CAIRNS 2023
INTERNATIONAL
SYMPOSIUM
4TH - 7TH SEPTEMBER

Symposium Proceedings

The End to End Electricity System

Transition, Development and Integration

Hosted by the Australian National Committee of CIGRE

CIGRE Cairns International Symposium

The Australian National Committee of CIGRE hosted an International Symposium in Cairns, Australia from the 4th to the 7th of September 2023.

It was a resounding success with over 1300 attendees, over 50 sponsors and exhibitors, 240 presentations, 12 tutorials and workshops and 51 meetings of committees and working groups.

The event was actually three coordinated events — an international Symposium with 11 Study Committees, the Australian Conference on Integrating DER (CIDER) and the South East Asia conference on Protecion and Controal (SEAPAC).

The theme of the Symposium

The session theme was “The End to End Electricity System: transition, development and integration”. This theme was divided into three topic streams:

1. Learning from experiences. What can we draw from past experience to develop the end-to-end electricity system?
2. Developing practices, functionalities and applications. What are the current developments and their application for an end-to-end electricity system?
3. Towards a sustainable power system. What are the future needs and requirements of an end-to-end power system?

The symposium focused on the integrated electricity system and the transformation into the electricity system of the future. It sought to identify what can be learned from the experience with current developments in technology, equipment, controls as well as electricity system architecture, operational practices and planning criteria.

The topics then covered the changes that are necessary to meet community expectations and policy requirements. The conference embraced many of the CIGRE domains of work — see the list of study committees — by including planning, operations, markets and economics as well as the technical aspects of the network and then through to the integration of distributed energy resources. It examined new ideas, approaches, technologies and operations.

Study committees that supported the Symposium

Eleven study committees attended the Symposium:

A3 — Transmission and Distribution Equipment
B1 — Insulated Cables
B3 — Substations and electrical installations
B5 — Protection and automation
C1 — Power system development and economics
C2 — Power system operation and control
C4 — Power system technical performance
C5 — Electricity markets and regulation
C6 — Active distribution systems and distributed energy resources
D1 — Materials and emerging test techniques
D2 — Information systems and telecommunication

Opening session

The Symposium opening saw a Welcome to Country from the Minjil people, the local Aborigines, who welcomed the attendees and peformed traditional dances and the Wiwin (a traditional gift giving ceremony).

The session was then opened by Australian Chairman Dr. Sean McGoldrick and saw presentations from Keynote Speakers Mr David Shankey, Deputy Director Energy for the Queensland Government and Mr Adam Middleton, VP Western Europe, Siemens Energy.

Mr Michel Augonnet, President of CIGRE, Mr Philippe Adam, Secretary General,
Mr Marcio Szechtman, Chair of the Technical Council and Mr Phil Southwell, the chair of the Symposium also addressed the delegates at the opening.

CIGRE Learning Program — some statistics

The Symposium was part of the CIGRE knowledge programme and attracted 339 synopses from 35 countries and over 1,000 authors. The 11 Study Committees and their review panels — 184 reviewers in total — conducted 1,561 reviews, including providing guidance to authors. This resulted in 243 papers from 30 Countries being accepted. During the Symposium 240 of these papers were presented by the authors or colleagues. Of thse papers

- 119 were from Australia or New Zealand
- 29 were from Japan, the next highest contributing country

There were also 10 tutorials and 2 workshops presented by the Study Committees.

The Symposium was conducted in parallel to two biennical Australian conferences:

- Conference on the Integration of Distributed Energy Resources. There were 32 presentations at CIDER, including 11 papers that were selected via the Symposium process
- South East Asia Protection and Automation Conference. There were 31 presentations at SEAPAC

Importantly, there were also 51 meetings of Study Committees, advisory & working groups and Australian panels during the period from Saturday 2 September to Friday 8 September, using the Cairns Conference Centre as well as much of the facilities of the Pullman International Hotel.

The Technical Council met on the Friday and the eleven Study Committees held their meetings and SAG/WG meetings during the week.

All of these meetings were able to include remote attendees, although the time zone differences no doubt reduced remote attendance.

Symposium proceedings

The proceedings of the Symposium, comprising the papers, presentations and summaries of the discussions will be available to delegates that attended the symposium, via links mailed to them.

In addition, the proceedings of the Symposium and the recordings of the tutorials will be available from e-CIGRE.

The best papers from each Study Committee are to be published in Electra CSE. With so many quality papers, the SC Chairs are having difficulty selecting just one per SC.

Organising Committees

Symposium Steering Committee

Chair..... Phil Southwell
TC Chair..... Marcio Szechtman
CIGRE Secretary General..... Philippe Adam
Local Co-ordinator..... Terry Killen

Local Organizing Committee

Chair	Phil Southwell
Local Co-ordinator	Terry Killen
Technical Chair	Alex Cruickshank
Secretary	Sally Earnshaw
Event Co-ordinator	Debbie Haddock

Members:

David Pita	SC A3
Russell Wheatland	SC B1
Crina Costan	SC B3
Peter Bishop	SC B5
Christian Schaefer	SC C1
Greg Hesse	SC C2
Babak Badrzadeh	SC C4
Greg Thorpe	SC C5
Ray Brown	SC C6
Yi Li	SC D1
Louise Watts	SC D2

Technical Organising Committee

Co-Chairs:	Jayme Macêdo (SC C2)
	Alex Cruickshank (SC C5)
Secretaries:	Yannick Phulpin (SC C5)
	Flávio Alves (SC C2)
ATC Chair:	Angela Klepac

Members:

Nenad Uzelac	SC A3
Geir Clasen	SC B1
Koji Kawakita	SC B3
Rannveig Løken	SC B5
Antonio Iliceto	SC C1
Marta Val Escudero	SC C4
Greg Thorpe	SC C5
Kurt Dedekind	SC C6
Simon Sutton	SC D1
Victor Tan	SC D2

Closing remarks

It seems the Cairns23 Symposium has broken many CIGRE records, from the most number of delegates, number of exhibitors and the number of presentations and papers delivered. Overall the Symposium was well received and enjoyed by delegates and provided not only the expert broad technical opinion and input that CIGRE is known for, but also provided a platform for renewal of old acquaintances and development of new regional and global technical contacts which will no doubt serve delegates for many years.

The Local organising Committee is proud to have been able to present the Symposium and to have it recognised as a global success and again thanks all those involved in its organisation, the sponsors exhibitors, presenters and of course the delegates for their support and attendance.

Session Summaries

The End to End electricity system: transition, development and integration

Cairns, Australia, 4 — 7 September, 2023

General

At the conclusion of the Symposium, each Study Committee provided summaries of their sessions and tutorials. These are provided in the following pages.

A common template has been used as much as possible, but each Study Committee provided their own responses.

Papers, presentations and tutorials

The papers, presentations and tutorials referred to in these summaries are available from e-CIGRE and via links provided to attendees at the Symposium.

Associated conferences

There were two conferences associated with the Symposium:

- the biennial Conference on Integration of Distributed Energy Resources (CIDER) conducted by Australian Panel C6 and
- the South East Asia Protection Automation Conference (SEAPAC) conducted by Australian Panel B5.

The proceedings of these two conferences have been published separately.

Study Committee summaries:

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SC A3 papers

Monday September 3rd 2023

1. Overview

Eleven papers have been received and divided in two sessions the first dealing with assets and the second focusing more on technology.

Session 1 - Assets: Making the best use of T&D equipment

Session Chair: Frank Richter

Secretary: Nicola Gariboldi

Paper ID	Title	Submitting author
1115	CIGRE fourth reliability survey on transmission & distribution equipment	Ito, Hiroki
1138	Operation and Maintenance of High Voltage Disconnectors, Importance of Thermography and Live Substation Methods to Mitigate Asset Risk	Zarb, Clayton
1156	The use of partial discharge monitoring and failure analysis of a 275 kV oil filled current transformer	Ward, Brody
1178	TSO experiences on SF6 issues, its related maintenance strategy and best practices.	Blanchet, Guilhem
1317	Development of stationary measuring equipment in circuit breaker and highly-developed maintenance	Nakamura, Keisuke

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with a restricted population from transmission level. The paper emphasizes the need to investigate factors affecting reliability and announces the establishment of CIGRE WG A3.48 to provide equipment life management insights. Full survey results will be published in 2023.

Q: Which is the main reason for Failure Rate Increase?
A: 2 countries had very old CB (>40 years), DTB are in average younger. Data are influenced by mainly 1 country

1138 discusses the operation and maintenance of high voltage disconnectors. Different maintenance practices are described in particular with live substation method to minimize the outage and still ensuring a proper maintenance level and consequent asset reliability. Powerlink Queensland's experiences are shared, including a case study of a thermal failure of a 132 kV disconnector, explained in detail from measurement carried out and the investigation process followed which emphasizes the significance of maintenance practices and training for defect identification and mitigation without disrupting the power grid.

Q: Are all the result saved?
A: Only in case of a problem.

1156 paper examines the failure of a 275 kV oil-filled current transformer and the application of partial discharge monitoring techniques. It underscores the importance of early fault detection in transmission environments and shares insights into maintenance practices and risk mitigation strategies. The study includes a case study of a transformer failure, forensic investigations, laboratory measurements, and recommendations for asset owners. Overall, it emphasizes the critical role of partial discharge monitoring in enhancing network reliability and safety.

Q: Company strategy?
A: Strategy is to move from oil to gas CT, when possible.

1178 discusses the evolution of Gas Insulated Switchgear (GIS) technology over the last 40 years and the environmental concerns associated with SF6 gas, which has a high Global Warming Potential (GWP). It emphasizes that SF6 emissions are a major source of greenhouse gas emissions for some operators. The paper explores challenges related to SF6 gas pressure, maintenance, and interface issues. It highlights the main issues faced by operators: high GWP and the need for repairs due to leaks. Alternative gases are considered, but their reliability, maintainability, and PFAS-free nature are uncertain. The second part of the paper examines the origins of SF6 leaks, leakage rates, and provides recommendations for addressing gas leakage issues in switchgear.

1317 reports the measurement of the opening/closing time of circuit breaker main contacts as a crucial method for ensuring interrupting performance during periodic inspections. Over time, wear and tear on mechanical parts and grease deterioration can affect the circuit breaker's performance. Traditionally, these inspections were done in person, and due to operational constraints, sometimes at night or on holidays, posing logistical challenges. To address these issues, the paper presents a stationary measuring equipment that measures the open/close time of auxiliary contacts, which are essential for determining the circuit breaker's state. The device can be permanently installed inside the circuit breaker cabinet. It includes wireless data transmission capabilities, which makes the installation easier and less expensive. The verification of the wireless transmission has been verified in outdoor substations required the installation of repeaters to improve communication. Future work involves studying communication methods for indoor and underground substations with devices installed on different floors.

Session 2 - Technology: Development of T&D equipment for the future

Session Chair: Nenad Uzelac

Secretary: Nicola Gariboldi

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1367	The digitalisation of the Electrical System: new opportunities for a smarter and more accurate measurement infrastructure	Mazza, Paolo
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1217 discusses introduces a method for determining the capacitance values of CVTs on-site without dismounting the units, allowing for accurate assessment of their health. It also presents a modification involving the addition of a C3 capacitor for power quality (PQ) measurements, expanding the CVT's frequency bandwidth. Frequency response measurements are conducted on standard CVTs and modified CVTs, revealing that standard CVTs have limitations for PQ measurements due to resonance points. In contrast, the modified CVT shows potential for PQ measurements from approximately 200 Hz to 3 kHz. The paper concludes by providing an overview of various voltage measurement systems and suggests that the new product standard IEC 61869-5 Edition 2.0 should offer more guidance on high-frequency measurements and PQ applications.

Q: Impact of C3 applied on Class? Temperature dependency coefficient in case C3 is added.
A: the impact should be minimum but it can be calculated, C3 can be integrated in the standard design.

1214 explores how asymmetrical currents, generated during the switching of a Mechanically Switched Reactor (MSR), affect the performance of circuit breakers. It highlights the increased wear and erosion on circuit breaker contacts due to these currents, especially with frequent switching. The paper proposes solutions, including optimizing control logic to reduce MSR operations, regular maintenance. It suggests the use of pre-insertion resistors, to mitigate the impact of DC offset currents during reactor energization as a more reliable method with respect of controlled switching technology.

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Q: SAMU developed by a standardization body. Quite interesting. What was preventing the industry to come with a solution?
A: the proposed design is public available and meant to offer a reference of how a SAMU should work. It is not engineered for production.

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SC A3 papers

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SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	B1	SESSION NUMBER	1
Date:	05 September 2023	Time:	13:20 – 15:10

FINDINGS AND CONCLUSIONS:

The theme of the Cairns 2023 Symposium was energy transition, defined as the global shift from mainly fossil fuel-based energy sources (such as coal, oil, and natural gas) to cleaner and more sustainable alternatives, such as renewable energy sources (solar, wind, hydro, geothermal) and improved energy efficiency. This transition is being driven by the need to address several interconnected challenges, including climate change, air pollution, energy security, and the depletion of finite fossil fuel resources. The energy transition is transforming the power engineering field by demanding innovative solutions for integrating renewable energy, ensuring grid stability, and enhancing overall energy efficiency. Power engineering is pivotal in driving this transition towards a more sustainable and resilient energy future. Substations have an important part to play in this transition.

This Session was led by Session Chair, **John Martin**, Ireland, and Secretary, **Carl Erik Hillesund**, Norway.

Session Chair, **John Martin** introduced the session theme and introduced the presenters and the papers that represented a broad range of aspects of the energy transition and the engineering challenges impacting cable solutions. There were six submitted, and five papers presented in the Session:

Paper #	Paper	Presenter
1106	**Improved Cable Ampacity Calculations by Combining the IEC Standard with the Finite Element Technique**	**Patrick, Jayson, AU**
1130	**New pressure monitoring system for 132kV OF cables**	**Rob Bradley, AU**
1165	**Rebounding and learning from a HV Cable Mid-life Crisis**	**Glenn M Stapleton, AU**
1175	**Condition based maintenance and replacement of medium voltage XLPE cables in Singapore**	**Not presented**
1348	**Low voltage cables – the end is near**	**André Cuppen, NZ**
1433	**Field experience on PD measurement for MV cables using different voltage sources, DAC and sinusoidal VLF**	**Dong Curl Lee, AU**

SYNOPSIS OF PRESENTATIONS

The presentation, **Improved Cable Ampacity Calculations by Combining the IEC Standard with the Finite Element Technique** shows method to a development of a computer software that combines the familiar IEC standard methods with FEM – this further ensures the calculations are compliant with CIGRE TB 880:2022. An automatic meshing algorithm identifies the components lying inside other elements. For example, a cable may lie inside a duct, or it may be directly buried. The algorithm identifies the elements that are enclosed within other elements. The next process is the meshing of the area under study. Meshing is carried out with linear triangular elements. The inputs to the meshing algorithm are the minimum and maximum triangular element edge length and the growth gradation of the triangular elements. This is required so that the areas forming a boundary with other elements must be tightly meshed. The vertices of the triangle are called the nodes and the solution to the FEM problem results in the temperature of every node. The maximum cable surface temperature or if the cable is installed in a duct, the maximum of the duct surface temperature is used to calculate T4 for each cable in the study.

The paper, **New pressure monitoring system for 132kV OF cables** describes how Ausgrid is replacing its original oil-filled cable pressure alarm systems with a modern & flexible monitoring system.
The original systems consist of pressure gauges with in-built adjustable alarm contacts and/or pressure switches with signal transmittal to the substation SCADA system via twisted pair pilot cables. These systems require regular maintenance checks and gauge calibration. Pilot cables are becoming unreliable and can require costly repairs. The chosen system is based on off-the-shelf components that uses the mobile network for reliable monitoring for the rest of the lifetime of the cables.

The paper **Rebounding and learning from a HV Cable Mid-life Crisis** describes abnormalities that was detected in silicon oil dissolved gas analysis in samples taken from a cable termination for a 275 kV XLPE cable system. During routine maintenance, oil samples were taken to initially assist with planning a simple repair and refurbishment of an outdoor sealing end to correct a minor fluid leak from the metal wiping system. The paper outlines the risk assessment framework and key technical milestones identified and addressed along a complex journey to successful reinstatement cable system reliability.

The paper **Low voltage cables – the end is near** describes the coming issue with an ageing LV cable network. Cables were installed 55 years ago are approaching the end of their life. The paper describes mitigation and repair, but large-scale replacement strategies are needed.

The paper **Field experience on PD measurement for MV cables using different voltage sources, DAC and sinusoidal VLF** describes field testing experiences on PD measurements for 22kV MV cables. A group of 15 to 25 years, service aged cables were tested for PD using DAC and sinusoidal VLF which are the two most used voltage sources for testing of MV cables. On these cables, both DAC and sinusoidal VLF voltages were applied on the same cables one immediately after another for the PD measurement. This paper could be the first large collection of field-based data which can directly compare DAC PD measurement outcomes to those from sinusoidal VLF PD measurement. The data used for the paper were obtained from the testing over 100 km cable length including over 100 individual circuits as well as 400 joints and terminations.

CONCLUSIONS

The audience (more than 100 attendees) showed a great enthusiasm on the presented papers. They showed many aspects of how to maintain and prolong life of cable systems.

Many good questions were asked and were useful feedback to the authors to improve the research on several topic.

The Study Committee B1 wishes to thank to all paper authors and presenters for their work in support of the Cairns 2023 Symposium and the audience to their great support.

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1342 discusses the challenges of specifying current transformers (CTs) for power transformer protection in early project stages. It emphasizes the importance of choosing the correct CT parameters to ensure the reliability of protective relays. Key points include the need for guidance from standards, the significance of transient dimensioning factors (Ktd), a case study on CT specification, and the practical application of Ktd for relay comparison. The paper concludes that Ktd simplifies CT selection and recommends updates to industry standards for better guidance.

TUTORIAL SUMMARY

STUDY COMMITTEE	B1	TUTORIAL NUMBER		1
Date:	September, 04, 2023	Time:	10:30 – 12:20	

Title: Fault Location on Land and Submarine Links (AC & DC), TB 773

Presenter: Geir Clasen

Geir has 28 Years with Nexans/Alcatel. Currently he is Senior Expert in HV cable testing. Geir has been active in CIGRE since 1992 and has participation in the following.

WG 21-02 - Electra Brochure 171 (Mechanical testing of submarine cables), Electra Brochure 189 (Testing of long XLPE cables), Electra Brochure 189 (Testing of long Lapped insulation cables)
WG B1.27 - TB 490 (Testing of submarine XLPE cables)
SC B1 National Member for Norway (2008-2014)
WG B1.43 - TB 623 (Mechanical testing of submarine cables)
WG B1.52 -TB 773 (Fault location of cables)
SC B1 TAG - Convener (2017 - 2022)
Special Reporter 2020 & 2021
CIGRE Technical Council Award B1 2021
Chair SC B1 2022 -

Precis of the tutorial:

The increasing number of land and submarine cable assets globally has created a focus on cable fault location capability
There are many well established cable fault location techniques, particularly for buried underground cables
Successful cable fault location depends to a great extent on applying the appropriate technique or combination of techniques
Methods for locating cable faults require competent engineers and service providers
Guidance is required for engineers on the correct application of the various techniques available

The TB 773 covers the most common methods for fault location, in addition new and emerging techniques are also included. Chapters on emergency planning is also part of the brochure.

It was attended by ~60 attendees and concluded with an engaged Q&A session.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	B3	SESSION NUMBER	1
Date:	07 September 2023	Time:	10:20 – 12:10

FINDINGS AND CONCLUSIONS:

The theme of the Cairns 2023 Symposium was energy transition, defined as the global shift from mainly fossil fuel-based energy sources (such as coal, oil, and natural gas) to cleaner and more sustainable alternatives, such as renewable energy sources (solar, wind, hydro, geothermal) and improved energy efficiency. This transition is being driven by the need to address several interconnected challenges, including climate change, air pollution, energy security, and the depletion of finite fossil fuel resources. The energy transition is transforming the power engineering field by demanding innovative solutions for integrating renewable energy, ensuring grid stability, and enhancing overall energy efficiency. Power engineering is pivotal in driving this transition towards a more sustainable and resilient energy future. Substations have an important part to play in this transition. This session addresses challenges for substation engineering.

Session 1 began with a presentation by Study Committee B3 Chairman, **Koji Kawakita** who welcomed the more than 300 attendees representing over 40 countries at the symposium, also sharing details of the structure and activities, and the work of the Study Committee over the past year.
This Session was led by Session Chair, **Terry Krieg**, Australia, and Secretary, **Doug Ray**, New Zealand.

Session Chair, **Terry Krieg** introduced the session theme and introduced the presenters and the papers that represented a broad range of aspects of the energy transition and the engineering challenges impacting substations. The five papers presented in the Session were:

Paper #	Paper	Presenter
1343	**Mobile substations incorporating HV GIS**	**Jose Lopez-Roldan (AU)**
1174	**BESS Integration to Substations – Electrical Design and Australian Standards Compliance**	**Crina-Miana Costan (AU)**
1339	**The First Medium Voltage DC Station Project in Korea**	**Minsoo Lee (KR)**
1382	**Application of 3D Technologies in Substation Engineering Works**	**Daniel Stafford (AU)**
1291	**Air Cored Reactors Installations in Substations**	**James Smithson (AU)**

SYNOPSIS OF PRESENTATIONS

The presentation, **Mobile substations incorporating HV GIS** was based on the work of WG B3.41 and discussed the design, testing, implementation, and use of mobile substations for a range of applications. Existing IEC standards such as IEC 62271 and IEC 61936 were reviewed by the working group concluding that no changes were required to address pre-assembled or mobile substations. A

clear understanding of the use and expected outcome operating the mobile substation can be expected to streamline preparation and mobilization aspects such as choosing the correct mobile substation type, transport options, installation, safety, risks, and on-site testing considerations.

The next paper, **BESS Integration to Substations** summarised the experience gained in Battery Energy Storage Systems (BESS) since the first in 2017 including both the design to achieve electrical safety and electrical compliance and operational and maintenance experience. The presentation included how the Australian Standards are used together with a risk-based approach to assess the new installations to ensure safe installation design, operations, and maintenance.

The First MVDC Station Project in Korea reported an interesting pilot project to address growing DC loads and to enable transfer of energy at medium voltage levels to accommodate expected additional renewable energy to 2036. The Korean power utility project involved the installation of a ±35kV/30MW station, increasing the MV line power capacity from AC 20MW to DC 30MW, modifying the insulation distance from the previous AC of 20m to DC and 6m~7m clearances. Potential concerns on magnetic field levels associated with proximity to new DC lines were raised in questions.

Application of 3D Technologies in Substation Engineering Works gives an overview of the application of current and emerging 3D modelling technologies and techniques including the use of LIDAR, surveying equipment and computer aided design and shared project experiences where 3D models were successfully used to avoid design errors, assist in client decisions regarding equipment or structure requirements and assist in construction activities. Focus is given to project experience where a construction sequence was developed to avoid equipment clashes and maintain vehicle access through all stages of the project. The direct savings are cost, time, and resources.

Air Cored Reactors Installations in Substations addressed that air cored reactors are mostly used in conjunction with shunt capacitor banks for de-tuning the fifth harmonic. Design considerations included reducing the effect of induced currents in the nearby metallic objects, some of the criteria in selecting a circuit breaker for switching the reactive plant, and the typical de-energisation and energisation sequence for safe switching the reactive plant. Simulations found that the installation of two sets of back-to-back air cored reactors can lead to induced currents, but these can be minimised using fibre concrete instead of steel rebar and earth stakes instead of an earth grid to prevent closed loops being formed in the earthing. Similarly, avoiding earthing of cable sheath at both ends to avoid induced circulating currents and other measures was discussed. The use of Point-On-Wave (POW) enabled circuit breakers able to accommodate the required TRV and RRRV was discussed.

CONCLUSIONS

The energy transition is clearly well underway, and this will impact substation engineering together with many other aspects of society as the transition occurs for many years to come. We are already seeing adaption and change in the way we as engineers do things. The interesting and well attended session (more than 300 attendees) with good participation and questions addressed a wide range of aspects of the challenges impacting substation engineering in the energy transition and how these challenges are being addressed. The session chair reflected that none of these issues were visible or discussed when he started in the power sector in 1976. The session presentations represented some of the ways that these new challenges were being addressed by the global power industry. Thanks to all paper authors and presenters for their work in support of the Cairns 2023 Symposium.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	B3	SESSION NUMBER	2
Date:	September, 07, 2023	Time:	13:10 - 15:00

FINDINGS AND CONCLUSIONS:

Session 2 was on Condition monitoring and managing assets in substations. Overall, four papers were presented by authors from AU, CA and JP. They cover a wide range of research topics, from comprehensive managing assets in substations (3 papers), and challenges to the estimation of the failure rates for the substation equipment (1 papers).

This Session was led by Session Chair, **Crina-Miana Costan**, Australia, and Secretary, **Samuel NGUEFEU**, France.

Paper #	Paper	Presenter
1126	**Challenges in implementing comprehensive asset online monitoring solutions**	**Terry Krieg (AU)**
1149	**Using Automated Infrared Monitoring to Reduce Substation Maintenance Costs**	**Ali Hamze (CA)**
1320	**Development and Implementation of an Asset Information Platform for Substations**	**David Peters (AU)**
1180	**Estimation of degradation curves for substation equipment using text mining**	**Tomohiro Kobayashi (JP)**

SYNOPSIS OF PRESENTATIONS

Presentation 1, **Challenges in implementing comprehensive asset online monitoring solutions** focused on examples where online condition monitoring were installed, such as quality control for power transformers. The benefits of the online condition monitoring were proven many decades ago.

The key requirements to ensure the effectiveness of the online monitoring are the ability to extract and report the data in a meaningful way and to have the required expertise to interpret the results.

Presentation 2, **Using Automated Infrared Monitoring to Reduce Substation Maintenance Costs** presented a comparison between infrared measurements taken from the substation equipment on a one-off measurement versus the continuous online monitoring.

Continuous online infrared monitoring can provide real-time information about the health of the substation equipment. Occasional infrared scanning of equipment does not provide sufficient information about the potential equipment faults that can then lead to failures. When coupled with machine learning techniques that can be trained to identify normal operation results patterns, the continuous infrared online monitoring can lead to an efficient

automated way to monitor the health of the substation equipment. The location and the projected angles of the probes are very important part of the setup of the online condition monitoring. The actual equipment temperatures are obtained by comparing the temperature rise between the phases, in this way the influence of the ambient temperatures or the solar radiation are excluded.

Presentation 3, **Development and Implementation of an Asset Information Platform for Substations** described the 'journey' of a utility in developing the in-house tools for data acquisition and the creation of an asset information platform. With time more tools -MAIT - were developed that allowed portable data acquisition to be downloaded to the platform with information taken from site by the use of barcoding and linked to the equipment photos. Lastly the DAIT system was implemented that allowed for the maintenance tasks to be listed and prioritised in the order of their urgency and the importance.

Presentation 4, **Estimation of degradation curves for substation equipment using text mining.**

This paper is a continuation of a trial which was reported at a previous symposium – in Chengdu - and involves the use of machine learning to determine the degradation curves that will assist with the estimation of the failure rates for the substation equipment.

Actual test data combined with data received from the web was used to plot the degradation curves for equipment such as power transformer, OLTC, circuit breaker etc. A large percentage of the data was randomly selected from the total correct data in each equipment was used as training data for the classifier, and the remaining 25% was test data. The degree to which the parts matched those originally assigned by humans was used as the definition of the accuracy. The trial demonstrated that if sufficient actual data is used, when mixed with randomly data an accurate equipment degradation curve is obtained. While this is an experiment and requires further work, the results of using machine learning techniques in estimating the equipment failure rates is very promising.

CONCLUSIONS

All papers included very useful information related to the online condition monitoring and asset management. A brief description is presented.

Overall, the session provided a comprehensive view of the evolving landscape of online condition monitoring and asset management, showcasing innovative solutions and methodologies.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	B3	SESSION NUMBER	3
Date:	September, 07, 2023	Time:	15:30 - 17:20

FINDINGS AND CONCLUSIONS:

Session 3 was on Sustainable substation solutions considering environmental impacts. Overall, six papers were presented by authors from JP, AU and NZ. They cover a wide range of research topics, from minimising GHG emissions towards net zero carbon targets (4 papers) to addressing seismic challenges in substations (2 papers).

This Session was led by Session Chair, **Mark Kuschel**, Germany, and Secretary, **Andres Laubi,** Australia.

Paper #	Paper	Presenter
1188	**Gas tightness technology for SF6 Gas Insulated Switchgear and application to synthetic air insulated switchgear**	**Koma Sato (JP)**
1172	**Long-Term Use of Substation Equipment considering Environmental Impacts**	**Soichi Moriguchi (JP)**
1247	**An SF6 Switchgear Network Emissions Model to Inform Strategic Decisions**	**Evan Lamplough (AU)**
1366	**Sustainable substation solutions**	**Lara Kruk, Daniel Stafford (AU)**
1378	**Development of Seismically Strengthened 500kV Air Insulated Disconnector and Practice of Seismic Countermeasures Based on the Experience of a Huge Earthquake**	**Yuki Ishikawa (JP)**
1333	**New Zealand's new National Seismic Hazard Model (NSHM): implications for the design of substations and electrical equipment**	**Doralba Valencia Restrepo (NZ)**

SYNOPSIS OF PRESENTATIONS

Presentation 1, **Gas tightness technology for SF6 Gas Insulated Switchgear and application to synthetic air insulated switchgear** aims to describe the application of the gas tightness technology to the synthetic air insulated switchgear, that is based on the experience accumulated in previous SF6 GIS. Gas leakage is calculated and also estimated in the case of synthetic air. The authors investigate the long-term data of gas leakage obtained from the substations and attempt to compare and evaluate the field data with the data obtained from the factory elemental tests. The result of the estimation satisfies the requirement of 1%/year specified in IEC-62271-1.

Presentation 2, **Long-Term Use of Substation Equipment considering Environmental Impacts** describes the activities and efforts studied and implemented in substation operation and maintenance to deal with reducing the environmental impacts during long-term operation of SF6 gas switchgear (e.g. gas leakage

prevention, IoT utilisation to reduce the number of inspection), and also describes the effect of the reduction of GHG emissions in its lifecycle by them.

Presentation 3, **An SF6 Switchgear Network Emissions Model to Inform Strategic Decisions**

Transgrid is the transmission network operator and manager in NSW and has been tracking SF6 emissions for many years. To support long term strategic planning, an emissions model has been developed which considers key variables, including existing population, expected asset growth, predicted leak rates, strategic scenarios for non-SF6 technology adoption. The tool provides a valuable resource to help inform decisions on the strategies to be chosen to reduce SF6 emissions across a large fleet of high voltage assets and monitor performance over time against expected values.

Presentation 4, **Sustainable substation solutions**

The Energy Transition requires building an increasing number of substations to provide connections for renewables to the grid. This supports the de-carbonisation of the electricity system, but there are also opportunities to build substations with less embodied carbon than current practices. There are numerous innovative solutions with sustainability benefits that can be implemented on projects. Items include cross laminate timber buildings, composite materials, low carbon concrete, SF6-free switchgear, alternatives to diesel generators and the use of electric vehicle construction machinery.

Presentation 5, **Development of Seismically Strengthened 500kV Air Insulated Disconnector and Practice of Seismic Countermeasures Based on the Experience of a Huge Earthquake**

In this paper, the evolution of seismic design and testing technologies and further seismic strengthening technologies developed through the experience of the Tohoku Earthquake, using 500 kV air insulated disconnector as a subject, are described. And also, this paper describes the learning of seismic countermeasure that should be taken into account by electric power companies based on experience of damage at substations.

Presentation 6, **New Zealand's new National Seismic Hazard Model (NSHM): implications for the design of substations and electrical equipment** examines the new National Seismic Hazard Model (NSHM) for Transpower (TP) substation sites in terms of Spectral Acceleration (Sa), Peak Ground Acceleration (PGA), and Hazard factor (Z). It identifies the implications of these updated seismic loads on TP assets. For equipment, this paper compares the IEEE 693 qualification spectrum to the new NSHM. For existing buildings, this paper recognises the seismic load increase that may result from adopting the new NSHM. For new buildings, it also explores the use of Mass Timber as an alternative to conventional precast concrete wall design.

CONCLUSIONS

The session encapsulates a comprehensive overview of critical topics within the electrical power industry. Presentations covered a wide spectrum of subjects, ranging from gas tightness technology applied to synthetic air insulated switchgear, to long-term environmental considerations in substation operation, and the development of strategic emissions models for SF6 switchgear. Additionally, there was a focus on sustainable substation solutions in light of the energy transition, including the adoption of low carbon materials and SF6-free switchgear. The session also explored seismic strengthening technologies, with a case study on a 500kV air insulated disconnector, and highlighted lessons learned from past seismic events. Lastly, the implications of New Zealand's National Seismic Hazard Model (NSHM) on substation and equipment design were discussed, along with innovative alternatives. These presentations collectively underscored the industry's dedication to efficiency, sustainability, and resilience in a dynamically changing energy landscape.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	B5	SESSION NUMBER	1
Date:	September 04, 2023	Time:	10:30 – 12:20

FINDINGS AND CONCLUSIONS:

Dr. Nirmal Nair chaired the 1st session of SC B5. The session was focused on protection, automation and control issues related to operational experience. Approximately 130 people attended the session. The following papers have been presented:

1. **1112 - Practical experience of maximising Safety, Reliability and Efficiency of rural distribution networks**
   Presented by Hugh Borland
   Anseris IQ, Ireland

   As earth faults predominate at Medium Voltage (MV), the primary requirement is for optimum safety at the fault site which is achieved by minimizing energy release. The low energy release of Compensated Neutral (CN) systems is compared with non-CN systems showing many orders of magnitude difference. The selection of a CN approach was shown to provide optimized reliability with the significant improvements in SAIFI and SAIDI quantified. The application of Synchronised Data Monitoring (SDM) exploiting data analytics delivers maximised efficiency in returning supply to customers.

2. **1202 - The Need for Simplicity in Arc-Flash Protection Design**
   Presented by Luke Napier
   Schweitzer Engineering Laboratories, Inc., Australia; papers@selinc.com

   This paper discusses the impact that arc-flash design decisions have on the tripping time and the need for simplicity in arc-flash protection systems. These decisions include the use of IEC 61850 to distribute the three main functions of arc flash: light, current detection, and tripping among multiple devices. The paper also includes an assessment using standard logic to perform additional logic checks for arc-flash protection systems. The simplification of complex arc-flash protection is demonstrated using practical examples experienced during a recent project at a power station in Australia.

