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Welcome to the Paris Session!

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Editorial

By Michel Augonnet
President of CIGRE

Dear Colleagues,

Welcome to this edition of ELECTRA which is highlighted by several very interesting articles contributing to the Energy transition through organization or technology enhancement. These are just a part of the changes happening in our industry sector and a collection of examples of what Cigre contributes.

Watts & Bits: How Power Grids and Cloud Computing Are Working Together to Implement "Utility 3.0" Through Electro-Cyber Integration, by Hiroshi Okamoto, PhD; CTO and EVP, TEPCO Power Grid

The electro-cyber integration is not just a technological advancement; it's a paradigm shift that promises to revolutionize how we generate, distribute, and consume energy, while simultaneously propelling advancements in digital technologies. The solution proposed by the author is to co-locate data centers with energy sources like nuclear or renewable plants. This minimizes transmission losses and reduces the need for grid expansion, while also ensuring a reliable power supply for these energy-intensive facilities.

Challenges for Electric Grid Development, by Javier Iglesias, President, CIGRE Spanish National Committee Member, CIGRE Steering Committee Project Director, Red Eléctrica de España (Spanish TSO)

The final consumption of global electricity has nearly doubled since 2000, making it possible for the electricity's share to grow up to 20% of final global energy consumption.

To achieve a net zero emission level in 2050, a global view is needed to align the development model to system needs, depending on geography, maturity, and evolution of the technologies. This means integrating the different sectors (e.g., industry, transport, building) and coordinating all the actors (authorities, investors, grid operators) and involving the end user to include behind-the-meter distributed resources, etc., that can provide the flexibility needed in a transparent and affordable way. The International Energy Agency (IEA) affirms that the electric grid would need to double by 2050 to reach the Net Zero Emission scenario. Balancing the speed of generation and grid deployment with the evolution of demand is critical. The stress on supply chain, raw materials, and workforce will be a similar challenge.

Fostering Grid Flexibility and Renewables Integration with Advanced Composite Overhead Conductors, by Léo Richard Product Manager, Epsilon Cable, CIGRE France

This article describes the benefits of composite conductors and their contribution to the energy transition through energy and time savings:

High Tension Low Sag (HTLS) conductor networks inherently possess the:

- Ability to handle high peaks at elevated operating temperature – rather short time window - during which extra power flow is required (extra intermittent production, N-1 scenario, etc.),
- Ability to save up to 30% of electrical losses, at regular traditional conductor thermal capacity (day-to-day business)

Such duality ideally addresses the unpredictability and variability of renewables. It enables the necessary adjustments that grids will have to face in a world where most of our electricity will be coming from intermittent renewable sources and consumed intermittently as well (e.g. EVs).

Industrializing the Energy Transition: Flexing the Power of Hydrogen, by Adam Middleton & Ertan Yilmaz from Siemens Energy

Bringing renewable energy from the power sector to other sectors to decarbonize the entire energy system is set to play a crucial part in the energy transition.

In 2023, the EU H2020 funded HYFLEXPOWER project demonstrated the first application of a 100% green H2 fired industrial gas turbine. It was also the first time an industrial scale power-to-hydrogen-to-power project was demonstrated in a real-world application. It proves that hydrogen can serve as a flexible energy storage medium and that an existing gas-fired power plant can be adapted to run on 100% green hydrogen. It also shows that there is insufficient, cost-effective green hydrogen readily available today for wholesale migration to 100% hydrogen-fueled gas turbines.

In other news, we are only a few weeks from our **Paris Session 2024** which will have a record number of paper presentations and overall participants. This will be a very exciting Session and I hope to see you there.

Best regards,
Michel Augonnet

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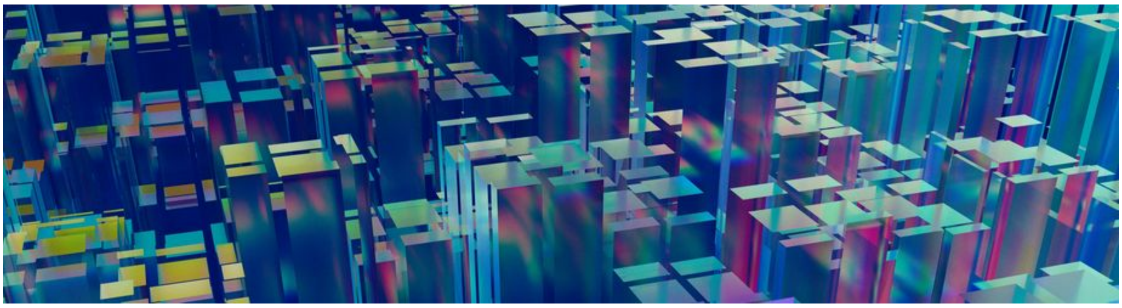
GLOBAL CONNECTIONS

Watts & Bits: How Power Grids and Cloud Computing Are Working Together to Implement “Utility 3.0” Through Electro-Cyber Integration

In our increasingly digital world, cloud computing and power grids are converging in ways that promise to reshape our society. Cloud computing, with its ability to orchestrate vast amounts of data and computing power, is transforming industries and everyday life. Similarly, power grids are evolving to integrate distributed energy resources and smart devices, driving the energy transition.



by Hiroshi Okamoto, PhD
CTO and EVP, TEPCO Power Grid

This article explores the powerful synergy emerging between these two domains. By integrating cloud technologies with power grids, we can address critical challenges such as balancing energy demand, managing complex power systems, and ensuring a sustainable future. This convergence, which I term "electro-cyber integration," holds the key to unlocking a human-centered and sustainable society.

In the following sections, I will delve into specific examples of how this integration will be implemented, from using artificial intelligence (AI) to optimize energy use to leveraging cloud-based platforms for grid management. I will also explore innovative TEPCO Power Grid’s (PG's) Machine-learning Energy System Holistic (MESH) concept to implement utility of future named “Utility 3.0,” which envisions a harmonious interplay between the cyber and physical worlds.

The electro-cyber integration is not just a technological advancement; it's a paradigm shift that promises to revolutionize how we generate, distribute, and consume energy, while simultaneously propelling advancements in digital technologies. This article serves as a guide to understanding and harnessing this powerful convergence for a brighter future.

Balancing Energy Demand with Cloud Computing

The AI Energy Paradox: Growth and Sustainability Concerns

The rapid growth of AI, particularly large-scale models (LLMs), is driving a surge in power consumption. This presents a challenge to balance the benefits of AI with the need for sustainable energy use. Figure 1 illustrates the rising demand from data centers in TEPCO PG's service area.

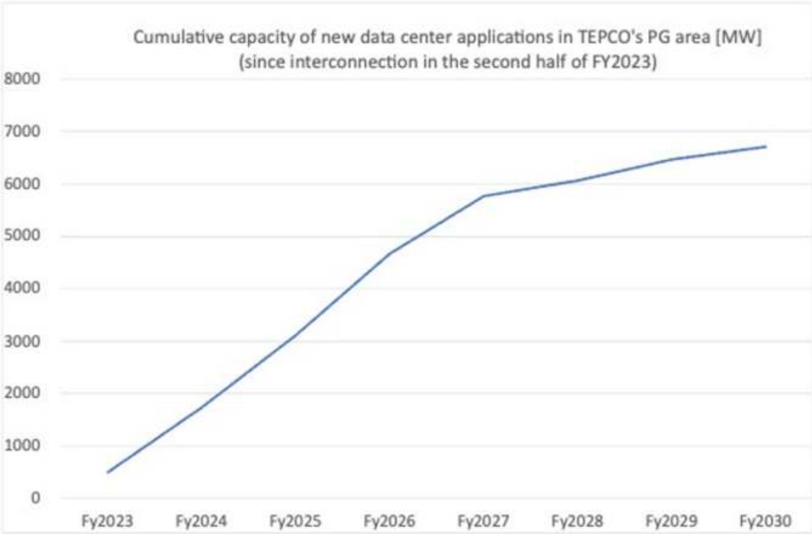


Figure 1 - Growth of Data Center Applications in TEPCO PG control area [1]

Bridging the Gap: Co-location and Intelligent Workload Management for Efficient Energy Use

One solution is to co-locate data centers with energy sources like nuclear or renewable plants. This minimizes transmission losses and reduces the need for grid expansion, while also ensuring a reliable power supply for these energy-intensive facilities.

Cloud computing's flexibility enables workload shifting. Applications with less stringent latency requirements can be run in regions with excess renewable energy. TEPCO PG is developing strategies to leverage this flexibility, optimizing energy use across the grid.

Training large AI models can be strategically scheduled during periods of low demand and lower CO_2 emissions, such as spring and fall. This approach effectively utilizes the internet's vast storage capacity as a form of energy storage, aligning AI processing with renewable energy availability. I call this strategy "the summer and winter vacations of AI students."

Nodal Pricing: A Key to Greener AI

Nodal pricing is a system where electricity prices change based on location and time, similar to how highway tolls vary during peak hours. This dynamic pricing encourages using electricity when and where it's cheapest and cleanest, particularly from renewable sources.

For cloud computing, nodal pricing is crucial. It incentivizes shifting energy-intensive tasks like AI training to times and places with abundant renewable energy. This not only makes cloud computing more sustainable but also maximizes the use of green energy.

To extend this benefit to distributed computing, we propose to extend nodal pricing to distribution networks [1], creating an interconnected market that accounts for carbon emissions. This market could use a carbon price within nodal pricing or a separate system for trading carbon emissions data. This approach would give data center operators and investors a clearer picture of the environmental impact of their decisions, helping them to make more sustainable investment decisions.

Furthermore, accurate forward curves, derived from the nodal price spot market and incorporating CO_2 emissions data, are crucial for data center operators and investors to make informed decisions about where to locate their facilities and when to schedule energy-intensive tasks.

By leveraging nodal pricing, forward curves, and managing workloads strategically, the cloud can actively contribute to decarbonization efforts while optimizing costs. This approach is essential for ensuring the sustainable growth of AI and a greener digital infrastructure.

— Empowering the Grid with Cloud Technologies

The Evolving Grid: Challenges of Complexity and Data

The power system environment is becoming increasingly dynamic. The rapid expansion of distributed energy resources, heat pumps, electric vehicles, drones, and robots connected to distribution grids is creating complex, bidirectional power flows. Traditional monitoring and control systems are struggling to keep up with the pace of change and the increasing volume of data.

Cloud as a Solution: Agile Development and Data Management

Cloud computing can address this by building an integrated data infrastructure for the increasingly complex power system and enabling the agile development of loosely coupled applications. In Japan, a system to consolidate smart meter data from 10 Transmission and Distribution System Operators is being deployed on the cloud, showcasing its benefits.

Data and Operational Sovereignty: A Key Consideration for Critical Infrastructure

Globally, some utilities are starting to use cloud computing in Operation Technology (OT) domains, such as monitoring and control systems. Cloud-native IT systems for Operation and Maintenance (O&M), handling vast amounts of vision and sensor data, can leverage AI/ML to enhance operations and decrease labor requirements.

