transition to net zero needs all levels of the industry to be on board with the vision for it to work.
- Finding the right balance between risk and opportunity will be important. Projects will need to be carefully assessed to decide whether a high risk and high reward opportunity should be pursued over a lower risk but lower reward opportunity.

3 CIGRE WORKING GROUPS

3.1 WORKING GROUP B5.78

Topic: *New Requirements of Network Protection and Control for Renewable Energy Integration*
Terms of Reference: Available here[22]
Objective:
To review existing codes of practices and standards for protection automation and control systems to identify distinguishable boundaries which will help ensure selectivity and effective coordination of networks across the world. This is particularly relevant with the growing penetration of renewables and inverter-based resources that are changing the status quo of how protection networks have traditionally operated.
Updates:
Meeting 2 – 26/05/2023:
Unfortunately I was not able to attend this meeting however the meeting minutes are summarised below:

- New members welcomed and provided introductions and backgrounds of themselves.
- Terms of reference discussed to narrow down the scope of the working group.
- Knowledge shares presented from a few of the WG members regarding relevant challenges and findings as experienced in their country.

Meeting 3 – 24/06/2023:

- Presentations provided by a couple of WG members as follow-up to discussions from Meeting 2.
- Structure of the technical brochure discussed with WG members sharing their area of expertise to help break into smaller teams to handle specific chapters of the brochure.
- Guidelines for writing a technical brochure were shared to ensure all WG members were aware of the process and how collaboration can be achieved while maintaining a standardised format.

3.2 WORKING GROUP C6.44

Topic: *Nodal Value of Distributed Renewable Energy Generation*
Terms of Reference: Available here[23]
Objective:
To discuss and analyse in practical terms how the variable renewable energy nodal value concept could be applied more broadly and systematically by public and private power sector planners and investors. This would allow for the joint optimisation in distribution and generation expansion of the scaling up of distributed variable renewable energy investments in different countries and energy system contexts.
Updates:
After attempting to contact the C6.44 working group convenor via email a few times and unfortunately failing to get a response I am unsure as to whether this working group is still active. An update presentation was provided to the C6 Study Committee during the 2022 Paris session however since then I don't believe there has been any activity. I have also checked-in with another CIGRE Australia member who is a member of this working group and they have not heard anything either. I will follow-up with the Australia C6 Panel Convenor and hopefully have a more promising update in my final quarterly report in a few months.

[22] CIGRE. (2022). *CIGRE Study Committee B5 – Proposal for Creation of a New Working Group, B5.78*
[23] CIGRE. (2021). *CIGRE Study Committee C6 – Proposal for Creation of a New Working Group, C6.44*

4 PLAN FOR NEXT QUARTER (JULY 2023 – OCTOBER 2023):

During my final three months at NG ESO I will be looking to wrap-up my ongoing work with the regional inertia project and will have involvement in a couple of ongoing stability projects. This last three months will be a great opportunity to continue learning all I can about system operation and I hope to improve my understanding from a broader perspective than the scope of work the Operability Product team gets involved with.

After the conclusion of this placement with NG ESO at the end of September, I will be returning to Australia and to my nominal role within the Technology Innovation team at Energy Queensland.