3. **1207 - Detection of Open-Circuit Downed Conductor Faults – Problems and Solutions**

   Presented by Stephen Chiu
   Powerco, New Zealand

   This paper presents the results of the New Zealand (NZ) CIGRE B5 working group's research on protection of open-circuit downed conductor faults. It gives an overview of this type of faults in the distribution network and summarizes the learning of a literature review on the subject matter. The paper presents the results of a survey that the group developed to explore the current practices and challenges that NZ distribution utilities are facing. Furthermore, the paper describes the trials of alternative technologies that are currently undertaken by two NZ utilities. Finally, it discusses the next steps for the working group.

4. **1455 - Experiences and Learning on Monitoring Digital Substation Communication Networks**

   Presented by Paulo Junior
   Conprove, Brazil

   This paper aims to carry out an analysis of the importance of monitoring the network in the context of IEC 61850, highlighting the requirements necessary for monitoring and discussing its implementations, disseminating experiences and learning acquired in digital substations, and complying with power system best practices of the Brazilian Transmission System Operator (TSO).

The discussion covered the following aspects:

- Several utilities in Australia discussed about the use of compensation in their networks and discussions ensued about effectiveness, cost and applicability.
- Some discussions around arc-flash sensors and what advantages does IEC 61850 bring to the table happened.
- As digital substation installations increase in coming year, the role of monitoring of the health and effectiveness of the underlying communication networks that was presented generated some good questions and discussions.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	B5	SESSION NUMBER	2
Date:	September 04, 2023	Time:	13:20 – 15:10

FINDINGS AND CONCLUSIONS:

Dr. Bogdan Kasztenny chaired the 2nd session of SC B5 with the help of Richard Adams. The session was focused on protection issues related to unconventional sources, low and unusual fault current, and low system inertia. Approximately 130 people attended the session. The following papers have been presented:

1. **1132 - Line Protective Relays Suitable for Systems With a High Penetration of Unconventional Sources – Operating Principles and Field Experience**
   Presented by Bogdan Kasztenny
   Schweitzer Engineering Laboratories, Inc., Canada

   The transient-based line protection principles presented in this paper were implemented in 2017 in a high-performance, fully digital, ultra-high-speed relay. These relays have been in service since then, including in systems with a high penetration of unconventional sources. To date, the relays have accumulated significant field experience. The relays routinely trip on the order of 1 to 5 ms, reducing the fault clearing time to 1.5 cycles when using two-cycle circuit breakers. The paper briefly explains the protection principles, discusses application factors, and presents field cases.

2. **1405 - Frequency Measurement in protective relays and impact by Renewable Energy Sources**
   Presented by Chirag Mistry
   GE Grid Solutions, Australia

   Frequency measurement algorithms implemented in the numerical relays today have been based on the synchronous generation. Increasing penetration of renewable energy sources is resulting in lower system inertia leading to faster frequency excursions. This makes it challenging to strike a balance between frequency response time and measurement accuracy.

   This paper identifies these challenges and discusses improvements that can be made to the algorithms. A thorough evaluation of the improved frequency measurement algorithm is performed, using both field cases and simulated signals.

3. **1440 - Novel algorithm for actual boundaries of distance protection in case of fault current contribution from power electronic systems**
   Presented by Manuel Galler
   Institute of Electrical Power System, Austria

   The problem addressed in this work is the fault current contribution of power electronic systems, which affects the distance protection algorithms. Therefore, a combined hardware-in-the-loop system is used to study the impact on the reliability of protection relays. The use of real power converter systems enables holistic testing of protection device behavior, and the novel distance protection algorithm is applied in post-processing. The results demonstrate the possibility of using novel algorithms where conventional distance protection relays are already reaching their limits.

4. **1243 - Fault Analysis of Large-Scale Renewable Energy Only Fed System**
   Presented by Craig Aumuller
   Amplitude Consultants, Australia

   As modern power systems progress to the point where they primarily contain inverter-based renewable energy generators with little to no synchronous machines the fault currents in the system will need to be carefully considered. This paper presents the results of fault analysis undertaken for a large-scale power system which contains only inverter-based generators and investigates the pros and cons of fault calculation methods to ensure an adequate picture of the available fault contributions are captured.

5. **1143 - Directional Overcurrent Protection Near the Inverter-Based Resources**
   Scheduled[1] to be presented by BILLY F. YANCEY III
   EPE Electric Power Engineers, USA

   This paper presents a new technique to achieve directional overcurrent protection using microprocessor relays even if the grid-tied generating unit is not supplying any negative-sequence current. This proposed scheme is easy to implement in any digital relay that is equipped with negative-sequence current polarized directional overcurrent element. A real-life IBR interconnection project is modelled using an inverter vendor model in PSCAD/EMTDC. The digital relay and the proposed scheme are added to the PCC recloser. The performance of the scheme is demonstrated for various faults.

[1] The presenter was not in the room. A spontaneous presenter emerged and claimed to be asked by the author(s) to present. This presentation was not great. We need to think about the procedure to prevent this kind of ad hoc presentation without sufficient quality.

The discussion covered the following aspects:

- Transient-based line protective relays that use traveling waves and fast incremental quantities provide an excellent option for line protection near unconventional sources (inverter-based sources and induction machine-based sources).
- Initial fault transients are independent of source characteristics and therefore allow protecting lines near unconventional sources.
- Transient-based relays are relatively dependable. Faults do not occur at voltage zero-crossings and as a result one can count on robust transient-based operating signals.
- Increased reliance on protection channels (pilot protection schemes, direct transfer trip, breaker failure with DTT) is a simpler solution than relying on distance protection for line protection and remote backup protection. R-GOOSE is one of new ways to provide station-to-station protection communications.
- Frequency measurement used for frequency protection and related functions such as to make phasor measurement accurate, need improvements for applications in systems with low inertia and unconventional sources. Special attention shall be given to “security post-filtering” and rejection of invalid momentary measurements of frequency.
- The distance protection principle implemented without polarization, i.e. purely based on an apparent impedance, performs better in system with unconventional sources. Fault resistance and infeed effect are a larger challenge in system with unconventional sources, so is the issue with directionality. These issues remain important concerns for the future of distance protection in the new and changing networks.
- Fault current calculations and modeling remain challenges in systems with unconventional generation. Frequent changes in the source control algorithms enacted via firmware upgrades may invalidate the short circuit models. Also, unconventional sources have a number of “settings” and when these settings are changed, the fault current calculations can be questioned.
- Directional protection in distribution networks can be sometimes obtained by using the fault current level, taking advantage of the week feed from an unconventional source, and strong feed from the grid.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	B5	SESSION NUMBER	3
Date:	September, 04, 2023	Time:	15:40 – 17:30

FINDINGS AND CONCLUSIONS:

Volker Leitloff chaired the 3rd session of SC B5, which was focused on experience feedback with IEC 61850 based substations. Approximately 130 people attended the session. The following papers have been presented:

1. **1147 - Functions implemented in fully digital protection automation and control system R#SPACE supporting end-to-end applications**
   Presented by Volker Leitloff
   Rte, France

   Fully Digital PACS offer the opportunity of regrouping the process interface, pre-processing capacity and providing gateways for remote applications. This allows significant synergies. One key element is the use of a common data model shared by the different applications. Based on the process interface defined and implemented in the fully digital PACS R#SPACE project developed by Rte, this article illustrates how these measurements can be interfaced with the PACS. The relevant experience feedback from the “Postes Intelligents” demonstrator project is described.

2. **1157 - Interoperability test of IEC 61850 process bus system and establishment of design policy for process bus application system**
   Presented by Shotaro SAKAI
   Chubu Electric Power Grid Co.,Inc, Japan

   This paper introduces the configuration of the process bus application system to be introduced to the Chubu Electric Power Grid Co., Inc. the main contents of the system specifications, and the verification results of the interoperability test. As a result of the verification, it was confirmed that each function including protection works correctly in a combination of multi-vendor IEDs and Mus.

3. **1276 - Success deployment of 6 digital substations in Vietnam 2020-21 – Return of experience**

   Presented by Chirag Mistry
   GE Grid Solutions; Australia

   This paper describes the success of 6 digital substations in Vietnam 2020-21, its design principles, architecture adopted, reliability analysis of protection and control (PAC) scheme in digital substation, benefit of digital substation standardization, proven benefit of IEC 61850 process bus, lessons learned and the return of experience of deploying these six digital substations.

4. **1395 - The Implementation and Design Decisions of Process Bus Technology for Distribution Substations at Endeavour Energy**

   Presented by Ray Robinson
   Endeavour Energy, Australia

   Sydney, Australia, is undergoing significant growth and redevelopment. To support the required upgrades to electrical infrastructure, the project team chose IEC 61850 digital substations and process bus technology to expedite construction, reduce costs, and enhance operational efficiency.

   Extensive research and development resulted in modular prefabricated buildings for concurrent construction and compact control room layouts with reduced cabling. The project demonstrated the agility of digital substations and achieved substantial cost savings.

   This paper has been elected as best B5 paper of the Cairns symposium.

5. **1402 - Modelling and Challenges of Power Quality in the context of Full Digital Substations**

   Presented by Chirag Mistry
   GE Grid Solutions; Australia

   Renewable energy sources have electronic interfaces and they behave different to synchronous generators resulting in numerous challenges, power quality being one of the major ones. Class A of IEC61400-30-4 imposes stringent set of requirements on power quality meters. This paper discusses Class A PQ meters in the context of IEC61850 modelling and introduces conceptual Class A meter deployed in distributed architecture composed of a generic Stand-alone Analogue Merging Unit sharing data with hypothetical IED. Advantages, challenges and ideal specifications are discussed.

The discussion covered the following aspects

- Is it preferable to use HSR, PRP or doubled star-linked protection chains without IEC 61850 redundancy? There are several opinions. It was pointed out that this was covered by the survey of WG B5.69, the conclusion of which was that any of the three options can be selected, depending on user constraints and requirements.
- The assumptions used in reliability studies of fully digital PACS are mostly based on data extrapolated from components used in PACS deployed over the past decade. The experience feedback regarding reliability of components in fully digital PACS will provide in time updated reliability data.
- There are concerns regarding electronic components used as process bus interface installed in the switchyard. These components potentially experience higher levels of constraints of EMC and temperature.
- The extension of data acquisition via the process bus to monitoring quantities of HV equipment may require a review of the corresponding utility organisation.
- Use of SV acquired via Merging Units and Process Bus for revenue metering. This possibility is not taken into account by a part of the national regulations.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	B5	SESSION NUMBER	4
Date:	September, 07, 2023	Time:	10:20 – 12:00

FINDINGS AND CONCLUSIONS:

Cedric Moors chaired the 4th session of SC B5, which was dedicated to applications for protections, automation, control and monitoring. Approximately 150 people attended the session. The following papers have been presented:

1. **1246 - Powerlink's Journey to a Wide-Area Monitoring, Protection, and Control System**
   Presented by Daniel Moulds
   Powerlink Queensland, Australia

   Powerlink, as Queensland's Transmission Network Service Provider, responded to a mandated non-credible system contingency, paving the way for the ground breaking WAMPAC system. The 18-month journey encompassed design, testing, and commissioning. This paper delves into the technology, challenges, and the significance of scalable/standardised infrastructure for supporting Queensland's future energy plans. The reader will embark on a captivating exploration of this transformative endeavour.

2. **1185 - Use of ML and AI for automated outage prediction and risk management for improved system resilience**
   Presented by Mladen Kezunovic
   Texas A&M University, United States of America

   The development of data models for automated faults analysis using synchrophasor data is discussed first. The concept of State of Risk (SoR prediction, and associated optimization techniques aimed at minimizing or eliminating the distribution system outage impacts through appropriate risk management and mitigation measures is introduced next. The issue of aggregation of DERs with a purpose of meeting Ancillary Service Product (ASP) requirements designed to help market operators maintain power system reliability and integrity during imbalances between supply and demand is elaborated last.

3. **1270 - Experiences with implementing IP based Metering Solution**
   Presented by Manu Chauhan
   Powerlink Queensland, Australia

   Powerlink Queensland is a Transmission Network Service Provider (TNSP) within the state of Queensland and is responsible for the provision of metering services for several direct customer connections. As a result of several technological changes in telecommunications networks, there has been a need to change the way metering data is supplied securely to the National Energy Market. This paper describes a proactive approach taken to identify a solution that minimised the use of 3rd party infrastructure for metering data access allowing the TNSP to drive more value out of its existing assets.

4. **1271 - On-line Equipment Status Monitoring for Reliability Improvement of New 6kV Solid Insulated Switchgear (Smart SIS)**
   Presented by Tomoya Yoshimura
   Meidensha Corporation, Japan

   In this paper, the on-line condition monitoring of Smart SIS was explained, and some examples of the good verification results were introduced. There are three online sensing items in smart SIS: " operation time of circuit breakers, disconnectors, and earthing switches ", "zero-phase voltage and current", and " Temperature and humidity in movable panel ". This paper also describes the concepts of workload saving and upgrading of operation and maintenance using the sensing information and the results of verification tests.

5. **1398 - DSO-driven implementation of OT integration platforms for data driven operation and maintenance**
   Presented by Anders Johnsson
   Vattenfall Eldistribution, Sweden

   The paper presents how the Swedish DSO Vattenfall Eldistribution has developed and implemented an integration platform for operational data. Use cases include collection of transformer monitoring data, retrieval of fault recording data, power quality data and transfer of operational data from the control center. The integration solution include a multipurpose substation gateway working in parallel to the standard RTU interface. The gateway can handle different data streams using open standard protocols such as IEC 61850 on station level and CIM-based data exchange in the integration platform.

The discussion covered the following aspects

- In some countries, SIPS deployment has become mandatory to face the fast growth of onshore and offshore decentralized production (PV production, wind production) and the load increase as a consequence of decarbonisation. The discussions pointed out some important aspects of the design, such as redundancy and test plan, but also the need for a proper coordination between SIPS whose decision processes could influence each other.
- The use of AI in PAC applications, especially in monitoring applications, is becoming quite popular and can bring a real added value to build useful information from all data collected in substations. A specific attention must be paid in using these methods on a well-understood way: carefully choosing the learning set and the test set, knowing when the learning process has to be relaunched are key success factors to maximize the benefits offered by those methods.
- Nowadays, plenty of data are available in substations and can be used to improve our decision processes. These data come from PAC IEDs, but also from dedicated sensors that are installed close to primary equipment in order to get specific measurements. The discussions showed the importance to design a clear acquisition chain aimed at gathering all these data and at formatting them in such a way that they can be used seamlessly at a higher level. The integration of this acquisition chain in the classic control architecture (RTU/DCS or substation gateway) is also an important consideration.
- An increasing number of applications make use of packet-based telecommunication technologies, such as MPLS or 4G. These technologies have a limited lifetime (phase-out of 3G has already announced in some countries), this aspect must be taken into account when deploying new solution in order to mitigate the risk of early replacement (example: use of 4G/5G compatible equipment).

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	B5	SESSION NUMBER	5
Date:	September, 07, 2023	Time:	13:10 – 15:00

FINDINGS AND CONCLUSIONS:

Alex Apostolov chaired the 5th session of SC B5, which was dedicated to design and time synchronization of IEC 61850 based substations. Approximately 150 people attended the session. The following papers have been presented:

1. **1199 - Establishing Reliable Time Synchronization for Digital Substations**
   Presented by Fred Steinhauser
   OMICRON electronics, Austria

   Digital Substations have made time synchronization a necessity for electrical power systems. The delivery of precision time is an essential task for the infrastructure. Redundant time distribution is an evolving field of expertise. To efficiently tackle it, parsimony might be the key. Obtaining precision time is still very much seen in connection to the availability of GNSS only, but alternate concepts exist. The timing industry has advanced options available. With these measures applied, GNSS attacks can be detected. Sufficient holdover enables riding through any realistic attack scenario.

2. **1236 Definition of communication function specifications for interoperability and interoperability test results on IEC 61850 station bus system**
   Presented by Takashi KOBAYASHI
   Toshiba Energy Systems & Solutions Corporation, Japan

   The application of IEC 61850 and the realization of multi-vendor connections will lead to many benefits. In order to achieve a multi-vendor connection, each PACS device must communicate according to common rules. IEC 61850 defines a huge data model, but most data models are optional and unnecessary for devices. The authors created communication specifications for IEDs to tackle challenges. This paper introduces the main contents of the specifications, the system configuration adopted by Chubu Electric Power Grid, the functions of each device, and the results of verification tests.

3. **1258 - Development of Multi-vendor Protection Relay System Employing PTP with IEC 61850 and Evaluation of Time Synchronization Accuracy for Current Differential Calculation**
   Presented by Hiroyuki Yusa
   Central Research Institute of Electric Power Industry, Japan

   This paper shows Merging Unit (MU) and Intelligent Electronic Device (IED) prototypes manufactured by multiple vendors for Japan's protection functions, and the results of functional examinations using IEC 61850 Sampled Values (SV) and Generic Object Oriented Substation Event (GOOSE) communication are presented. Furthermore, we propose a next-generation system architecture that combines MUs and IEDs; this system can realize sampling inside and outside an electrical station using an IP network and PTP time synchronization.

4. **1380 - Protection Automation and Control Systems Top-down Engineering Process – From SSD File to Device Configuration**
   Presented by Mateus Alexandrino
   Eletrobras CGT Eletrosul, Brazil

   The paper presents the IEC 61850 data representation design conceived to a 230 kV transmission line bay on a double bus (main – main/transfer) with four switch disconnectors bus bar scheme Protection, Automation and Control Sytems (PACS), including Logical Nodes (LN) distribution among PACS devices and new Data Objects (DO) configured. Following, it shows the SSD file developed considering the application of PIU digitalizing all primary equipment and the tests performed with commercial IED and PIU in laboratory enabling a top-down engineering process for PACS developed with IEC 61850.

5. **1422 - The overwhelming task to design a GGIO-less Protection & Control System**
   Presented by Guilhermme Lisboa
   Belden, Brazil

   This abstract discusses the challenges encountered while deploying a process bus-based PAC system without using generic logical nodes in accordance with the IEC 61850 standard. The goal was to create an easily understandable SCD file by leveraging the full potential of the IEC 61850 data model. However, the absence of desired data objects in the standard and the time-consuming process of customizing IED configuration led to difficulties in modeling primary equipment. Despite delivering a substation without generic LNs, the required effort for bottom-up design outweighed the benefits.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	B5	SESSION NUMBER	6
Date:	September, 07, 2023	Time:	15:30 – 17:20

FINDINGS AND CONCLUSIONS:

Anita Oommen chaired the 6th session of SC B5, which was focused on experience with asset management of PAC systems. Approximately 150 people attended the session. The following papers have been presented:

1. **1374 - Harvesting Intelligent Device Data to Improve Asset Management and Operational Outcomes**
   Presented by David Prestwich
   Schweitzer Engineering Laboratories, Inc., United States of America

   This paper described the diverse device-centric information available to a modern utility and how such data can be used to better learn from power system events while also being able to manage aspects such as network security and expansion. The paper described a specific utility's experience of moving operational data from devices in the field to a centralized location for enhanced presentation and analytics. Focus was on the iterative development process, laboratory testing, application design, and deployment required to integrate legacy and contemporary IEDs.

2. **1416 - The shape of the IED settings tool to come: an essay focused on configuration and standardization**
   Presented by Guilhermme Lisboa
   Belden, Brazil

   With a significant rise in the load of configuration and testing as the number of IEDs in substations grows, this paper proposed an alternative method for configuration and testing on multiple projects, utilizing IEC 61131-3 for PLC, libraries and structured programming based on instances. The target is related to identifying ways to handle multiple similar devices as a group instead of individually, which could minimize the number of IED configurations and testing, as well as optimise the configuration process. It also enables settings to be standardized and reproduced easily on other projects, with a method that can share a significant portion of this structure between different vendors.

3. **1452 - Post-fault analysis for the end-to-end power system**
   Presented by Marco Antonio Macciola Rodrigues
   Electrical Energy Research Center - CEPEL, Brazil

   This paper described enhancement of an existing fault analysis system. Simulated fault recordings obtained from an EMTP system model are used to assess the performance of the fault analysis system for both fault diagnosis and fault location. Enhancements of phasor estimation, as well as new algorithms focused on phasor and travelling wave data filtering, integration of information from other sources such as SCADA, PMUs and georeferenced data (such as vegetation burnings and lightning strokes) are discussed. Communication of results of data analysis or system alerts are to stakeholders is also mentioned.

4. **1427 - Standardizing the protection calculation process of Renewable Plant Protection system to ensure the coordination and consistency of Vietnamese Protection system**
   Presented by Ngoc Han NGUYEN
   National Load Dispatch Center of Vietnam, Vietnam

   This paper described the standardisation process followed by the Vietnam National Load Dispatch Centre for RE plants. A guideline was developed for protection engineers in their task and was the basis for the creation of an automatic protection setting calculation tool. The tool uses a popular short-circuit software to simulate faults and calculate short-circuit current required for setting for each protective function of the RE plant. Furthermore, the automatic tool could also evaluate the aspects such as different configurations of plant, grounding methods of MV grid.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	B5	SESSION	TUTORIAL SC B5
Date:	September, 07, 2023	Time:	08:00 – 09:50

FINDINGS AND CONCLUSIONS:

Anita Oommen chaired and opened the Tutorial Session of SC B5, which was focused on Applying Synchrophasor Technology for Protection of the Power System. Approximately 200 people attended the session. The following presentations were made:

1. **Introduction to/concepts of synchrophasors**
   Presented by Mladen Kezunovic, Texas A&M University, USA

   This presentation covered the basic understanding of synchrophasors. Content covered included the principles of the technology, potential areas of deployment of end-to-end voltage measurement via SCADA visualisation for operator control, WAMPAC visualisation, and protection applications and listed the various available IEEE and IEC standards that apply to synchrophasor technology. A comparison of the realisation of mainstream adoption of various applications against what was planned was given, with applications ranging from operations, engineering, asset management, fault analysis, model improvement, stability analysis to SPS and RAS, WAMPAC applications. Future aspirations include control in smart grids, monitoring of IBR and DER interfaces, protection applications, monitoring and analysis of low frequency oscillations, asset and outage management.

2. **WGB5.62 TB843 Summary - Life Cycle Testing of Synchrophasor Based Systems used for Protection, Monitoring and Control**
   Presented by Ritesh Bharat, CitiPower &Powercor, Australia

   This presentation covered the benefits of testing of synchrophasor based systems as part of life cycle management including life span extension, cost saving, reduced downtimes, improved efficiencies and better decision making. The WG sought to cosolidate applicable standards to this technology and define a framework for testing and certification of PMUs. The testing requirements of various applications across the world were reviewed in order to formulate the recommendations for this work. Interoperability across products of different manufacturers and end to end testing is vital for integration. Calibration and certification is needed to ensure that the PMUs are fit for the specific application. Backward compatibility and interoperability with legacy systems is necessary.

More rigorous testing practices must be developed for in-service testing and users must be adequately trained.

3. **Market Operator AEMO Wide Area Monitoring System (WAMS) Synchrophasor Project & Associated Standard Data Guidelines)**
   Presented by James Guest, AEMO, Australia

   This presentation described the WAMS solution developed in response to network challenges experienced by AEMO and NEM. These include large load areas around cities separated by very long distances, very distinct inter area oscillation modes, very high penetration of IBRs some in very weak parts of the network, new challenges in managing system inertia, strength and frequency response as a result of decommissioning of synchronous generation. Less damping in the network, greater voltage fluctuations for even small disturbances are experienced. High penetration of IBRs in weak parts of the network further aggravate the problem as they offer no system strength which results in instability of the network. The voltage oscillations between 5-25Hz are not visible on SCADA which renders the operator 'blind'. Visibility is critical to operate the network and PMU based WAMS provides this. PMUs have been deployed, named for easy identification and common settings have been developed for application across the NEM networks and real-time monitoring is available. Future developments include use of data for control purposes.

4. **South Australia Wide Area Protection Scheme (WAPS) Synchrophasor Application associated with increased renewables and interstate connection**
   Presented by Filip Ivanovski, CSE, Australia

   This presentation described the WAPS solution developed in response to network challenges experienced on the South Australia network. The WAPS system detects multiple generation loss and initiates control action to prevent severing of the SA system from the NEM. 3 stages are activated namely energy injection from BESS, load shedding and out of step tripping to island the SA network. The WAPS responds to triggers of angle and frequency changes for angular stability events, power balance changes, large and fast frequency and ROCOF drop. Complex multi event simulations were used to test and tune the scheme. Hybrid application of hardware in the loop and simulation was used during FAT and the power system model was thus validated. Future steps include establishment of a geographically diverse redundant AC connection into South Australia with SPS able to detect non-credible loss of either connection, with associated control of preventing tripping of the remaining interconnector due to transient instability.

5. **Powerlink Synchrophasor WAMPAC Anti-islanding scheme**
   Presented by Daniel Moulds, Powerlink, Australia

   This presentation described Powerlink's WAMPAC anti-islanding solution developed in response to increased IBR penetration in the network. A combination of PMUs and PDCs is used for monitoring and control. Anti-islanding and overvoltage related tripping is effected by comparison of voltages and frequencies of the generation bus with a reference bus. Importance is stressed for the aligning of synchrophasor frames for logical processing. Delays can result due to asynchronous packet arrival and associated timeout settings. If all PMUs are healthy there are no scheme implications, if one PMU is unhealthy, all schemes may be affected by subsequent wait-time delays. The 9 anti-islanding schemes in service use standard anti-islanding and overvoltage function blocks, and standardised testing and test plans. The positive aspect is that synchrophasor based protection schemes are relatively inexpensive to deploy due to low complexity and modularity. The negative aspect is the inherent time delays that may be associated with this technology.

6. **Synchrophasors – TasNetwork's Experience and Applications**
   Presented by Muhammad Zakir, TasNetworks, Australia

   This presentation described TasNetwork's use of synchrophasor systems in response to reduced synchronous generation and increased dependence on synchronous condensers. With changing dynamic network behaviour, synchrophasor technology enables post event analysis, evaluation of fault ride through capability of generators, perform network model validation, evaluate protection scheme behaviour, review input to state estimator, and improve situational awareness in the control room. Both dedicated hardware substation integrated, and fully integrated solutions applied. Maloperation of an anti-islanding scheme due to glitch with GPS clock was rectified. Future applications include real time FCAS metering, real time line stability limit monitoring.

7. **Applications of Synchrophasors to distribution networks - An Evaluation of a grid scale data acquisition trial**
   Presented by Martin van der Linde,Nojapower, Australia

   The presenter was not available in person to do this presentation and so a playback of the recorded presentation was made. This presentation covered the benefit of synchrophasor applications in Dx networks, namely lowering costs for DER connections to MV networks, accelerating transition to a sustainable energy future and improvement of system planning under high renewable penetration. It covered performance requirements to maintain Total Vector Error as well as technology description of a new generation of recloser controller. Use of PMU data instead of SCADA for state estimation is more accurate and yields faster

results. Using PMU data, an accurate Distribution network voltage stability index can be calculated. This provides a data driven safe limit for renewable penetration on a per feeder basis. PMU based reclosers can detect partial discharge and insulator flashover by means of a machine learning algorithm that has been designed. Machine learning can also serve to flag faults where conventional protection may fail to do so.

8. **Transpower New Zealand Synchrophasor Synchronism Check Auto-reclose Application**
Presented by Peter Bishop, Transpower, New Zealand

This presentation described Transpower's use of synchrophasor based synch check for auto-reclose. With increased penetration of renewable generation, there is a higher probability of causing equipment damage and posing safety risks without anti-islanding or synch check facilities. The challenge with conventional synch check relays is the need for both bus and line VTs. With embedded generation, synch check requirements are more necessary. 110kV lines do not generally have line VTs, hence there is a cost implication to enable conventional synch check. The synchrophasor based scheme avoids this requirement and therefore there is a cost saving. It utilises a synchrophasor communication channel for voltage signal transmission, as well as a dedicated protection signalling channel for permissive voltage checks. Voltage and frequency information is utilised to determine whether a synchronous condition exists to allow the circuit breaker to close. System studies may be required for some setting parameters particularly voltage transient conditions.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C1	SESSION NUMBER	1-4
Date:	5 September 2023	Time:	08:00 --- 17:25

FINDINGS AND CONCLUSIONS:

This session was split into four sequences, covering a total of 25 papers addressing the preferential subjects:

- Developing practices, functionalities and applications
- Learning from experiences
- Towards a sustainable power system

The papers provided a broad geographic coverage of these subjects in regions as diverse as Australia, Japan, and Europe. Some of the papers dealt with interconnection projects/studies within and across national boundaries. While all papers met CIGRE's exacting quality standards, the 'best paper' from the C1 Session was presented by Professor Pierluigi Mancarella and is entitled "Flexible planning of low-carbon power systems under deep uncertainty".

The presentations were well received and provoked lively discussion, the highlights of which are captured below:

- The opportunities and challenges facing the Australian system were discussed, including; the limited extent of meshing within networks, transmission systems which do not span the (huge) country, and the centralised planning both of major RES development and of transmission and storage assets (including ongoing work to build the world's largest pumped hydro energy storage plant, 5GW). Current issues to address include supply chain constraints, industry uptake, local availability of manpower, and budgetary pressures.
- Demand forecasting, including the impact of consumer behaviour on both maximum and minimum demand, is a prerequisite for robust system planning.
- Microgrids and distributed energy resources: their growing role in supporting the wider system was discussed.
- The enablement of RES deployment was discussed including the roles potentially played by factors such as: designated development zones, standardised decision/investment procedures, regional / national planning processes for new generation (even if investments are then private), and community engagement. The particular challenge presented by offshore wind connections required to meet national needs at, potentially, the environmental expense of coastal communities was discussed.

- The planning methods and tools being deployed to address uncertainty, the scenario planning and long-term development plans being developed, and the multi-factor optimisation being undertaken at system level all reinforce the importance of the transmission system in driving decarbonisation.
- The representation of RES plant in network studies, both static and dynamic, was discussed as was system adequacy, resilience, and RES capacity to provide grid services.
- Least-cost pathways to decarbonisation were discussed, and the complementary roles to be played by probabilistic planning, stochastic planning, and lowest worst-case regret analyses.
- We discussed power system design and the roles to be played by new RES (balance and optimisation), generation curtailment, transmission, storage (ideal split between batteries and pumped hydro), the value of storage to the system, and the optimal use of batteries.
- The use of non-firm connections as a means of providing flexibility, and the efficiency of revenue cap systems, was discussed.
- We discussed asset management: predictive maintenance, maintenance outage planning, and risk analysis.
- The use of technical devices to defer grid reinforcement/investment was discussed: modular reversible compensators, and design examples for remote connections (mining) - balancing economic, environmental and reliability factors.

Antonio Iliceto (C1 Chair)

Peter Roddy (C1 Technical Secretary)

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C2	SESSION NUMBER	1
Date:	September, 06, 2023	Time:	08:00 --- 09:50

FINDINGS AND CONCLUSIONS:

This session presented papers on the theme of "The End-to-End electricity system: transition, development, operation and integration" with the preferential subject focusing on developing practices, functionalities, and applications. The five papers were presented at this session as follows: -

- **Calculation of Dispatchable Region for Renewables with Advanced Computational Techniques** – presented by ***Bin (Brian) Liu***
- **Use of Advanced System Strength Metrics to Identify Critical Regions of a Power Network during Day-to-Day Operations** – presented by ***Hoang Tong***
- **Development of an Application for Rescheduling Unit Commitments Considering Operational Constraints** - presented by ***Satoshi Nomoto***
- **Decoupling Approach for A Unit Commitment Problem with Thermal- and Hydro-Generator Units** – presented by ***Tomoki Takeuchi***
- **Insertion in operation of Renewable Energies Curtailment automatons** – was presented on behalf of ***Florence DELEPOUVE*** (as they were unable to travel)

The session was opened by of Mr. Jayme Darriba Macedo, chair of SC2, followed by a short introduction of the session by the session chair, Prof. Anjan Bose. Through careful stweardship the session ran to time and included many questions (over 30 questions were asked across the sesssion).

The central theme running through both the papers and the presentations were novel approaches and techniques need to be considered, tested and if successful then rolled out. The challenges that low interia and growth of renewable generation can be assited by using modern computing techniques (parralel and high performance) to break the problem space to managable regions. New technigues to highlight areas of low system strenght need to be adopted and automatic load management schemes installed to assit in controling these regions. Also returning to understanding the different elements involved in the challenges in Unit commitment of renewable generation to test and develop new approaches can provide improvements and increased effienecy in the solution space.

In conclusion the papers aligned to the overall theme of the end-to-end electricity system and aligned with the opening ceremony presentations which examined the magnitude of the journey to net zero (from a Queensland perspective) and the need to do things different to achieve the net zero goals (the use of standardisation to simplify some of the supply chain challenges). We cannot meet the global ambition of a net zero carbon energy system by 2035 by doing what we have been doing to date and we need to find new approaches to addressing the challenges of a low inertia system with a wide range of different source of energy at different voltages with the whole energy system.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C2	SESSION NUMBER	2
Date:	September, 06, 2023	Time:	10:20 --- 12:20

Session chair: Anjan Bose, Washington State University (USA)
Special reporter; Gerard Doorman, Statnett TSO (Norway

FINDINGS AND CONCLUSIONS:

A common denominator of the papers in this session could be "using innovative approaches to maximize grid utilization in the context of increasing penetration of weather dependent renewables or weak grids". The papers focus on operational problems and how to solve them. Two papers from Australia describe the use Special Protection Schemes and frequency management after islanding respectively. A paper from India discusses the use of HVDC interconnectors within the synchronous system for power exchange as well as offering relevant grid services. The contribution from Vietnam presents a modified AGC scheme to reduce renewable generation in an equitable way when required. Finally, the paper from South Africa focuses on the low voltage network and the use of smart meters to limit the load when needed to preserve system security.

Paper 1288, "Management of network constraints due to low system strength during network outages using Special Protection Scheme" from Australia shows an application of a Special Protection Scheme (SPS) using Wide Area Monitoring, Protection and Control (WAMPAC). The SPS is capable of managing system strength impacts to IBR plants under planned outages. During a planned outage, the critical transmission lines are monitored. Upon detection of disconnection of a critical transmission line, the pre-selected IBR plants are tripped post-contingent. With this SPS in service, the IBR can operate at a higher output by avoiding the need to have pre-contingent constraints due to system strength.

During the discussion there was a question if other measures had been considered, but this was not the case because of the need for a very fast reaction, within 200 ms. Further there was concern about too much generation being tripped by the SPS scheme, but the presenter replied that the amount of tripping was case dependent and based on offline analysis. Finally, there was a question about compensation to IBR for participation in the scheme. Such compensation was however not deemed necessary as IBRs were allowed much higher production under the scheme than they otherwise would, this being significant compensation in itself.