The biggest challenge in cloudifying critical infrastructure such as the power grid is ensuring data and operational sovereignty in the OT and privacy data domains, where high availability and rapid recovery are paramount. Sovereign clouds, such as those being deployed in Europe, may be the key to addressing these concerns.

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— Collaboration for a Better Future

MESH: A Holistic Approach to Energy Management

Collaboration between power grid and cloud operators offers mutual benefits, but it also brings broader advantages to society.

Figure 2 illustrates TEPCO PG's initiative called MESH (Machine-learning Energy System Holistic). This concept is based on analogy that compares cyberspace to the nervous system, the physical world to muscle system, and the power grid to the vascular system. As decarbonization progresses in power generation, the increasing share of intermittent renewable sources as well as base-load generation necessitates demand-side adjustments to balance supply and demand. This is similar to how the human body maintains homeostasis through neuro-vascular wiring (Figure 3) [3].

By utilizing the market mechanisms of the wholesale electricity exchange, fine-grained price signals can be transmitted to incentivize autonomous behavior changes in the cyber-physical space. Cloud computing enables not only the monitoring of vast numbers of distributed energy resources and consumer devices but also the flexible shifting of power demand through workload management.

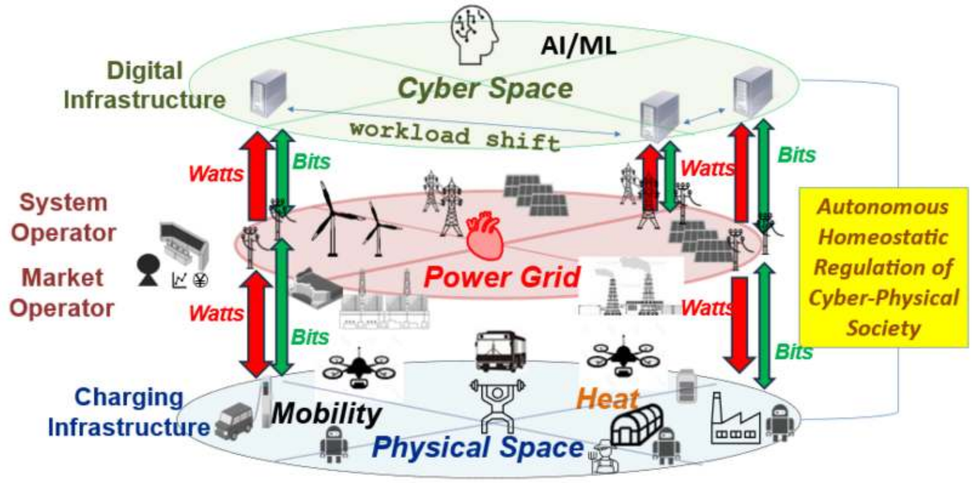

Figure 2 - MESH (Machine-learning Energy System Holistic) for Homeostatic Regulation in Cyber-Physical Society

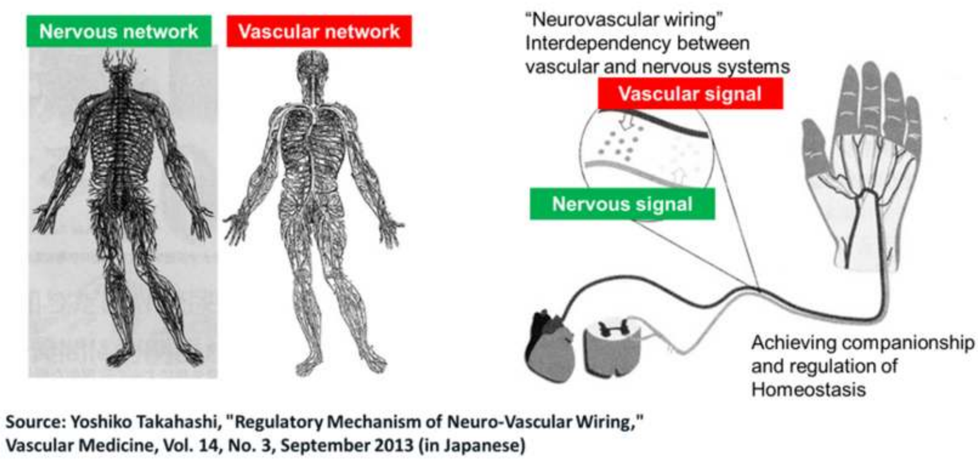

Figure 3 - *Neuro-Vascular Wiring* for Homeostatic Regulation in the Human Body [1]

Smart Mobility: Orchestrating a Sustainable Ecosystem

One example of MESH in action is an orchestration service for automated mobility (Figure 4) as proposed by the author [4]. By integrating price signals from the electricity market, the charging and discharging of self-driving electric vehicles and charging spots can be controlled to stabilize the grid and optimize charging costs. Additionally, digital twins of infrastructure on the cloud can be used to optimize drone routes for efficient infrastructure inspection and regional logistics. Combining these elements creates a mobility platform that optimizes charging costs and accumulates mobility data on the cloud for urban and rural area development.

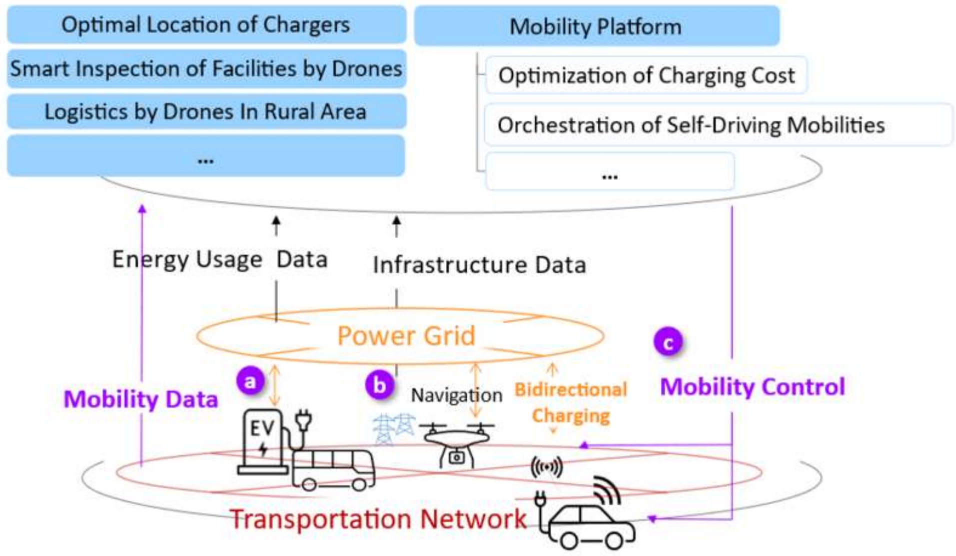

Figure 4 - Smart Mobility Platform

Global Connectivity: Optimizing Resources Across Borders

This concept can be generalized to encompass urban and rural area planning and global connectivity (Figure 5). Cyberspace is globally connected through optical fiber and satellite communication, allowing seamless utilization of resources. For example, Artificial Intelligence and Machine Learning (AI/ML) trained on surplus hydropower in Norway could be used for digital services in Tokyo.

Given the substantial cost advantages of digital infrastructure compared to physical infrastructure, a *cyber-first* approach is essential for maximizing the overall efficiency and sustainability of our interconnected world.

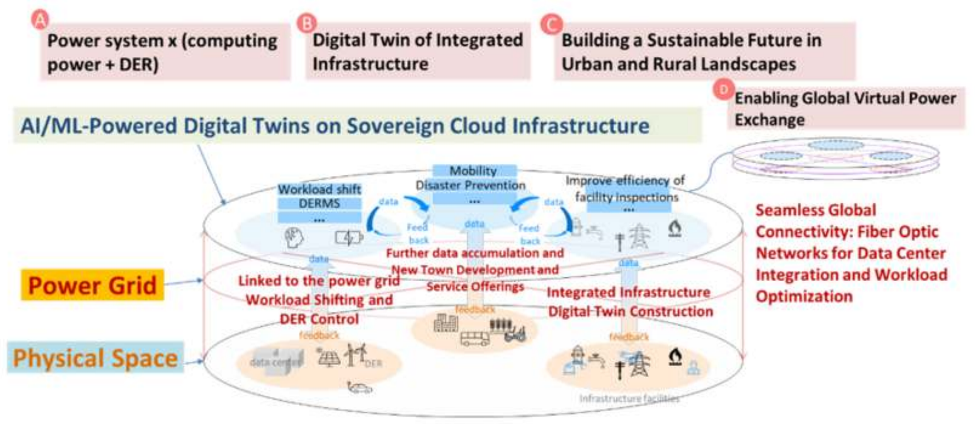

Figure 5 - Global MESH Interconnection: A *Cyber-First* Approach to Optimizing Resource Utilization

Layered Collaboration Framework: Building the Future of Electro-Cyber Integration

TEPCO PG proposes a layered collaboration framework (Figure 6) to integrate power grids with multi-cloud environments. This framework consists of:

1. **Foundation Layer**: An energy management platform that interfaces with the power grid and operates across multiple cloud environments.
2. **Sovereign Cloud Layer**: A secure and private cloud platform built upon the foundation layer, ensuring data sovereignty and regulatory compliance.
3. **GIS Layer**: A Geographical Information System (GIS) layer that leverages the underlying cloud infrastructure to enable infrastructure inspection, mobility services, and spatial data analysis combined with digital twins.
4. **AI/ML Layer**: A layer that provides cutting-edge Artificial Intelligence and Machine Learning (AI/ML) capabilities as Software-as-a-Service (SaaS), empowering various applications with advanced analytics and decision-making tools.
5. **M2M Layer**: A software-defined foundation for low-latency Machine-to-Machine (M2M) communication, facilitating real-time interaction between the power grid, mobility devices (e.g., electric vehicles), robots, and other connected entities.

This layered architecture enables the delivery of a wide range of services, including traditional Transmission and Distribution (T&D) operations, innovative T&D solutions that leverage cloud computing for demand-side energy management, City OS platforms for smart city applications, and advanced mobility platforms.

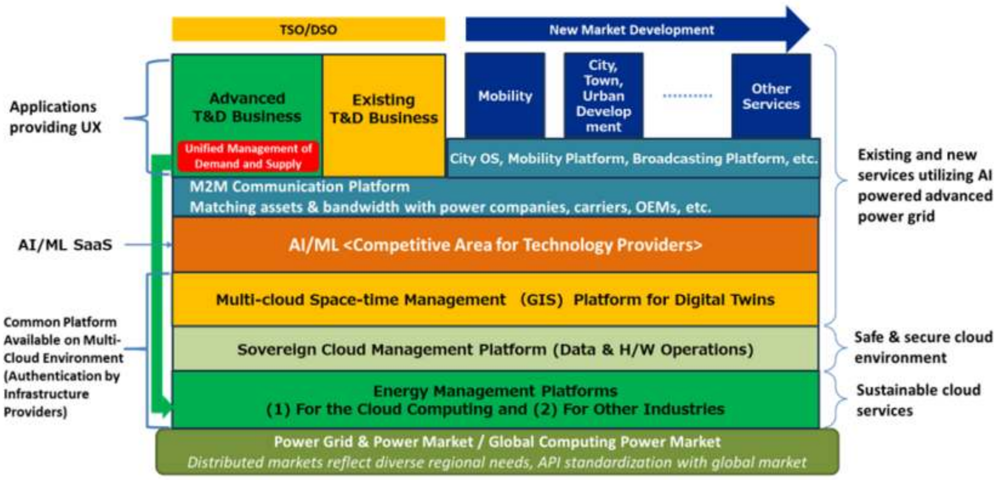

Figure 6 - Collaboration Framework for Electro-Cyber Integration

Conclusion

The rise of digital platforms has changed the world. However, in the future cyber-physical society, both digital platforms and power system operators will play critical roles in driving innovation towards the human-centric industrial revolution that I call "Utility 3.0." My conclusion is that collaboration between these two domains will be key to shaping a better future.

I would like to express my gratitude to everyone involved, especially Professor Hiroshi Esaki of the University of Tokyo for his support of the cyber-first approach, the hyperscale cloud providers, Mr. Jack Dangermond of Esri for his insight into GIS implementation of the digital twin, and the "Electro-Cyber Integration Project Team" of TEPCO Power Grid, supported by Accenture and Bitmedia Corp. along with its President, Mr. Masaharu Takano, for his knowledge in workload shifting using Kubernetes. I also thank the Distributed Market Design Working Group, led by Mr. Hikaru Yamada (Sprint Capital) and Mr. Manabu Inoue (Mitsubishi Heavy Industry), for their valuable insights into the effectiveness of nodal price markets in our distribution system.

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GLOBAL CONNECTIONS

Fostering Grid Flexibility and Renewables Integration with Advanced Composite Overhead Conductors

The past two decades have seen a soaring deployment of renewable generation capacity across the globe, mainly solar or wind power, which is now creating operational challenges for transmission and distribution operators as well as concerns about efficient connexion with existing networks. The flexibility of future power grids will require flexible operating infrastructures. This article details the case of overhead polymeric composite core conductors, also known as High Temperature Low Sag (HTLS) or Advanced Conductors, and the benefits to enabling operating flexibility and capacity.

by Léo Richard

Product Manager, Epsilon Cable, CIGRE France

— About composites for overhead conductors

Composite materials

Modern composite materials have been in the industry since the middle of the 20th century, although composite cores were introduced to the transmission market only 20 years ago. The composite materials considered in this application are organic matrix reinforced with carbon and/or glass fibres with a predominant fibre volume fraction of about 60-70%. The matrix is a mixture of various monomers and curing agents, which together create the final polymeric network responsible for the thermal, chemical, and mechanical composite properties. Carbon composite materials have an intrinsically very low coefficient of thermal expansion (roughly ten times lower than conventional steel) and impressive specific properties in tension (twice stronger than steel for a fourth of the density).

Composite core conductors

In comparison with conventional bare conductor technology, mechanical, and electrical functions of HTLS composite solutions are uncoupled. The excellent composite material properties allow the core to bear all the mechanical load, hence the possibility for the conductive layer to use higher conductivity soft annealed aluminium, with compact trapezoidal wires (similarly to ACSS designs). The resulting conductors possess significantly improved properties, such as high temperature capability (up to twice the thermal ratings of conductors reinforced with steel members, around 200°C), low sag characteristics at any temperature (carbon fibres having no thermal elongation), low electrical resistance of the conductive layer, outstanding corrosion properties and low density.

Advanced conductors have already been deployed in all biomes and continents - from the tropical jungle of South-east Asia, barren deserts across Middle East, to the icy mountains of Scandinavia. For high load areas (e.g. ice) where composite core conductors have been said to sag more than conventional options, one mitigation option is to increase the stringing tension (possible as the composite core provides 30% more strength than steel). Several HTLS designs with high elastic modulus also exist. Perceived core fragility during installation has also been cited as a barrier to HTLS deployment, especially in an industry only accustomed to handling metals. Lack of composite knowledge and inadequate team training indeed can create issues where core is damaged during installation. Tackling these technical challenges is among the manufacturers' missions, working alongside network owners to that extent, providing the necessary tools and knowledge to accompany the ongoing paradigm shift that our industry is experiencing.

Figure 1 – composite core after tensile testing (result approx. 200 kN/45 kips), conductor

(credit: Epsilon Cable)

— Upgrading yesterday's grids

Racing toward COP28 goals, global renewable growth continues to increase year after year. As of late 2023, there were close to 3,000 GW of renewable capacity entangled in grid modernisation queues [1], a large share of it in the United States [1, 2]. This grid congestion is causing a significant financial impact on private companies as well as consumer prices, but is also hindering efforts to reduce greenhouse gas emissions. It is estimated that over 80 million kilometres of powerlines must be added or refurbished by 2040, which equals the entire existing global grid [3]. The global network development effort must keep up with this colossal need, however conventional practices for grids extensions often lack the flexibility and effectiveness that are required. Whenever an operator needs to open up a new land corridor, several years of negotiations are expected resulting from current policies and local development works (public consultations, acquiring right-of-way, etc.). With tens of thousands of kilometres already electrified worldwide, composite core HTLS conductors have been developed to specifically alleviate these issues.

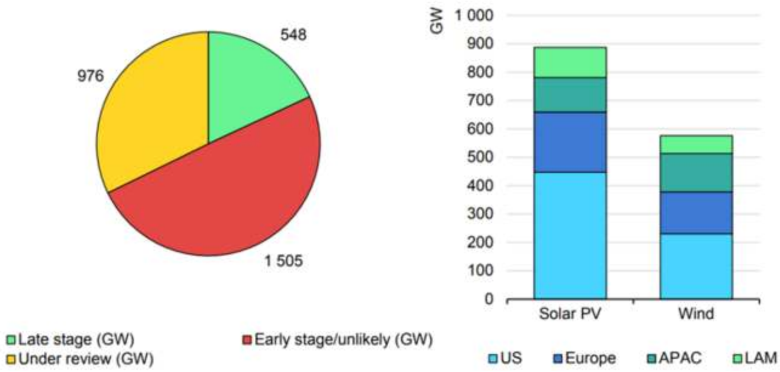

Figure 2 – 2023 Renewable energy capacity in connection queues (left), and advanced stage solar PV and wind projects by region (right).

Source: [1]

Reconductoring for high capacity

Upgrading existing lines was historically done by removing and replacing structures with stronger (and/or higher) towers with heavier conductors. However, a new approach invites the operator to increase the transit power of existing lines without the need for new installations, only replacing the conductor. HTLS conductors, especially type 4 (see CIGRE classification [4]), perfectly meet this need, explaining their increasing success over the past 10 years [5]. Leveraging on a **doubled ampacity/weight ratio**, reconductoring with these advanced conductors means no impact on existing towers (no lattice strengthening). Such conductors are not subject to thermal sag, arguably in favour of reusing existing structures without modifications. This benefits wildfire prevention as in many areas (e.g. Western USA, Australia) several large fires have been caused by conductors sagging too close to existing vegetation, a phenomena unfortunately more and more common as the climate warms up and in turn increases traditional conductors sag during severe heat waves. The main rationale for a rapid development of these technologies is perhaps the fact that the operational line disruption is extremely short in comparison with building new infrastructures (1 to 10 factor), yielding a very short time to commissioning.

Building for high flexibility

When addressing a new construction project, including such conductors is an ideal way to create a large reserve factor for possible capacity peaks in the network. New projects can be dimensioned so that thermal ratings equal conventional conductor technology, hence allowing close to 100% of safety margin capability. Ampacity peaks will either be envisioned at deployment time, but in some case can also be prospective in areas where future developments could occur (unforeseen renewable or datacentre integration). HTLS conductors are enhancing the physical grid flexibility to accommodate a larger array of electrical load.

Savings

Better materials, high ampacity, and high performance naturally induce a more elevated price, estimated in between two to three times more than a conventional conductor. This gap could initially be seen as a challenge, but modern advanced conductors on the contrary bring significant return on investment through line loss reduction. Electrical losses in power lines are mostly induced by Joules effect (conductor heating under the influence of flowing current). Designs using compact trapezoidal wire, such as HTLS or ACSS, have significantly lower resistance thanks to the increase aluminium content. When these conductors also incorporate higher conductivity/lower resistivity annealed aluminium, both advantages combined yield about 30% electrical savings in comparison with traditional wires. HTLS conductors upfront cost is rapidly balanced thanks to these savings, yielding return on investment in about 4 to 8 years depending on load, country, and generation costs.

This effort on loss prevention could help save thousands of GWh of wasted electricity every year [6]. In turn, this can be associated to direct emission reductions whenever power comes from fossil resources. This also means less generation capacity required, less land, and capital allocated to power generation, less indirect emissions linked to renewable and fossil fuel fired plant construction. Water savings enabled by a reduced need for power plant cooling is also an interesting side benefit, especially in dry areas.

Reduction of electrical losses is definitely another item that has yet to be included into a larger scope for climate change mitigation and adaptation solutions. Although being technically proven, regulation policies unfortunately too often overlook this factor (life cycle analysis of power lines or financial management of electrical losses). Several recent proposals (e.g. [7] [8]) promote incentivization for using such technologies and pathways to alleviate barriers to their large-scale deployment.

High-level deployment

Mass deployment of smarter conductors – smarter as they are more versatile enablers than their predecessors were – will create new opportunities for transmission and distribution owners. When adopted at a larger scale, fully equipped networks display significant advantages in comparison with traditional technologies used since the early 20th century. Such HTLS conductor network inherently possess the:

- Ability to **handle high peaks** at elevated operating temperature – rather short time window during which extra power flow is required (extra intermittent production, N-1 scenario, etc.),
- Ability to **save up to 30% of electrical losses**, at regular traditional conductor thermal capacity (day-to-day business)

Such duality ideally addresses the unpredictability and variability of renewables. It enables the necessary adjustments that grids will have to face in a world where most of our electricity will be coming from intermittent renewable sources, and consumed intermittently as well (e.g. EVs).

Synergies with alternative enhancing technologies

Alongside composite core conductors, additional systems have been developed in recent years as enablers for added capacity within existing grids. Some examples include:

- Dynamic Line Rating (DLR) systems – when commissioned, transmission lines are given static thermal ratings, which assume worst environmental conditions, in order to keep them from overheating. DLR provide live monitoring of operational conditions, enabling operators to increase factory ratings.
- Advanced Power Flow Control (APFC) technologies automatically adjust the impedance of power pathways (preventing power from always flowing through the path of least resistance). Electricity supply spreads evenly in different branches of a meshed network, hence enabling a better usage of all available assets of a congested network.
- Topology Optimisation (TO) can similarly reroute power flows, now by modifying the grid topology, i.e. reconfiguring bus connections or switching off/on transmission lines.