Paper 1146 "Management of frequency during non-credible events leading to islanding of network regions with Queensland islanding from NEM as a case study". As renewable energy sources displace traditional synchronous generators, power systems face reduced system strength, inertia, and frequency control ancillary services (FCAS). This paper focuses on the integration of wind, solar, and distributed photo voltaic (DPV) sources and analyzes over and under frequency management. A case study investigates the islanding of Queensland from the Australian regions due to a trip in the Queensland - New South Wales interconnector (QNI).

A question came up if such conditions were expected to become more common with climate change, but this was not expected. There was also a question about the conditions in the remaining system. These were however not considered, because while the interconnector tripping is a large event for the Queensland system, this is not the case for the remaining system.

Paper 1426 "Applying AGC system creatively to automatically control multiple power plants resolving grid congestion and maximizing absorption of renewable energy" presents a tool based on AGC, which has the capability of controlling power plants automatically and continuously, allocating power to each RE power plant using selected forecasting capacity ratio. At the same time, it ensures equality and transparency for the power plants involved, while keeping all grid elements in a safe and stable mode. The tool using newly-developed algorithms such as “power ceiling”, “line in series” supports all possible cases in power system operation such as complicated ring or radial line configurations, grid congestions happening at the same time at multiple points and different voltage levels

This is an interesting alternative to mitigate congestion while maximizing grid utilization, but it is dependent on central control and the question remains how this could work in a market environment. The approach prioritizes fairness between renewable generators at the cost of offering some efficiency. This in contrast with Paper 1309 from France, presented in the previous section, where the most effective generators are selected, while compensation for curtailment addresses the issue of fairness.

In the discussion there was a question about inertia. This is not a problem in Vietnam so far, as there is still enough conventional generation in the system at any time. Another question was why renewables were curtailed. It was emphasized that this was only done after conventional generation was reduced to levels that were acceptable under the given operating conditions. After the curtailing of renewable, the system balance is furthermore ensured by hydro units.

Paper 1431 "Optimal Utilization of HVDC Links in Indian Power System for Transmission Flexibility in a High Renewable Regime" addresses the rapid increase in renewable penetration in India, mainly solar and wind, which are concentrated in specific parts of Northern, Western and Southern grids only. This has resulted in bi-directional flows on corridors and various new constraints in the transmission network. The robust HVDC links in the country provide the required transmission flexibility & the system operators of India optimize the utilization of the HVDCs, both in terms of power and direction, to address these unprecedented operational challenges, relieve congestion, and ensure optimal utilization of the network.

During the discussion there was a question about how to obtain more flexibility, which might have solved some of the challenges addressed in the paper. This is a general question regarding all systems. Hydro appeared to be important in India, but like everywhere it will depend on natural conditions and in all cases be limited. There was also a question about load shedding, and the presenter confirmed that this was sometimes used, but only as a last resort. A final comment mentioned the existence of Regional Coordination Centres (RCC) in Europe. The presenter pointed out that also India has regional control centres that cooperate with the national control centre.

Paper 1357 "Using smart meters for low voltage network control and demand management" moves the discussion to the demand side and focuses on how smart meters in South Africa are used for low voltage network control and demand management when the network is constrained and facing various challenges. The paper also highlights a pilot project where load

limiting through smart meters was applied as an alternative to load shedding (rolling blackouts) in South Africa to minimize the impact of load shedding on customers and the community. The load limiting project is yielding positive results. A "staggered" power comeback is used to avoid the well-known rebound effect after all kinds of demand control. The paper also zooms into other demand management initiatives implemented through smart meters.

In the discussion there was a question about under-frequency load shedding and to what extent the meters could take that into account. This appears to be the case, but it had not been used so far. This can be an interesting option to distribute UFCL between more consumers by limiting their power to a small share of their original consumption, and thus avoiding fully shedding whole parts of the grid. The issue of complexity for consumers was also discussed, especially if such schemes become part of the grid tariffs instead of being purely used for system purposes. It may be that consumers have a higher tolerance for this kind of intervention, as power outages are more common than in many other countries outside Africa. In this pilot, they were not given a choice. A final question was about the cost of the meters. It appears that old meters normally meter less than actual consumption, and that the increased consumption measured by the new meters to some extent compensates for the cost of the meters.

Overall conclusions:

The power sector is ready to address unprecedented change from the high voltage down to the consumer level, using technology and innovation to prepare for a carbon free future.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C2	SESSION NUMBER	3
Date:	September, 6, 2023	Time:	13:10 --- 15:00

FINDINGS AND CONCLUSIONS:

The session started on time by short welcome speech of Mr. Jayme Darriba Macedo, chair of SC2, followed by a short introduction of the session by the session chair, Mr. Jens Jacobs. Five papers were presented in the second C2 session:

1. Establish Real-time Pre-commissioning Platform for Integrating Distributed Photovoltaic Energy Resource
2. Advanced initializing and coordination technique for simulation of large scale off-grid network using composite load model, grid forming and grid following inverters
3. AEP's practice in Utility Big Data Management Concerning Real-time System Model Upgrades
4. Coordinated design of Master Power Plant Controllers in Hybrid Plants and Wind Farms with different OEM controls
5. Sub-Synchronous Resonance (SSR) analysis in real-time thanks to the data exchange between the SCADA/EMS system and the offline study tool

All papers were presented by the corresponding authors. First paper was presented by Mr. Richard Yan, second paper by Mr. Sam Maleki, third paper by Ms. Yidan Lu and Mr. Pedro J. Aneses Nieves, fourth paper again by Mr. Sam Maleki and the fifth paper by Minh Quang Nguyen. All presentations were performed within the designated time of 10 minutes, allowing the audience and authors to engage in the question and answers sessions afterwards. In total, fourteen questions were asked by the symposium delegates among the audience, whereas the presentation with most questions was the fifth one.

The papers and presentations shared a common subject: power system modelling and use of models for studies in the off-line domain and for supporting real-time operations. The main takeaway from the session is that although significant advances in modelling and simulation techniques have been made in recent decades, to take full advantage of modern simulation environment under the realm of maintaining power system security while allowing for market transactions and ever-increasing integration of renewable energy, still several challenges must be given an expert attention. Detailed and accurate representation of complex systems, availability of vendor specific equipment in most case only as black-box models, model verification processes and techniques, hardware-in-the-loop testing procedures and test setups, standardization, common model exchange formats, translation of off-line know-how and practices to operational domain and others.

These concerns have been strongly highlighted during the Q&A discussions, which leads to a conclusion that steps made in the past have been significant and have led to major improvements in the equipment hence system design and operations , however rapid developments of various technologies and integration of those into the power system under

the pretext of energy transition is raising the bar for the engineers and their efforts to master the power system complexity.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C2	SESSION NUMBER	4
Date:	September, 06, 2023	Time:	15:30 hrs – 16:30 hrs

FINDINGS AND CONCLUSIONS:

Paper information

Paper number	1280
Paper title	Widespread PMU Installation: Australian Experience
Study Committee	SC C2 – Power system operation and control
Paper Stream	1. Learning from experience
Authors	James Guest, Daniel Lavis
Affiliations (optional)	AEMO
Email address	James.guest@aemo.com.au; Daniel.lavis@aemo.com.au

Summary
As power systems around the world develop and evolve, so do the modes of failure.
In the last several years, the Australian Energy Market Operator (AEMO) and Australian Network Service Providers (NSPs) have observed many new phenomena (such as sub-synchronous control interactions) that have not been seen previously in the National Electricity Market (NEM) and have little or no basis in historical power system literature.
One of the drivers is the technology that interfaces renewable sources of energy to the grid. AEMO is deploying Phasor Monitoring Units (PMUs) to analyse and detect these modes of failure and with advanced analytics, AEMO is developing detailed control room procedures to act on these new modes of failure in real time.

Discussion
The catalyst for the study was an incident in 2022 in South Australia when AEMO received a phone call from a customer at 4am advising that their supply voltage was unstable. Normally SCADA would advise when such conditions existed but AEMO's SCADA did not alert AEMO of instability in voltages; this was an "Unseen Phenomena". With low system strength in South Australia, this condition being unseen, represented significant risk to security of power supply in South Australia and other states with increased Inverter Based Resources (IBR) deployed.

Hence AEMO embarked on a program of installation of over 1,200 SEL 451 relay Phasor Measuring Units (PMU) to provide a 20 ms update time Wide Area Management System (WAMS) view of the grid.

AEMO is currently investigating how to act of the notifications received from their PMUs, including using the Dissipating Energy Flow (DEF) method to determine what to do about sub-sychronous oscillations.

Findings, Conclusions

- Visibility is critical for managing Power System Security
- Phenomena related to low system strength such as Sub-Synchronous oscillations cannot be observed using traditional SCADA
- Wide Area Monitoirng Systems using PMUs have a much higher accuracy and data rate, and are able to detect these oscillations
- AEMO has developed a tool to monitor and alert sub-synchronous oscillations in areas of low strength
- AEMO is investigating the DEF method for identifying the source of sub-synchronous oscillations

Q&A

1. Q: Is the installation of PMUs allowing operators to make changes in close to real time? How can you use this data?
   A: AEMO will be better able to comment on more PMUs are installed and they learn more about what the indications are that they're receiving

2. Q: AEMO has limited the osciallation frequency band to between 5 Hz and 25 Hz – why?
   A: 25 hz is half the sampling rate (50 Hz) so whilst AEMO won't know the exact frequency of the oscillation when it occurs, they'll at least know that there is an oscillation problam.
3. Q: Can you identify when there are multiple oscillations occuring at the same time?
   A: The tool is just looking at frequency. It doesn't care where it's coming from so it's agnostic to the source of the oscillations
4. Q: How long before into production?
   A: This depends on the number of PMUs and hence the resolution. Actually locating the source of the oscillations is a harder problem.
5. Q: Are there NSPs with WAMPACs?
   A: Yes PMUs are being installed at an NSP level e.g. Electranet and Powerlink

Paper information

Paper number	1295
Paper title	Resilience test of Indian power system during extremely severe cyclone 'Tauktae'
Study Committee	SC C2 – Power system operation and control
Paper Stream	1. Learning from experience
Authors	**Raj Kishan, Aman Gautam, Priyam Jain, Mohit Kumar Gupta, Rahul Shukla, Vivek Pandey, S. C. Saxena**
Affiliations (optional)	Grid-India
Email address	amangautam@grid-india.in

Summary
In May 2021, the west coast of India was exposed to a rare and destructive tropical cyclone called "Tauktae". It was the first cyclone in the category of extremely severe cyclonic storm and occurred at the same time as COVID-19 Pandemic restrictions. The presentation described the operational challenges faced in the management of the power system and expanded on the resiliency of that power system to the Tauktae cyclone, including the emergency management procedures deployed for the event.

Discussion
The Indian Power System is very large and the peak demand is around 2225 GW (c.f. Australian NEM of around 36 GW). The part of the grid affected by this cyclone was in the western area of India which has a capacity of 410 GW of which 167 GW is made up of renewables. The Indian grid is affected by weather and other natural phenomena including cyclones, thunderstorms, earthquakes and floods.

Cyclone Tauktae was graded as an "extremely serious cyclone" with winds gusting to 100 knots (185 km/h). It was active over an 1,880 kms front for 5 days and 9 hrs, and made landfall on 17th May for over 12 hrs. The Indian Meteorological Department forecast the event a week before it occurred and hence there was intense operational planning before and then during the event.

This was a high consequence, low probability event. Efforts throughout the event were put into grid security and resource adequacy. System demand was reduced in multiple states as the cyclone moved from South to North on the western coast of India. Key grid impacts included:

- In Goa, 8 EHV lines tripped
- In Gujurat on 18th May, 10 GW load shed and 91 EHV lines affected
- Wind generation backed off due to wind speed
- Solar generation was low due to clouds
- Energy market and prices crashed

Findings/Conclusions

- Early warning of cyclone helped operational planning
- Geo-mapping of transmission assets is required for impact assessment and restoration coordination
- Pandemic affected restoration activities and availability of skilled personnel due to lockdowns
- Adequate pumping to remove water inundation in substations from the cyclone induced rain
- Demand crash due to extrme weather event was successfully managed

- Redundant communcations systems helped to overcome the disruption of data while the cyclone impacted the grid
- System visibility through WAMS and PMUs provided good “Situational Awareness”
- Platforms created for information exchange between agencies helped with effective crisis management

Q&A

1. Q: Has this event changed design standards from impacts?
   A: Grid standards evolving for construction of plant still under research based on wind zones and likely impacts areas
2. Q: No 765 kV lines collapsed. Whay was that?
   A: Did not loose 765 kV because not many lines that voltage in areas of the passage of the cyclone
3. Q: Back up comms systems? PMUs and SCADA – did it hold up?
   A: Back up comms = satellite phones; SCADA and WAMS during cyclone worked ok
4. Q: How was PMU data used in real time?
   A: PMUs provided intel on permanent vs transient faults. Also it informed operators on the passage/direction of the cyclone, as well as the inertia impacts and angular impacts between systems.

Paper information

Paper number	318
Paper title	Managing Operational Risk of Special Protection schemes (SPS)
Study Committee	SC C2 – Power system operation and control
Paper Stream	1. Learning from experience
Authors	Sudarshan DAHAL[1], Peter McCARTHY[1], Chris SCOTT[1]
Affiliations (optional)	Powerlink Queensland
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[1] Powerlink Queensland

Summary

The high uptake of renewable energy resources means increased inverter-based generation and increased risk of thermal overloads, frequency and voltage instability, islanded operations and reverse power flow. Hence Special Protection Schemes (SPS) are being deployed to recover from abnormal network conditions. The major challenge is detecting an abnormal conditions from monitoring a wide area network. While Powerlink has substation based SPSs, sometimes they mal-operate. But addressing all known SPS risks is difficult. This paper presented Powerlink's experience in managing the risk of failure of SPS using EMS.

Discussion

Special Protection Systems (SPS) are installed to detect abnormal system conditions and automatically effect a predetermined corrective action to preserve system integrity.
In a quickly developing and changing electricity grid, SPSs are becoming essential for responding to the dynamics of the grid. The SPS types include logic base, speed base and infrastructure base (WAMPAC, SCADA). SPS provides constraint management, reduced market impact, better customer experience. Signals from SPSs are interfaced to EMS, and local protection schemes are interfaced to WAMPACs and then to EMS protection. The SPSs have different speeds of response i.e. high speed protection devices and slow speed protection devices. The SPS Risks include failure to share real time in-service status with operators, undetected failures, design limitations and that one SPS can interfere with another SPS. Operators are having to quickly upskill to understand how the changing grid behaves.

The paper presented Powerlink's experience with SPS and highlighting the potential for SPSs to malfunction, plus the role of EMS to address these risks.

Findings/Conclusions

- As the dependency on SPS is growing, there is a greater need to build the knowledge base and expertise in understanding SPS better and maintaining them
- There are growing operational risks of SPS due to risks of failures such as undetected faults, design limitations, interactions and communications channels
- Early detection of failures is crucial so that operators are more confident on SPS – can operate when required
- EMS can help to address some risks such as:
  - providing early alarms of SPS failures to the operators
  - complimentary inputs to address design limitations

Q&A

1. Q: Modelling of contingency analysis scheme – do they take SPS into account?
   A: Haven't done that yet
2. Q: Building knowledge base – how?

A: Providing training to controllers, team of engineers and commissioning engineers document fidings and provide to operators, mainly experience base

3. Q: Schemes changing with changing configuations – how often change the configuration of SPS?
   A: When new key asset installed then reqivew scheme after studies done. No change, no change to SPS just testing.
4. Q: Operational time frame changes to SPS?
   A: There is some flow from the realtime models into the SPS operation, depend son the SPS they're utilising

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C2	SESSION NUMBER	5
Date:	September, 07, 2023	Time:	13:10 --- 15:00

FINDINGS AND CONCLUSIONS:

This session consisted of papers related to developing practices, functionalities and applications. The presenters provided information from development of new tools and analyses using modern PMU resources, available to face the new challenges of the new configurations of electrical systems.

A main finding from these papers is the common contribution to solutions providing **increased observability and controllability in the over-all power system perspective.**

Challenges delt with, include: decreased levels of inertia; increased levels of integrated renewable resources; insufficient observability of grid and events; and increased complexities in grids which are operated closer to their limits.

To cope with these challenges, various items throughout the power system are foreseen to be utilised: smart meters, inverter-based resources, battery energy storage systems, phasor-monitoring units, and system integrity protection schemes.

Solutions presented include:

- Wide-Area Monitoring Control and Protection Schemes – to improve the system security and provide prevention of large disturbances,
- Hybrid State Estimator – to increase the situational awareness in distribution grids,
- Grid Event Analyser – to provide the grid operator with detailed knowledge of occurring events, and
- Inertia Provision Quantifier – to enable the assessment of synthetic inertia provision available to strengthen the grid.

In the discussion during the session, some of the highlights included:

- How to take the steps from research towards implementation.
- How to classify event severity and to filter non-crucial operational information.
- How to integrate interdisciplinary methodologies to provide broader values.
- How to address risks, values and benefits of solutions for the society.

In conclusion, it is obvious that the **development of new interdisciplinary solutions which are able to provide enhanced operation of the grid are necessary** in order for the grids to manage the increased strain and requirements arising from the energy transition as well as from society at large.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C2	SESSION NUMBER	6
Date:	September, 07, 2023	Time:	03:30 --- 05:20pm

FINDINGS AND CONCLUSIONS:

This session had as Chair Greg Hesse and as moderator Jayme Darriba Macêdo.

The main topics covered were experiences and new developments to improve the controls, tools, methodologies, and new technologies to operate the power systems with great, quick, and growing renewable sources.

The first paper, presented by Marina Delac, is titled **Impact of Grid-Forming Inverters on Frequency Control of a Grid with High Share of Inverter-Based Resources.**

This paper showed a comparative inertial response by a Grid Forming BESS and a Grid following BESS on power system frequency stability.

It was shown in the simulations of a scenario with 100% of BESS inverters using GFM and another with 100% of BESS inverters using GFL.

After a system was disturbed, the frequency was reduced to a lower value in the 100% of BESS inverters GFL scenario than in the system with 100% of BESS inverters GFM. This occurred because the increase in power in the GFR scenario was faster and higher than in the GFL scenario. The presenter explained that a system with higher GFMI allows the BESS to respond more quickly to frequency change.

Another remarkable aspect presented was the better behaviour of the droop control with GFMI at long-term frequency response. A more aggressive droop cannot mitigate the delay in the response of the GFL BESS, compared to the immediate inertial response of GFM BESS.

The damping constant needs to be adjusted, considering the inertia constant to achieve the desired damping behaviour.

GFMI can improve the frequency stability of the grid mainly through its immediate inertial response.

• Using an aggressive droop for the FFR of a GFLI cannot fully replace the inertial response provided by a GFMI due to the inherent delay in the GFLI's FFR.

• Using large inertia constants in a GFMI does not necessarily improve the frequency stability, while it might deteriorate the damping performance.

• The damping constant needs to be adjusted along with the inertia constant to have adequate damping in the response of GFMI.

• Fault current contribution and system strength support of GFMI can improve the grid's frequency stability, by improving FRT of nearby GFL IBRs.

The second paper, presented by Gaurab Dash, is titled **Suggestions for Strengthening of Technical Regulations for Renewable Generation Interconnection (Connection Code) in Indian Power System.**

This paper shows India's Renewable energy footprint. The wind is about 44GW and the solar is about 71.3 GW total installed. The wind installed capacity increased by more than 6GW in 6 years and nearly 60 GW of solar plants in the same period.

The author shows the future vision of solar and wind growth in India. The goal is to be net zero in 2070, but until 2032 the wind and solar installed capacity will be twice India's demand.

It shows the current requirements (Technical Standards) for wind and solar connection to India Power systems such as Low Voltage Ride Through (LVRT), High Voltage Ride Through (HVRT), Reactive Power Support at grid normal conditions, Power Quality Requirement and Frequency or Active Power Control.

The paper shows some cases at Power India Systems Operation that give opportunities to improve their Technical Standards. It shows a dip voltage followed by a high voltage. However, the wind reactive response wasn't efficient or quick enough to control the voltage at the right frames. An important suggestion to improve the LVRT requirement is to submit the right value to "k" factor because the reactive response should be after the transient current period.

The RE provides reactive support during the fault current period. Then it results in an inverter trip on high voltage and causes RE outages.

The LVRT reactive power/current response time requirements shall stay within 20-30ms after the event begins. This proposed change is to not introduce more reactive power than necessary and cause high voltage and consequent inverters trip.

For HVRT compliance at POI, suitable overvoltage and time delay margin in Inverter/WTG terminal settings shall compensate for the voltage difference between POI and Inverter/WTG terminal.

Another challenge to Indian RE requirements is the absence of regulatory provisions for RE to contribute to voltage control in steady-state operation. The actual required is linked to the power factor, although the inverters can contribute with + -33% of the installed capacity. It is another suggestion to improve the India Grid Code.

Low-frequency Oscillations (0,5-0,1Hz and 2-3Hz) have been observed in one of the major RE complexes. The analysis of the oscillations is ongoing and PPC communication delay has been identified as one of the probable reasons for the oscillations.

Some performance metrics will be specified for ensuring reliable control from PPC, like reaction time, step response time, and others specified by IEEE Standard 2800-2022.

Standards for Grid Forming Capability of Inverters was suggested:

• Standards for grid-forming capabilities of inverters may be specified in the regulations.

• This will enable the inverter-based resources to play a constructive role in reliable grid operation by providing grid-forming services, especially the black-start capability.

This paper presented several suggestions for strengthening the existing regulatory framework for the connectivity of IBRs in the Indian power system. And suggest that the regulatory requirements are reviewed at regular intervals.

The third paper, presented by The Van Nguyen, is titled **Optimization of Fault-Ride Through Parameters for Renewable Plants to Improve the Vietnamese Power System Stability.**

It was an interesting article about the Vietnamese power system and the main challenges to integrating renewable.

First of all, despite the capacity of the current electrical matrix being made up of 33% coal-based sources and 55% renewable sources, the share of energy production (mil.kWh, %) is still supplied by 50% coal-based.

Another fact is the sharp growth of solar energy. In two years, it grew by 16 GW, 8.5 GW of which were power plants and 7.5 GW of rooftop.

In Vietnam, as in many countries, engineering is learning how to operate a system with large generations connected to the grid through inverters, with control loops operating in normal operating conditions and in situations of fault-ride through in the system.

After an event that occurred on 13/05/2021 with a large variation in frequency, reduction in generation due to the activation of the renewable Fault-Ride Through (FRT) mode, the engineers at the National Load Dispatching Center of Vietnam were dedicated to studying the best way to adjust the FRT mode.

Three main challenges were identified:

1. The difference between voltage at inverter and the POC. It needs to be considered on FRT adjustment. In the FRT mode, the inverter will do the control. The inverter will behave based on its parameter settings instead of the setpoint from PPC.
2. The dynamic mode of inverter. The selected strategies must ensure the balance between grid support and stability during the fault. The amount of active/reactive current injection must be carefully determined because a wrong adjustment can make the fault situation worse instead of better.
3. The third important recommendation is to study the stability of Grid during the FRT mode operation. The strength of grid connection can impact the stability during the transient period and the ramp rate of active/reactive current injection must ensure the stability of grid.

To perform the FRT control parameters, an optimization tool was presented in this article that has been used successfully in Vietnam.

Very interesting work and contribution for all countries that are in a similar situation of high integration of renewables in a short space of time.

The fourth paper, presented by Russell Frost, is titled **Utilization of a Real-Time Frequency Stability tool to support operating decisions in a reduced inertia power system**.

This paper showed an Australian experience with a Real-Time Frequency Stability tool to help the operator overcome the challenge before the behaviour of minimum load in Australia. The minimum operational load in the Southwest Interconnected System has decreased every year. This behaviour is resulting from the rooftop solar growing. This value was 1.44 GW in 2016 and 0.626 GW spring of 2022.

The Australian Energy Market Operator (AEMO) is responsible for ensuring security and reliability in the power system, setting ancillary services, managing the network, and facility outages. The main difficulty is translating power system simulation studies into operational decisions when conditions change so rapidly. The power system security studies in the planning horizon are too conservative at times and not enough at others. The simulations in real-time are a way to produce security advice for safe system operation.

Simulations in real-time need simplified models but with the capability to produce security advice for more operational and miscellaneous conditions. Some questions were investigated, such as the single-mass model based on swing equations, single-order lag representations of governor models to simulate droop response with high-speed event data, estimation of load relief and load inertia, and estimation of DPV and load tripping.

The tool developed was trialled in the control room and the results were positive: Producing outcomes according to real system conditions, providing clear indications where the action is required, and improving the power system condition analysis to better security of the system.

After the presentation, some questions arose about why not seek solutions to the cause of the problem, because there are additional services that could be affected by this load behaviour.

The fifth paper, presented by Matt Nichol, is titled **Frequency Operating Standards to maintain a secure and resilient power system across the energy transition.**

This paper presentation shows a study about frequency operations standards and their impact on the energy transition.

The search was done with two main goals: The assessment of the impact on the power system from the current mandatory Primary Frequency Response (PFR) framework by varying the Primary Frequency Control Band and an explanation of an international survey about RoCoF.

A monthly frequency histogram for the National Electricity Market (NEM) of Australia was shown (Frequency System x date x Percentage of Time). In this information, a decrease in frequency performance occurred after the increase in the integration of wind RE into the Australian power system. As a solution, the 2020 Mandatory PFR rule change re-established a frequency distribution that is more tightly controlled around the 50Hz nominal frequency and does not

exceed the Normal Operating Frequency Band (NOFB) of +/- 150 mHz. This change was efficient in improving the system frequency behaviour. And the economics studies confirmed the solution implemented.

The second part presents the survey answers about the international experience with high RoCoF.

The sixth paper, presented by Ngoc Chien Pham, is titled **Estimation of transmission line positive sequence parameter using data of WAMs in Vietnam.**

This article presents a methodology for determination of positive sequence parameters of overhead transmission lines using the signals line from WAM system installed at both ends of the transmission line.

The main objectives are improving the accurate transmission line and implementing precise relay protection settings, increasing the precision in identifying fault locations and performing an accurate simulation in real-time computing applications.

This methodology also contributed to determining transmission line parameters used in the Vietnam computational programs and enhanced the accuracy of input factors in power system calculations.

TUTORIAL SUMMARY

STUDY COMMITTEE	C2	TUTORIAL NUMBER		1
Date:	September, 04, 2023	Time:	13:20 --- 15:10	

Title: Mitigating the risk of fire starts and the consequences of fires near overhead lines for System Operations

Presenter: Franco Crisci

With more than 40 years' experience in the electricity distribution business, Franco Crisci has been responsible for the delivery of a number of significant projects. They include project managing the conversion of thousands of kilometres of bare lines to insulated conductor, developing and implementing comprehensive bushfire risk management procedures and establishing and managing the distribution Control Centre in South Australia. He has presented on international studies in bushfire risk management and has consulted to electricity utilities and is a member of international bushfire risk management organisations. He has co-authored papers on bushfire risk management with Australia's CSIRO, led the development of predictive models on outages from weather, a tool for prioritising and sequencing power outage jobs and estimating end-of-event restoration time following a major storm event.

Precis of the tutorial:

The catastrophic consequences of wildfires from distribution lines, and the impacts on system security of wildfires around transmission lines, was the catalyst for this study. The system operating practices of distribution and transmission utilities which operate their networks in elevated wildfire danger environments was surveyed. The results of the survey were collated into the Prevent, Prepare, Respond, Recover (PPRR) framework of Emergency Management, a framework which utilities can use as a checklist against which to compare and optimise their existing network operations. Topics to be covered include protection practices for fire risk mitigation, technologies used to detect low-level asset defects, utility cooperation with firefighting agencies and research institutions, and shutting down power to avoid fire starts.

TUTORIAL SUMMARY

STUDY COMMITTEE	C2	TUTORIAL NUMBER		2
Date:	September, 04, 2023	Time:	15:40 --- 17:30	

Title: Power System Restoration Accounting for Rapidly Changing Power Systems and Generation Mix

Presenter: Babak Badrzadeh, Vikas Singhvi, Lalin Kothalawala and Cheryl Noronha

Babak Badrzadeh is currently a Technical Director, Power Systems with Aurecon, an Adjunct Professor with Monash University, a distinguished lecturer with IEEE PES, Associate Editor of IEEE Power and Energy Magazine, and Australian panel converter for CIGRE Study Committee C4. His focus area is power system modelling and analysis, including the impact of grid-connected and distributed inverter-based resources from operational, connections and planning perspectives. He is also the chief editor of CIGRE Green Book on ''Power system dynamic modelling and analysis in evolving networks''.

Vikas Singhvi is a Program Manager of EPRI's Transmission Operations research with over 13 years of industry experience in transmission and distribution operations and planning. He manages research portfolio encompassing real-time operations, operations planning, emergency operations and analytics for operations. He is an active member in the IEEE Power and Energy Society and CIGRE and participates activities throughout the power industry.

Lalin Kothalawala has more than 20 years of experience in different areas of the power system applications including power generation, control and simulation. Upon joining MHI, he worked as a consulting engineer to provide engineering services to a variety of client projects, including power system simulation studies, engineering design analysis, and commissioning support. In his current role as Manager, Simulation and Design Analysis, Lalin is supervising a team of engineers involved in electromagnetic transient analysis and renewable integration studies. Lalin has closely worked with many equipment vendors (including solar, wind, battery and SVC/STATCOM) to develop their models to meet the grid code requirements. Additionally, Lain has conducted more than 50 PSCAD training workshops on a variety of topics for a number of global clients.

Cheryl Noronha is a Principal Engineer Grid Control Planning with Powerlink Queensland. Prior to joining Powerlink in May 2021, she was with Australian Energy Market Operator (AEMO) for nine years with experience in both network connections

and power system operations primarily focusing on dynamic simulation studies. Her areas of interest include grid connection of inverter-based resources, and power system restoration.

Precis of the tutorial:

Summarising the work conducted by the recently concluded WG C2.26, this tutorial discusses lessons learned and actions taken from recent blackout events, the role of grid-following and grid-forming inverters in system restoration, positive and negative impacts of distributed energy resources, physical testing of black start capability at the system level, and tools and techniques for analysing and planning for system restoration.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C4	SESSION NUMBER	1
Date:	September, 04, 2023	Time:	10:30 --- 12:30

FINDINGS AND CONCLUSIONS:

This session received 5 contributions covering all the preferential subject.

Lightning and Insulation co-ordination aspects was discussed in different papers, as following:

- An ongoing project was presented with the goal of achieving more accurate predictions of thunderstorms combing different fields of lightning research. This project's result will be of great importance as a pre-warning and resumption of outdoor activities leading to safety and economic benefits.

- The importance of carrying out detailed analysis to select surge arrester at wind farms was emphasized considering not only lightning overvoltages but also TOVS. It pointed out that the number and the location of the arresters must be carefully evaluated.

- Negative impacts on transformer due to metro and high-speed train operation were discussed as they may lead to damages to the winding. Metro operation creates what is called 'grounding coupling phenomenon 'due to DC current and induced current from the system that penetrates the transformer through the grounding grid. A suppression method was proposed for this case. High speed train operation requires a significant number of vacuum circuit breaker switching with high frequency overvoltage being imposed at transformer terminals with associated risks.

- The EMC impact of the building a double-circuit 315-kV overhead transmission line and three 315/25-kV substations near the Montréal-Trudeau International Airport was discussed. An ongoing project is analyzing the risk and regulatory context involved considering the maximum interference limits to be complied with the limits.

Some conclusions can be derived from the contributions such as:

- Different forms of transient interaction of transformer and power system should be evaluated due to nonlinear load operation near substations, such as high-speed railways.

- High frequency interference of transmission lines with air space could be a new topic for utilities, national operator, and regulators to discuss.

- Accurate prediction of thunderstorms is still a challenge, and it is of great importance to assure safety in the presence of these natural events.

- The insulation of coordination of wind farms deserves special attention due to their high exposure and loading rejection occurrences.

Conference Agenda

CIGRE Symposium Cairns 2023

Session

C4: Insulation Co-Ordination, Lightning and EMC

Time:
Monday, 04/Sept/2023:
10:30am - 12:20pm

Location: **Trinity Room**

Auditorium setting hold 450 people

Session Chair: **ANGELICA COSTA OLIVEIRA ROCHA**
Moderator: **Genevieve Lietz**
Session Topics:
Learning from experiences, Developing practices, functionalities and applications, Towards a sustainable power system

Session Abstract

This session will focus on EMC, Lightning and Insulation Co-Ordination.

Presentations

10:30am - 10:35am

Welcome and introductory remarks

ANGELICA COSTA OLIVEIRA ROCHA
ATG ENGENHARIA; ANGROCHA1@GMAIL.COM

10:35am - 10:52am

Theoretical analysis of corona-induced high-frequency interference caused by 315 kV transmission lines located near airport

Olivier Turcotte, Marc-André Joyal, Martin Edgar Cormier
Hydro-Québec, Canada; turcotte.olivier@hydroquebec.com

This submission presents a study demonstrating that the planned 315-kV transmission line complies with maximum interference level suggested by NAV CANADA whose responsible for the management of Canada's civil airspace.

The different communication, navigation and surveillance (CNS) equipment used by aircraft and airports will be described as well as for the criteria used for compliance evaluation.

Assumptions considered to generate the worst possible interference

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10:52am - 11:09am

Reliable Protection of Wind Farm Assets from Lightning Strikes and TOVs Considering Surge Arrester Failure Probability

Behnam Mahamedi, Samuel Stark
Arcadis Australia Pacific, Australia; samuel.stark@arcadis.com

This paper presents a systematic approach for selecting and positioning surge arresters within a 140 MW wind farm in Australia to provide comprehensive protection against lightning strikes. It highlights the importance of effective lightning protection by investigating a case where a limited number of surge arresters were used due to cost constraints. The study shows that the minimal design failed to provide adequate protection. A modified approach is proposed to suppress lightning overvoltage, reduce surge arrester failure probability, and maintain design practicality. Additionally, the paper considers temporary power-frequency overvoltages (TOV) and explores surge arrester performance under TOV scenarios, proposing mitigation strategies for such situations. The research emphasizes the critical significance of proper surge arrester placement and sizing to safeguard wind farm assets and ensure reliable operation during lightning events.

11:09am - 11:26am

Lightning Risk Assessment in Real-Time in the Vicinity of Power Systems

Lukas Schwalt, Sebastian Schatz, Stephan Pack
Graz University of Technology, Austria; lukas.schwalt@tugraz.at

In power systems, lightning discharges can endanger the power quality and security of supply. Such impacts can cause transient stress in the grid and can lead to line outages. Optimizing the timing of thunderstorm pre-warning and resumption of outdoor activities would lead to safety and economic benefits in the operation of critical infrastructures and the management of power systems. The risk assessment of the occurrence of individual lightning discharges on a limited geographical area and the determination of an all-clear as precise as possible are the main goals of the presented analyses.