Network resilience and more effective asset usage will require the combination of such methods in order to achieve full capacity of existing infrastructures. Such endeavour is still at feasibility phase, with some users having performed initial pilot trials [9] but this will become more and more common in the upcoming years.

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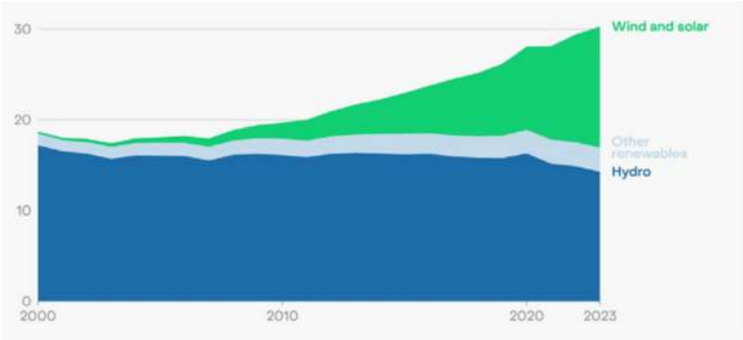
Challenges for Electric Grid Development

The consensus on decarbonising electricity supply is clear across the globe, with the only differences being the pace of achievement. The need for reaching a Net Zero Emission scenario for the electric sector as soon as possible is crucial, since it serves as an engine to reduce other sector's emissions through progressive electrification. The electric grid development will play an important role to achieve the goal of a free-carbon economy in a few decades. However, there are challenges to face.

by Javier Iglesias
President, CIGRE Spanish National Committee Member,
CIGRE Steering Committee Project Director,
Red Eléctrica de España (Spanish TSO)

Where are we...?

We can affirm that significant progress is being made in the path to these objectives. Renewables covered 30% of the world's electricity demand in 2023, with higher shares in some regions (44% in the EU, for example). This remarkable take-off seen in the last decade has been driven mainly by Solar and Wind technologies, which have experienced the fastest increase of generation technology in history.



Share of global electricity generation from renewable sources (%)
Source: Global Electricity Review 2024. Ember

Over the past five decades, the electric grid has grown steadily, enabling increased connectivity and reducing capacity constraints. This growth comes mainly from the distribution network, which represents more than 90% of the grid length, and with developed economies increasing their investments. In transmission, certain countries, like China, have also importantly increased the grid over the last ten years. In particular, HVDC projects (mainly used to transport bulk power from remote areas to high density consumption loads) have tripled their global length in this period.

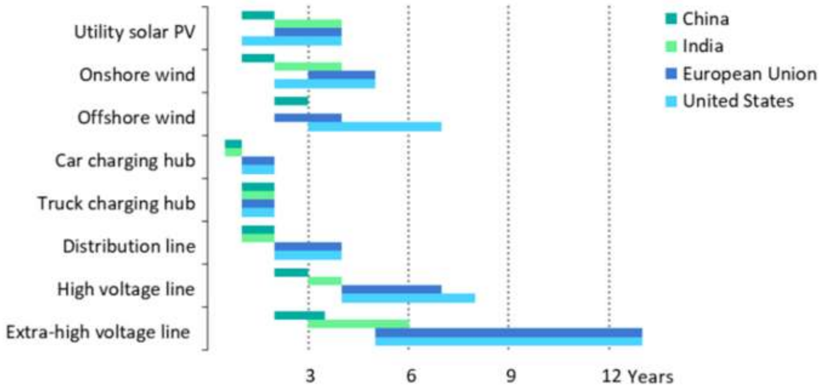
The trend towards electrification of the economy continues. The final consumption of global electricity has nearly doubled since 2000, making it possible for the electricity's share to grow up to 20% of final global energy consumption. Some sectors, such as transportation, although still a small share of the electricity consumption, are experiencing a solid development, mainly due to the boost of Electric Vehicles.

Therefore, climate goals have been included as a principal player in the process for planning the economy, together with the objectives of ensuring a secure, reliable and cost-effective delivery of power. But still important uncertainties are present in the path.

Uncertainties…

Estimations by some organizations seem to be very challenging. For instance, the International Energy Agency (IEA) affirms that the electric grid would need to double by 2050 to reach the Net Zero Emission scenario. This requires that most countries would need to increase dramatically their investments in grid development for the next five-to-ten years. In particular emerging markets and developing economies would need to double their investments. In addition, half of the grid would need to be replaced due to aging infrastructure. In developed economies, half of the assets are more than twenty years old, and an important amount of assets (mainly overhead lines) are sixty or seventy years old. This is an outstanding concern for grid reliability in the electric expansion. It is true that many regions show high reliability levels, but large outages occur all around the globe with enormous impact. Many of the failures are caused by cascading effects involving localized grid failures, and some assets are in particular risk due to extended lifetimes (transformers, underground cables, others…).

Keeping this in mind, grid development timelines need to be improved. Although some countries present reasonable times for permitting and construction (mainly due to centralized decision-making and clear prioritizations), many others maintain them as a bottleneck. In general, this is due to complex processes for the infrastructure deployment, multiple authorities and jurisdictions, lack of social support and absence of political consensus on the long-term strategy. The important delays of the transmission projects represent an obstacle for green energy that is deployed much faster in general.



Typical deployment time for electricity grids, solar PV, wind and EV charging stations

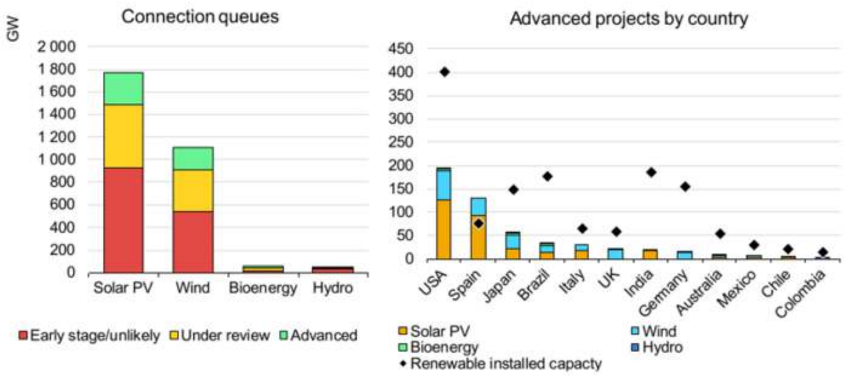
Source: IEA 2024

Another important aspect is assuring costs are adequately assigned and shared. The remuneration mechanisms that have been used in the different parts of the world to afford grid expansion have evolved differently. Some of these mechanisms can create distortions with greater gid development. For example, lack of affordability (excessive increase of the bill for end users), lower quality of service (if the control is not appropriate), and lack of innovation and development (if the incentives are not well oriented) may occur with disparate development. It is also remarkable that, in some regions (e.g., US, EU), the distribution network has much lower incentives compared with transmission, causing relevant unbalances in the grid. Ultimately, we need a grid developed properly and we need to make sure electricity remains affordable.

Additionally, the supply chain is already showing tightness. Grid developers are starting to see important delays due to equipment delivery limitations for particular goods, like transformers, GIS (gas-insulated substations) and submarine cables, for example. Also, raw materials (aluminum, steel, copper...) are facing significant constraints. In some cases, it is estimated that they will double their demand in few years creating greater supply chain limitations. The concentration of suppliers (geographically or economically) is also a concern, as it is the lack of workforce that many companies are experiencing.

We also have greater needs. New types of generation are being massively integrated that require certain tools and technologies to assure security and quality of supply. Issues such as supply intermittency of some sources, voltage and frequency instabilities, and lack of inertia will need to be addressed. Fortunately, there are plenty of developments in process, but more are needed for safe operation and management of the electric system in this profound energy transition. In addition, greater utilization of the network (for example, improved load factors), which is underutilized in many places, will require greater tools and technologies, often not well incented.

And the development of the electric sector is unequally deployed. As stated before, we have experienced a great boost of Solar and Wind power generation investments (more than US$700b worldwide since 2022, according to IEA). However, the investments in the electric network are estimated to be less than half for the same period. That brings risk to many projects which may be delayed awaiting grid connection. Of course, demand may or may not increase accordingly, with some demand exceeding expectations! Some countries, for example, have implemented processes that allow the integration in the following 3-4 years for much higher renewable generation than the realistic evolution of the demand emerging. This is a risk for the continuity and stability of private generation investments. The other risk factor that may develop is demand exceeding supply growth, whether renewables or other carbon-friendly forms.



Capacity of renewable energy projects in connetion queues by technology

Source: IEA 2024

— Challenges

Enabling investments is a priority. We need to continue adding carbon-free generation, including technologies that are emerging such as small modular reactors and hydrogen enabled supply. Renewables such as Solar and Wind are important to grow as well. And it has to be coordinated with investments in transmission and distribution. This will require us to keep adequate incentives for all electricity needs, so they can be economically feasible. We should also engage key stakeholders to ensure growth is environmentally and socially feasible.

Balancing the speed of generation and grid deployment with the evolution of demand is critical. A global view is needed to align the development model to system needs, depending on geography, maturity, and evolution of the technologies. For that, we have to integrate the different sectors (e.g., industry, transport, building) and coordinate all the actors (authorities, investors, grid operators). And let’s not forget to involve the end user to include behind-the-meter distributed resources, etc., that can provide the flexibility needed in a transparent and affordable way.

We have to improve grid utilization for the assets we have and will have in place. An adequate set of incentives for innovative solutions is necessary. These solutions have to be capable to enhance grid efficiency and optimizing investments. A greater focus on digitalization is crucial. For example, management of Control Centers, smart technologies, communications with greater and greater control points, and much more will need to be managed and cyber secure. But it is also very important to get more from the existing assets: upgrading and uprating, monitoring systems, condition-based tools, and other grid enhancing technologies (GETS).

Also, it is necessary to secure supply chains. We will have to facilitate and incent companies to commit needed investments for new manufacturing capacity. Integration or coordination of supply chain can widen options and incent new companies. Also, we should find ways for better utilization and availability of raw materials, with standardization and diversification to tackle this acceleration.

Finally, we have to engage and expand workforces to manage the expansion. The companies need new talent (mainly digital and technological abilities) as well as re-skilling current employees. It will be necessary to work with educational institutions, to elaborate co-operative programs, etc., and to bring the knowledge to the current workforce. In this regard, CIGRE is playing a principal role in sharing the power system expertise needed to achieve professional and technology development to support the climate goals desired across the globe.

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Industrializing the Energy Transition: Flexing the Power of Hydrogen

The potential of hydrogen as an energy vector – capable of decarbonizing heat, industry, power, and transport – has long been recognized. To date, transferring that benefit to industrial processes has so far been limited. Many industries, from cement to steel, rely on processes that are not driven by electricity, which makes decarbonizing them more difficult than simply replacing conventional electricity generation with renewable sources. It is only in recent years, with the reducing cost of renewable power from wind and solar, that developments to remedy this dilemma have escalated.

The integrated industrial power-to-hydrogen-to-power solution with a gas turbine type SGT-400 at Smurfit-Kappa, Saillat-sur-Vienne, France *(Courtesy: Engie)*

 

By Adam Middleton & Ertan Yilmaz

Introduction

Using renewable electricity to decarbonize energy across all sectors has huge environmental and business benefits. With the first significant projects now taking shape, this so-called 'sector coupling' – bringing renewable energy from the power sector into the other sectors to decarbonize the entire energy system – is set to play a crucial part in the energy transition.

This endeavor has enormous potential, and over the last few years, the energy industry has therefore been ramping up investment in power-to-X (P2X) technologies that enable sector coupling (Figure 1).

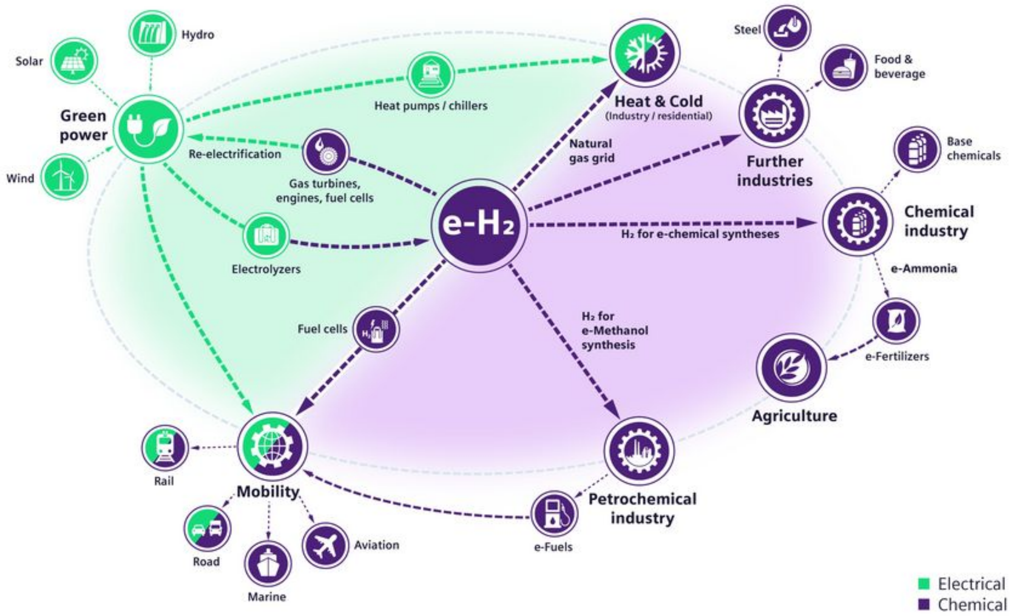

Figure 1 - Sector coupling: using renewable electricity to decarbonize energy across all sectors has huge environmental and business benefits *(Courtesy: Siemens Energy)*

The increase in energy efficiency and using renewable electricity directly are the most efficient and cost-effective ways to decarbonize industry. However, not all industrial processes can be driven by electricity and that is where hydrogen as an energy vector comes in.

In power generation, hydrogen can play a significant role in the energy transition. Mixing hydrogen with natural gas can substantially reduce the carbon emissions from gas turbine power plants. EU member states are phasing out coal-fired power plants and prioritizing renewable energy to achieve carbon neutrality by 2050. To reach this goal, they need also to decarbonize their gas-fired power plants. Substituting natural gas with hydrogen is a viable option for operating powerplants to achieve net-zero, as hydrogen combustion produces no CO_2 emissions. Hydrogen fuel can enable gas turbines to participate in electricity storage and re-electrification. Produced through electrolysis of water during periods of surplus renewable energy generation, hydrogen can act as a chemical storage medium. It can then be used when needed to power gas turbines or sold to other industries.

Thus, what practical measures can be taken to achieve the decarbonization goals of industrial power generation, with the current base of gas-fired units in place? Considering the limited availability and higher cost of green hydrogen, what actions must industry, government and regulators take to expedite its large-scale deployment effectively?

— Small but key steps towards decarbonization

While the power sector has already achieved notable progress by transitioning from coal to gas and by adopting large-scale renewables, the focus on utilizing hydrogen to reduce carbon dioxide (CO_2) emissions in power generation has not been as pronounced as in other sectors. Consequently, deep decarbonization of the industry is dependent upon the application of hydrogen as a fuel for gas turbines.

Launched in 2020, the HYFLEXPOWER project is the world's first integrated power-to-hydrogen-to-power demonstrator on an industrial scale, running over a four-year period, with planned completion in April 2024. The project represents a pivotal advance in demonstrating hydrogen's role in the decarbonization of power generation and is poised to significantly impact the decarbonization of gas turbines. HYFLEXPOWER features an advanced SGT-400 Siemens Energy hydrogen gas turbine at the Smurfit Kappa paper recycling factory site in Saillat-sur-Vienne, France. Engie Solutions operates a combined heat and power (CHP) plant there, generating 12 MWe of electricity and 20 MWth of thermal energy as steam, vital for the paper recycling process.

The aim of the project was to prove that hydrogen can be produced from renewable electricity, via an electrolyzer, stored, and then blended up to 100% by volume with the natural gas currently used at the CHP plant. This would enable the CHP unit to be fully dispatchable, even with limited hydrogen supply.

Of specific note is that the SGT-400 gas turbine, when operating on 100% green hydrogen, at baseload, could reduce CO_2 emissions by up to 65,000 tons annually from the Smurfit Kappa facility.

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Such complex applications require multiple partners and close collaboration in order to realize such a first-of-its-kind transition. For HYFLEXPOWER, a consortium of partners has come together led by Siemens Energy and including Engie Solutions, Centrax, Arttic, the German Aerospace Center (DLR), Lund University, University of Duisburg-Essen, National Technical University of Athens, and University College London, implementing a project funded by the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 884229.

Power-to-hydrogen-to-power application

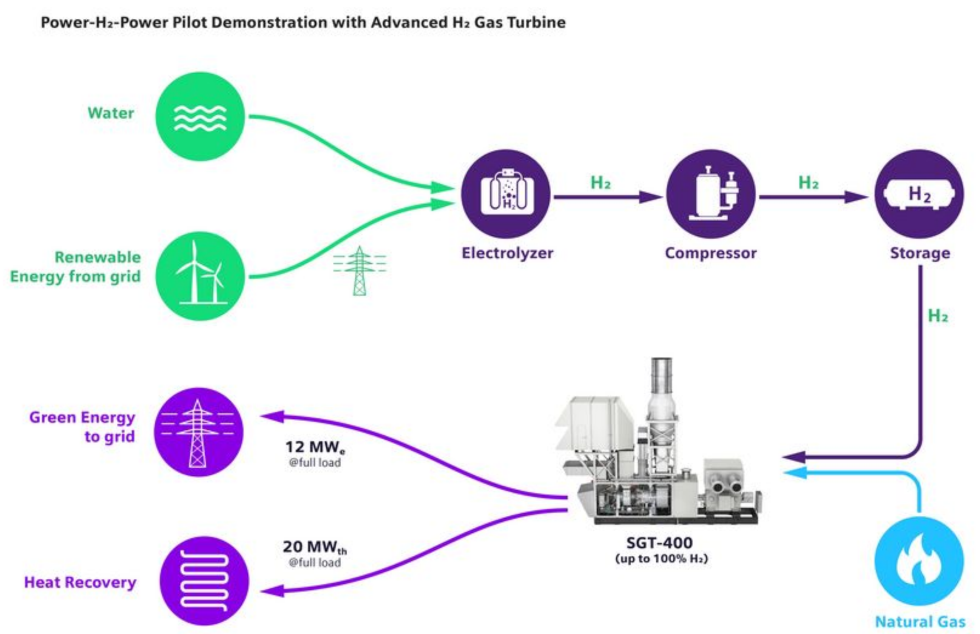

Figure 2 - Power-to-hydrogen-to-power pilot demonstrator with an advanced hydrogen gas turbine *(Courtesy: Siemens Energy)*

Under the project, the CHP plant in commercial operation fired by natural gas was upgraded to the power-to-hydrogen-to-power advanced plant concept (Figure 2). An electrolyzer supplied by Siemens Energy, powered by renewable energy, was used to generate green hydrogen, then storage tanks to contain the hydrogen, and a fuel mixing station to meter and supply the hydrogen and natural gas mixture that feeds the gas turbine.

Siemens Energy upgraded the existing SGT-400 industrial gas turbine combustion system enabling the operation with hydrogen (figure 3), whilst Centrax provided upgrades to the overall gas turbine integration package. Engie took responsibility for the implementation of an advanced plant concept.

The universities supported the project's implementation with their research and played a vital role in understanding the detailed physics as well as the project's social impact. The National Technical University of Athens performed the techno-economic analysis and had the responsibility for the social impact assessment. The German Aero Space Center (DLR) studied the flame behavior to support the combustion system development. The Universities of Duisburg-Essen, Lund University, and University College London also contributed to the hydrogen combustion system technology.

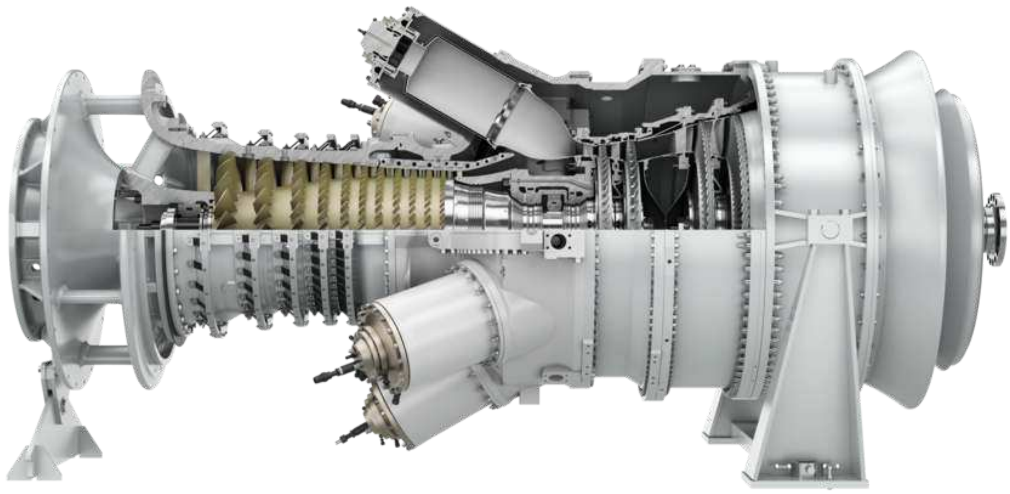

Figure 3 - SGT-400 Gas Turbine of the type installed at Smurfit-Kappa, France *(Courtesy: Siemens Energy)*

— Context: Why is this pilot so important?