11:26am - 11:43am

Classificação da informação: Interno

The influence of the traction power supply system for the metro on the grid substations with corresponding suppression

Guangning Wu, Song Xiao, Xiaoyan Ning, Guoquang Gao, Ye Cao, Yujun Guo, Xueqin Zhang
Southwest Jiaotong University, China, People's Republic of; hv-swjtu@163.com

In recent years, with the rapid development of urban rail transit, the negative impact brought from the Direct Current (DC) traction power supply system, which is applied by most of the metro lines, on the grid substations becomes increasingly intensified, which may lead to damages occurring in transformers and other major accidents, threatening the safety of both the primary grid and the distribution grid. When the metro approaches the nearby grid substations, the stray current tends to invade into the transformer's winding through its grounding grid through the surrounding earth, resulting in DC bias effect. In this paper, the magnetic coupling characteristics of power transformer induced by traction current of metro are studied, the current characteristics of stray current and induced current of metro are analyzed, then a neutral point current decomposition method of transformer is proposed. The proposed neutral point current decomposition method can be used for any grounding transformer affected by the metro in the power system, exploring the influence factors leading to the DC magnetic bias of each transformer, so as to develop the corresponding suppression measures.

11:43am - 12:00pm

Influence Analysis of the Frequent Overvoltage Impulses on the Terrestrial Traction Substations for High-speed Railway

Song Xiao, Guangning Wu, Zijing Wang, Ye Cao, Guoqiang Goa, Yujun Guo, Xueqin Zhang
Southwest Jiaotong University, China, People's Republic of; xiaosong@home.swjtu.edu.cn

When the train passes through the split-phase section, in order to prevent the locomotive from passing spilt-phase section with electricity, it is usually necessary to isolate the on-board power supply system and the contact line by operating the VCB before entering the split-phase section and after leaving the split-phase section. In the process of operating VCB, the oscillation circuit formed by the energy storage elements in the system and the current interception of the circuit breaker cause large induction voltage together constitute the operating overvoltage., so it is necessary to study the terrestrial traction substation by high-speed trains. In this paper, the time-domain analysis equivalent circuit model of the train operating VCB is constructed, and the magnitude-frequency characteristics of the overvoltage during the operation of VCB are investigated. In addition, a two-dimensional finite element model of the traction transformer is constructed to specifically observe the multi-physics field distribution in the windings during overvoltage shocks.

12:00pm - 12:20pm

Q&A and concluding remarks

Genevieve Lietz[1], ANGELICA COSTA OLIVEIRA ROCHA[2]
[1]AEMO; [2]ATG ENGENHARIA; g.lietz@ieee.org, ANGROCHA1@GMAIL.COM

Classificação da informação: Interno

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C4	SESSION NUMBER	2
Date:	September, 04, 2023	Time:	13:20 --- 15:10

FINDINGS AND CONCLUSIONS:

The PQ-1 session was titled “Power Quality in the energy transition - Focus on modelling” and was run on Monday, September 4th from 13:20 – 15:10.

Five papers were presented from two continents and three countries. The harmonic modelling of Inverter Based Resources (IBRs) was a significant theme across most papers. Three investigated impacts such as frequency dependence, component tolerances and external tolerances on IBR modelling outcomes. The accurate assessment of harmonic emission levels and amplification of IBRs was shown to have both material and economic consequences. A methodology using long-term field measurements to identify Norton equivalent models of IBRs was presented, and differences to OEM-provided models discussed. One paper was presented on the optimal location of harmonic filters in a meshed power system, based on a case study from Denmark.

The sensitivity of harmonic emission results to various factors internal and external to the plant under consideration was the key focus. The impact of external factors considered two primary areas. The first of these was the impact of existing IBRs in the wider network. It was demonstrated that excluding the impact of existing IBRs for the assessment of the new IBR may result in higher or lower emission levels and amplification factors than those in reality. As a result, this could prompt the need for larger or smaller harmonic filters than actually required. The second focus area was the impact of external network parameters on IBR harmonic modelling, which was shown to be minimal except around resonance points.

The impact of internal factors also considered two primary areas. The first of these was the impact of component tolerances which showed that both low and high-order harmonics can be impacted by the variation of impedances due to the tolerances of different components. When designing harmonic filters the worst-case tolerances should be accounted for. Secondly, the impact of OEM-supplied Norton equivalent was shown via model validation against actual field measurements to require large adjustments to obtain accurate results compared to the measurements.

In terms of criteria and considerations for the optimal placement of system-wide harmonic filters, the resulting effectiveness of such filters was shown to drop noticeably if not located at the optimal point in the network. This differs from experiences with locating system strength solutions. The locations of emitting source, the highest system impedance and highest observed distortion are the most important considerations.

Conference Agenda

CIGRE Symposium Cairns 2023

Session

C4 PQ-1: Power Quality in the energy transition. Focus on modelling.

Time:
Monday, 04/Sept/2023:
1:20pm - 3:10pm

Location: **Trinity Room**

Auditorium setting hold 450 people

Session Chair: **Genevieve Lietz**
Moderator: **Babak Badrzadeh**
Session Topics:
Learning from experiences, Developing practices, functionalities and applications, Towards a sustainable power system

Session Abstract

This session will focus on modelling techniques, assumptions and methodologies for the analysis of harmonics in power systems with increasing levels of inverter-based resources (IBR).

Presentations

1:20pm - 1:25pm

Welcome and introductory remarks

Genevieve Lietz
AEMO; g.lietz@ieee.org

1:25pm - 1:42pm

Assessment to Quantify the Impacts of Omitting the Frequency Dependent Modelling of Existing IBR Plants on Grid Harmonic Impedance Computation for New Connections

Lasantha Perera[1], Mojtaba Saleh[1], Vimeshan Pillay[2]
[1]APD Engineering, Australia; [2]APD Engineering, New Zealand; mojtaba.saleh@apdeng.com.au

This paper discusses outcomes of an investigation conducted to quantify the impacts of inclusion or omission of operational or committed IBR plants on harmonic impedance polygons derived for a new IBR connection. The investigations were carried out using a Simplified 14-Generator model of the South-East Australian Power System. The detailed frequency dependent model of a 1000MW wind plant was integrated into the network model to study the impact of this IBR plant on the impedance polygon at the nearby buses. The study results demonstrated that both at the existing IBR bus and at one bus away from that, inclusion of the existing IBR shifted the reactance and resistance values of the grid harmonic impedance towards and away from the origin of the R-X plane for different ranges of harmonic orders.

1:42pm - 1:59pm

Impact of Component Tolerances on Frequency Domain Representation of Inverter Based Resources

Alvaro Jose Hernandez Manchola[1], Amir Kazemi[2], Grazia Todeschini[3], Chi Su[4], Kairlyn Babiarz[5], Miguel Ochoa[6]
[1]Siemens-Energy, Germany; [2]GE Power, USA; [3]Kings College London, UK; [4]Siemens Gamesa, Denmark; [5]Mitsubishi electric power products, USA; [6]Huawei, Spain; alvaro.hernandez_manchola@siemens-energy.com

Connection of large inverter-based resources (IBRs) such as solar panels, wind generators, battery energy storage units, etc are on the rise.

Harmonic studies are carried out in both design and compliance phase of IBR installations. These studies require frequency domain models of the IBR units and are typically based on nominal component values.

This paper investigates the influence of component tolerances of different equipment on the harmonic model representation of the IBR unit in the frequency domain. The effect of tolerances on different types of converters is quantified.

1:59pm - 2:16pm

Impact of external conditions on the development of frequency domain models of Inverter Based Resources

Jason David[1], Oscar Lennerhag[3], Chi Su[2], Sarath Perera[1]
[1]University of Wollongong; [2]Siemens Gamesa Renewable Energy; [3]Independent Insulation Group; jasond@uow.edu.au

Frequency domain models of inverter-based resources (IBR) are used in pre-connection compliance assessment processes to estimate the impact of a particular device, or devices, on the power system harmonic distortion. Past projects, studies and industry experiences have suggested that substantial variation related to the appropriate frequency domain representation of IBR is possible due to sensitivities associated with both internal and external conditions. The aim of this paper is to propose a methodology to assess these potential sensitivities to external conditions .The outcomes of this study provide practical recommendations with respect to the importance of the conditions of the reference network when developing the frequency domain model of IBRs. Namely, it was found that altering the representation of the reference network had limited impact on the harmonic impedance representation of the IBR in many cases.

Classificação da informação: Interno

2:16pm - 2:33pm

Revision and Validation of IBR Harmonic Models Using Field Measurements

Jason David[1], Don Geddey[2]
[1]University of Wollongong; [2]TransGrid; don.geddey@transgrid.com.au

The representation of grid-scale inverter-based resources (IBR) at harmonic frequencies is commonly used to undertake pre-connection compliance assessment studies. Industry experiences continue to be reported that identify significant inaccuracies in the application of the IBR harmonic models developed. A study presented in this paper has been undertaken to analyse Point of Connection (PoC) harmonic measurements made over a four-month period for two individual solar farms and also developed equivalent circuit models based on the measured data. For some harmonic orders, the study found that the developed models were able to produce IBR harmonic models that were consistent across both solar farms. Further, the developed harmonic models were compared with those provided by the OEM, revealing significant differences. Use of the revised models was found to have a substantial impact on calculated PoC harmonic-voltage contributions from the connected plants.

2:33pm - 2:50pm

Determining Optimised Harmonic Filter Locations in a Meshed Power System – A Case Study from Denmark

Bjarne Søndergaard Bukh[1,2], Vladislav Akhmatov[1], Chris Liberty Skovgaard[1], Claus Leth Bak[2], Filipe Faria da Silva[2]
[1]Energinet Eltransmission, Denmark; [2]Dept. of Energy, Aalborg University, Denmark; ffs@energy.aau.dk

Four philosophies for identifying possible primary filter locations in the meshed grid have been proposed and an analytical evaluation of these philosophies is conducted using a case study. A simple sensitivity index is used to propose additional candidates for placing the filter as alternative to the primary locations. The results are comparable across the four philosophies and the set of substations. Advantages and disadvantages of each philosophy are evaluated and a ranking in relation to the efficiency of the filter effect is presented.

2:50pm - 3:10pm

Q&A and concluding remarks

Babak Badrzadeh[1], Genevieve Lietz[2]
[1]AURECON GROUP; [2]AEMO; Babak.Badrzadeh@aurecongroup.com, g.lietz@ieee.org

Classificação da informação: Interno

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C4	SESSION NUMBER	3
Date:	September, 04, 2023	Time:	15:40 --- 17:30

FINDINGS AND CONCLUSIONS:

The PQ-2 session was titled "Power Quality in the energy transition - Focus on compliance assessment" and was run on Monday, September 4th from 15:40 to 17:30.

Paper session PQ-2 addressed a broad spectrum of power quality compliance topics, from initial allocation of limits through to assessment against those limits in the field. All four papers in this session – one from Germany and three from Australia – were directed towards harmonics, rather than other power quality disturbances, with focus on increasing confidence across all steps of the compliance assessment process. Discussions concentrated on the effects of the energy transition, recognising the increased attention on harmonic compliance under extensive inverter-based resource (IBR) connection activity.

A recurring theme throughout the presentations and discussion was the exponent α in the IEC/TR 61000-3-6 general summation law, with the session recognising the limitations of the indicative values offered by this Technical Report and seeking further work in refining the summation law and its application.

Key contributions from the session included:

- A comparison of methods for allocating limits within a transmission network, with the performance of the existing IEC/TR 61000-3-6 approach (assuming disparate harmonic sources exhibit no diversity in phase angle, time or space) and proposed optimal allocation framework found to be well in advance of the existing German standard, VDE-AR-N 4130.

- A demonstration of the substantial impact of differing measurement windows when calculating the 95th percentile of a time series of 10-minute harmonic voltage measurements.

- Emphasis on the uncertainties arising throughout the process of assessing desktop or in-situ harmonic compliance of a plant.

- A proposed high-level process for managing the study, measurement and analysis work associated with managing harmonic compliance for a new transmission network development for high levels of IBR-based generation, to be connected on to an existing transmission network.

- A proposed approach to compliance assessment which uses field measurements of harmonic voltage and current to estimate harmonic Norton-equivalent circuit parameters for a plant, and then uses these parameters as a basis on which to assess compliance, rather than relying on OEM-provided models which may not align with observed conditions.

The session offered a range of views on how various aspects of the harmonic compliance assessment problem might be improved as the energy transition continues and IBR penetration increases.

Conference Agenda

CIGRE Symposium Cairns 2023

Session

C4 PQ-2: Power Quality in the energy transition. Focus on compliance assessment.

Time:
Monday, 04/Sept/2023:
3:40pm - 5:30pm

Location: **Trinity Room**

Auditorium setting hold 450 people

Session Chair: **Tim Browne**
Moderator: **Marta Val Escudero**
Session Topics:
Learning from experiences, Developing practices, functionalities and applications, Towards a sustainable power system

Session Abstract

This session will review harmonic performance challenges associated with connection of large volume of IBRs in power systems. Various international harmonic limit allocation methods will be compared. Risks and uncertainties in the power quality compliance processess for new IBR connections will be discussed.

Presentations

3:40pm - 3:45pm

Welcome and introductory remarks

Tim Browne
Qualis Power; tim@qualispower.com

3:45pm - 4:06pm

Optimal allocation of harmonic emission limits applied to a real transmission grid

Marco Lindner
TransnetBW GmbH, Germany; m.lindner@transnetbw.de

Previous contributions revealed that the methods reported in VDE-AR-N 4130 and IEC/TR 61000-3-6 do not reliably allocate harmonic emission limits and can result in harmonic voltages exceeding the planning levels. The Optimal (Harmonic) Allocation Framework promises reliable allocation and com-pliance to planning levels while relying on the same input data. The preceding work compared the three harmonic allocation methods using the exemplary IEC study case with positive sequences only. This paper conducts a comparison of the three methods regarding their allocation performance and reliability in a realistic and unbalanced transmission grid model. The results con firm the findings of preceding works and indicate that the novel method avoids the shortcomings of the VDE and IEC method, namely under- and over-allocation as well as their significant uncertainty, and may form the basis of a reliable harmonic grid planning proc ess. In examining the IEC method, it is observed that fixing the summation exponent to unity reveals very good allocation performance of the underlying principle, leaving the summation exponent for further analyses and more precise definition by system ope rators.

Short CV of Presenting Author:

Marco Lindner received the B.Sc. degree in Mechatronics from the University of Applied Sciences, Darmstadt, in 2011 and the M.Sc. in Power Engineering and the Ph.D. in Electrical Engineering from the Technical Universi ty of Munich, Munich, Germany, in 2013 and 2019, respectively. He is currently with the German transmission system operator TransnetBW as expert engineer for the grid integra tion of power electronic assets with special focus on power quality as well as harmonic and transient interactions. His research interests are performance and control of power electronic coupled assets (e.g. HVDC, storage, FACTS) as well as their interaction and stability issues from a power system perspective.

4:06pm - 4:27pm

Harmonic assessment and emission allocation for future grid

Umberto Maria Cella, Levin Mardira
DIgSILENT, Australia; umberto.cella@digsilent.com.au

Power electronics technology has been changing significantly since the Technical Report IEC61000-3-6 was released. Inverter-based resources (IBR) are replacing thyristor-based converters, thus changing the emission spectra and adding the complexity of non-negligible harmonic equivalent impedance. This paper is a summary of literature relevant to summation law, and lists issues that are of interest especially for connection of renewable energy to the grid, with the intention of fostering discussion and highlighting areas that require more research and consensus from the engineering community.

Short CV of Presenting Author:

Umberto Cella received his PhD from University of Queensland in 2009, and worked in the electronics industry prior to joining the railways in 2010 as an electrical engineer, working on the traction power system. In 2018 Umberto joined DIgSILENT, working on power q uality, generator testing and electrical measurements.

Classificação da informação: Interno

4:27pm - 4:48pm

A Comprehensive and Innovative Approach to Manage Harmonics for Renewable Energy Zones (REZ)

Tuan Vu, Vic Gosbell, Adam Peard, Mark Shilliday, Jamie Gabb, Alan Crombie, Nalin Pahalawatta, Henry Olivares, Jake Rowe
Power System Consulting Engineers; tvu.tvu.999@gmail.com

Renewable Energy Zones (REZ) are being developed to allow easy connection of large amounts of renewable generation to the existing transmission systems. This concept of the REZ brings many benefits as well as new harmonic-related challenges to the network operators. This paper details the harmonic challenges of the REZ and the interconnected transmission network/s and provides a comprehensive and innovative approach to managing harmonic compliance, including: (i). the roles and responsibilities of REZ generators, the REZ Network Operator and the adjacent Network Operator/s; (ii). joint harmonic planning studies, including software tools and procedures; (iii). harmonic allocations; (iv). harmonic compliance and assessment; (v). comprehensive and innovative management of harmonic resonances within the REZ and between the REZ network and the adjacent networks; (vi). recommended comprehensive measurement systems; and (vii). harmonic online monitoring, active trending and non-compliance report in daily operation regime.

Short CV of Presenting Author:

Tuan is a highly experienced Power System Engineer with over 27 years in the electricity supply industry. He has extensive experience in Power Systems Harmonics, Substation Design, Renewable Integration, System Studies, Network Analysis and Fault Investigation, SVC and STATCOM, Secondary Systems, Wide Area Monitoring Protection and Control, WAMPAC, Special Protection Schemes, SCADA, Digital Assets, Asset Management. He successfully led multi-disciplined specialists and delivered high-voltage projects worth over $230M. He has a PhD in Power Systems Harmonics, a Master of Systems Engineering and a Bachelor of Electrical and Electronics. He is a fellow member of Engineers Australia and an active member of Standards Australia, IEC Standards and CIGRE Working Groups. He also delivers CPD technical training courses in Australia and overseas.

4:48pm - 5:09pm

Certainty in power quality compliance, from desktop to evolving reality

Marius Jansen, Mikael Kotaniemi
Optimised Network Equipment, Australia; mikael.kotaniemi@onegrid.com.au

The article describes the methodology and a set of tools and procedures that can be used to quantify the actual performance of any generator or load at any time during project start-up and thereafter, and under any network conditions, including changes in network impedance and prevailing harmonic distortion not originating from the evaluated generator. It involves an approach to network management by the network operator including the process of setting limits on harmonic emissions in the network, measurement techniques and processing of measurements, ongoing refining of modelling of generators (or loads) used in conjunction with these measurements. The outcome is correctly shared responsibility for compliance in a quantified and clear manner that significantly reduces uncertainty to all stakeholders.

Short CV of Presenting Author:

Mikael has more than twelve years of experience in the areas of power system analysis and design, and a decade of experience in the manufacture and delivery of power quality solutions to clients in the electricity utility, mining, industrial and commercial sectors. His involvement ranges from early identification of opportunities to improvement of power quality, development of solutions, specification and procurement of primary and secondary plant, site supervision and commissioning and product life cycle support.
Mikael has conducted numerous harmonic assessment and filter design studies for renewable projects, from conceptual stage to final implementation. Attention to detail, exhaustive investigations and a pragmatic engineering approach has resulted in several highly effective designs and deliveries.
He has previously worked as an asset management, planning and protection engineer in the electricity transmission sector.

5:09pm - 5:30pm

Q&A and concluding remarks

Marta Val Escudero[1], Tim Browne[2]
[1]EirGrid; [2]Qualis Power; marta.valescudero@eirgrid.com, tim@qualispower.com

Classificação da informação: Interno

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C4	SESSION NUMBER	4
Date:	September, 05, 2023	Time:	08:00 --- 09:50

FINDINGS AND CONCLUSIONS:

Six papers were presented from three continents and four countries. The session was well attended with approximately 150 people in the audience.

The impact of Inverter Based Resources (IBR) on the power system was a significant theme, with several papers investigating the impacts of power electronics when connected as load devices rather than as generators. A great deal of time, effort and cost has been devoted by industry to understand the performance characteristics of generators (including the development of dynamic models). As the characteristics of 'loads' are also changing, similar attention needs to be given to the end users of electricity. The importance of ongoing diligence when assessing new generator connections was also presented. A case study from Texas (in the ERCOT interconnection) examined the performance of a large solar power plant that was subjected to a typical network fault event. Power system resilience was also discussed, which is being impacted by a number of the issues outlined above.

Several common themes were identified, including what industry can draw from past experiences. Detailed, site specific load models are capable of reproducing post-fault system voltage responses for planning and operational studies and can reasonably predict consequential load loss. Generic models are less likely to deliver robust simulation outcomes under a wide range of operating conditions. Lack of detail on power electronic interfaces is a primary concern for system planning and operation, which can be addressed by the use of as-built models or even derived equivalents. Also, unexpected tripping of IBR can occur and may be due to controller settings and voltage effects that are not observable even in detailed analysis when using aggregated models. Aggregated plant models need to have adequate granularity to identify their impacts in root cause analysis or other studies intended to correct observed problems.

The modelling of electric vehicle (EV) charging systems and their application in power system studies was presented. Large scale integration of EV's is expected to alter the aggregate response of power system load and therefore impact network performance. The risks associated with variable fault ride through behaviour and delayed active power recovery were specifically discussed, with an example of how such characteristics can impact frequency control at the transmission network level. The need for defined performance measures for EV charging systems was considered. From many perspectives, this emerging load component needs to be studied and properly understood by industry. To enable the increasing penetration of EV's to be properly accounted for in network planning studies, RMS load models that represent EV charger characteristics during disturbances are now required and are starting to be developed.

The challenges of integrating a large HVDC interconnection into a relatively small power system was presented, specifically the impacts on rate of change of frequency (ROCOF) following interconnector contingencies. The use of a system protection scheme (SPS) to maintain stable

frequency control was presented. Such schemes can increase operational flexibility and network hosting capacity, however consideration needs to be given to minimum practical operating times and how this impacts on network security and grid code compliance obligations.

Finally, an analysis technique to assess network resilience was discussed. How to maintain resiliency in a transitioning power system is an ongoing concern for industry. Contemporary methods to evaluate risk beyond traditional reliability analysis are being developed for application in network planning studies. Work that could be used by industry was presented, with proposed definitions and methods to evaluate how well a system can recover after an emergency event.

Conference Agenda

CIGRE Symposium Cairns 2023

Session

C4 PSD-1: Power system dynamics in the energy transition

Time:
Tuesday, 05/Sept/2023:
8:00am - 9:50am

Location: **Auditorium B/C**

Plenary and Papers Max 1,000 pax

Session Chair: **Andrew John Halley**
Moderator: **Wayne Allan Guttormson**
Session Topics:
Learning from experiences, Developing practices, functionalities and applications, Towards a sustainable power system

Session Abstract

The papers presented in this session focus on three key areas relevant to the analysis of dynamic system performance with high levels of inverter based resources: (1) Load modelling, (2) dynamic behaviour of low inertia power systems and (3) resiliance of power systems. A system incident in the ERCOT system in May 2021 resulting in the partial trip of 200 MW solar power plant will be analysed in one presentation.

Presentations

8:00am - 8:05am

Welcome and introductory remarks

Andrew John Halley
Tasmanian Networks; andrew.halley@tasnetworks.com.au

8:05am - 8:21am

Root-Mean Square Model of EV Charging Inverter for Balanced Fault

Muneki Masuda, Hayato Satoh
Central Resarch Institute of Electric Power Industry, Japan; masuda3749@criepi.denken.or.jp

There is a risk that the large-scale integration of EVs can significantly affect power system operation and control. To characterise this impact and consider future countermeasures, a load model that considers the characteristics of EV chargers is required for power system analysis. Therefore, through the lab tests, the authors presented an RMS-based three-phase EV charger model that accurately represents the dynamic response following balanced faults. The developed model was validated by comparing responses measured at the test lab with responses simulated using the RMS simulation tool.

8:21am - 8:37am

Assessing the response of electric vehicles during network fault conditions

Evan Franklin[1], Nathan McKillop[1,2], James Lord[2], Chris Wembridge[1,2]
[1]University of Tasmania, Australia; [2]TasNetworks, Australia; evan.franklin@utas.edu.au

In this paper, we use a programmable regenerative grid emulator to investigate the response of four different electric vehicles (EVs) to a range of network fault conditions. EVs are exposed, during charging operations, to connection point voltages of between 0.1 pu and 0.7 pu, for durations of between 60 ms and 480 ms, and their active power response is measured and analysed. For 120 ms durations, consistent with transmission-level fault clearing times, we find that all EVs tested continue charging if voltage drops to 0.5 pu or above. However, EVs were observed to either cease charging temporarily for between about 2 and 10 seconds or otherwise locked out and ceased charging completely when connection point voltage drops to 0.3 pu or below. Based on the measured fault responses, we use a real-time simulator with the Tasmanian power system as a case-study, to investigate the potential impact at power system level of a large fleet of EVs responding in aggregate to a plausible 2-phase-to-ground fault in the 220 kV transmission system. We find that the coincident fault response of aggregated EVs can cause frequency excursions outside of normal operating bounds.

8:37am - 8:53am

Challenges of Modelling Complex Industrial Loads for System Studies

Jagath Fonseka, Manjula Dewadasa
Powerlink Queensland, Australia; jagath.fonseka@powerlink.com.au

This paper investigates the benefits and challenges of modelling detail industrial loads in as-built form for power system studies. The benefits are, superior model performance compared to static load models and avoidance of parameterisation burden of standard composite load model. The challenges are lack of modelling capability, at this stage, to represent power electronically coupled loads and the additional effort required to gather detail information. These benefits and challenges are demonstrated and discussed in the paper utilising actual event

Classificação da informação: Interno

measurements and system simulations. Furthermore, the load modelling awareness discussed in this paper can be helpful in integrating new complex loads to the system.

8:53am - 9:09am

Management of power system frequency excursions with the integration of large HVDC interconnection

Daniel Fracalossi[1], Luke Roberts[1], Paul Rayner[1], Owen Gibson[2]
[1]Marinus Link, Australia; [2]TasNetworks, Australia; Paul.Rayner@marinuslink.com.au

Tasmania is an island, with a current maximum demand of less than 1800 MW and one existing 500 MW HVDC link to Victoria. The proposed new Marinus Link will increase the total HVDC interconnection capacity to 2000 MW. This large ratio of interconnection capacity to the size of the power system means that without an effective System Protection Scheme (SPS), the loss of one HVDC link would create an energy imbalance that, if not addressed quickly, can result in large frequency deviations, triggering emergency shedding of loads or generators. A SPS will be used to rapidly trip contracted loads or generators following the loss of an interconnector, containing Tasmanian power system frequency and rate of change of frequency (ROCOF) within allowable limits.

Power system studies have shown that the rate of change of frequency (ROCOF) will be the limiting factor for operation of the Tasmanian power system. This paper focuses primarily on the effects of SPS timing and inertia on the frequency and ROCOF following the loss of an interconnector. It finds that with reasonable values of SPS operating time and inertia, it is possible to contain both frequency and ROCOF within allowable limits.

9:09am - 9:25am

Advanced Coordination Between Controller and Protection Settings of Inverter-Based Resources in Response to TOVs After Ground Faults Clearance

Sam Maleki, Billy Yancey, Tamojit Chakraborty, Sibin Mohan, rahim jafari
Electric Power Engineers, Canada; byancey@epeconsulting.com

This paper presents the root cause analysis performed to investigate the partial tripping of a 200 MW solar power plant after being subjected to a distant Single-Line-to-Ground (SLG) fault for a real event in the ERCOT system in May 2021. The fault occurred on a generator step-up transformer at a combined cycle plant near Odessa, Texas. The fault cleared and voltage recovered to pre-disturbance levels within 3 cycles, yet several solar PV plants tripped offline or reduced their MW output to varying degrees following the disturbance.

9:25am - 9:41am

Resilience Estimation of Electrical Power Systems

Iony Patriota Siqueira
Tecnix, Brazil; iony@tecnix.com.br

This paper describes a formal method to assess the resilience of electric power systems using the results of contingency analysis. A model of disturbance propagation is proposed to avail its impact on resilience indicators of Power Systems, and the contribution and cross impact from several market agents and actors during outages in the electric grid. The method is based on cascade disturbance propagation through the topology of the electric grid and its impact on the inoperability of the components. Besides intrinsic forced and programmed outage rates, as well as protection reliability and dependability, time to manual or automatic reclosing are also modelled. Their joint contribution determines the final resilience and inoperability level of each grid node, and the fraction of responsibility of each agent. A working software implementation has been developed and documented. A simple case study illustrates its application to a typical power network comprising several generation, transmission, and distribution companies.

9:41am - 9:50am

Q&A and concluding remarks

Wayne Allan Guttormson[1], Andrew John Halley[2]
[1]SaskPower; [2]Tasmanian Networks; wguttormson@saskpower.com, andrew.halley@tasnetworks.com.au

Classificação da informação: Interno

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C4	SESSION NUMBER	5
Date:	September, 05, 2023	Time:	10:20 --- 12:10

FINDINGS AND CONCLUSIONS:

The theme of the PSD-2 session was "Power system dynamics in the energy transition - WAMS applications".

The session PSD-2 on Power System Dynamics encapsulated a variety of papers from three different continents - Europe, Oceania, and Asia, featuring perspectives from Finland, Australia, and India. The diversity in geography also reflected in the multitude of challenges and experiences faced by different power systems worldwide.

Impact of Renewable Generation: The shift from traditional to renewable energy sources has been prominent. Finland's massive wind power integration served as a poignant example of the challenges and potential that come with a renewable transition. India, meanwhile, provided insights into assessing system inertia with increased renewable energy, offering solutions for a common concern in power system dynamics.

Oscillatory Behavior and Dynamics: The oscillatory behavior in power systems emerged as a prominent theme. Whether it's through the lens of real-time instability monitoring, assessing the influence of large synchronous units, or discussing the sub-synchronous oscillations in grids - the session shed light on the intricate balance of ensuring stability in a rapidly changing energy landscape.

Innovative Techniques & Approaches: The session was not without its innovative solutions. The use of Phasor Measurement Units (PMUs) for real-time monitoring and the proposal of a stochastic perspective to address undamped oscillations showcased the forward-thinking approach needed to tackle the evolving challenges in the power sector.

Emerging Challenges & Solutions: Several papers addressed the specific challenges posed by Inverter-Based Resources (IBR) with Australia's grid serving as a case study. The dynamics of changing resource mixes, with Finland's wind power integration and India's evolving grid inertia, echoed the global challenge of maintaining grid stability amidst rapid changes.

Conclusions: It's evident that as the world leans more towards renewable energy sources, there's a paramount need to understand their impact on power system dynamics. With novel tools and methodologies at our disposal, ensuring grid stability in the face of changing energy resources is challenging but achievable.

Conference Agenda

CIGRE Symposium Cairns 2023

Session

C4 PSD-2: Power system dynamics in the energy transition. WAMS applications.

Time:
Tuesday, 05/Sept/2023:
10:20am - 12:10pm

Location: **Auditorium B/C**

Plenary and Papers Max 1,000 pax

Session Chair: **Behrooz Bahrani**
Moderator: **Peter Mayer**
Session Topics:
Learning from experiences, Developing practices, functionalities and applications, Towards a sustainable power system

Session Abstract

The transition towards IBR dominated power systems is resulting in reduced system strength and increased risk of sub-synchronous oscillations (SSOs). This session will review SSO phenomena and will present some WAMS applications for its detection and analysis. A WAMS application for the estimation of system inertia will also be presented.

Presentations

10:20am - 10:25am

Welcome and introductory remarks

Dr. Behrooz Bahrani
Monash University; behrooz.bahrani@monash.edu

10:25am - 10:42am

Real-time oscillatory instability monitor – development and field test results

Umberto Maria Cella[1], Sylvester Njoku[2], Jaleel Mesbah[3]
[1]DIgSILENT, Australia; [2]DIgSILENT, Australia; [3]DIgSILENT, Australia; umberto.cella@digsilent.com.au

Sub-synchronous frequencies which appear as modulations on the grid frequency in the power system can be extracted using various techniques.

A monitor which has the following parameters is used as the equipment for the investigation. The device is capable of triggering on small oscillations on V, P and Q. It is capable of processing the recorded data and performing oscillation frequency detection, and it saves a recorded file which can be examined after the event has occurred. The instrument automatically calculates the phase difference between V and Q at the dominant oscillation frequency.

10:42am - 10:59am

Impact of a large synchronous unit on the oscillatory stability of the changing power system

Janne Seppanen, Liisa Haarla, Mikko Kuivaniemi, Antti Harjula
Fingrid Oyj, Finland; antti.harjula@fingrid.fi

The paper analyses how a large turbine-generator having a high kinetic energy affects the dominant inter-area oscillation mode in the Nordic system. The paper presents cases where the large synchronous generator was connected and disconnected during the commissioning tests. The damping, frequency and amplitudes of the dominant inter-area mode were identified with an ambient modal identification method. The results indicate that the synchronous unit connected at the smaller system has a significant effect on the frequency and the damping of the inter-area mode.

10:59am - 11:16am

Impact of massive increase in wind power on system dynamics in the Finnish power system

Antti Harjula, Olli-Pekka Janhunen, Riku Korhonen, Pauli Partinen, Hock-Lim Cheng
Fingrid Oyj, Finland; antti.harjula@fingrid.fi

Finnish power system is experiencing a transformation towards being dominated by converter connected generation like wind and solar. This change is causing challenges for system performance. This paper presents events with multiple wind power plants participating in converter driven oscillations that have been recorded in the Finnish grid. The study includes analysis of the cause of oscillations and mitigation methods. The paper also presents the changes the Fingrid has so far implemented in processes and practical steps to mitigate new dynamics of the power system.

11:16am - 11:33am

Classificação da informação: Interno

Fading oscillations in grid with low damping

Umberto Cella, Jaleel Mesbah
DIgSILENT Pacific, Australia; umberto.cella@digsilent.com.au

This article investigates the possibility of small fading oscillations being excited and sustained by load variations, modeled as noise, interacting with poor damping of natural frequencies of the dynamic system representing the grid. The oscillations are activated and deactivated by changing the damping of the complex conjugate poles. The stochastic approach of adding noise to loads in a simulation can be a valuable tool to discover poorly damped frequencies, and to get an idea of transfer functions between electrical variables.

11:33am - 11:50am

Analysing Impact of Renewable Energy Penetration on Power System Inertia of Indian Grid Using Synchrophasors

Abdullah Siddique, Sudeep Mohanan, Rakesh ., TR Ganesh, SP Kumar
GRID CONTROLLER OF INDIA LTD , GRID-INDIA; abdullah@grid-india.in

An attempt has been made in this paper to calculate the inertia of the Indian power system from PMU data across the grid. The system inertia has been computed from field data for several cases of disturbances; across seasons, low and high demand and also lower and higher renewable energy mix in generation. Analysis has been made in this paper, for lower or higher inertia in each study case and to establish a tool for calculating inertia of the Indian synchronous grid online using PMU data.