Challenges

H_2 gas turbine technology

Hydrogen differs from hydrocarbon fuels by its combustion characteristics, which pose unique challenges for gas turbine combustion systems designed primarily for natural gas fuels. One important characteristic is hydrogen's higher reactivity compared to natural gas.

The key challenge is developing state-of-the-art gas turbines with dry low emissions (DLE) combustion technology that can operate on various mixtures of hydrogen and natural gas – from zero to 100% hydrogen. With this technology, fuel and air are mixed in a premixing zone before it is combusted. The tricky part is to stabilize the flame in the appropriate location of the burner that is designed to sustain higher temperatures, in the combustion zone. However, the high reactivity of hydrogen results in significantly faster flame speeds in the combustion zone than with natural gas. This forces the flame to stabilize closer to the burner exit where the premixed gas enters the combustion zone. This can cause flashback, a phenomenon where the flame propagates upstream of the combustor into the premixing zone, which can result in hardware overheating, damage, and failure. As the volume of hydrogen is increased, the challenge of flashback becomes greater for combustion designers and engineers.

H_2 availability

About one tonne per hour of hydrogen is needed to operate the SGT-400 on 100% hydrogen at full load, a significant amount, requiring substantial renewable electricity to power the electrolyzer. This is important, therefore, as it highlights the required investment in renewables to meet decarbonization goals. It needs to be clearly understood that green hydrogen, even at this project scale, is not readily available, and the cost and availability remain one of the key challenges.

Industrial relevance

In 2023, HYFLEXPOWER demonstrated the first application of a 100% green H_2 fired industrial gas turbine. The pilot project was also the first time an industrial scale power-to-hydrogen-to power project was demonstrated in a real-world application.

This is of great significance for the development of hydrogen as a key part of the decarbonization process, with an industrial site converting to green hydrogen fuel.

The scaling up of such projects, from pilot to full real-world applications, is critically important if green hydrogen is to become a fuel in complement to and eventually replacing natural gas. Global hydrogen use reached 94 Mt in 2021, the vast majority of which was grey hydrogen, produced by steam methane reforming fossil fuels. The production of low-emission hydrogen was less than 1 Mt in 2021. However, according to the International Energy Agency, meeting governments' climate pledges would require 34 Mt of low-emission hydrogen production per year by 2030; a path that achieves net zero emissions by 2050 globally would require around 100 Mt by 2030. This will require a huge push by both policy and market design, as well as an acceleration of renewables deployment and continued scale-up of electrolyzer manufacturing capacity and deployment.

Equally relevant is the fact that it takes approximately 10 tonnes of water to produce 1 tonne of green hydrogen. We must be cognizant of the requirements for both green energy and water supply when scoping and scaling our green hydrogen plans.

_ Learning points and implications for the energy sector

It is evident that there is insufficient, cost-effective green hydrogen readily available today for wholesale migration to 100% hydrogen-fueled gas turbines.

However, the HYFLEXPOWER project marks a major step forward in power generation decarbonization. It proves that hydrogen can serve as a flexible energy storage medium and that an existing gas-fired power plant can be adapted to run on 100% green hydrogen. HYFLEXPOWER's importance has already been recognized through several accolades, including the Technology & Innovation Award from COGEN Europe in 2023, and the Hydrogen Project of the Year Award at the Connecting Green Hydrogen MENA 2024 conference.

Further, this project shows that technology is not the limiting factor in the energy transition. It highlights that migration is feasible through active collaboration of industry, research, academia and government. It is an important stepping-stone in the exploration of scale-up and commercialization of decarbonized electricity generation. In fact, innovation in technology, plus EU funding together with cross-industry collaboration has confirmed this solution's benefits.

A level playing field with appropriate boundary conditions is necessary for the European industry to transition and to remain globally competitive. The EU has taken initial steps by funding a new project at the same facility, known as HyCoFlex, which started in February 2024. Its goal is to develop a retrofit decarbonization package for the cogeneration of power and industrial heat using a 100% hydrogen-fired gas turbine. This will establish credible pathways for upscaling and replicating the retrofit package.

HYFLEXPOWER, the first fully integrated power-to-H2-to-power demonstrator with an 100% hydrogen gas turbine

Subsequently, there is a need for more projects like HYFLEXPOWER on a larger scale, supported by the necessary government, financial, and technical backing, to create a viable roadmap for decarbonizing power generation and industrial applications. Clearly, this endeavor has many critical pieces: what is needed now is a cohesive strategy for using green hydrogen as a fuel. And there is still much to learn and accomplish on our journey toward Energy Transition.

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Managing Voltage issues caused by Rooftop PV and battery – case study from New Zealand

Electricity utilities are continuously evaluating new customer technologies for possible impacts if they become mainstream. A forthcoming future is for residences to be self sufficient in electricity generation by installing rooftop solar and battery storage, and making a side income by exporting their excess power to the grid. Where this occurs on a large scale what does it mean for the utility? Already, for new-build housing estates in New Zealand a developer is requiring that every dwelling has rooftop PV installed [1]. In this article the analysis of one such installation is given along with conclusions.

By Dan Martin, Essential Energy, Australia, and Russell Watson, Northpower, New Zealand

In NZ a rural customer connected a battery and rooftop solar system to the local grid, giving us the opportunity to study and make conclusions. While the power output of individual community installations is very small compared to traditional large generators on the entire network, there will be a growing cumulative effect which may change how we manage networks.

In this case, the installation elevated the line voltage over statutory limits resulting in curtailed export, and so possible solutions were sought. There is also the revenue and expenditure side of the utility to consider, as they make the most of their income from supplying electricity to customers. If customers purchase less energy then the distribution businesses will need to change ways to fund infrastructure development and operation.

This manuscript is split into the following sections. Firstly, an overview of the applicable standards for managing inverter voltage rises. Secondly, tapping the distribution transformer to obtain the desired voltage. Thirdly, our local experience how the power factor of LV networks has been changing which affects the voltage. Fourthly, the case study on the rural block with rooftop solar and battery. Lastly, the implications for the network and conclusions.

Applicable standards and managing voltage rises

As most networks were designed before rooftop PV became mainstream, the general strategy was to keep voltages as high as permitted, expecting voltage drops to the load. This strategy reduced the chance of customers experiencing low voltage, for instance sluggish motors on farms. However, it is well known that LV connected generation can raise the voltage above statutory limits. There is an Australian and New Zealand standard, AS/NZS4777.2 [2], which specifies two methods to reduce a voltage rise. One is that the inverter gradually reduces its active power output once the voltage exceeds 242 V. Two is the inverter begins to absorb reactive power once the voltage passes 235 V, although this option is disabled by default for a high proportion of inverters as it only became required in the 2020 standard update.

The voltage can be tapped down either using the distribution transformer, or at the zone substation power transformer. However, a network may then experience a too-low voltage when there is no, or insufficient, local generation. Household batteries add extra complexity to voltage management since now energy from solar PV might not be exported as expected during the day.

Set point	Volt-var				Volt-Watt			
	2015		2020		2015		2020	
	Voltage	Reactive power	Voltage	Reactive power	Voltage	Active power	Voltage	Active power
V_1	In the 2015 version the volt-var control was disabled by default		207 V	60 % (lead)	207 V	100%	-	
V_2			220 V	0 %	220 V	100%	-	
V_3			235 V	0 %	244 V	100%	242 V	100%
V_4			244 V	60 % (lag)	255 V	20%	250 V	20%

Table 1 - Voltage set points for volt-var and volt-Watt response according to AS/NZS4777.2 [2]

— Tapping the distribution transformer voltage

The allowable network voltage is 243.8 to 216.2 V at the point of connection with the customer, and to achieve this the distribution transformers are tapped to the nearest to 240 V at no load. On rural blocks there may be a significant voltage gradient between this point of connection and the house caused by long LV wires. Whereas there is a 24 V fall permitted due to impedances between the transformer and customer, there is only a 4 V rise. The permitted voltage band is therefore asymmetrical.

The voltage control within a zone substation is also often asymmetrical, e.g. a power transformer can have twenty-two steps to maintain voltage, although only six are to buck and the others to boost. Some distribution transformers only have one buck tap which can reduce the voltage by about 6 V. This is a coarse control of voltage compared to its allowable range, and that the voltage may fall in the evening at peak load.

In Australia there is a move to transition from 240 to 230 V. However, this assumes that there is a sufficient capacity to tap down both in the distribution transformer and the upstream power transformer. Some networks cannot tap to 230 V because the ends of many LV spans would have a too-low voltage. In rural areas farms can operate motors which reduce the voltage. Clusters of houses can have a peak evening load, especially in the winter with electric heating, which also causes the voltage to fall at night. This can prevent the local transformer being tapped down, and then the solar PV causes the voltage to rise in the summer daytime.

— Changing nature of networks

Local LV networks are being seen to have a leading power factor, for instance as shown in Figure 1, even when there is no rooftop solar. Both distribution and power transformers are highly inductive, and so a leading power factor will result in a voltage rise, compounding the effect of rooftop solar. This reactive power has been observed to be relatively steady across a day, unlike active power, and so has not caused more operations in the upstream transformer tap changer. At the transmission level, an excess reactive power can elevate voltages requiring shunt reactors [3], [4], [5], [6].

Considering the future, there may be a need to manage capacitive reactive power flows in a zone substation. An aim is to maintain the power factor close to unity at the point of connection with the transmission network. As networks are usually expected to be slightly inductive, capacitor banks are often installed in the zone substation to balance power factor. The control centre may be able to remotely switch these off to lower the line voltage if the power factor is too leading, and vice-versa.

If customer loads become more capacitive overall, then this is counterproductive to efforts to prevent significant voltage rises along the LV.

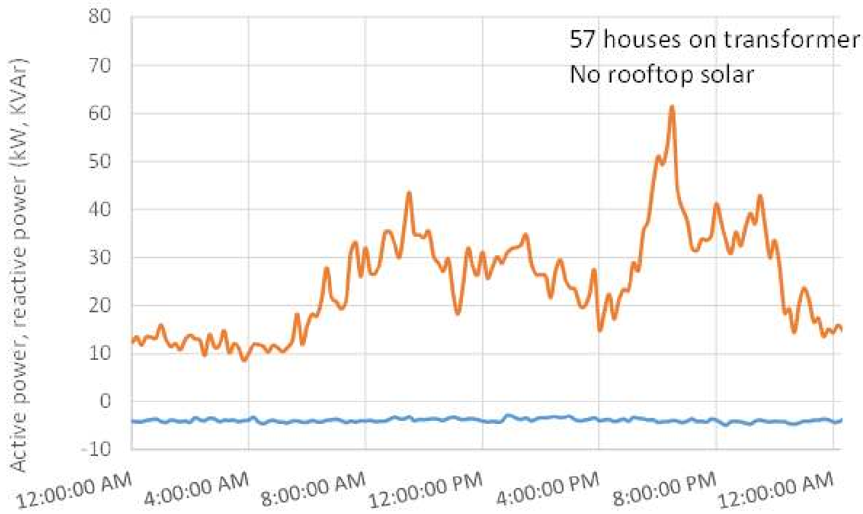

Figure 1 - Load profile of housing showing leading power factor

— Rural block with rooftop solar and battery

One house was set up with self-sufficiency in mind, where the rooftop PV and batteries were rated so that the customer would not need to import power, Figure 2. The rooftop solar starts charging the batteries in the morning, and once the batteries are charged then the excess power is sold to the grid. Only excess solar is exported, i.e. not from the battery. The customer complained that the grid inverter was shutting down due to over-voltage, and so they were not realising the full benefit of the solar. A study was carried out on this installation, and consideration what could happen to a utility if many dwellings became like this.

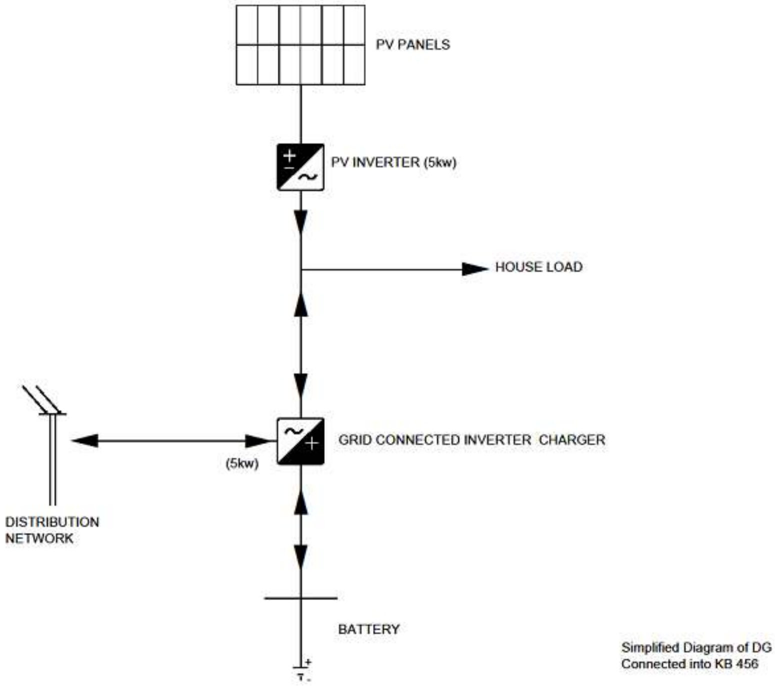

Figure 2 - Simplified diagram of DG system, showing the rooftop PV inverter supplying the house load, and a separate inverter connected to the grid

The site was 11 km along the 11 kV overhead line from the nearest zone substation, connected on one phase of a 15 kVA three phase transformer. Approximately 230 m of underground four core sectorial cable, 70 mm2 aluminium, was run to the metering station, and then another 100 m to the house, shown in Figure 3 and Figure 4. The impedance of long stretches of LV runs can lead to significant voltage swings. The utility is only responsible to keep the voltage at the point of connection with the customer property within statutory limits. If there is a further voltage rise to the dwelling then the customer has the responsibility to correct this. The site had been set to follow the 2015 version of AS/NZS4777.2 because the manufacturers were given a year to comply, and then time allowed for the inverters to be sold and installed. This means that the volt/var setting to manage voltage is disabled by default.

A preliminary evaluation of the site indicated that the tap of the distribution transformer was set too high, at +2.5%. The tap was then switched down once to its neutral position, and then loggers set up to check that the problem had been resolved. In this scenario there was only one customer connected to the transformer. If there were multiple houses and long LV lines, then this would add complexity to the solution. Most distribution transformers have one buck tap, while some have two, which provides some capacity to reduce the voltage.

After this analysis the distribution transformer was tapped down to -2.5%, its last setting, as this provided an optimum solution for the customer.

Figure 3 - LV supply to the distributed generation site

Figure 4 - Pole-top distribution substation

Monitoring was attached to both the distribution transformer and in the metering station, confirming the elevated voltage. The rise between the transformer and metering station regularly reached up to 5 V, Figure 5. Given that the house is 100 m further, the voltage rise is likely to be actually higher.

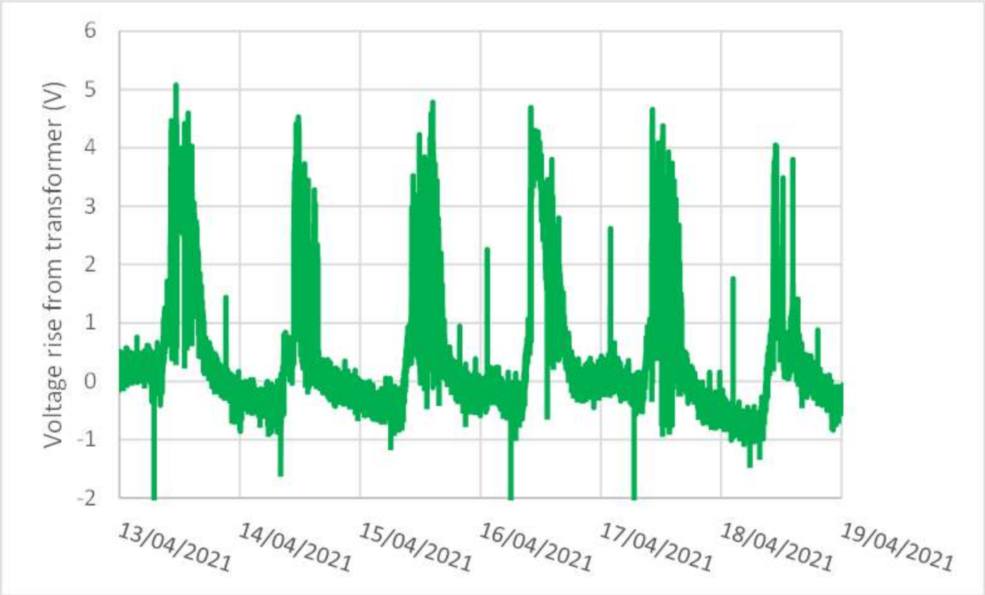

Figure 5 - Voltage rise between the distribution transformer, shown in Figure 4, and the customer's metering point

An elevated voltage can be caused by upstream set points as well as by embedded generation. Therefore, the rises and falls in LV was correlated with the 11 kV MV and 33 kV subtransmission voltages. Data was collated and analysed for a 24-hour period. As can be seen in Figure 6 and Figure 7 the voltage is high at night, and the peaks and troughs in the LV waveform correlate with the upstream 11 and 33 kV network. The 33 kV line voltage is lowest in the early evening, correlating with when the consumers return from work. The 11 kV line voltage has another minima in the early morning, although the 33/11 kV power transformer has a tap changer which keeps this falling outside regulatory limits. The significance of this is that the higher nighttime voltages are not caused by this installation, but by the upstream network overall loading, line reactive characteristics, reactive compensation equipment, and transformer tap changer available range.

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The substation power factor is slightly leading at night, Figure 8, which will contribute to the voltage rise. There is a 750 kVAr capacitor bank permanently connected, installed to reduce the reactive power offtake from the subtransmission network. The utility targets a unity power factor, and in future may need to remove capacitor banks or install reactors if the consumer load becomes more leading.

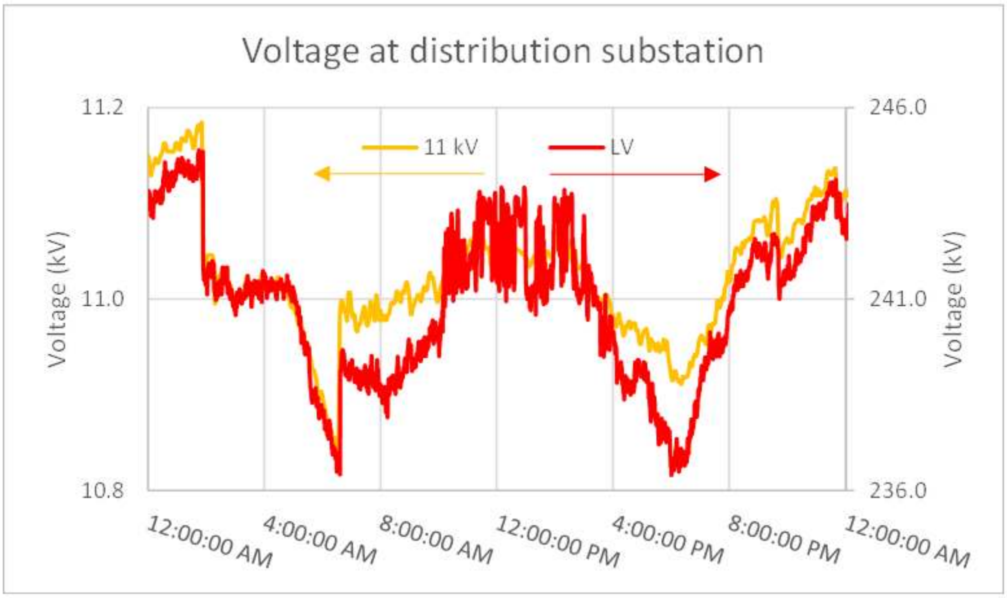

Figure 6 - Graph of LV and MV bus voltages at the distribution substation. The rises and falls in LV largely correlate with the upstream bus, indicating that the network is mainly responsible for voltage changes

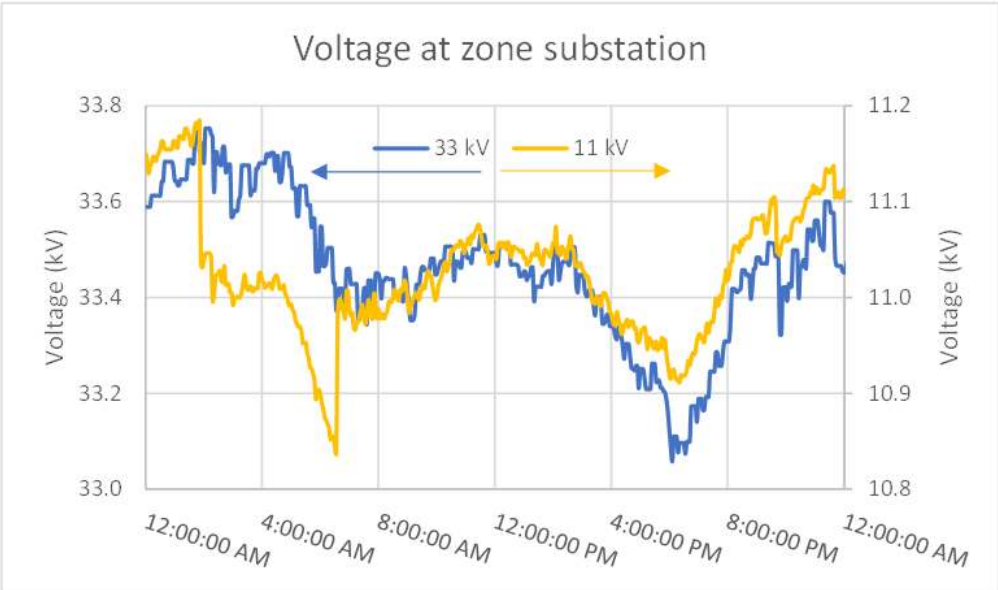

Figure 7 - Graph of zone substation 33 kV & 11 kV bus voltages. The waveform of the MV can be seen to be mainly following the HV, with some changes caused by the on-load tap changer of the power transformer