11:50am - 12:10pm

Q&A and concluding remarks

Peter Mayer[1], Dr. Behrooz Bahrani[2]
[1]Manitoba Hydro International; [2]Monash University; pmayer@mhi.ca, behrooz.bahrani@monash.edu

Classificação da informação: Interno

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C4	SESSION NUMBER	6
Date:	September, 06, 2023	Time:	08:00 --- 09:50

FINDINGS AND CONCLUSIONS:

There were six papers presented during the session focusing on role of grid-forming technologies to improve the performance of the power system. The fucus has been on impact of high penetration of inverter-based resources (IBR) power system and how new technologies such as grid-forming technologies can help to address some of the challenges.

The potential applications and advantages of grid forming devices in the power system that were discussed during this session are outlined below.

- Grid-forming BESS excels as a black start option due to rapid response to voltage and frequency disturbances, with both generator and load capabilities
- Replacing diesel generators with GFM inverter BESS in various DER scenarios maintains network stability, voltage, and frequency performance.
- IBR wind plants with grid forming control connect to weak grids, maintaining stability under very low SCR conditions
- Grid forming control compensates unbalances, improves power quality, and dampens sub-synchronous oscillations.
- Wind turbine blade kinetic energy offers transient inertial response; energy storage enhances inertial support if needed.

The session also discussed some of the challenges associated with implementation of the grid-forming technologies.

- Accurate inverter modeling is challenging; aggregated models show substantial impact on system strength.
- While incorporating a current limiting scheme is inevitable to protect the inverter switches, the results show that any type of current limiter has a negative impact on the stability of a grid forming inverter.
- Integrating a large number of grid forming units in the low-voltage grid leads to open issues that require careful consideration such as protection, unintentional islanding, etc.

The session attracted large number of attendees which resulted into a very productive discussion during the session.

Conference Agenda

CIGRE Symposium Cairns 2023

Session

C4 PSD-3: Power system dynamics in the energy transition. Technical analysis of performance and capabilities of new grid forming technologies.

Time:
Wednesday, 06/Sept/2023:
8:00am - 9:50am

Location: **Auditorium B/C**

Plenary and Papers Max 1,000 pax

Session Chair: **Nilesh Modi**
Moderator: **Torsten Lund**
Session Topics:
Learning from experiences, Developing practices, functionalities and applications, Towards a sustainable power system

Session Abstract

This session will examine the effects of increasing levels of conventional inverter based resources on the system strength and stability of power systems. The capabilities and limitations of new grid forming controls to address emerging system needs, including blackstart capabilities, will be presented.

Presentations

8:00am - 8:05am

Welcome and introductory remarks

Dr. Nilesh Modi
Australian Energy Market Operator; nilesh.modi@aemo.com.au

8:05am - 8:21am

Impact of Distributed Photovoltaic System on System Strength

Yi Zhou[1], Deepak Ramasubramanian[2], Parag Mitra[2], Manjula Dewadasa[1], Sachin GOYAL[1]
[1]POWERLINK QUEENSLAND, Australia; [2]Electrical Power Research Institute; sachin.goyal@powerlink.com.au

This paper tries to understand the effect of DPV on system strength and its impact on the IBR hosting capacity of the network. EMT simulations are conducted using Queensland Wide Area Network model, and two approaches using static and dynamic modelling of DPV have been adopted and compared. In the static modelling method, the DPV is represented as a negative static load and reflects as a reduction in load demand at the transmission connection point. In the dynamic modelling approach, an aggregated generic single phase DPV inverter model was used to represent DPV connected at distribution network level. Results demonstrate that the fast growing penetration level of DPV can have a material impact on available system strength.

8:21am - 8:37am

A Comparative Analysis of Grid Forming and Grid following Control in Full Power Fed Wind Turbines in the Australian Grid

Blessy John[1], Abbas Abbasi[1], Priank Cangy[1], Zhiqian Yang[2], Shuang Jing[2], Xiao Yu[2], Rui Sun[2], Shaoru An[2], Xuelian Huang[2], Hong Yan[2]
[1]Goldwind Australia, Australia; [2]Source-Grid-Load-Storage BU, R&D Centre, Goldwind Technology, China;
blessyjohn@goldwindaustralia.com, abbasabbasi@goldwindaustralia.com

The high penetration of inverter based resources has brought significant benefits to the Australian grid, but it has also introduced new challenges. The grid forming inverters can address these challenges by providing essential grid support services and maintaining the grid stability during periods of high renewable energy penetration, ensuring the continued reliable operation of the grid. As the renewable energy integration continues to grow in coming years, the deployment of these technologies is becoming increasingly critical for the future of the NEM. This paper presents Type 4 WTGs grid forming capability to adapt to the weak grid conditions by providing adequate grid voltage stability and system strength support. Superior features of the grid forming scheme is verified through laboratory testing and detailed simulation studies. The results demonstrate better real power and reactive power responses in response to frequency or voltage disturbances in the network. Moreover, the performance of commercially available Type 4 grid forming technologies and currently operational grid forming wind plants are exhibited.

8:37am - 8:53am

Transient Stability Investigation of Grid-forming Inverters in the Presence of Various Types of Current Limiters

Si Phu Me[1], Salah Hajtaleb[1], Mohammad Hasan Ravanji[2], Bruno Leonardi[3], Deepak Ramasubramanian[3], Jin Ma[4], Behrooz Bahrani[1]
[1]Monash University, Australia; [2]Sharif University of Technology, Iran; [3]Electric Power Research Institute (EPRI), USA; [4]The University of Sydney, Australia; si.me@monash.edu

Classificação da informação: Interno

This paper explores the impacts of various current limiter (CL) types on the transient stability (TS) of virtual synchronous generators (VSGs). All CL types negatively affect VSG stability, with the q-prioritised CL (q-CL) demonstrating an advantage in maintaining the stability of the power-synchronising mechanism of a VSG, yet causing voltage control loop instability. The study tests the TS in various grid conditions and evaluates fault-ride-through (FRT) capability enhancing methods, including angle freezing and modified q-CL. These methods are able to improve the FRT capability of VSGs.

8:53am - 9:09am

Combined zonal and local control using grid-forming inverters in a complex medium- and low-voltage island grid: a study case in a realistic German network.

Luis David Pabon Ospina
Fraunhofer IEE, Germany; luis.david.pabon.ospina@iee.fraunhofer.de

This paper proposes a zonal control in an island grid that hosts grid-forming (GFM) and grid-following inverter-based generators. It addresses the following: What is the minimum required GFM installed capacity for stable operation in island mode? Is it better to have several distributed GFM inverters in the low-voltage grid, or to have a few large GFM inverters connected at medium-voltage? Is the inverter local control enough to guarantee long-term stability and adequate island operation, or is a centralized control necessary? Conclusions are derived using a representative German network.

9:09am - 9:25am

Dynamic challenges of a hybrid plant with a grid forming technology in a remote area.

Sajjad Hadavi, Aditya Upadhye, Hitesh Bavarva
GridWise Energy Solution, Australia; sajjad.hadavi@gridwiseenergy.com

The study focuses on the challenges posed by the increasing penetration of renewable energy sources in power systems, especially in microgrids., which traditionally rely on fossil fuel-based generators. Renewable sources lack inherent grid stabilizing properties, leading to technical issues related to frequency and voltage control. To address these limitations, emerging battery energy storage systems (BESS) with grid-forming inverters are being utilized to increase renewable penetration and eventually replace conventional sources. The study presents practical modelling experiences by replacing a diesel generator with a hybrid plant (solar farm combined with BESS and grid-forming inverter) in Energy Queensland's Thursday Island microgrid. Various dynamic scenarios are analysed to understand the impact of virtual inertia from a grid-forming BESS compared to a conventional diesel generator in a 100% renewable microgrid setting.

9:25am - 9:41am

Dynamic modelling and simulation of grid-forming and grid-following inverter-based resources for system restoration studies

Babak Badrzadeh, Nathan Crooks, Milad Zarif Mansour, Madison Coppard
Aurecon, Australia; nathan.crooks@aurecongroup.com

This paper investigates the contribution of various possible black start capable generators in power systems with a high share of inverter-based resources. Options investigated include a grid-forming (GFM) battery energy storage systems (BESS), a synchronous generator, and a combination of a grid-following (GFL) BESS and a nearby transmission connected synchronous condenser (SynCon). The response of each option is assessed with the use of vendor-specific electromagnetic transient (EMT) simulation models. These studies investigate the response of each candidate black start option in energising network transformers and transmission lines, as well as their ability in restarting large induction motor-based loads and GFL. Vendor-specific models of different types of GFL including wind and solar farms, and GFL BESS were analysed. Studies conducted simulate the step-by-step energisation process for each candidate black start option.

9:41am - 9:50am

Q&A and concluding remarks

Dr. Torsten Lund[1], Dr. Nilesh Modi[2]
[1]Vestas Wind Systems; [2]Australian Energy Market Operator; tolud@vestas.com, nilesh.modi@aemo.com.au

Classificação da informação: Interno

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C4	SESSION NUMBER	7
Date:	September, 06, 2023	Time:	10:20 --- 12:10

FINDINGS AND CONCLUSIONS:

Five papers were presented, all focusing on matters concerning the Australian east-coast network. The major theme throughout the papers was how inverter-based resources (IBR) can help deliver resilient system performance in an IBR-dominated grid.

There were two main areas of discussion. Firstly, work was presented on future-looking requirements for grid-forming (GFM) inverters and the specific characteristics that such devices will need to bring to maintain the health of the power system. A general overview of desirable GFM characteristics such as virtual inertia, system strength support and fault current injection was followed by an overview of a voluntary specification for GFM inverters, designed to aid in bridging the gap between ISOs and OEMs such that OEMs can have a preliminary view as to the desired performance of GFM devices from an ISO/TSO perspective. Details of the voluntary specification were specific and outlined both core requirements of GFM devices to support a resilient grid, along with additional desirable characteristics.

The second area of discussion largely focused on the reactive current injection performance of IBR devices, both for grid-forming and 'traditional' grid-following (GFL) plant. Presenters first focused on the ability of legacy GFL plant to better support unbalanced faults by virtue of alterations to control system strategies, before the discussion moved on to how recent rule changes to minimum standards allowed for IBR plant with large reticulation networks (e.g., wind farms) to efficiently meet reactive current injection requirements. An in-depth view of the technical analysis supporting the change was provided. This was then followed by a presentation offering an alternative view that reactive power control standards for wind farms already allowed compliance to be fairly evaluated and restating the need for strong reactive power control requirements to support reduced fault propagation.

Audience participation throughout the session was very high and showed great interest and passion in striking a balance between the needs of the evolving grid and the capability of IBR plant, supporting the main premise of the session: "Matching grid code requirements with capabilities of new IBRs".

Conference Agenda

CIGRE Symposium Cairns 2023

Session

C4 PSD-4: Power system dynamics in the energy transition. Matching grid code requirements with capabilities of new IBRs.

Time:
Wednesday, 06/Sept/2023:
10:20am - 12:10pm

Location: **Auditorium B/C**

Plenary and Papers Max 1,000 pax

Session Chair: **Sorrell Grogan**
Moderator: **Antti Harjula**
Session Topics:
Learning from experiences, Developing practices, functionalities and applications, Towards a sustainable power system

Session Abstract

The papers in this session examine the capabilities of conventional and emerging grid forming IBR technologies to meet some grid code requirements such as the provision of active and reactive current, in the positive- and negative-sequence, during fault conditions. Possible enhancements to grid code requirements to account for new technologies will be discussed along with new voluntary grid forming IBR specifications developed in Australia.

Presentations

10:20am - 10:25am

Welcome and introductory remarks

Sorrell Grogan
AusNet Services; sorrell.grogan@ausnetservices.com.au

10:25am - 10:42am

Accounting for capabilities and limitations of new and emerging generation technologies

Nathan Crooks, Majid Fard, Babak Badrzadeh
Aurecon, Australia; Majid.Fard@aurecongroup.com

This paper discusses pathways for accounting for grid support opportunities, technical withstand capabilities and susceptibilities of emerging technologies. Aspects considered include virtual inertia, rate of change of frequency (RoCoF), fast frequency response, system strength support and susceptibility, response to network faults and provision of active and reactive current, both the positive- and negative-sequence. The delineation between high and low system strength grids will also be provided. This paper also offers suggestions on possible enhancements to account for new technologies in the grid code requirements. Also, by using electromagnetic transient (EMT) type simulation, a comparison between a synchronous generator and grid-forming inverter regarding their respective dynamic characteristics are provided.

10:42am - 10:59am

Voluntary grid-forming specifications to support the transition to low-carbon power system

Jingwei Lu[1], Ahvand Jalali[1], Nilesh Modi[1], Chris Mock[1], Jennifer Crisp[2], Joseph Leung[2], Jaleel Mesbah[2]
[1]Australian Energy Market Operator, Australia; [2]DigSilent, Australia; chris.mock@aemo.com.au

This paper presents the voluntary specification that highlights key capabilities that can be provided by GFM IBR to support power system performance. This includes core control system capabilities that are expected to be relatively simple to achieve with minimum hardware changes when compared with a GFL solution. It also includes more advanced (or additional) capabilities that may necessitate upgraded hardware or changes to the operation practice of the IBR. This paper includes discussion on key aspects of the GFM specification.

10:59am - 11:16am

Negative sequence control of six-pulse inverters for improved performance during network faults

Christopher Wembridge[1,2], Mark Davies[1], Evan Franklin[2], Michael Negnevitsky[2], Sarah Lyden[2]
[1]TasNetworks, Australia; [2]University of Tasmania, Australia; chris.wembridge@tasnetworks.com.au

This paper has demonstrated that modifications can be made to the control system of six-pulse bridge inverters that would allow the independent delivery of positive and negative sequence current injection. This paper highlights the benefits from the viewpoints both of the grid and the converter, while still following similar recommendations such as VDE-AR-N 4120 (Germany) and IEEE Std 2800-2022.

11:16am - 11:33am

Classificação da informação: Interno

Investigation of reactive current injection of grid-following and grid-forming inverter-based resources during fault conditions

Babak Badrzadeh[1], Damiano O'Connor[1], Julius Susanto[2], Ashok Kaniyal[2], Stuart Norgorve[2]
[1]Aurecon, Australia; [2]Australian Energy Market Commission, Australia; babak.badrzadeh@aurecongroup.com

This paper discusses results obtained from vendor-specific electromagnetic transient (EMT) models of various inverter-based resources (IBR). These includes grid-following wind and solar farms and battery energy storage systems (BESS), and grid-forming BESS. The key objective is to determine the extent to which each of these technologies can meet the existing minimum technical performance requirements with respect to reactive current injection during faults outlined in Australia's National Electricity Rules (NER). Several hundred simulation case studies were conducted on practical IBR projects investigating the impact of factors such as fault type, duration, severity, initial active and reactive power dispatch levels, network short circuit ratio (SCR) and X/R ratio, IBR project size, total impedance between the generating unit, e.g., wind turbines, and the connection point, and the presence of other nearby IBRs.

11:33am - 11:50am

Benefits in harnessing the latent reactive current injection capability of inverter-based resources in the Australian power system

Mark Davies[1], Joshua Paoli[1], Christopher Wembridge[1,2]
[1]TasNetworks, Australia; [2]University of Tasmania, Australia; joshua.paoli@tasnetworks.com.au

This paper provides an analysis and discussion on the ability of asynchronous generators (AG) to provide their latent reactive power capability through improved controller design, using older Type 3 wind turbine technology as a case study. It was prepared in response to a proposed rule change by the AEMC to lower the minimum access standard for reactive current provision from AG. The paper reiterates the importance of reactive current provision during network voltage disturbances, demonstrates how basic control modifications can be made to facilitate reactive current provision from AG, and discusses the critical importance of maintaining robust minimum access standards for network operation and planning.

11:50am - 12:10pm

Q&A and concluding remarks

Antti Harjula[1], Sorrell Grogan[2]
[1]Fingrid Oyj; [2]AusNet Services; antti.harjula@fingrid.fi, sorrell.grogan@ausnetservices.com.au

Classificação da informação: Interno

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C4	SESSION NUMBER		8
Date:	September, 06, 2023	Time:	13:10 --- 15:00	

FINDINGS AND CONCLUSIONS:

The PSD-5 session was titled "Power system dynamics in the energy transition. Challenges, experiences and opportunities with the interconnection process in Australia" and was run on Wednesday, September 6th from 13:10 – 15:30.

This section focused on experiences from Australia. Six papers were presented.

The papers covered broad range of stakeholder perspectives: system operator, transmission network owner, equipment manufacturer, software vendor and consultant (plant developers' perspective)

Challenges with integrating Inverter Based Resources (IBR) in the power system was a significant theme across most papers. The presentations discussed emerging limitations and challenges with:

- control strategies and control parameters of IBRs
- existing models and simulation tools
- compliance with some of the applicable interconnection requirements – providing recommendations and solutions

Finally, from the grid's perspective, the paper from Australian Energy Market Operator (AEMO) focused on the importance and challenges with delivering new transmission assets in timely and reliable manner to enable further integration of IBRs.

<u>What can we draw from past experience to develop the power system?</u>

Tuning of inverters and plant controller is critical to comply with the technical performance standard set in the Australia's National Electricity Rules (NER) while remaining stable in all operating conditions. Generic recommendations and considerations wewe provided for tuning IBRs (both grid following and grid forming), especially in weak parts of the network.

There are certain limitations specific to the Australian grid and some NER requirements that are more onerous when compared to the other jurisdictions, making it challenging for some IBRs to connect to the Australian grid. Initiatives have been developing to overcome some of these issues such as the Connection Reform Initiative, the development of Renewable Energy Zones (REZs), and several rule change requests.

Early performance assessment using steady state and dynamic models during the connection process is important to ensure compliance with agreed Generator performance standards. Practical limitations in generating system models may lead to unexpected issues during commissioning, affecting compliance and causing delays and increased costs.

What are the current developments and their application to the future power system?

Decreasing system strength impacts the performance and consequently limit the renewable energy penetration in weak networks. Advanced control approaches can be developed to enhance the wind turbine performance to increase the stability margins, and thus help connecting more distributed generation into weak grids where the renewable resources are located.

Increasing level of IBR connections to the power networks has revealed emerging problems with stability including small signal stability. The impedance-based stability analysis method could prove to be a useful design tool during the plant connection process.

What are the future needs and requirements of the power system?

The energy transformation is occurring at a rapid pace and poses a range of challenges for the safe and timely integration of new capacity and services, including major network augmentations that impact the performance of the power system. A collaborative approach between NEM network businesses and the system operator supports a range of activities that help achieve the desired outcome from major network augmentations.

Conference Agenda

CIGRE Symposium Cairns 2023

Session

C4 PSD-5: Power system dynamics in the energy transition. Challenges, experiences and opportunities with the interconnection process in Australia.

Time:
Wednesday, 06/Sept/2023:
1:10pm - 3:00pm

Location: **Auditorium B/C**

Plenary and Papers Max 1,000 pax

Session Chair: **Julia Matevosyan**
Moderator: **Hieu Dinh Nguyen**
Session Topics:
Learning from experiences, Developing practices, functionalities and applications, Towards a sustainable power system

Session Abstract

This session will discuss weak grid connection challenges in Australia and will examine opportunities for improving system stability margins with new advanced controls and appropiate parameter tuning. Experiences with the interconnection and comissioning process and initiatives taken to overcome some of the challenges and accelerate connections will be presented.

Presentations

1:10pm - 1:15pm

Welcome and introductory remarks

Dr. Julia Matevosyan
ESIG; julia@esig.energy

1:15pm - 1:31pm

Wind Power Integration in Weak Grids

Janakiraman Sivasankaran, Miguel Campos, Roozbeh Kabiri
Vestas Wind systems A/S; JASIV@vestas.com

Managing power delivery from windfarms is becoming more challenging as system strength is decreasing, since the stability issues causes unreliable performance and reduces the renewable energy penetration. Advanced control approaches can be developed to enhance the wind turbine performance to increase the stability margins, and thus help connecting more distributed generation into weak grids where the renewable resources are located. This paper addresses some of the key weak grid connection challenges which are affecting the performance of inverter-based resources. Furthermore, this paper presents a control scheme using dynamic voltage control at wind turbine generator terminals and optimizing the reactive current injection rate to help overcome these challenges. Simulation results are provided to verify the mitigation influence of these control strategies on weak grid operation.

1:31pm - 1:47pm

Tuning of Inverter-Based Renewable Generation in Australian NEM: Opportunities, Issues and Challenges

Tyler Coetzee, Mohammad Seidaliseifabad, Hesam Marzooghi
Power System Consultants (PSC), Australia; tyler.coetzee@pscconsulting.com

Over the past decade, intermittent Renewable Energy Sources (RES) have been integrating into the Australian National Electricity Market (NEM) at an accelerated pace. These intermittent RES are Inverter Based Resources (IBR) and their increased penetration accompanies the decommissioning of large central synchronous generators, altering power system dynamics. RES developers require adhering to the performance standards of the National Electricity Rules (NER) Clause S5.2.5. Hence, tuning of IBRs to provide performance as close as possible to the Automatic Access Standard (AAS) requirements is vital while remaining stable is all the operating conditions. This paper provides an insight into tuning of both grid forming and grid following IBRs, especially in weaker network areas.

1:47pm - 2:03pm

Challenges in connection of renewable energy sources to Australia's electricity grid

Amir Mehrtash, Michael Shaw
Power Systems Consultants, Australia; amir.mehrtash@pscconsulting.com

Australia's National Electricity Market (NEM) is facing many challenges due to the high penetration of Renewable Energy Sources (RES), with an ambitious target set for achieving Net Zero Emissions by 2050. Whilst there are potentially sufficient RES available to achieve this target, several technical challenges are slowing this process down. In this paper, we discuss the common technical challenges experienced from the very early stage of the project feasibility study to commissioning and operation. We also discuss which clauses of the National Electricity Rules (NER) are proving the most problematic for generators, and why these problems arise. We also compare these requirements

Classificação da informação: Interno

with other international grid codes. Simulation results showing how new technologies such as grid forming batteries could improve system stability following a grid disturbance are also presented in this paper.

Actions have been taken by different parties to overcome some of these issues, including rule change requests, the Connection Reform Initiative, and the development of Renewable Energy Zones (REZs). We provide an overview of some of these initiatives and propose suggestions where appropriate.

2:03pm - 2:19pm

Commissioning experiences with Inverter Based Renewable plants: Observed plant behaviours and issues

Jabir Kalai Kuni, Alex Hugall, Kevin Paice, Sachin GOYAL
POWERLINK QUEENSLAND, Australia; Jabir.Kalaikuni@powerlink.com.au

This technical paper discusses experiences and insights gained from commissioning tests of Inverter-Based Renewable (IBR) plants to ensure compliance with agreed Generator performance standards. The study emphasizes the importance of early performance assessment using steady state and dynamic models during the connection process. However, practical limitations in generating system models may lead to unexpected issues during commissioning, affecting compliance and causing delays and increased costs. These unexpected performance challenges include oscillatory behaviours, active power reductions, instability, control issues, and inadequate provision of active and reactive power.

The paper suggests incorporating the learnings from these challenges in the initial stages of IBR projects to mitigate risks during commissioning tests and ensure successful commercial operation.

2:19pm - 2:35pm

Application of impedance scan stability techniques to support new generator connections in the Australian NEM

Scott Hagaman, Jaleel Mesbah
DIgSILENT Pacific, Australia; scott.hagaman@digsilent.com.au

Integration of increasing quantities of Inverter Based Resources (IBR) into power grids has revealed emerging problems with stability including small signal stability. This issue is particularly acute in the Australian NEM, where simulated and measured system oscillations have impeded the connection of new IBR to the grid.

This paper provides an appraisal of the impedance scan approach in analysing the stability of a hypothetical IBR based plant with the objective of connecting within an interconnected power system like the Australian NEM. The small signal stability of the example system is shown with various controller tunings and in different system configurations. Potential mitigation strategies are analysed including controller retuning and the impacts of synchronous condensers. The results are validated by conventional EMT domain simulation.

The paper concludes that the impedance-based stability analysis method could prove to be a useful design tool during the plant connection process.

2:35pm - 2:51pm

Commissioning of major power system upgrades

Luke Robinson, Callan Masters
AEMO; callan.masters@aemo.com.au

Around 6 GW of new interconnector capacity is expected to connect to Australia's power system over the next 20 years. This paper outlines the Australian Energy Market Operator's (AEMO) approach to inter-network testing of interconnector projects that have a material impact on the power system. The paper outlines the pre-requisites to inter-network testing, the purpose of inter-network testing and provides an overview of potential disturbance tests that can be applied during testing. Finally, the paper shares AEMO's recent experience during testing of the Queensland – New South Wales interconnector minor upgrade.

2:51pm - 3:00pm

Q&A and concluding remarks

Dr. Hieu Dinh Nguyen[1], Dr. Julia Matevosyan[2]
[1]AMP Energy; [2]ESIG; hnguyen@amp.energy, julia@esig.energy

Classificação da informação: Interno

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C4	SESSION NUMBER	9
Date:	September, 06, 2023	Time:	15:30 --- 16:20

FINDINGS AND CONCLUSIONS:

The PSD-6-1 session was titled "Power system dynamics in the energy transition. Focus on small signal analysis" and was run on Wednesday, September 6th from 15:30 – 16:30. Three papers were presented.

With increase in inverter based resources, a system planner/operator can no longer rely on only numerical time domain simulation to assess the impact of the resources on the grid. The ability to identify the impact of resources across multiple time scales and also multiple configurations are important. Further, newer forms of inverter controls are being developed, which could have benefit in a close to 100% inverter system. This benefit however cannot be assumed and has to be evaluated.

Small signal stability and virtual synchronous generators were a significant theme across the papers. Importantly, the three papers investigated the stabilization and voltage regulation properties of inverter devices under a variety of operating conditions and parameter values.

The sensitivity of grid forming inverter performance to various SCR and control parameters was discussed:

- State – space modelling.
- Close loop frequency response.
- Time domain response.
- Impedance based analysis.
- Nyquist analysis.

Additionally, and approach to develop small signal model for system level analysis was proposed:

- Model validation using time domain and frequency domain results.

Conference Agenda

CIGRE Symposium Cairns 2023

Session

C4 PSD-6: Power system dynamics in the energy transition. Focus on small signal analysis.

Time:
Wednesday, 06/Sept/2023:
3:30pm - 4:20pm

Location: **Auditorium B/C**

Plenary and Papers Max 1,000 pax

Session Chair: **Deepak Ramasubramanian**
Moderator: **Sachin GOYAL**
Session Topics:
Learning from experiences, Developing practices, functionalities and applications, Towards a sustainable power system

Session Abstract

This short session will concentrate on small signal modelling and analysis to assess stability of IBR dominated power systems.

Presentations

3:30pm - 3:33pm

Welcome and introductory remarks

Deepak Ramasubramanian
Electric Power Research Institute; dramasubramanian@epri.com

3:33pm - 3:48pm

Comprehensive voltage regulation performance analysis of Virtual Synchronous Generator

Jingzhe Xu, Weihua Zhou, Behrooz Bahrani
Monash University, Australia; Weihua.Zhou@monash.edu

The extensive adoption of PLL-based converter-interfaced generations in power systems has led to a declinein the secure operation of the grids, particularly with regard to inadequate inertial support and voltage waveform stability. As one of the most promising technologies, the virtual synchronous generator has the potential to combat the degradation of operational security, provide inertia support, and strengthen the voltage waveform. This paper presents an analysis of the performance of a tuned VSG that ensures very-fast port voltage regulation by assessing its time-domain responses to step changes and sinusoidal perturbations. By utilizing the derived transfer functions of frequency domain closed-loop magnitude responses, it becomes possible to validate and predict the VSG behavior. The study focuses on assessing the performance of the voltage response with respect to various parameter variation possibilities. Additionally, it quantitatively determines the interference between active power and voltage. The work provides another perspective on interpreting the performance of the VSG and sheds light on further studies and developments toward a greener grid.

3:48pm - 4:03pm

Virtual Synchronous Generators: Small-signal Stability Analysis under Varying Operating Points, Grid Strengths, and Control Parameters

Nabil Mohammed[1], Weihua Zhou[1], Majid Fard[2], Behrooz Bahrani[1]
[1]Monash University, Australia; [2]Aurecon Australia Pty, Australia; nabil.mohammed@ieee.org

Grid-forming inverters have emerged as a promising technology to mitigate instability challenges caused by grid-following inverters, especially in weak grids. Among the primary control strategies that achieve grid-forming capability, the virtual synchronous generator (VSG) is the most appealing feature due to its ability to provide inertia to the grid during disturbances.

This paper presents both time and frequency domain analyses to gain comprehensive insights into how VSGs perform under various scenarios, including the impacts of varying VSG operating points, grid characteristics, and control parameters such as inertia, damping, virtual impedance, and gains of the current and voltage controllers.

4:03pm - 4:18pm

Small signal model development and testing of inverter-based renewable plants

Huajie Gu[1], Fred Howell[2], Yue Yi[2], Yi Zhou[1], Peter Mayer[3], Sachin GOYAL[1], Xi Lin[2]
[1]POWERLINK QUEENSLAND, Australia; [2]Powertech Labs Inc; [3]Manitoba Hydro International; Huajie.Gu@powerlink.com.au

This paper uses a generic IBR plant model to demonstrate how to expand the use of small signal stability analysis to assess control interactions due to the IBR plants.

The validation of an IBR small signal model could be done against a black-box EMT model such as those often provided by OEMs.

The eigenvalue analysis can be used to troubleshoot which controllers of IBR plants contribute to the oscillations.

Classificação da informação: Interno

The generic IBR small signal model and stability assessment method developed in this paper aim to show a way to improve the use of small signal stability analysis of IBR dominated power systems to study the control interactions.

4:18pm - 4:20pm

Q&A and concluding remarks

Sachin GOYAL[1], **Deepak Ramasubramanian**[2]
[1]POWERLINK QUEENSLAND; [2]Electric Power Research Institute; sachin.goyal@powerlink.com.au, dramasubramanian@epri.com

Classificação da informação: Interno

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C5	SESSION NUMBER	1
Date:	September, 4, 2023	Time:	13:20 --- 15:10

FINDINGS AND CONCLUSIONS:

The first presentation provided an introduction to Australian Electricity Markets. Questions focused on the effectiveness of capacity markets to support investments for security of supply, like battery storage and behind the meter facilities.

The second presentation focused on the market suspension of the NEM in June 2022. Questions focused on the role of knowledge transfer to manage future situations, and the potential for NGN activities in this regard, on the role of intertemporal optimization run by AEMO to manage more and more energy-constrained resources Vs actions by traders based on the actual practice.

The third presentation focused on payment mechanisms for frequency control services in Australia. Questions focused on the expected impact of the frequency payment mechanisms in terms of savings, on the qualification of the service, and on the consideration of demand-side deviations Vs scheduled generation.

The fourth presentation addressed the consideration for non-network solutions to congestions in distribution networks. Questions focused on the effectiveness of the 6 M$ threshold, on the likelihood of DNSP developing effective and efficient solutions, and on the development of new technologies to provide responses rapidly.

The fifth presentation focused on tariff design to promote services to distribution operator by grid-side batteries. Questions focused on the applicability of this scheme to transmission, and on the coordination of the scheme with other economic signals such as connection charges or market prices.

Conference Agenda

CIGRE Symposium Cairns 2023

Session

C5 Markets AU: Developments and issues in the Australian NEM

Time:
Monday, 04/Sept/2023:
1:20pm - 3:10pm

Location: **Auditorium D**

Max 500 Pax

Session Chair: **Alex Cruickshank**
Secretary: **Yannick Phulpin**
Session Topics:
Learning from experiences, Developing practices, functionalities and applications, Towards a sustainable power system

Session Abstract

This session papers in this session are focused on events and developments in the Australian National Electricity Market. This will include an overview of the NEM, its suspension, management of frequency, as well as non-network and network pricing.

Presentations

1:20pm - 1:35pm

Introductory remarks - first session

Alex Cruickshank
CIGRE, Australia; alex.cruickshank@cigre.org

1:35pm - 1:52pm

Overview of the Australian NEM

Gregory Thorpe
Oakley Greenwood pty ltd, Australia; gthorpe@oakleygreenwood.com.au

This submission is designed is intended to be an overview of the NEM only. It is provide a description of the Australian NEM that can be drawn on by what are expected to be multiple submissions about the NEM to reduce duplication.

Short CV of Presenting Author:

Greg Thorpe holds a Bachelor of Engineering (Elec) from Monash University, a Graduate Diploma in Management from Deakin University and a Professional Certificate in Arbitration and Mediation from the University of Adelaide
Greg has 40 years experience in the electricity sector and also in gas. Greg assists businesses and market authorities operating under a range of different industry structures and market designs used in Australia and internationally.

1:52pm - 2:09pm. misbehavour?

Suspension of the Australian NEM: The events and lessons

Gregory Thorpe
Oakley Greenwood pty ltd, Australia; gthorpe@oakleygreenwood.com.au

The multi-day suspension of the Australian National Electricity Market in all regions in June 2022 was a landmark event. This paper is a compilation of the reviews and reports by the Australian Energy Market Operator (which is also the System Operator), the Australian Energy Regulator which enforces the market rules, Australian Energy Market Commission which makes the rules and a major industry association. The paper reviews the lead up to suspension and why it was needed, its impact and subsequent regulatory actions and lessons learned.

Short CV of Presenting Author:

Greg Thorpe is currently the convenor of AU C5 and has worked in the Australian electricity sector for 45 years. During his career he has been involved in transmission planning, system operation, market design, market governance, reliability settings and dispute resolution across Australia and internationally.

2:09pm - 2:26pm

Frequency performance payments in the NEM

Ben Hiron[1], Sebastien Henry[1], Julius Susanto[1], David Scott[2], Kevin Ly[2], Hugh Bannister[3], Jabez Wilson[4]
[1]Australian Energy Market Commission; [2]Australian Energy Market Operator; [3]Intelligent Energy Systems; [4]Private;
ben.hiron@aemc.gov.au

In September 2022, the AEMC made a rule to support the provision of primary frequency response in the NEM and introduce new frequency performance payments to incentivise plant behaviour that helps to control system frequency.

The new frequency performance payments build on an existing performance-based approach for the allocation of costs for the enablement of regulation services. The new arrangements will make payments to all market participants whose plant acts to control system frequency and allocate costs to market participants whose plant cause the need for corrective action.

Short CV of Presenting Author:

Ben is a principal policy adviser at the AEMC whose work is focused on regulatory and market design issues related to the secure operation of the power system. This includes consideration of the economic trade-offs related to power system resilience, managing system security risks and the role of regulation, incentives and ancillary service procurement.

2:26pm - 2:43pm

Non-network solutions: how effective are the current rules in Australia?

Marco Lenzi Castro, Stephen Hinchliffe
Mott MacDonald, Australia; stephen.hinchliffe@mottmac.com

TBA

Short CV of Presenting Author:

Stephen Hinchcliffe is Executive Consultant - Power and Energy Transition with Advisian, a division of Worley Parsons. He is a Chartered Engineer (UK) and a Fellow of the Institute of Engineering and Technology (UK). He holds a PhD in power inverter technologies and Masters' degrees in Electrical and Electronic Engineering, Business Administration and in Commercial Law. Stephen has more than twenty five years' energy sector experience, working on projects in the UK, Europe, Northern Africa, Indonesia, Chile, PNG, Australia and New Zealand.

2:43pm - 3:00pm

How efficient network tariffs can drive more deployment and efficient use of grid-side batteries

Rohan Ashley Harris, Lance Jeffrey Hoch
Oakley Greenwood Pty Ltd, Australia; rharris@oakleygreenwood.com.au

The objective of this paper is to discuss how network tariffs can be structured such that they incentivise more grid-side batteries being deployed, more efficient investments being made in those grid-side batteries, and more efficient operation of those grid-side batteries.

The paper is timely, given the significant discussion around the potential use of grid-side batteries to provide firming services to the market, and the broader discussion around incentive mechanisms focused on storage facilities.

Short CV of Presenting Author:

Rohan Harris is an economist who has worked in the energy, water and consulting industries for more than 20 years.

Rohan has significant experience in the areas of: tariff design; regulatory strategy and analysis; cost benefit analysis; energy and water policy; and electricity, gas and water demand forecasting.

Rohan's focus has predominately been on either the theoretical, economic, aspects related to these topic areas, or on the quantitative assessments (modelling) required to support the decisions or outputs related to these topic areas.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C5	SESSION NUMBER	2
Date:	September, 4, 2023	Time:	15:40 --- 17:30

Introduction

The session was well attended and each paper attracted a lot of questions and discussions

FINDINGS AND CONCLUSIONS:

Paper 1 dealt with modelling outages in Singapore and the options to redress those outages. The discussion firstly focused on the issue of strategic bidding by participants, which the authors had considered in their analysis. The discussion continued on this topic, noting that CCGTs were a significant factor and were required to offer their plant in at Short Run Marginal Cost, which limited the possibility of strategic bidding. It was confirmed that he modelling assumed CCGT would be cold started and that normal startup times were required.

It was noted that the paper did not consider a "do nothing" option. The authors noted that a 600MW generation loss would not cause customer outages but that there still needed to be mechanisms to deal with further losses. The costs incurred by interruptions could be used to more closely value the potential loss of loads.

Paper 2 dealt with a period of extremely high prices in Nordpool. It was noted the water inflows were normal during the event, but high market prices had caused a larger than normal drawdown of the hydro resources. The Norwegian operators had assumed that the prices would drop but they continued causing a large drawdown of their resources. In modelling the event, it was noted that applying a cost penalty to reduce drawdowns has been considered but not in the model included in this paper. Rather that consider a pricing model change, a stochastic model across all of Europe was applied.

Noting that the primary cause of the issue was high prices in Europe and the flows across the HVDC lines to the UK and Germany, the authors noted that it was not possible to restrict flows for pricing but it could be done for system security reasons.

A related question discussed prices in Australia, where it was noted that, after a period of high prices, a price cap is imposed to limit losses. This would not have reduced the drawdown if applied to this case as it is a pricing not a generation cap.

Paper 3 dealt with the difference between the actual costs of delivered Hydrogen compared to the costs required for its take-up. It was noted that the already high prices shown in the study did not include transportation, which would increase the costs by about $20/kg. The discussion then veered onto alternatives to Hydrogen, particularly Nuclear and Geothermal generation. It was noted that while there is a lot of discussion about nuclear generation it has not amounted to the level of policy change. Geothermal, while an interesting resource, has not been successfully tapped in Australia and is unlikely to be used generally.

Paper 4 also dealt with Hydrogen adoption issues. It was noted that people are unlikely to invest if the delivered cost is so high. While financial contracts and PPAs would assist investors, a more significant return is required. Commentators noted that hydrolysers could participate in the wholesale demand response market in Australia, and they are a large energy user, the returns from this are still small, even with contracts. The proposed two-sided market for

Conference Agenda

CIGRE Symposium Cairns 2023

Session

C5 Markets Other: Market developments in other countries and developments in Hydrogen

Time:
Monday, 04/Sept/2023:
3:40pm - 5:30pm

Location: **Auditorium D**

Max 500 Pax

Session Chair: **Yannick Phulpin**
Secretary: **Gregory Thorpe**
Session Topics:
Learning from experiences, Developing practices, functionalities and applications, Towards a sustainable power system

Session Abstract

This session will continue the focus on markets, with security and reliability issues in other markets and finishing with developments around Hydrogen.

Presentations

3:40pm - 4:00pm

Ensuring energy security and reliability in Singapore's Wholesale Electricity Market with a future of high-capacity renewable imports

Ben Vanderwaal, Joel Bulow, Jeremy Varendorff, Damon Sahota
EY, Australia; joel.bulow@au.ey.com

In order to drive towards net zero emissions by 2050, Singapore has proposed to import firmed renewable energy using subsea HVDC cables from surrounding regions. This may present an increased risk to maintaining a secure power system. This paper investigates the impact of a potential subsea cable outage on the Singaporean wholesale electricity market by modelling three scenarios: no supply response, the commissioning of a backup combined cycle gas turbine, and temporarily allowing import of energy through the existing interconnector between Malaysia and Singapore.

4:00pm - 4:20pm

Electricity markets during a period with extreme prices - Experiences from the NordPool market.

Birger Mo[1], Stefan Jaehnert[1], Gerard Doorman[2]
[1]SINTEF Energy Research, Norway; [2]Statnett, Norway; birger.mo@sintef.no

Electricity prices in Norway increased to new levels starting in the late summer of 2021. The paper summarizes experience from this period and focuses on analyses the authors have contributed to as part of the government's analyses to understand and implement possible relieving measures. More than 90 % of electricity production is based on hydropower with storage.

The main conclusions from this investigation are:

European electricity prices are the main reason for observed reservoir operation.

The HVDC cables to UK and Germany contributed significantly to higher prices for the reported period

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4:20pm - 4:40pm

Commerciality of green hydrogen for electricity generation: balancing supply costs with customer expectations

Stephen Hinchliffe[1], Patrick Ross-Taylor[2], Charles Allen[2]
[1]Advisian (Worley Parsons); [2]Mott MacDonald, Australia; Stephen.Hinchlife@Advisian.com

To accommodate the Australian transition from fossil fuels, as in many other jurisdictions, there is a need to develop firming and long duration storage energy systems to help balance energy supply and demand from intermittent sources. In this paper we concentrate on the current imbalance between international customer price expectations for green hydrogen and the costs of production. We also argue that capital cost reductions of electrolyser construction arising from economies of scale will not have the same reduction of capital costs as other renewable technologies when scaled up.

4:40pm - 5:00pm

Impact of Hydrogen demand side participation on industry financial in National Electricity Market

Ben Vanderwaal, Afsaneh Narimani, Abhishek Varghese, Ryan Powell
EY, Australia; ben.vanderwaal@au.ey.com

Hydrogen electrolyser flexibility and dispatchability enable potential provision of substantial services to the Australian National Electricity Market and its customers. These services include delivering demand flexibility, alleviating minimum demand conditions, frequency control and relief of network congestion issues. In this paper the concept of demand side participation (DSP) by hydrogen electrolysers is investigated

to estimate the extent to which provision of DSP services may deliver a financial return for hydrogen projects compared to the lost revenues from curtailed hydrogen production

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C5	SESSION NUMBER	3
Date:	September, 5, 2023	Time:	13:20 --- 15:00

FINDINGS AND CONCLUSIONS:

The first presentation focused on initiatives for stakeholder engagement in energy transition, with perspectives in the Republic of South Africa. Questions focused on the assessment of employment impact, on the assessment of alternatives to projects, like load shedding, on the speed of deployment for these projects, and on the engagement of local communities.

The second presentation presented a scheme implemented in the Australian Northern Territory to size reserve requirements and price them to network users generating deviations. Questions focused on the possibility to use any other incentive to push network users to balance instead of assessing statistics on forecast errors, and on cost allocation principles used in this scheme.

The third presentation focused on network tariff setting approaches. The questions focused on the cost reflectiveness of a fixed charge independent on the actual energy demand/injection, the effectiveness of economic signals to distribution network users – and the role of aggregators and service providers-, the assessment of the customers' response, and the reward for export at night time.

The fourth presentation focused on long-term load forecasting for grid planning. Questions focused on the consideration of social classes in geographical correlations, the consideration of new technologies.

The fifth presentation focused on functional standards for appliances subject to demand response. Questions focused on the consideration of Electrical Vehicles in the scheme, on the entity that has control on the demand-response devices.

Conference Agenda

CIGRE Symposium Cairns 2023

Session

C5 DER: Developments and practices for DER/CER in energy markets

Time:
Tuesday, 05/Sept/2023:
1:10pm - 3:00pm

Location: **Auditorium B/C**

Plenary and Papers Max 1,000 pax

Session Chair: **Vincent Ringeissen**
Secretary: **Alex Cruickshank**
Session Topics:
Learning from experiences

Session Abstract

This session will focus on distributed energy resources, also described as community energy resources or demand side response. The session will examine equity and regulatory issues as well as pricing and forecasting.

Presentations

1:10pm - 1:30pm

Creating a JUST energy transition for embedded generation via customer empowerment in South Africa

Aradhna Pandarum
Council for scientific and industrial research, South Africa; apandarum@csir.co.za

The paper will provide insight into how this business model could possibly be achieved, enabling factors and barriers, technical and operational considerations, and its role in the future of the South African energy transition. Lastly, policy recommendations for interventions within this landscape will further be made.

Short CV of Presenting Author:

Aradhna Pandarum is currently the Acting Research Group Leader for both the Energy Industry and Energy Systems research groups in the Energy Centre of the Council for Scientific and Industrial Research (CSIR) in South Africa. She holds a Bachelor's degree in Electronic Engineering from Howard College UKZN and a Master's Degree in Electrical Engineering (Renewable Energy) from University of Witwatersrand. She serves as a technical board member of Cigre South Africa, representing the country in the international C6 study committee on active distribution systems and distributed energy resources. She is also registered as a Professional Engineer with the Engineering Council of South Africa (ECSA). She is an international technical expert on energy economics and power system analysis of renewable energy. Whilst working at Eskom, she has gained immense experience in research, testing, and development, that was predominantly centred on embedded generation and its' technical, economic, operational, and environmental impact.
At the CSIR, Aradhna is the portfolio manager and acting group leader for all research work related to the Just Energy Transition as well as Energy Modelling and grid impact analyses. The focal point for the Just energy transition work is to promote social justice and create unique opportunities within the green energy economy hence touching lives through innovation with the aim targeted at combating poverty, unemployment and inequality in South Africa; and the focal points for energy systems research is to provide the most feasible energy mix for the country, provide insights into the technical impacts of variable renewable energy on the electricity grid and to provide thought leadership on microgrids via hosting the microgrid centre of excellence. She is also a national expert working on various projects related to the green hydrogen economy in South Africa.

1:30pm - 1:50pm

Regulating Service provision for intermittent inverter-based sources in tropical environments

Peregrine Michael Tonking, Jake Saunders, Dr Daniel Marshman
Power and Water Corporation, Australia; jake.saunders@powerwater.com.au

Electricity market design and associated power system management tools should therefore accommodate technologies with various technical and economic characteristics.

This work explores a market design and methodology to determine requirements for a firming service for solar resources in particular, where such resources are unable to meet certain minimum forecast accuracy standards.

Short CV of Presenting Author:

Jake Saunders is from Katherine in the Northern Territory and studied a Bachelors of Engineering in Photovoltaics and Solar Energy at UNSW. He started his career in solar thermal modelling and commercial behind the meter solar installations before joining Power and Water in 2016.
Initially as a field engineer in SCADA and Communications, he was responsible for the commissioning and on-call support of substation RTUs and distribution automation. At Test and Protection, he worked on UFLS RoCoF relay bench testing and scheme updates, commissioning of distribution fault anticipation (DFA) system and AVR upgrades. From his field role, Jake then joined the Energy Management System team in 2018 and was responsible for SCADA and Network modelling, display building and routine EMS database updates including brownfields transmission and substation augmentation projects.

Since 2019, in the Market Systems team at System Control he has worked on the design and implementation of 5-minute interval operational tools for demand forecasting and the dispatch and compliance of registered solar generators. These tools allow the system operator to meet obligations of the market reform and provide decision support into the control room for the regulating service provision in tropical island power systems with high penetration of intermittent inverter-based generation. This is Jake's first CIGRE conference and he is excited to share the regulation service methodology and unique experiences from the Northern Territory.

1:50pm - 2:10pm

Innovative network tariffs to better integrate DER with the grid

Lance Jeffrey Hoch, Rohan Ashley Harris
Oakley Greenwood Pty Ltd, Australia; lhoch@oakleygreenwood.com.au

About 34% of Australia's households now have rooftop PV. This has raised the potential for breaches of the minimum demand level needed for stability in the generation/transmission system and over-voltage conditions in local network areas.

This paper reviews seven innovative tariffs that are testing the appetite of both traditional consumption customers and prosumers to actively manage their consumption and export of electricity in response to price signals. The tariffs include solar sponge tariffs, cost-reflective pricing for both consumption and export, and controlled load tariffs for EVs.

Short CV of Presenting Author:

Lance Hoch has over 40 years of experience as a government policy advisor and a consultant to the electricity industry and the government and regulatory agencies that are involved with it. He specialises in utility/customer interface issues and has particular expertise in demand management, energy efficiency, the integration of distributed energy with the grid, pricing, regulation and policy matters in the distribution and retail portions of the electricity supply chain.

He has helped several Australian electricity distribution companies in regulatory matters including setting or responding to pricing principles, reviewing and strengthening their energy and demand forecasting methodologies, and assessing and developing innovative tariffs.

2:10pm - 2:30pm

DER-integrated geospatial load forecasting

Hiromu Hanakago[1], Hiroki Ichinomiya[1], Nozomi Ando[1], Naoyuki Otani[1], Megumi Fujita[1], Tomohiko Kimata[2], Kengo Kobayashi[2]
[1]Mitsubishi Research Institute, Inc., Japan; [2]Chubu Electric Power Grid Co., Inc.; hiromu_hanakago@mri.co.jp

Aiming for Japan's 2050 Carbon Neutrality goal, optimizing distributed energy resources (DER) and establishing robust DER-integrated networks are essential. For this, we explore an advanced Long-Term Load Forecasting (LTLF)—'DER-integrated geospatial load forecasting'. Our prototype accounts for regional demand and DER variations, enhancing grid planning. The system offers high-resolution forecasts till 2050, dynamic updates, and adaptability for planning scenarios. This underscores its potential impact on network operators' efficient grid operations, aiding carbon neutrality targets.

Short CV of Presenting Author:

The presenting author is a member of the Energy Business Group at the Innovation Service Creation Division of the Mitsubishi Research Institute (MRI). His expertise lies in regulatory research focusing on Distributed Energy Resources (DER) flexibility, as well as IT strategy planning in the energy industry, with an emphasis on digital applications in the transmission and distribution sector. Furthermore, he demonstrates proficiency in energy data analysis and data-driven consulting using AI and Machine Learning. He has been pivotal in developing and systematizing a Geospatial Long-term Load Forecasting / DER Forecasting algorithm and system for use in grid planning.

2:30pm - 2:50pm

Alignment of Retail Demand Response with Wholesale Markets through Functional Standards for Flexible Demand Appliances

Angela Chuang, David Showunmi, Doug Lindsey
EPRI, United States of America; achuang@epri.com

TBA

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C5	SESSION NUMBER	4
Date:	September, 5, 2023	Time:	15:20 --- 17:00

FINDINGS AND CONCLUSIONS:

The first presentation focused on governmental initiatives to support the energy transition in Queensland. Questions focused on the responsibility of the parties on social licensing of transmission projects, low carbon alternatives like nuclear power, and consideration for distributed energy resources in the plans.

The second presentation discussed the challenges requiring transmission network development in Australia. Questions focused on the system strength (short-circuit ratio) expectations.

The third presentation was about energy transition plans in Singapore. Questions focused on the likelihood of the long-term scenarios presented by the author, and on the conditions for firm capacity requirements.

The fourth presentation was about the connection rules for new assets in Australia. Questions focused on the testing of the performance of newly-connected assets, on interoperability requirements for new assets, and requirements for offshore wind interconnection.

Conference Agenda

CIGRE Symposium Cairns 2023

Session

C5 Transition: Markets in transition — delivering the future

Time:
Tuesday, 05/Sept/2023:
3:30pm - 5:20pm

Location: **Auditorium B/C**

Plenary and Papers Max 1,000 pax

Session Chair: **Alex Cruickshank**
Secretary: **Gregory Thorpe**
Session Topics:
Towards a sustainable power system

Session Abstract

This session will focus on how markets are proposing to develop for future issues. The focus will be on how the futher differs from today and how markets need to respond.

Presentations

3:30pm - 3:50pm

Queensland Energy and Jobs Plan - Power for Generations

Jacqueline Bridge
Powerlink Queensland, Australia; jacqui.bridge@powerlink.com.au

This paper highlights the Queensland Energy and Jobs Plan, that provides the foundation for transitioning Queensland's energy supply to a low emissions future.

Lack of alignment on climate change response across Australia has led to the introduction of state specific energy legislation and renewable energy targets. An overview of emerging renewable energy persona's across Australia's National Electricity Market (NEM) jurisdictions is provided to illustrate how each jurisdiction is responding to resource availability, environmental, political, economic and community factors.

Short CV of Presenting Author:

Jacqueline Bridge is an energy sector leader with a focus on decarbonisation of the electricity sector. Jacqui leads the Energy Futures Division of Powerlink Queensland, the government owned corporation that owns and operates the electricity transmission network in Queensland.

3:50pm - 4:10pm

Delivering the transmission system required for a clean energy future in the Australian National Electricity Market

Rainer Korte[1], David Swift[2]
[1]ElectraNet, Australia; [2]ESCOSA, Australia; korte.rainer@electranet.com.au

This paper outlines the nature and scale of the clean energy transition in the Australian National Electricity Market, including market and regulatory changes designed to support timely and efficient transmission investment required to enable the clean energy transition.

Changes outlined address more streamlined project approvals, the development of Renewable Energy Zones, network development and technical issues such as shortfalls in frequency control, system strength and inertia services, and market developments to ensure efficient operation and utilisation of the transmission network.

Short CV of Presenting Author:

Rainer is an experienced Electricity Industry Executive who is responsible for overseeing the delivery of safe, reliable and sustainable electricity transmission services to customers in South Australia.

Rainer is passionate about energising our clean energy future and has led key ElectraNet energy transformation initiatives in South Australia. He has extensive leadership experience within the market and regulatory frameworks of the Australian National Electricity Market.

Rainer is a member of CIGRE AU C5, a Fellow of Engineers Australia (FIEAust), a Chartered Professional Engineer (CPEng) and Engineering Executive (EngExec).

4:10pm - 4:30pm

Singapore Energy Transition Plans

Zhenhui Li, Vincent Wise
Energy Market Company, Singapore; vincent.wise@emcsg.com

Since 2003, the National Electricity Market of Singapore (NEMS) has been a critical enabler for the Singapore government in managing the energy trilemma. The Energy 2050 Committee concluded that it is realistic and achievable for Singapore's power sector goal to reach net zero by 2050 and provided recommendations and planning paradigms on how Singapore can evolve its power systems and markets towards a sustainable, green future.

As a result of the high energy prices caused by global turbulence, many countries have been introducing stabilisation measures. Singapore is not immune to energy price turbulences as it imports almost all its energy needs. Energy price surges severely tested the functioning and financial integrity of the NEMS.

The Singapore government recently announced measures to strengthen the energy market structure to fulfil the energy transition and security objectives. While Singapore's government agrees that a market-based system remains relevant, they also acknowledge that 'guardrails' should be in place to ensure that the market continues to function well under volatile conditions.

Short CV of Presenting Author:

Vincent is an Economist at the Energy Market Company, the Singapore Wholesale Electricity Market (SWEM) market operator. He supports the SWEM's Rules Change Panel in analysing market rule change proposals to evolve the market. He also facilitates the registration of market participants and their facilities in the NEMS.

4:50pm - 5:10pm

The role of technical standards in the energy transition

Jennifer Crisp[1], Eric Lauro[2], Erika Twining[2], Julian Eggleston[1], Lance Frater[2], Jaroslaw Krata[2], Andrea Marinelli[2]
[1]DIgSILENT Pacific; [2]AEMO; jennifer.crisp@digsilent.com.au

This paper explores the role of technical standards for connection within the Australian National Electricity Market, in its transition to a low carbon energy future. It sets out emerging and future challenges of this energy transition and makes practical recommendations as to how technical standards can be adapted to meet future needs. It is informed by a review of technical standards under the National Electricity Rules, which the Australian Energy Market Operator (AEMO) is undertaking.

Short CV of Presenting Author:

Dr Jennifer Crisp is a power systems engineer with more than 30 years' experience, across transmission, generation, operations support, generator connections and regulations. She is an Associate at DIgSILENT Pacific, a specialist power systems analysis and consulting firm, which undertakes projects across Australia, Asia and the Pacific region. Dr Crisp has a strong interest in technical regulation and has supported the development of technical standards and related technical regulation both in Australia and internationally.
Dr Crisp is leading a team from the Australian Energy Market Operator (AEMO) and DIgSILENT Pacific on the Technical Standards Review and industry consultation, which AEMO is required to undertake at least every five years under Australia's National Electricity Rules.

Australia could also help with the Hydrolysers operating flexibly to minimise their costs and take advantage of their flexibility. It was noted that flexible contracts would be required. The proposed new market design for the NEM, with the expected high penetration of wind resources, will require a significant amount of flexible load.

Some commentators suggested that Hydrogen would be a premium product in its early years, but this had not been modelled in this work and therefore not reflected in the paper.

TUTORIAL SUMMARY

STUDY COMMITTEE	C5	TUTORIAL NUMBER	1
Date:	6 September 2023	Time:	1:10pm to 3.00pm

Title: Hydrogen Certification (progress report on JWG C5/C1.36

Presenters: Ricardo Gedra (Br), Anant Venkateswaran (US)

Ricardo Gedra is an engineer with a master's degree in electrical systems, a specialization in business administration and an MBA in IT management. He is information manager at CCEE and has more than 25 years of experience in electrical sector and has had 6 books published.

He is responsible for developing hydrogen certification in Brazil and convener of the CIGRE working group on hydrogen certification. He is a member of the Advisory Committee of the Green Hydrogen Organization and CCEE representative in the World Bank's initiative Hydrogen for Development Partnership – H4D, where he is co-chair of the group dealing with hydrogen certification.

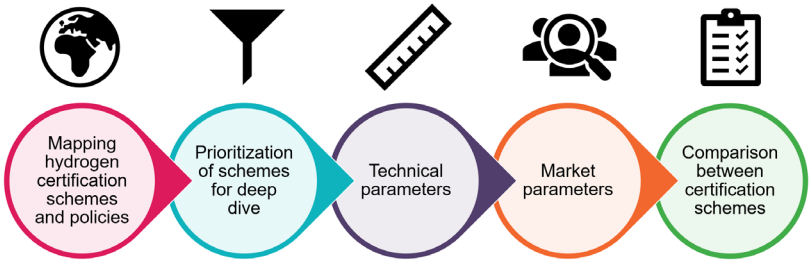
Anant Venkateswaran is an experienced industry professional with over two decades of international experience in business, financial, regulatory, policy, operations and technology aspects of the energy and utility & industrial sectors. Anant serves on several technical, standards, advisory and tutorial committees and is a teacher, presenter, panelist, moderator and speaker at international venues including Distributech, IEEE, CIRED, CIGRE and Global Smart Grid events (like ISGW).

Working across the globe, he has managed major technology investments and advised clients from visioning to validation. A senior member of the team accountable for strategy, trusted advisory/ consultative, thought leadership and partnerships, Anant has worked both in the traditional aspects of the grid as well new and emerging areas of Big Data, IoT, Cloud Computing and Smart Energy. Anant has worked with several industrial, utility & Govt customers globally. Anant is currently based in Denver, Colorado and is currently with Hitachi Energy's Grid Automation business.

Precis of the tutorial:

Hydrogen has been presented as one of the solutions to help the global target of decarbonization. As it can be produced with or without a carbon footprint, the certification become a very important attribute of this product. For this reason, in 2022 a Cigre Working Group was created to address the certification of hydrogen. In this tutorial, we will present the study carried out by this WG to establish the most appropriate requirements to certify the emissions of the electricity used in the production of hydrogen. This certification will facilitate hydrogen becoming as a global commodity in the future.

The tutorial reported on the the methodology used by the WG, which shown in this diagram:



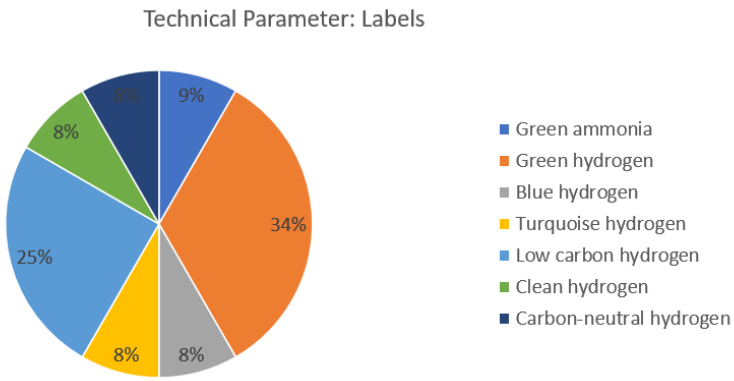
It is essental, for hydrogen to be able to assist in decarbonizing the power system, that there are no emissions throughout the fuel production chain, that is that only green hydrogen should be used. As noted above, there may be a transitionary phase where grey & blue hydrogen are used but the emissions should be measured as they are reduced to a low level and, eventually, eliminated.

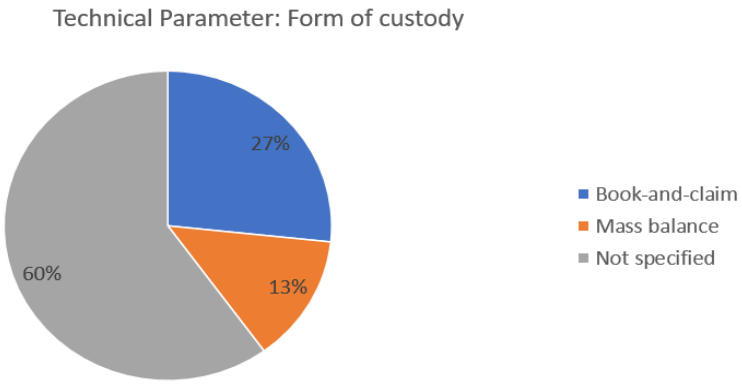
In order for the hydrogen buyer to be sure of the carbon content associated with the fuel, a certification can provide the necessary security to know the fuel's emission footprint. This requirement is very new and there is no standard on how to certify the electrical energy used in this process.

As hydrogen will have domestic and international markets, it is necessary to standardise how to address this issue for different regional conditions and that there are internationally recognised standards.

With this background, the tutorial noted that certification well be:

- Vehicle to help set policy, regulation, support structures
- Key input in accurate price determination
- A guide to the attributes of renewable hydrogen
- Key to create a fair, equitable and transparent system
- Enable prosumer engagement and participation
- Drive innovation in market design
- Lastly, enable cross-border and cross-region transportation with trust





The tutorial then presented a series of case studies from Europe, Australia, the United States and the middle east and noted the need for the process to be documented and verified at each stage.

Key tasks yet to be completed by the working group are:

- Consolidation and analysis of results
- Identify main points of convergence and divergence for each jurisdiction
- Establish recommendations for harmonizing certification schemes

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C6	SESSION NUMBER	1
Date:	September, 6, 2023	Time:	08:00 --- 09:50

FINDINGS AND CONCLUSIONS:

This session covered various papers around how to operate and control distribution systems with increasing levels of DER. During this session, the following papers were presented:

Paper	Presenter	Topic
1122	Dr Emil Hillberg	Active Network Management to support increased grid utilisation – ANM4L project results
1135	Xu Li	Control Scheme of Battery Energy Storage System for Black Start of Gas Turbine
1141	Dr Yogendra Vashishtha	How to manage the network to maximise the value proposition of increasing customer owned DER?
1292	Dr Alireza Barzegar	Decentralised Calculation of Dynamic Operating Envelopes for Distributed Energy Resource Management in Distribution
1384	Nando Ochoa	From Model-Driven to Model-Free: Comparisons using Real Smart Meter Data and Real Distribution Network from Australia
1379	Leila Rajabpour	Study of Transient Oscillations in Emergency Shedding of Legacy Distributed PV Generation through Substation Voltage Management

Some main findings, discussions and conclusions during the session were:

- Network planning will have to change. Traditional network reinforcement is insufficient to meet demand. Both planning and operation of distribution grids is going to change, moving away from fit-and-forget.
- Not only the way we plan our networks may have to change, the way we model our grids may be done more efficiently as well. For example, by using actual measurements and training neural networks, being more efficient for certain use-cases than getting our electrical models right. Though, not all traditional models may be replaced as, e.g. short-circuit calculations do require a full network representation. Similarly, to generate models from smart meter data, one would need all the measurement data from all customers, which generally is not possible. As the network topology or voltage control is changed, the

neural network needs to be updated (as would a conventional network representation).

- Controlling algorithms may help to create higher grid utilisation. However, there is a balance between increasing network loading, requiring less assets, and managing technical grid losses. Hence, the business case should be considered.
- Influencing DER behaviour must be done in the right way to adequately limit the network impact.
    - Time-of-use tariffs for DER, for example EVs, may lead to new peaks (at different moments in time) at high adoption rates. Demand side management may resolve this issue, and the combination of both may lead to minimal investment. Also, multiple time-of-use schemes may have to be implemented to obtain the desired behaviour
    - As we are reinforcing our grids, DERs may have to be controlled to prevent undesirable network loading. Markets specifically designed for LV networks are not likely part of the solution. Rather, dynamic operating envelopes may be considered.
    - Controlling DER such that they all have equal relative dynamic operating envelopes may seem fair, but from a system perspective it leads to inefficient results.
    - Various control schemes have various degrees of effectiveness. Simulating behaviour on the MV/LV transformer level might prove valuable.
- Emergency generation shedding may lead to undesired transient behaviour. Fortunately, this impact can be limited, e.g. by changing the inverter requirements (as was done in Australian Standard 4777.2:2020).
- Battery energy storage systems are a crucial part of the energy transition. Along the way, they may also support the grid in the form of aiding in black start of gas-turbine units. They may require a specific design for the black-start purposes, as the one presented in the paper.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C6	SESSION NUMBER	2
Date:	September 6, 2023	Time:	10:20 --- 12:10

FINDINGS AND CONCLUSIONS:

This session covered the area of the customer interface and its impact on distribution operations. During this session, the following papers were presented:

Paper	Presenter	Topic
1124	Laura Jones	An end to end electricity system, but where does the customer fit? How can customers help us build the right distribution networks
1164	Dr Yogendra Vashishtha	Building Network Visibility Architecture to gain and use insights for the low carbon transition.
1169	Yoshifumi Ikemoto	Eliminating overload in distribution systems by utilizing DER
1198	Joshua Snodgrass	Importance of Automating Distribution Resiliency Analysis for Climate Hazards
1414	Dr Mihai Ciobotaru	Three-phase voltage balancing using active power transfer between phases

Some main findings, discussions and conclusions during the session were:

- Customers are not being included in energy change processes in the way they want to be. Better outcomes for customers and engineers alike involve making effort to engage customers in change processes early, defocusing specific technology uses, and basing discussions on common values.
- Important tools and methods to operate and plan for distribution networks include high network visibility from customer smart meters, grid support from electric vehicles, automated resiliency analysis, and phase voltage balancing from stat-coms. These tools reflect the changing make up of distribution load, and allow for more informed decision making, risk analysis, operations, and planning.
- Distribution networks are becoming increasingly independent, due to more sophisticated tools and distributed energy resources (DER) like distributed PV, electric vehicles, and batteries. However, in the short to medium term, both advancement in the distribution and transmission generation is required to meet climate targets. Furthermore, due to the inequitable uptake of DER, transmission networks are required for trade and for energy support in the instance of wind or solar droughts. Considerations for active distribution management depends on the specific customer profiles and needs served by the network and requires similar tools and methods to solve different technical challenges.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	C6	SESSION NUMBER	3
Date:	September, 6, 2023	Time:	13:10 --- 15:00

FINDINGS AND CONCLUSIONS:

This session covered various papers around how to operate and control distribution systems with increasing levels of DER and utilising BESS for network support. During this session, the following papers were presented:

Paper	Presenter	Topic
1403	Alan Luc	Community Battery Trial – Control and Optimisation of Power Capacity
1144	Xing Zhang	Comparison of Reactive Power Support Capability between Grid-Forming Energy Storage System and Condenser under HVDC Commutation Failure
1160	Kento Yonezawa	Demonstration of Multiple Voltage Source Control and Ground Fault Detection Using LVDC Distribution Facilities
1194	Tobias Lechner	Energy Balance Tool for the Operational Planning of Hybrid Mobile Generators – Islanded Grid Operation with the Infeed of Distributed Generation Systems
1219	Leonardo Leite	Voltage Regulation and Load Relief in Medium Voltage Feeder Supported by Battery Energy Storage System
1302	Fernandes R.O.	Hybridization in the Balbina Hydroelectric Power Plant Reservoir

Some main findings, discussions and conclusions during the session were:

- Increasing levels of DER connected on the distribution network presents new challenges around network planning and operational practices. Reverse power flows and voltage rise due to high levels of DER penetration are key issues which need to be managed by the system operator whilst maximising DER utilisation.
- Distributed Battery Energy Storage Systems (BESS) installed and managed by the system operator can be utilised to provide a range of functions to support DER penetration whilst mitigating the need for network reinforcements. These functions include:

    - Voltage regulation of distribution feeders can be implemented by the system operator based on real-time meter readings at distribution transformers.
    - Reverse power flows can be managed at times of peak generation on the LV network to limit the need to curtail DER through “peak shaving” practices.
    - Market partners can operate these distributed BESS in the whole-sale market as part of virtual power plants, through wholesale arbitrage and Frequency Control Ancillary Service (FCAS).
- The tariff schemes and operational procedures applied to these distributed BESS need to be carefully considered. With a number of different factors – time of use etc. - to be considered that need to optimise uptake whilst benefitting the customers. The main priority for these systems are ensuring safe network operation.
- Grid forming BESS are becoming increasingly crucial in the transition to net zero with these inverters being suitable to replace typical rotating plant for a number of uses:
    - Synchronous condensers and grid forming inverters of the same capacity can provide similar levels of grid support when considering HVDC faults, especially when providing reactive power support.
    - Mobile generators, typically diesel based, are often used to provide power to areas of the grid when that network becomes islanded due to maintenance works or faults. In these scenarios DER is often curtailed to ensure safe management of the island network but mobile grid forming BESS can enable DER to remain connected and safely support the network through forecasting demand and generation profiles.
- Increased uptake of inverter based generation and energy storage could lead to multi-terminal DC network applications on the LV network. This approach is still largely considered a concept with minimal known applications globally, but application of a DC network would improve efficiency and negate the need for frequency synchronisation on the grid. Limited studies are being conducted around the implications of a DC network but the initial findings show some promise. DC networks are likely to be most suited to island or privately owned distribution grids.
- Globally DER is being utilised in parallel to existing infrastructure to optimise operation and utilise existing network infrastructure. Innovative approaches are being used to reduce the cost of connecting DER whilst accelerating the transition to net zero.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	D1	SESSION NUMBERS	1&2
Date:	September, 5, 2023	Time:	13.20 - 17.30

FINDINGS AND CONCLUSIONS:

The D1 paper sessions were split into two parts: (1) Online monitoring and alternatives to SF6 and (2) HV measurements, diagnostics and materials.

Attendance varied throughout the session but was generally between 30 and 35. There was good engagement with all of the papers. Remarks on the papers that resulted from the discussions:

Monitoring

Utility members present prefer not to use DGA monitoring over the lifetime of a transformer, rather selecting such devices based on risk and asset management strategies, although monitoring installed before an issue arises does provide the investigator a history prior to the observation of the problem.

The differentiating cost factor between monitoring devices could be its reliability and this may be difficult information for utilities to acquire. A third-party testing facility providing independent perspectives on different monitors would be desirable to some but would there need to be an accepted protocol for performance?

Communication with devices such as DGA monitors enables remote assessment. But there are different methods to provide this connectivity with advantages and disadvantages. Some services may need to be replaced when the technology changes e.g. retirement of 3G and others may rely heavily on skilled resource that could be hard for utilities to maintain. Utilities need to consider the long-term factors involved for devices that may remain in service for 15 years or more. Alternative approaches based on IoT sensors offer the possibility of cost reduction and plug-and-play implementation, however, as yet there are few practical deployments in the energy sector.

Alternative Gases

Moisture has an impact on by-product creation in alternative gases to SF6, this has to be controlled and understood when investigating the health and safety implications of any breakdown materials in SF6 alternative gas mixtures.

We are still learning about partial discharges in alternative gas mixtures, these are much better understood in SF6. CIGRE WG D1.78 has been set up for this purpose.

Solid Materials

Nanocomposites offer the promise of improving several physical properties simultaneously with little negative impact on other properties: WG D1-73 is addressing the state of the art in this field. The biggest challenge remains scaling up laboratory sized samples to the volumes

need for mass production in a consistent manner. It remains to be seen if these materials will ever become mainstream replacements for traditional materials or will only find use in small volume niche applications.

Ageing tests on an alternative type of paper based on an agricultural crop created a good discussion. This early work shows promise, but ageing under a wider set of conditions is needed to be able to benchmark the results against traditional kraft paper.

Diagnostics and Measurements

Frequency domain spectroscopy is an old technique which is being reassessed for cable testing in the field. Although the method gathers more data than a single frequency VLF tan δ measurement, whether this justifies the increased measurement time as still an open question and needs further investigation.

Harmonic frequencies have always existed in the power network, but the increasing use of power electronics is driving the need to both understand the impact on material ageing and to be able to measure accurately the harmonic content. Standardised techniques needed to be developed to measure the accuracy of CTs and VTs. Gaps in existing standards were also discussed for testing under DC voltages with superimposed lightning impulses.

Conference Agenda

CIGRE Symposium Cairns 2023

Session

D1 Papers 1

Time:
Tuesday, 05/Sept/2023:
1:20pm - 3:10pm

Location: **M10/M11**

Max 500 pax

Session Chair: **Simon Sutton**
Secretary: **Gordon Wilson**
Special reporter:
Moderator:
Session Topics:
D1 Monitoring: Online monitoring and alternatives to SF6 gas

Session Abstract

In this session we will have the presentation and debates of 5 full papers from 4 different countries. There will be presentations of methods to assess performance of DGA devices and their lifetime cost in service, a perspective on communicating with monitoring devices. There will also be presentations on the analysis of an SF6 alternative gas mixture and how partial discharge monitoring of gas insulated switchgear might be improved.

Presentations

1:30pm - 1:50pm

Dissolved gas analysis (DGA) monitor performance testing and evaluation methods

Toni Mellin, **Senja Leivo**, Ari Laiho, Mikko Aronniemi, Jarkko Larkio - Vaisala Oyj, Finland.

The paper discusses DGA monitor testing and evaluation. It has an introduction to measurement uncertainty in relation to DGA monitors and laboratory analysis. Testing with transformers and simulated laboratory tests are covered. Experiences related to laboratory tests are discussed with explanations on some details. There is a short guideline for tests in a laboratory setting. Examples of results in comparison to reference measurements are shown for a laboratory test and a field case.

1:50pm - 2:10pm

Leveraging Home Automation Principles for OLCM Integration at Utilities

Sam Murali, Evan Lamplough, Lance Wee, Hazem Khamis -Transgrid, Australia.

On-Line Condition Monitoring (OLCM) is crucial for non-intrusive early identification of asset degradation and useful in preventing failures in power transformers and high voltage switchgear. The demand for OLCM systems will continue to grow as the power industry shifts to sustainable practices, adopts new technologies, and as governments start to regulate of SF6 emissions. This paper leverages home automation principles to significantly decrease OLCM deployment for utilities. Wireless networks are deployed with adherence to cybersecurity policies in substations to transport condition data to an organisation's asset management information platform for asset failure prevention and early detection of asset degradation.

2:10pm - 2:30pm

Lifetime cost evaluation of continuous online dissolved gas analysis (DGA) monitoring

Toni Mellin[1], Senja Leivo[1], Mark Gross[2] - [1]Vaisala Oyj, Finland; [2]Vaisala Inc., USA.

The paper presents a method to calculate total cost of ownership (TCO) for DGA monitors. Demonstrated equations cover cost of consumables, maintenance, and other potential additional costs during monitor lifetime. These cost sources during monitor lifetime are combined to present the total cumulative lifetime

costs of a DGA monitor, which essentially is TCO of the DGA monitor. The intention of the paper is to provide reproducible and structured framework to calculate DGA monitor TCO.

2:30pm - 2:50pm

Production, Analysis and Identification of Crystal By-products in C3F7CN Mixtures

Paul Coffey[1], Ali Arafeh[1], Lujia Chen[1], Philip Martin[1], Gordon Wilson[2], Mark Waldron[2] - [1]The University of Manchester, United Kingdom; [2]National Grid Electricity Transmission, United Kingdom.

This paper examines the production, analysis and identification of crystal by-products, such as perfluoroisobutanamide (C3F7CONH2) and metal complexes from perfluoroisobutyronitrile (C3F7CN), produced under different environmental conditions, examined by a suite of mass spectroscopy instruments, Fourier transform infrared and Raman spectroscopy techniques.

2:50pm - 3:10pm

Required Improvement of UHF PD Detection for gas-insulated Systems

Uwe Schichler[1], Claus Neumann[2] - [1]Graz University of Technology, Austria; [2]Technical University of Darmstadt.

Today's design of modern GIS shows a high compactness regarding the size of equipment. This is combined with an increased gas pressure, higher electrical stress on the electrical insulation system and increased risk of breakdown due to minimized safety factors between IEC test voltages and withstand voltages. Defects in the electrical insulation system like protrusions become more dangerous. This requires an improvement of the PD detection sensitivity of UHF PDM systems to e.g. an equivalent of 2 pC for protrusions.

Conference Agenda

CIGRE Symposium Cairns 2023

Session

D1 Papers 2

Time:
Tuesday, 05/Sept/2023:
3:40pm - 5:30pm

Location: **M10/M11**

Max 500 pax

Session Chair: **Simon Sutton**
Secretary: **Gordon Wilson**
Special reporter:
Moderator:
Session Topics:
D1 Challenges: HV measurements, diagnostics and materials

Session Abstract

In this session we will have the presentation and debates of 6 full papers from 4 different countries. Testing and properties of cable insulation will be explored. An experimental insulation for transformers will be introduced and testing challenges will be explored with reference to standardisation and verification.

Presentations

3:40pm - 3:58pm

Application of On-Site Frequency Domain Spectroscopy Measurement on Medium Voltage Cross-Linked Polyethylene Power Cables

Pongpon Singkhawat, Ronachart Gatechompol - Electricity Generating Authority of Thailand (EGAT), Thailand.

This paper discusses the FDS on-site measurement of 11 circuits of MV XLPE power cables, which are divided into 5 groups, to assess their conditions. Referring to the FDS test results, each group of cables shows different characteristic curves that are uniquely dependent on the function of usage, cable length, service life, installation pattern (direct burial or laid on trench), and also cable terminations. Practically, for newly installed cables, the FDS can be tested as a fingerprint for condition-based maintenance by considering the trend of changing the %Tan delta curve in cables.

3:58pm - 4:16pm

Dielectric properties of polypropylene/UHMWPE nanocomposites for power cables

Thomas Andritsch, Phichet Ketsamee - University of Southampton, United Kingdom.

Present work shows the effects of surface–modified magnesium oxide (MgO) nanofillers on the AC breakdown strength, thermal conductivity, and mechanical properties of PP, as well as composites with ultra–high molecular weight polyethylene (UHMWPE). When MgO nanoparticles are mixed in, the composites move from separate crystallisation to co–crystallisation peaks, acting as a compatibilizer, allowing the mixture of otherwise incompatible compounds. The UHMWPE improves thermal conductivity from 0.21 W/m·K to 0.31 W/m·K due to its long molecular chains.

4:16pm - 4:34pm

Performance evaluation of sugar graze paper for transformer solid insulation application

Anupam Dixit, Jordan Pennells, Hui Ma, **Chandima Ekanayake**, Pratheep Kumar Annamalai, Tapan Saha - The University of Queensland, Australia.

In this work an insulation paper is developed from an agricultural crop biomass (Sorghum bicolor L. Moench) derived nanofibre sorghum derived in a lab-based environment and its performance is evaluated for the application of transformer paper insulation. An accelerated thermal ageing test is performed at 100℃ in mineral oil and synthetic ester liquid in a sealed test cell. The tensile strength, DP, and moisture of insulation papers are measured multiple times during the ageing experiment to compare the mechanical properties of the kraft paper and the sorghum derived insulation paper.

4:34pm - 4:52pm

Aspects of Standardization of RCR Dividers for Measurement of Composite Voltage on DC Cables and DC GIS/GIL

Oliver Pischler, **Uwe Schichler**, Johann Meisner - Graz University of Technology, Austria.

High voltage tests on DC cables and DC GIS/GIL with composite voltages have become important in recent years due to increasing number of HVDC projects. During these tests, the power equipment is simultaneously stressed with DC voltage and an impulse voltage (e.g. DC + SI/LI). Due to the composite voltage, measurement is ideally performed with universal voltage dividers (RCR dividers), which have not yet been fully covered by standards. This publication focuses on the performance of universal voltage dividers at different voltage combinations.

4:52pm - 5:10pm

Verification of a Current Transformer's Accuracy on Distorted Current Waveforms

Wei Yan, Tri Hai Vu, Yi Li, Frederick Emms - National Measurement Institute, Australia.

Current harmonics have emerged in power networks due to the increasing integration of non-linear loads, such as power electronic devices used in inverters. Traditional current sensors used in electrical substations measure the fundamental frequency currents generally for metering and protection purposes but their performance to be verified before being used for harmonic measurement and evaluation of power quality. In this paper, a reference current measurement system was tested against a current shunt using single frequency currents from the fundamental frequency up to the 99th harmonic and distorted current with the same harmonic profile and amplitude.

5:10pm - 5:28pm

Accuracy testing of a high-voltage transformer under rated fundamental voltage and superimposed harmonics

Yi Li[1], Imanka Dewayalage[2], Wei Yan[1]

[1]National Measurement Institute, Australia; [2]University of Wollongong, Australia.

The ratio and the phase errors of a 33 kV inductive voltage transformer (IVT) were measured under harmonic voltages up to 2500 Hz. Tests were performed not only with the harmonic voltages, but also with harmonic voltages superimposed on the rated fundamental voltage. Accuracy results were obtained with different levels of harmonic voltages. The test results showed that maximum ratio error and maximum phase displacement of this particular IVT were +4.5% and -1.2 crad respectively, and did not differ significantly from those measured with the individual harmonic voltages alone.

TUTORIAL SUMMARY

STUDY COMMITTEE	D1	TUTORIAL NUMBER		D1-012
Date:	September, 5, 2023	Time:	10:30 --- 12:20	

Title: Application guide for Partial Discharge (PD) detection in Gas-Insulated Switchgear (GIS) using Ultra-High Frequency (UHF) or acoustic methods

Presenter: Uwe Schichler

Uwe Schichler has been Head of the Institute for High Voltage Technology and System Performance at Graz University of Technology since 2014. He studied electrical engineering and completed his PhD at the Schering Institute of the University of Hanover in 1996. He then worked for Siemens in the field of gas-insulated switchgear and transmission lines. He is Member of IEEE, CIGRE, Austrian OVE and German VDE and active in several CIGRE working groups. From 2014 - 2022 Austrian representative in CIGRE SC B3 "Substations" and since 2022 Austrian member in CIGRE SC D1. The current focus of his research work is on condition monitoring and reliability of electrical equipment, partial discharge measurements, insulating materials and DC cables

Precis of the tutorial:

GIS has been in operation for more than 45 years and has shown very low failure rates. However, the return of experience shows that some of the in-service failures are related to defects in the insulation system. Many of these defects can be detected by PD diagnostics.

The UHF method for PD detection is used worldwide by GIS manufacturers in the factory, during commissioning and by utilities for monitoring in-service based on positive return of experience from the field.

In 1999 a CIGRE report was published which described the sensitivity verification on GIS using the UHF method. The proposed procedure ensures that defects causing an apparent charge of 5 pC or greater can be detected by the UHF method.

This CIGRE report describes the two-step procedure for sensitivity verification in a very general way. It later became obvious that a more detailed description of the sensitivity verification was necessary to avoid technical misinterpretations on the proposed two-step procedure and the required measures.

TB 654 collected the available experience of PD sensitivity verification for GIS. A detailed description of the two-step procedure is given and supported by examples. Guidelines help manufacturers and users in the effective application of the UHF method for PD detection on GIS.

Around 80 people attended the highly informative tutorial, which was followed by more than a dozen wide-ranging questions. These touched on the more practical elements of the tutorial, namely, the relative merits of UHF versus acoustic methods, the practicality of field measurements when no built-in sensors exist and the implications of adopting alternative gases to SF6.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	D2	SESSION NUMBER	1
Date:	September, 7th, 2023	Time:	08:00 --- 12:00

Session/Sequence Topic: Digital transformation and AI in asset management

Moderators: Mr. Gareth TAYLOR (GB); Kun Lun Gao (CN);

FINDINGS AND CONCLUSIONS:

Summary of session:

On average 100-120 delegates attended the session for sequence/segment 1: Digital transformation and AI in asset management. The sequence/segment started at 08:00 and finished around 12:00 as scheduled including a coffee break.

Segment/Session 1:

The appointed moderators were Gareth Taylor and Kunlun Gao. However, Kunlun Gao was not available to moderate the segment/session. The main topic of session/segment 1 was Digital transformation and AI in asset management. 11 full papers from 5 different countries, including 5 papers from Japan, 2 papers from Australia and 2 papers from India. The specific topic subjects as covered were as follows:

- Data Driven Approaches (4 papers)
- AI Applications (4 papers)
- Enhanced Asset Management (3 papers)

The presented papers addressed novel tools and technologies to address challenges relating to digital transformation and AI in asset management as well as enabling cost-effective, sustainable and resilient operation and management of future end-to-end electrical power systems.

Most presenters attended and presented 10 of the papers as scheduled. Gareth Taylor presented paper final paper of the segment/sequence; 'CIM for Network Planning and Power System Development', Nikolay Belyaev, Roman Bogomolov, Denis Pilenieks, System Operator of the United Power System (SO UPS).

D2 Papers – Digital Transformation and AI in Asset Management - Report

Paper 1111: IIoT Ecosystem approach; IoT, PoC Use Cases, Edge Hardware/Computing, Applications/Demos. Practical Approach with lessons learnt and conclusions drawn. Three potential configurations and the case of origin energy are discussed.

Q1 What was the geographical area considered? – Brisbane, Queensland. Due to the company requirements, mainly tested with the local site in Brisbane

Paper 1161: Drone photographic inspection / image processing of structural integrity of radio transmission towers. Drone pictures; System A1: Bolt's appearance change detection, correct rate 93%; System A2: IDA Ring attachment detection, 84% precision, 94% recall

Q1 How is image similarity measured or quantified? – Hamming Method

Q2: How to train for the algorithm to achieve the high accuracy?

Paper 1168: Motivation – Replace legacy tools, up-to-date network models, active network management, 2-way power flows. Data available: GIS, meter data management system, network analysis software standard type DB. Staged implementation. Model features: GIS and simplified schematic view. Challenges: data model differences.

Q1 Use of ADMS – Capture/share data for AVR settings

Q2 What is the business case for the proposed approach – cost saving, time saving

Q3 How is data obtained from other stakeholders/sources ie TSOs, GSP

Paper 1176: Image processing and enhancement using convolution

Q1 What is level of human participation in image processing/selection procedure

Paper 1177: Proposed methodology for data preparation with regard to vulnerability assessment. Clustering was used for classification/indexing

Q1 What computing resources/infrastructure was used

Q2 Have you considered vulnerability wrt forecasted weather conditions

Paper 1183: Automated data sharing; future company/enterprise data sharing, cybersecurity

Q1 What kind of natural language processing can be used (Japanese and English)

Q2 Use of chat or messaging tools for sharing data

Paper 1186: 3D image processing

Q1 What efficiencies are gained using the proposed approach – saving of maintenance time (100s hours pa)

Q2 What is the desired/required image resolution for the process – highest resolution available ie OCR

Q3 How is the data kept up-to-date? Will be considered in future work

Q4 Ho is the approach applicable to VR?

Paper 1187: Application of edge computing for fault detection by acoustic analysis, edge router, supports MPLS and OSPF

Q1 How developed is acoustic analysis compared to established image processing – significant R&D activity in acoustic analysis

Paper 1190: Addressed the challenges encountered when implement AI techniques.

Q1 What about false positives – How can you be certain that it is an actual anomaly?

Paper 1287: End-to-end approach for asset management in Brazil power system: obtaining best value, performance and flexibility from your assets

Paper 1351: CIM adoption for network planning and power system development

Q1 How is regulatory compliance performed? Incentives and training

Q2 Can CIM be adopted beyond power flows in transmission systems? Yes: Distribution and dynamic studies

Slido results for 7 questions 1.1 to 1.7 - session live audience poll:

1.1 What is your organisation's main challenge with regard to digital transformation and application of AI in Asset Management?

Multiple choice - Votes: 75

1.1 What is your organisation's main challenge with regard to digital transformation and application of AI in Asset Management?

- Developing Data Driven Approaches 24%
- Implementing AI Applications 31%
- Improving Asset Management 36%
- Other 9%

Multiple choice - Votes: 76

1.2 What would be the main aim of your organisation with regard to adopting data driven and information system approaches to asset management?

- Plant or Unit Condition Monitoring 37%
- Provision and specification of up-to-date network models 21%
- Enabling remote monitoring 32%
- Other 11%

Word cloud poll - Votes: 51

1.3 What do think is the main challenge for an organisation to enable digital transformation in asset management?

Cybersecurity - Votes: 7; Data quality - Votes: 5; Integration - Votes: 2; Accuracy - Votes: 2; Training - Votes: 2; The stage of plant life - Votes: 1; company policy - Votes: 1; Skills - Votes: 1; Lack of trust for new tec - Votes: 1; Engineers' expertise - Votes: 1; Intent - Votes: 1; Knowledge building Votes: 1; Data architecture - Votes: 1; architecture - Votes: 1; Data Formats - Votes: 1; change future -Votes: 1; To convince the organisation - Votes: 1; Multiple data sources - Votes: 1; Cross-techno knowledge - Votes: 1; deep learning - Votes: 1; Data storage - Votes: 1; Data analytics - Votes: 1; Security - Votes: 1; Making management confide - Votes: 1; Confidence - Votes: 1; belief - Votes: 1; data security - Votes: 1; Assumptions - Votes: 1; visibility system - Votes: 1; Basic data quality - Votes: 1; Legacy technology issues - Votes: 1; Training of AI - Votes: 1; Skilled experts - Votes: 1; Data integrity - Votes: 1; Involving all personnel - Votes: 1; Acceptance - Votes: 1; People accepting changes - Votes: 1; Willingness to change - Votes: 1; Lack of Data Scientists - Votes: 1; Management - Votes: 1; Knowledge - Votes: 1; Value - Votes: 1; Multi disciplinary skills - Votes: 1; Data access - Votes: 1; Competences - Votes: 1; Resource - Votes: 1; Transform the org - Votes: 1; Mindset - Votes: 1; Change - Votes: 1; Security strategy - Votes: 1;

Competence of people - Votes: 1; Productionizing - Votes: 1; ハイ - Votes: 1; Single source of data - Votes: 1

1.4 Rank the following potential benefits of AI applications to asset management in your organisation:

Ranking poll - Votes: 49

1. Enhanced feature extraction and pattern recognition for fault detection 2.41
2. Accurate image and signal processing for condition monitoring 2.39
3. Other 1.20

1.5 What do think is the greatest challenge for an organisation in order to apply AI techniques to asset management?

Word cloud poll - Votes: 51

Data quality - Votes: 12; Accuracy - Votes: 5; Business Priorities - Votes: 3; Skill sets - Votes: 3; Mindset - Votes: 2; Reliability - Votes: 2; Confidence in results - Votes: 2; Expertise - Votes: 2; Staff - Votes: 2; Data collection and access - Votes: 2; Training data - Votes: 1; Limitations of AI - Votes: 1; Data Security - Votes: 1; Systems to interpret - Votes: 1; System integration - Votes: 1; Illustrating value - Votes: 1; Persuading the boss - Votes: 1; Convincing management - Votes: 1; accuracy reliability - Votes: 1; Having expertise in-house - Votes: 1; Culture - Votes: 1; Capability - Votes: 1; "Catch the people" - Votes: 1; Understanding of AI can - Votes: 1; Past data for training - Votes: 1; Confidence - Votes: 1; Quality data - Votes: 1; Data confidence - Votes: 1; Integration - Votes: 1; Knowledge- Votes: 1; person - Votes: 1; Cyber Security - Votes: 1; Skillsets - Votes: 1; Expertise to deploy AI - Votes: 1; Data consistency - Votes: 1; Change management Votes: 1; Cultural shift - Votes: 1; Scale - Votes: 1; Black box - Votes: 1; Inconsistent data - Votes: 1; Staff knowledge - Votes: 1; Resources - Votes: 1

1.6 What do you think is the most important reason for end-to-end system asset management?

Word cloud poll - Votes: 51

Efficiency - Votes: 11; Cost - Votes: 6; Cost efficiency - Votes: 3; Value extraction - Votes: 2; Consistency - Votes: 2; Data-driven decisions - Votes: 2; Safety - Votes: 2; Control - Votes: 2; change - Votes: 1; Automation - Votes: 1; Risk control - Votes: 1; Flexibility in operation - Votes: 1; Service continuity/quality - Votes: 1; Return on investment - Votes: 1; Value to stakeholders - Votes: 1; Integrated - Votes: 1; Risk management - Votes: 1; Reduce double handling - Votes: 1; Profit- Votes: 1; Understanding - Votes: 1; Value stack - Votes: 1; Asset utilization - Votes: 1; Knowledge management - Votes: 1; Efficiency - Votes: 1; Economy efficiency - Votes: 1; Least cost life costs - Votes: 1; Visibility - Votes: 1; Lack of workforce - Votes: 1; make Votes: 1; Risk mitigation - Votes: 1; relief - Votes: 1; Enabling efficiencies - Votes: 1

1.7 What is the main area of Common Information Model (CIM) adoption in your organisation or field?

Multiple choice - Votes: 48

Transmission System 52%

Distribution System 29%

Markets 4%

Other 15%

Conclusion:

The three main topics areas as covered indicate the relevance to electrical power industry, observable trends, potential future work and ideas that can feed into SC D2 activities and preferential subjects.

Data Driven and Information System Approaches:

- Data Driven Unit Condition Monitoring
- Data Driven Network Models and Information System
- Data Driven Use Cases for Remote Monitoring and CIM Adoption

AI and Machine Learning Applications

- AI Applications for Enhanced Image Processing of ICT Infrastructure
- AI and ML for Enhanced Feature Extraction and Defect Pattern Recognition in Power Systems
- Novel Computational Approaches for Future Deployment of AI Applications

Enhanced Asset Management

- Enhanced Condition Monitoring and Vulnerability Assessment of Electrical Power Systems
- Novel ICT Infrastructure for Advanced Asset Management and Maintenance
- Advanced Asset Management Data Availability for Maintenance and Monitoring of End-to-End Electrical Power Systems

Conference Agenda

CIGRE Symposium Cairns 2023

Session

D2 Sequence 1

Time:
Thursday, 07/Sept/2023:
8:30am – 12:10am

Location: **Auditorium D**

Max 500 pax

Session Chair: **Victor Tan (AU)**
Secretary: **Joël Nouard (FR)**
Special reporter: **Gareth Taylor (GB)**
Moderator: **KunLun Gao (CN)**
Session/Sequence Topic:
Digital transformation and AI in asset management

Session Abstract

In this sequence of the session we will have the presentation and discussion of 11 full papers from 5 different countries. Including 5 papers from Japan, 2 papers from Australia and 2 papers from India. There will be presentations of novel tools and technologies as required to address the challenges relating to digital transformation and AI in asset management in order to enable cost-effective, sustainable and resilient operation and management of future end-to-end electrical power systems.

Presentations

8:55am - 9:05am

Practical Approach to Generation Site Using Digital Transformation Technology for Data Driven Monitoring: Case of Origin Energy

Ahmad Taufiq Abdullah Thani, Deepu Varghese
Origin Energy, Australia; ahmad.taufiq@origin.com.au

The increase in available digital transformation technologies and applications has introduced new methods for intelligent asset monitoring and real-time data collection. This has led to digitalization in energy industries using Industrial Internet of Things (IIoT) which will improve intelligent asset monitoring through real-time models with more emphasis on communications, modern protocols, and Artificial intelligence (AI) as the underlying requirements. Traditionally, generation sites have been slow adopters in implementing digital transformation technologies. This paper will look at how a traditional generation site has attempted to use digital transformation technology for data driven monitoring. The paper will also look at how the generation site has addressed topics associated with adopting digital transformation technologies, specifically evaluation criteria for IoT devices, interoperability and different architectures implemented on site. The paper will also present a completed end to end example of a practical install on a generation site.

9:05am - 9:15am

Development of a Radio Tower Inspection Method using Automatic Drone Photography and AI-based Image Judgment

Yuya SAGA[1], Taiki SATO[1], Yuta WAGATUMA[2]
[1]Tohoku Electric Power Network Co., Inc., Japan; [2]SRA Tohoku, Inc. Japan; saga.yuya.sp@tohoku-epco.co.jp

In Japanese EPUs, important communication lines are housed in microwave radio equipment, and they own many radio towers. In addition, regular inspections are done by climbing up the radio towers to check for loose bolts and rust on the tower members. In this report, we aimed to employ "mission flight," in which a drone automatically photographs the inspection target, and to build an AI-based system to evaluate the inspection items based on the photographs taken by the drone. We constructed and field-tested automated systems on the following two topics; A. Abnormality detection of bolts joining main steel angles: Detect bolts using AI from within images taken by AI-Spot shooting using a drone, and determine "detection of changes in the bolt's appearance" and " detection of whether or not IDA RING is attached". For System A, the detection of bolts in the image and the judgment of whether or not IDARING was attached could be judged with high accuracy. The AI for each function was tuned to have a high recall rate to prevent missing abnormalities. There was an unexpected problem where the image taken by the AI spotting function of the drone on a different day did not have a certain angle of view. However, with added correction processing implemented, we believe it is possible to apply this system to the bolt abnormality inspection at the current stage ; B. Detection of rust and peeling paint on the radio tower: Judging for rust and peeling paint from high-resolution grid images taken by a drone. System B can detect rust and peeling paint in images focusing on radio tower components. However, because the images taken of the steel tower included a large amount of background, the background was in many cases incorrectly detected as rust. Therefore, to create a system for detecting rusting only on steel towers, removing the background from the photographed image and extracting only the area of the steel tower is necessary. As described above, we would like to reduce opportunities for working at heights and further improve inspection efficiency by introducing drones and AI technology to regular inspections of radio towers.

9:15am - 9:25am

Automated creation of Distribution Network models from GIS and other data

Craig Owens[1], Fraser Hampton[2], Simon Laird[3]
[1]Mott MacDonald; Australia; [2]SA Power Networks; [3]1Spatial Australia; Craig.owens@mottmac.com

The paper discusses the experience of SA Power Networks (SAPN) in implementing an automated system to regularly generate distribution network models for its entire medium voltage distribution network. The models allow for automated or manual analysis in load flow, short circuit, contingency, connection assessment and other analysis available in industry standard network analysis software (NAS). Some of the

features of the models include: Accurate geographic coordinates; PV capacity summated at each distribution transformer; Load estimates at every distribution transformer; Automatic Voltage Regulator (AVR) settings; Both geographic and schematic views; Ready to run without adjustments. A collaborative, staged approach to project management has reduced risk at each stage of the project and produced results that align with SAPN business objectives. The system has been designed for maximum flexibility using the existing Geographic Information System (GIS) at SAPN and industry standard extract, translate and load (ETL) and NAS packages. The process has resulted in significant efficiency improvements in the process of creation of network models from GIS and other information. Further work continues to model low voltage networks, and further refinements in the existing medium voltage models.

9:30am - 9:40am

Innovative approach for Automatic identification of defects from photos captured through various transmission line patrolling modes using Artificial Intelligence and Machine learning

Neeraj Joshi, Sukdev Mondal, N Narasimha Rao, Nitish Tewary, Neelanjana Jain, Vijay Prakash Puri, Harsh Pareek, Sandeep Ramesh Bankar, Ravi Ranjan Jha, Binod Dev Barma, Dudapaka Sampath, Kuleshwar Sahu, Dharambir Kumar, A P Gangadharan
Power Grid Corporation of India Limited, India; njoshi@powergridindia.in

Regular inspection is the most widely used and accepted method for the condition assessment of transmission line. At present transmission line photographs are captured predominantly using Handheld GPS cameras. Photographs are also being captured using Helicopter and Drones. The logging and analysis of photographs was being done manually. This entire process is error prone and time taking. After tower wise segregation the photos, defects were identified manually from photos. An AI tool has been trained on tower defect photographs. Currently it is identifying 45 types of defects like Tree in ROW, Tower bolt missing, Bird guard missing, Glass disc damaged, Bird nest, Tower member bent, Grading ring reverse, Grading ring missing, Joint plate missing, Beehive, Polymer insulator damaged, Bushes or creepers. This paper presents a method of automatic defect identification from Transmission line photographs with the help of Convolutional Neural Network (CNN). This method not only identifies the defects but also creates the defect report and is integrated with inhouse APP based ground patrolling platform.

9:40am - 9:50am

Vulnerability estimation of Transmission lines for enhancing operational efficiency and Operation cost reduction

Neeraj Joshi, Vms Prakash Yerubandi, Akash Pratap Singh, Vijay Prakash Puri, Kuleshwar Sahu, A P Gangadharan
Power Grid Corporation of India Limited, India; njoshi@powergridindia.in

Transmission lines are one of the most critical component of power transmission system to transfer the electricity to various load centres. They play a major role in energy security of a country by connecting the major load centres and Generating stations. Transmission lines towers are located in different terrains and often same line passes through different climatic zones. Therefore, regular inspection of transmission lines is most widely followed condition assessment method for the monitoring of health of transmission lines. There was always a need to develop an analytic tool for vulnerability estimation of transmission line to prioritise efforts depending on vulnerability of transmission line to reduce the O&M cost & enhance the operational efficiency. In this direction an AI tool has been created for categorising the lines in 10 categories-Most critical, Very critical, Critical, Severe, Very High, High, Concern, Moderate, Normal, Least Concern- with different vulnerability. Model is predicting the vulnerability of transmission lines on seasonal basis. Tripping history (last 4 FYs) and transmission line patrolling data has been augmented by adding spatial features extracted using opensource GIS tools from historical maps of lightning, fog, wind speed etc, published by Indian Metrological Department (IMD). This paper presents a novel approach for vulnerability index determination of transmission line after considering environmental (Lightning, ROW encroachment, Wind zone change, pollution data) and operational factors (structural defects, Revenue loss, Tripping history).

10:20am - 10:30am

Case Study on Advancement of Electric Power System Maintenance Work Using ICT

Tomoya MIYAGI, Kazuya SAEKI
Tohoku Electric Power Co.,Inc., Japan; miyagi.tomoya.dw@tohoku-epco.co.jp

In this paper, we introduce our efforts to upgrade the operation and maintenance of electric power systems through DX (Digital Transformation), using a system that was quickly constructed by utilizing the latest ICT (Information and Communication Technology) technologies, such as cloud computing and AI (Artificial Intelligence) technologies, for advanced operations based on the knowledge and experience of skilled workers. The three main issues related to equipment maintenance and operation that are the focus of this report are as follows: One is that information on inspections and maintenance, paper and electronic data (text, numerical, images, etc.) are mixed, and the effort involved in extracting the most appropriate data when preparing documents to be managed as a report is enormous; Second, there is a large amount of work involved in preparing reports on the results of inspection and maintenance work; Thirdly, the analytical work required to draw up the next maintenance plan based on the information obtained from the inspection results is dependent on a limited number of specialists, making it difficult to link experience and wisdom to the next generation. As a system configuration for realizing these issues, a public cloud was adopted and a system combining cognitive AI technologies for image analysis and natural language processing was built. Two use cases are mentioned as references, and the labour savings in operations at power stations and work sites that have been implemented are presented. Looking ahead, all kinds of data will be shared throughout the company, including inspection history data on power system equipment, operational data and audio and image data from the field, creating an environment that facilitates the transfer of technology.

10:30am - 10:40am

Use Cases for Remote Maintenance Management of Telecommunication Facilities Using 3D Data in Japan

Koji SATO[1], Koichi SATO[1], Kazutoshi SATO[1], Hirokazu KANEKO[2], Atsushi MINEGISHI[2], Ryohei KAMO[2]
[1]Tohoku Electric Power Co. Inc., Japan; [2]Tsuken Electric Ind Co. Ltd., Japan; sato.koji.ns@tohoku-epco.co.jp

In the telecommunications division of a Japanese electric power company, there are a wide variety of facilities and sites for construction and maintenance. Therefore, it is difficult for our company to grasp the on-site conditions of various facilities, such as installation conditions and indoor travel routes, making it a challenge to improve productivity and ensure safety. The main method of ascertaining the on-site situation without visiting the site is to check the control drawings such as floor plans, but it is difficult to ascertain the detailed on-site situation from the current control drawings. Therefore, as a method for confirming in advance the installation status of various equipment and movement routes,

we converted the site conditions into 3D(three dimensional) data, and conducted a verification evaluation of the effects of using this data on various operations. Nine sites were selected as target sites, mainly large-scale hydroelectric power plants, but also thermal power plants and geothermal power plants, and point cloud data and omnidirectional images were collected at each site to create 3D data on the site conditions. The 3D data made it possible to obtain visual information on the site, which is difficult to express on a plan view, and to display panoramic views of arbitrary points and to simulate travel routes. The created 3D data was demonstrated to the staff members of the relevant departments and front-line business offices, and we received high satisfaction and high expectations regarding its operability and applicability to their work. Since the data is highly applicable to the operations of related departments, it is expected to help improve productivity and ensure safety throughout the company if the data can be shared within the company.

10:40am - 10:50am

Detecting Abnormalities in Power Facilities by Edge Computing Technology

Katsuhito Sawada[1], Shuichi Saito[2], Toshiyuki Munakata[3]
[1]Fujitsu Limited, Japan; [2]Furukawa Electric Co., Ltd, Japan; [3]Nishimu Electronics Industries Co, Ltd., Japan; sawada.katsu@fujitsu.com

In order to realize the smart maintenance of electric power facilities, the examination and practical application of the system which uses the image analysis technology and the acoustic analysis technology by AI (Artificial Intelligence) for the detection of abnormality of electric power facilities and the detection of the sign are advancing. This can be achieved by "collecting and detecting data in the cloud as a center" or "processing and detecting data at the edge using edge computing technology.". This paper describes a method for detecting abnormalities and signs of electric power facilities to be detected by edge computing technology. Some CPU (Central Processing Unit)s implemented by edge routers used in electric power communication networks have container environments for running applications in addition to implementing routing functions. For example, by operating the acoustic analysis technology in this container environment, it may be possible to analyze acoustic data without digitizing it or to reduce the network load. And this time, we thought that the CPU performance requirement of the acoustic analysis technology was lower than that of the image analysis technology, so we implemented the acoustic analysis technology in the edge router and constructed a system for performing the acoustic analysis in the field. In this system, a microphone is connected to a USB (Universal Serial Bus) interface of an edge router in the field. Then the acoustic analysis application in the container environment of the edge router processes the acoustic data collected by the microphone and creates various acoustic parameter data. In addition, this system supports a wired line and a wireless line as an upper line to the center in the basic function of the edge router, and redundancy in both is also possible. As a result, this system can be easily installed in the field and reliable notification of acoustic analysis parameter data is realized by a highly reliable communication network. In the future, it is thought that a reliable notification can be realized when an abnormality occurs or a sign is detected. An example of verification in which the edge router was actually used to process the acoustic analysis parameters of the circuit breaker and electric power storage facility will be introduced. We will continue to advance these studies and system construction to enhance smart maintenance of electric power facilities.

10:50am - 11:00am

Challenges and contrivances in application of in-house AI algorithm to inspect various electric power equipment

S. Araki, T. Sugiyama
Electric Power Development Co., Ltd., Japan; Shouhei_Araki@jpower.co.jp

In recent years, innovative drone technology has been significantly improving and is also widely utilized in inspection field of the electric power industry in Japan. Drones bring workers' safety as well as increase of efficiency in equipment inspection. Combining with drone camera or video as a device, AI algorithm for analyses of equipment images taken by drone's camera is actively applied in the industry. The marriage of drones and AI has resulted in a significant efficiency increase. This paper describes the challenges of how to repurpose and apply the AI, developed specifically for the purpose of inspection of wind turbine blades, to inspection of the other equipment such as power-transmission lines and overhead ground wires.

11:05am - 11:15am

Asset Data Management as part of the Strategy to Operate and Maintain End-to-End Electricity Systems

Marcelo Costa de Araujo, Marcos Marcelo da Silva Marques
Eletrobras Eletronorte, Brazil; marcelo.araujo@eletronorte.com.br

Asset management has become an important issue for electric power utilities worldwide. Equipment in substations and power plants have surpassed their technical useful life and decisions need to be made to choose between investments and maintenance. Data is essential in asset management, with a life cycle and requirements of their own. Data management should be treated as part of a larger asset management implementation plan. In this paper, the authors start with asset management concepts and their relation to data. A high-level view is given on the project being run by Eletronorte, part of the Eletrobras group, to implement an asset management system according to the ISO 55001 clauses. Then, it focuses on the work developed by one of three working groups created for the project. The group focused on the aspects of asset management related to information systems. It mapped the IT systems used in the entirety of an asset life cycle and is currently working to comply with all that is demanded by ISO 55001 in information systems and documentation. A description of how the mapped IT systems correlate to regulatory rules is presented, followed by the challenges and next steps in the strategic project. Finally, the paper concludes reflecting on the impacts brought by ineffective data management and the expectancy of having Eletronorte certified in ISO 55001 by the end of 2023.

11:15am - 11:25am

CIM for Network Planning and Power System Development

Nikolay Belyaev, Roman Bogomolov, Denis Pilenieks
System Operator of the United Power System (SO UPS), Russia; Belyaev-na@so-ups.ru

Network planning and power system development processes differ from one country to another depending on the system configuration, system limitations and other factors. The optimization purposes often lead to changes and modifications of these processes. However, invariably, these processes demand a huge number of calculations, which requires detailed models of a power system. The modelling granularity and number of steady state hypothesis vary depending on the approaches to network planning and system development. But either way there are a lot of data to be maintained. Therefore, it is extremely important to provide an effective methodology for creating and maintaining power system models. It is equally important to ensure the possibility of information exchange between different applications and systems to provide the most optimal methods and tools. Regardless of the approaches to network planning and system development, basic modelling approaches will be relevant for most of them. The United Power System (UPS) of Russia consists of more than 13 000 lines and

10 000 substations 110 kV and higher, 1000 power plants which operate synchronously, with the power consumption of more than 160 GW. After the reformation of power system development process in 2022 the six-year forecasting period has been settled for the mid-term network planning and power system development of UPS. Now System Operator of the United Power System (SO UPS) provides the centralized process of planning of the network of 110 kV and higher and generation of 5 MW and more development. The information models for mid-term period were created to perform the new tasks, and their maintenance methodology was implemented under the three-level hierarchy of SO UPS, including 49 RDOs, 7 IDOs and 1 CDO. The models for network planning and system development processes were built on the basis of the SO UPS CIM-based master model created in 2016 for UPS dispatching control and other tasks. The model building and maintaining technologies have been revised in order to speed up the process considering significantly increased size of the model. CIM usage helps to exchange the changes between different models and to provide their consistency as well as their integration with various applications and systems. The future challenges are to collect the information about grid facilities from their owners using CIM and to provide digitalization of consumers' connection requests which demand the CIM standard extension.

SESSION FINDINGS AND CONCLUSIONS

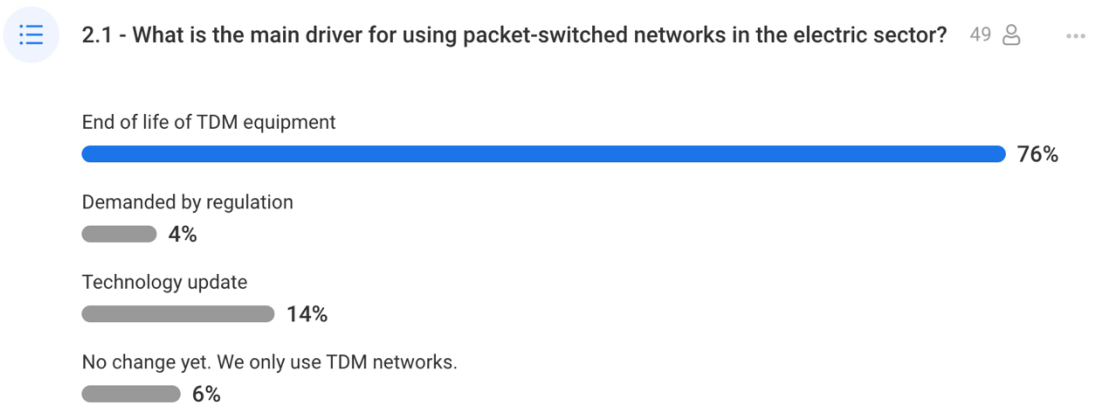
STUDY COMMITTEE	D2	SESSION NUMBER	2
Date:	September, 7th, 2023	Time:	13:15 --- 15:00

Moderators: Mr. Marcelo ARAUJO (BR); Mr. Lars SILSET (NO);

FINDINGS AND CONCLUSIONS:

The theme of migration from TDM to packet technologies has been discussed for at least 10 years now.

From the presented papers, it was possible to conclude that the main driver to migrate is related to the end of life of traditional TDM equipment. That was confirmed during session when a survey was made about that theme, as can be seen below:



In the past, there was a lot of debate on which technology would be leading one to replace circuit-switched networks. As could be seen from the papers presented in the session, it is in fact more a matter of which technology is better suited to the specific needs of a company. That understanding was confirmed when a quick survey was made with the attendants:

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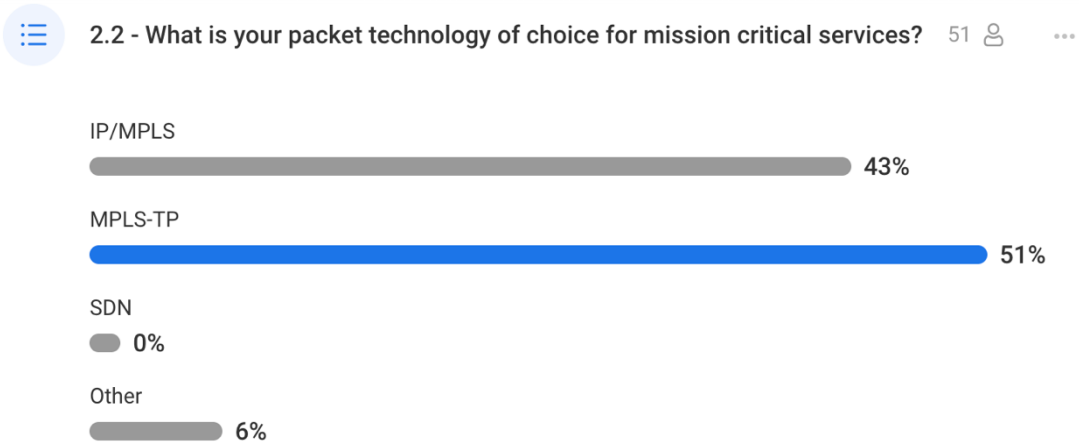
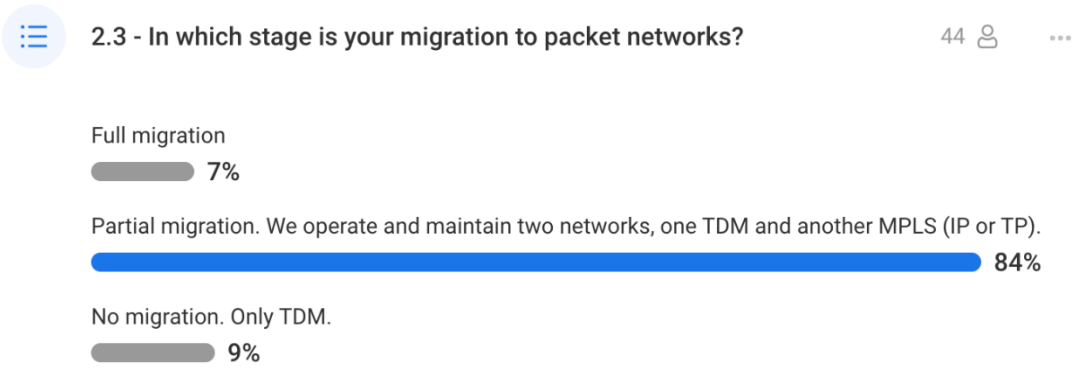


Utilities are still in a transition stage of their migration to packet networks, as could be assessed from the audience. Most of them are operating and maintaining two networks of different technologies at this point:



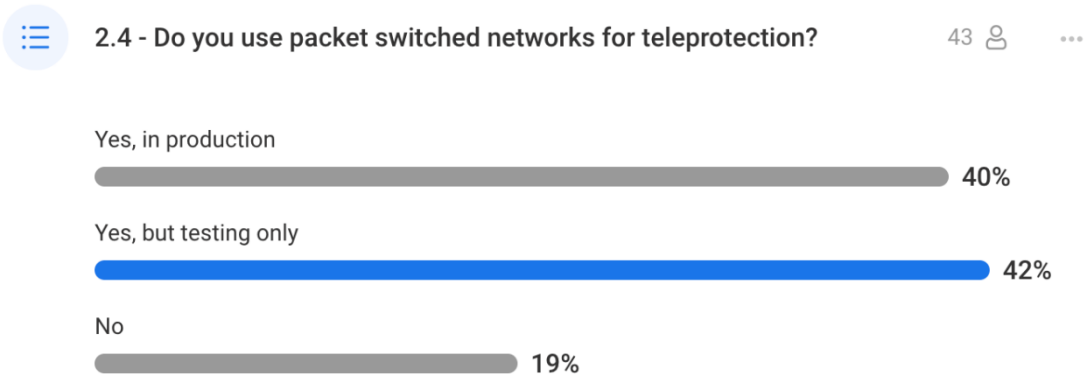
Tests have been run with both IP-MPLS and MPLS-TP, and they have both performed according to specifications required by mission critical services. Even when adding cryptography to the emulated circuits, they would still perform accordingly. Simulations with intense traffic in the links have proven that QoS configurations to prioritize critical services can maintain the expected performance.

Tests are essential to demonstrate to protection teams that packet networks can assure availability and reliability to distance and differential protection schemes. Diverse configurations can be tested. When a conventional substation in one side of the link and a digital one is on the other side, an additional element is needed to do the necessary conversions. Even when making testes with C37.94 relays, a translation of protocols is needed to implement the solution. Still, although there may be differences in the delays, both configurations can still achieve good timing results. However, in configurations where both substations involved have are full digital, using

CLASSIFICAÇÃO: PÚBLICA

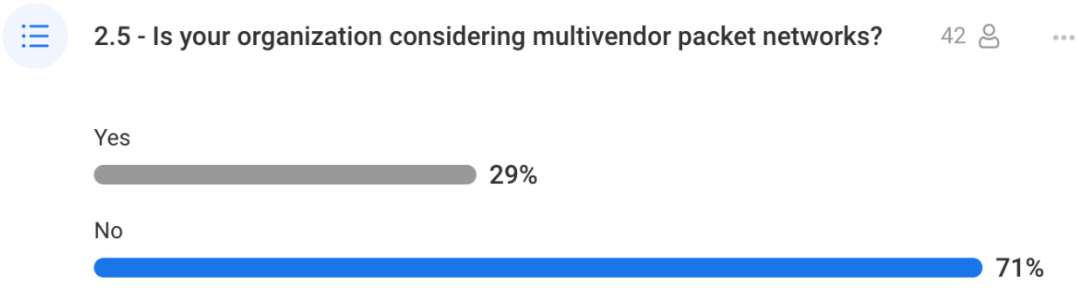
IEC 61850 GOOSE messages to transmit protection commands, tests have verified that the total time of the protection scheme were faster.

Slowly, protection services are migrating to packet networks, as demonstrated in a poll made during the session:



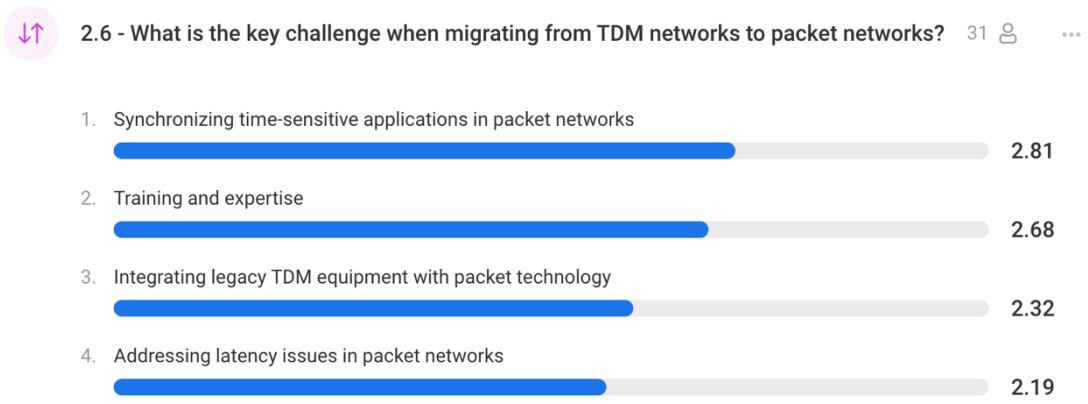
It was interesting to notice that MPLS-TP or IP-MPLS are not a one size fits all solution. Instead, some applications in distribution systems may require the usage of mobile solutions, like 5G, since, otherwise, it would be too expensive to implement fiber optics in the whole area to be covered.

It could represent a risk to rely on a sole vendor to provide the equipment in the network of a utility, since systemic failures, that is, unknown issues in the operating system of nodes could generate a total collapse of communication services. Still, a quick survey made during the session demonstrated that was not considered an issue by most respondents, as can be seen in the image below:



There is not a consensus on the key challenge when migrating to packet networks. It is possible that instead of a single point of attention, all of them should be treated for a successful migration.

CLASSIFICAÇÃO: PÚBLICA



Finally, the summary of the findings that could be extracted from the presented papers are:

- Electric power utilities are studying and implementing packet-switched networks because TDM equipment is reaching their end of life;
- Packet networks use virtual paths or circuit emulation services to continue offering legacy services, and synchronization can be distributed using PTP and SyncE;
- Testing different scenarios is essential to ensure that packet-switched networks can attend the requirements of services used in mission-critical infrastructures like the electric power sector;
- To prevent failures of mission-critical communication services, studies should be held to determine a network topology that can withstand disasters;
- A controller can automate troubleshooting tasks performed by technicians and engineers during network faults. It can also prevent failures by detecting abnormal logs and reporting them to the experts.

CLASSIFICAÇÃO: PÚBLICA

Conference Agenda

CIGRE Symposium Cairns 2023

Session

D2 Sequence 2

Time:
Thursday, 07/Sept/2023:
13:10 – 15:00

Location: **Auditorium D**

Max 500 pax

Session Chair: **Victor Tan (AU)**
Secretary: **Joël Nouard (FR)**
Moderator: **Lars Konrad Silset (NO)**
Moderator: **Marcelo Araujo (BR)**
Session Topics:
Network infrastructure and telecommunications

Session Abstract

In this session we will have the presentation and debates of 5 full papers from 4 different countries.

Besides the ongoing energy transition from fossil energy resources to decentralized renewable power sources, the power utilities are facing different challenges. This session will mainly focus on two of them:

- End-of-lifetime for SDH/TDM communication networks. A transition to modern packet based technology for transporting tele-protection services seems to be essential
- More and more edge services, e.g video recording with transmission in real time, requires IP network with wider bandwidth and enhanced resilience.

Presentations

13:20am - 13:40am

1107 Verification and validation of packet based (MPLS-TP) technology for transporting tele-protection (current differential) services with existing TDM based network trough lab testing and field trial

Kulbhushan Kul and Dhammika Perera (CommTel, Australia)
Diptiman Yadav (Jemena, Australia)

Due to end of life and end of support of existing legacy Time Division Multiplexing (TDM) based network, there is urgent need to evaluate and implement suitable modern equivalent alternative technologies such as packet technology. The multi service ethernet platform has emerged as the technology of choice for progressing from TDM based networks to packet switched transport network. This paper investigates how a Distribution System Operator (DSO) in state of Victoria, Australia, have tested and evaluated this technology by extensive and detailed field trial and lab testing.

13:40am - 14:00am

1182 Construction of an IP network for wider bandwidth and enhanced resilience

Taku Okamura and Akira Shibakawa (Chubu Electric Power Grid CO, Inc., Japan)

An increasing need for network cameras to improve the efficiency of operation and maintenance of distribution substations, and the fact that natural disasters are becoming severe, a drastically revised IP network topology on the edge side have been implemented. This paper describes how Chubu Electric Power Grid Co. in Japan has worked to increase the bandwidth and enhanced the resilience of their IP network.

14:00am - 14:20am

1184 Improving maintenance and operational efficiency of a telecommunications network infrastructure to transmit IoT information

Kentarou Wada and Toru Nakamura (Kyushu Electric Power Transmission and Distribution Company, Inc)
Akihiko Takeda (Nishimu Electronics Industries Co., Ltd., Japan)
Jumpei Makino and Satoshi Yoshimura (Fujitsu Ltd., Japan)

This paper describes how efficiency improvements have been achieved by automating some of the operations of fault investigation, fault prediction and congestion avoidance. Outcomes of the automation have been reduced load on workers and less dependency on individuals.

14:20am - 14:40am

1279 Implementing IP/MPLS network-based synchronization for line differential protection and control

Amadou Louh, Andrej Goerbing, Dominique Verhulst, René Loef, Keenan Royle, Philipp Stachel, Jörg Blumschein (The Netherlands)

This paper discusses how line differential protection relays was tested by Stedin in The Netherlands to operate across an IP/MPLS wide area network. Both IEEE C37.94 and Ethernet/IP based line differential protection communication were considered. The paper presents the different failure scenarios that were tested to observe the performance and resilience of the line differential protection scheme. In addition, an outlook on how a DNO like Stedin operational telecom team is intending to deliver "synchronization as a service" to their operational teams to enable C-PACS across the network.

14:40am – 15:00am

1283 Enabling distance protection between fully digital IEC61850 and contact based legacy substations

Eugenio LUCENTE, Ramon BAECHLI, Stefan MEIER, Adolf FREI (Hitachi Energy, Switzerland)

This paper presents a novel approach to smoothen the migration of conventional line distance protection to IEC61850 in an already built electrical grid. The solution provides the capabilities to connect conventional substations being based on electrical inputs and outputs for line distance protection with an IEC 61850 based implementation on the remote end, enabling to unleash the benefit of IEC 61850 standardization in existing networks. In this paper, performance of the end-to-end application of line distance protection is evaluated in terms of fault clearance time as well as conformity to IEC 60834-1 when the proposed IEC 61850 gateway solution is used for inter-substation communication.

SESSION FINDINGS AND CONCLUSIONS

STUDY COMMITTEE	D2	SESSION NUMBER	3
Date:	September, 7th, 2023	Time:	15:25 --- 17:00

Moderators: Mrs. Louise WATT (AU); Mr. Chen-Ching LIU (US);

FINDINGS AND CONCLUSIONS:

When we consider the theme of this symposium- the end to end electricity system Cyber security should be at the forefront of all members minds as it underpins all facets of the electricity system. From the IT systems and applications that run the operational network and maintain customer and business data. The communications networks that provide connectivity to monitor and control the grid. The electrical components, substations and even cables are critical to delivering power to customers. The cyber physical security we have heard spoke about throughout the session. In the current landscape we need to understand the cyber threats, the risks and how to protect the availability, confidentiality and integrity of these systems and components.

Today we have been able to learn from others experience, gain an understanding about the current developments in cyber security and see how we need to continue to develop our knowledge in the area to ensure we are meeting the current and future requirements of our end to end power system.

We thank the authors and the 5 presenters that we heard from during this session for the valuable contributions. All of the contributions are important work and we expect that for D2 and for many of the other domains we will continue to see an increase in effort and interest in the advancement of this space given the growing cyber threats to critical infrastructure globally and the increase in connected systems within our electrical networks

There were a number of interesting points made and to conclude this session I would like to present on 5 key takeaways from the presentations we just heard. Firstly all contributions outlined the

heightened need for cyber security and ongoing research and development in this space. Threats are growing and so to are the impacts to the electrical system which now heavily relies on the connectivity and data collected, especially when we consider energy transition dynamic energy management and real time systems.

In addition to this, as IT and OT systems become more intertwined, the ability for a threat actor to compromise the electrical network is increased. Understanding these threats is key to knowing where to focus efforts and the importance of threat communities to share information was highlighted, as well as using tools and intel to gather information on threats relevant to the industry.

We also need to then ensure that we have the methods to protect from these threats. Overall we need an increase in research and development of the electrical components that are now becoming more connected and prone to attack. It is almost inevitable that if an IT system is compromised that there is a high likelihood that the OT systems will also be affected. More development is also required in the standardisation and development of cyber security for electrical components.

We need to consider new technologies and the risks associated with these and how we can better secure these technologies. We heard about the risks that could potentially by introduced by a 5G network and how we might reduce the risk associated with these but we should also consider the impact of other new technologies for example cloud and virtual environments, new communications methods and infrastructure. WE need to ensure that these technologies align to our existing and developing security posture.

It is important to build and strengthen resilience in cyber security. We saw an example of building resilience by supplementing existing company policies and focusing on the organization, the policies and procedures and the technology in creating an overall framework specific to their company's risk and requirement. We also saw examples of building resilience through research and development of threat detection capabilities within the OT environment and focusing on the resiliency of electrical components in particular.

Finally it is Important to protect the systems through persistent monitoring and threat detection. We saw parallels between papers that highlighted that there are too many threats for a team to handle and the challenge of having limited access to qualified cyber security specialists. Both provided different solutions to mitigate these problems, one method was to share the SOC responsibilities across multiple distribution providers which also had the advantage of good visibility for their government across all their power systems. The other uses a hybrid model of in house analysts complemented by external service providers whilst also ensuring focus on areas that were the biggest threat to the organisation. Both authors described the use of advanced monitoring tools and well designed data capture.

Conference Agenda

CIGRE Symposium Cairns 2023

Session

D2 Sequence 3

Time:
Thursday, 07/Sept/2023:
15:25 – 17:00

Location: **Auditorium D**

Max 500 pax

Session Chair: **Victor Tan (AU)**
Secretary: **Joël Nouard (FR)**
Special reporter: **Chen Ching Liu (US)**
Moderator: **Louis Watts (AU)**
Session Topics:
Cybersecurity

Session Abstract

In this session we will have the presentation and discussion of 5 full papers from several countries. The papers cover a range of important topics related to cyber-physical system security of the power grid: 5G VPN and cyber security enhancement, cyber intrusion detection and mitigation on voltage/var control, a holistic approach to cyber resilience, as well as two papers on Security Operations Centres. These papers involve the vulnerability assessment, detection and mitigation as well as cyber resilience of the power grid through SOC.

Presentations

15:35 pm – 15:45 pm

1181 Security Risk and Protection Analysis for 5G Power Virtual Private Network

Baiji HU, Chaoyang ZHU, Liang ZHOU, Yayun ZHU, Xiaojuan Zhang, Siwei MIAO

China Electric Power Research Institute

PR China

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As emerging businesses such as big data, energy services and distributed energy continue to grow, industry is facing new challenges that require security protection measures. A security protection framework for the 5G power VPN was established to strengthen the network security protection of the new power system.

15:45 pm – 15:55 pm

1203 Detection and Mitigation of Cyber-Attacks on Volt-Var Control

Milad Beikbabaei, Ali Mehrizi-Sani

Virginia Tech

USA

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Cyberattacks can affect Volt-Var control causing unbalanced voltage, overvoltage, and undervoltage. A data-driven mitigation and detection method for a hybrid cyberattack, DoS, and FDI attacks, on Volt-Var control is developed.

15:55 pm - 16:05 pm

1225 Strategic Approach to Cybersecurity Resilience in Electricity Distribution Company

Peter CEFERIN, Bostjan TURINEK, Boris KUPEC, Roman PIRNAT

Smart Com; Elektro Celje

Slovenia

peter.ceferin@smart-com.si

A holistic approach to resilience cannot be achieved by technology alone; human resources, organization, processes, and policies also need to incorporated. At the technology level, mechanisms have been put in place through a three-tier architecture to proactively manage potential cyberattacks – Anomaly Detection System (ADS), Security Information and Event Management (SIEM), Security Operations Center (SOC).

16:05 pm - 16:15 pm

Classificação da informação: Interno

1299 Data-Driven Technique to Enhance Power System Cyber Resilience

Hossein Rahimpour, Naser Hashemnia, Tomasz Wegiel, Alsharif Abuadbba, Toan Phung, Aruna Seneviratne, Tomasz Chmielewski, Bret Toplyn

UNSW Sydney Australia, Hitachi Energy Australia, Hitachi Energy Poland, CSIRO Data61 Australia, Cybersecurity CRC Australia, Hitachi Energy USA

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The dynamic and complex environment of the grid requires advanced technologies to handle a large amount of data in real time to identify potential threats and anomalies. This study proposes a novel FDIA detection using a Temporal Convolutional Network (TCN) technique in a two - stage machine learning model.

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16:15 pm – 16:25 pm

1393 Building a Threat Led Security Operations Center (SOC)

Lindbergh CALDEIRA

Australia

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This paper showcases the organization's approach in building a threat-led Security Operations Center (SOC) capability to combat the evolving threat landscape. Enhancements are made across the areas of people, process, and technology to increase cyber resilience.

Classificação da informação: Interno

TUTORIAL SUMMARY

STUDY COMMITTEE	D2		
Date:	September, 4th, 2023	Time:	15:30 --- 17:30

Title: Time in Communication Networks, Protection and Control Applications

Presenter: Mr Antti Viro (FI)

CTO at Dedicated Network Partners, Finland

- Nokia 1999-2012
- DNW Partners 2013 ->
- Cigre SC D2 2020 –>

Specialties:

- Telecommunications, PDH multiplexers, SDH, MPLS-TP, network management systems
- PTP
- Teleprotection

Precis of the tutorial:

General trend is movement towards more intelligent and accurate monitoring and protections systems. In substation environment these are IEC61850 based applications and wide area monitoring systems that relay on accurate time and synchronization. Today we can see that time distribution has come essential part of modern power grids.

Satellite GNSS systems are commonly used because they can easily provide accurate timing. Multi constellation systems with several antennas provides redundancy, but there are still known vulnerabilities. Most of possible vulnerabilities related to time over the air transmission can be mitigated by using fiber connections and PTP.

PTP has several profiles and some of them are targeted to substation use also devices can have different operating modes. In large scale system hierarchal design is recommended where different profiles and modes can be combined. All of these leads to situations where carful design and acceptance testing are needed. Also, continuous monitoring of time and synchronization is recommended to ensure proper operation.

PACS requirements for synchronization vary of lot from 1µs to 1s depending the application. It's important to understand needed accuracy requirement and plan compliant system and same time avoid too complex and costly solutions.

Further study items:

- Design guidance and best practices for PTP over WAN distribution
- Synchronization over 5G networks.

TUTORIAL SUMMARY

STUDY COMMITTEE	D2		
Date:	September, 5th, 2023	Time:	08:00 --- 10:00

Title: Enabling Teleprotection over Packet Switched Networks

Presenters:

Brenton Aardenburg (AU)

Brenton Aardenburg is Principal Engineer Digital Technology in the strategic asset management team at ElectraNet in South Australia. Brenton has a background in information technology and telecommunications specialising in packet networks and cyber security. Brenton is currently managing ElectraNets telecommunications and digital substation strategy.

James Cole (AU)

James Cole is the Zone Substations and Secondary Systems Manager at Evoenergy in Canberra, Australia. James has an information technology and electrical engineering background and a Master of Business. James is currently leading the development and implementation of protection, substation automation and communication upgrades in the Evoenergy network.

Santosh Koirala (AU)

Santosh Koirala is a Telecommunications Engineer at SA Power Networks. Santosh holds a Master Degree in Telecommunications from University of South Australia. Santosh has been actively involved in rolling out MPLS routers for SA Power Networks and the migration of SCADA, Management and Protection from the TDM Network to MPLS network.

Precis of the tutorial:

In this tutorial we present considerations, challenges and opportunities for using teleprotection on packet networks. Topics include overview and criticality of teleprotection scheme applications; review of teleprotection time synchronisation methods; overview of TDM networks and IEEE C37.94; overview of packet networks including MPLS IP and TP; methods for C37.94 circuit emulation over packet switched

networks; teleprotection cyber security recommendations, and opportunities for using IEC 61850 GOOSE and R-GOOSE over packet networks between stations.

The tutorial also presents two case studies on an implementation of C37.94 over an IP/MPLS network for a three-terminal line differential protection scheme and a novel application of IEC 61850 GOOSE multicast over an IP/MPLS meshed network for protection intertripping.

The C37.94 over IP/MPLS case study provides an overview of teleprotection commissioning testing methods with Y. 1564 Ethernet network testers and protection injection test sets. Four tests are presented for validation of teleprotection traffic QoS prioritisation with background traffic oversubscription; recovery from C37.94-IP converter failure or restart; recovery from protection relay failure or restart; and MPLS network failure and recovery. Real world learnings and recommendations are provided for permissible communications latency, path asymmetry, jitter and protection system current vector angle deviation.

The GOOSE over IP/MPLS case study provides an overview of the lab testing performed and the results observed before the actual implementation of the GOOSE intertripping scheme in the Adelaide CBD for the 33kV network. The testing includes segregation of networks to provide redundant network, multicast traffic testing, VLAN encapsulation testing, QoS testing and the impact of breaking the link on the fibre ring. The findings and the outputs observed using the network tester and Wireshark have been provided.

The tutorial was well received (95 attendees) with many clarifying questions being asked. Two of note were:

Q. How are fixed paths provisioned over a non-deterministic network?

A. There are several traffic flow control protocols available for MPLS that allow fixed path provisioning. Examples include static label configuration, RSPV-TE and link colouring.

Q. Is there an outage risk of associated with running a single control plane for diverse services?

A. Yes, it is therefore important to have adequate configuration control processes to ensure only reviewed and approved changes are applied to the network.

Overall the tutorial provides practical considerations, test validation methods, and real-world learnings for the deployment of teleprotection on packet networks.