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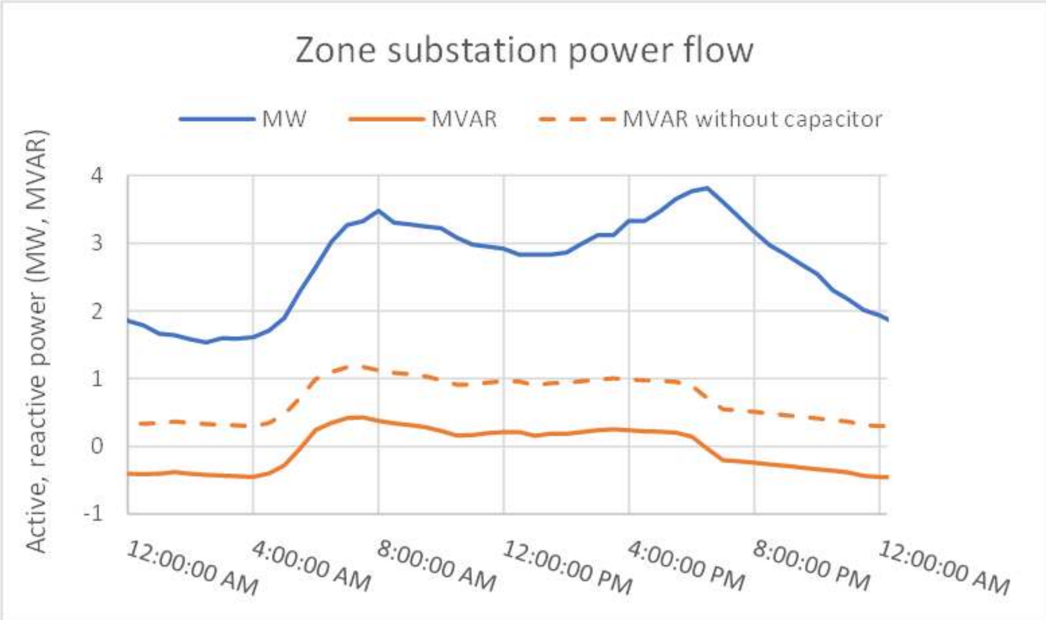

Figure 8 - Zone substation power flow

Analysis

Figure 9 shows the power exported from the site block and the respective voltages at the point of connection with the block and at the transformer. The parts of the graph can be explained by the following:

1. Up to 11 am there is no export from the site. The voltage profile follows the shape of the 33 kV and 11 kV lines (Figure 7). The behaviour of the tap changer in the zone substation is apparent, stepping the voltage down and up. At around 6 am the voltage falls as people are waking up and the load increases. The rooftop solar starts charging the battery bank in the morning.
2. After 11 am the site exports to the network, elevating the voltage. The export occasionally drops off as the battery bank is used and then the rooftop solar energy is diverted to replenish. The inverters begin ramping down power export at 244 V until 20% export at 255 V. The grid connected inverter is rated at 5 kW, and so a 3 kW output insinuates another 5 V rise between the metering station and the site because of the volt/watt curtailment. The volt/var response of the inverter was set to follow the 2015 standard, which is that it is not enabled.
3. At around 4 pm the export falls again as the sun sets. The battery bank supplies the local load until the following morning again.

The voltage shown in Figure 9 is still slightly too high, as the allowable range is between 216 and 244 V. The transformer could be tapped down again by 2.5%, or about 6 V, as the minimum voltage is still within the correct range. In other sections of LV network the long cables and heavy loads could result in low voltages where the transformer cannot be tapped down. In these cases other solutions would need to be sought. Another option considered for this section of LV was to parallel two phases between the three phase transformer and metering section, reducing the impedance, as only one phase was used.

When a connection request is made by a customer the utility will check if the network can handle the change in voltage and load. If the customer is requesting more capacity than the network can provide, the utility will provide options to the customer that they would be required to contribute payment for.

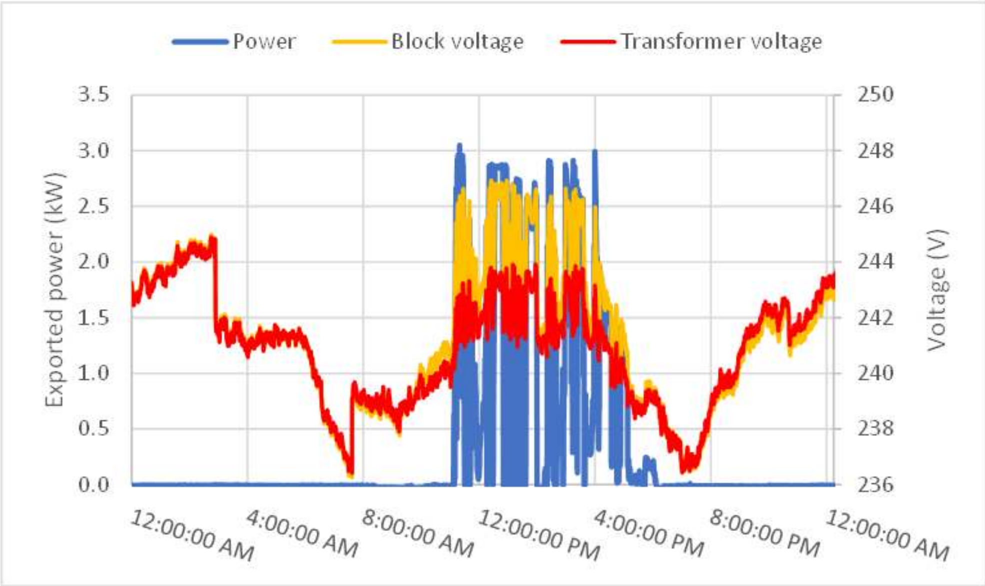

Figure 9 - Distributed Generation power flow & voltage at metering point

Network implications

At present, New Zealand utilities charge a daily network supply charge of NZ$0.1456 for low use, or NZ$1.3425 for standard and time of use, and a consumption charge of around NZ$0.25 per kWh. There is an export network charge of NZ$0.01/kWh introduced in 2022. A typical residence without solar may earn the utility NZ$1,000 annually. However, for one of these self-sufficient blocks the earnings are much lower, often less than NZ$100 per annum. Utilities will therefore need to consider other methods to recover costs from those customers forming a power injection community. Currently, the line charges for this site are being spread across all customers.

New installations must comply with the 2020 AS/NZS4777.2 standard for inverters, which mandates the use of volt/var response to lower voltage. Customers only receive income for their contracted active power supplied to the grid, rather than reactive power. If an elevating voltage activates the volt/watt or volt/var response, then the owner receives less income because they are not paid for reactive power. A positive side of volt/var response is that the power and distribution transformers forming the grid are highly inductive, and so some reactive power being absorbed from the LV system is very effective at reducing the voltage rise.

Conclusions

Changes to utility income models will likely happen as there is more uptake of batteries and solar.

While it is well known that rooftop solar elevates the line voltage, the industry was not so aware that the power factor of certain networks is becoming leading which also raises voltages. At the MV zone substation level the customer diversity is likely to still mean overall inductive loads. However, this might change as more equipment is retired and replaced with power electronic devices.

Changes to utility income models will likely happen with rapid uptake of batteries and solar. Presently, utilities are largely funded by selling energy to the consumer. An energy self-sufficient community will still require a utility to manage and operate the network.

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TECHNOLOGY E2E

A Consideration on Blade Receptors in Protecting Wind Turbines from Positive-polarity Lightning Attachments

As of 2022, the worldwide cumulative offshore wind capacity reached approximately 55.7 GW, indicating the global shift towards renewable energy and reduced reliance on coal fuel. According to market predictions, this significant trend is particularly evident in the proliferation of offshore wind plants, which are projected to expand by over fivefold to reach a scale of 315 GW over the next decade. This global trend underscores the urgency and importance of our research on lightning protection for offshore wind turbines.

As wind turbines continue to scale new heights, the surge in lightning accidents seriously threatens the safety and productivity of wind energy generation. This urgent issue has prompted numerous institutions to explore ways to protect wind turbines from positive and negative polarity lightning strikes. In this context, our study, which focuses on using a blade receptor to counter the positive polarity of a lightning strike, is not just a timely contribution but a significant and urgent one to this field of research. The findings of our study are of utmost importance, underlining the immediate need for practical solutions.

By Jeong-Min Woo, Ph.D.

Background

South Korea's offshore wind capacity reached 125 MW by 2022, with a target of 12 GW by 2030, underscoring the nation's commitment to renewable energy. However, the challenge of low offshore wind speeds, addressed by increasing wind turbine height, has inadvertently led to a surge in lightning accidents [1]. Wind power generators that exceed 100 meters in height and have a blade rotation radius of over 50 meters are particularly vulnerable to lightning accidents, with the potential for the lightning damage rate to skyrocket to a staggering 75%.

Lightning strikes can be categorized into two polarities: positive and negative. In East Asia, including South Korea, negative-polarity lightning strikes are more common in summer, while positive-polarity strikes occur predominantly in winter. Negative-polarity strikes typically happen when a significant amount of negative charges amass at the bottom of a thundercloud, forming a path to the ground. These account for nearly 90% of cloud-to-ground discharges. On the other hand, positive-polarity strikes stem from positive charges, primarily concentrated at the top of a thundercloud, when a path connects to the ground. In winter, when thunderclouds are closer to the ground and spread out horizontally, positive charges accumulate at the top of the cloud, leading to a lower occurrence of positive lightning strikes. However, rare lightning strikes are accompanied by an extensive maximum current and a simultaneous massive discharge of accumulated positive charges. Unfortunately, there is a significant gap in research on such phenomena at offshore wind power plants, where tall steel structures can attract positive lightning strikes as the distance between the highest point of the blade and the top of the thundercloud decreases. Our study aims to fill this gap, highlighting the novelty and importance of our research.

Investigation on Lightning protection for Wind Turbine

Model for simulating lightning protection

The downward lightning leader, originating from the thundercloud, is known to grow and then contact the upward leader emitted from a lightning rod or pointed conductor, and thus, handling blade receptors as lightning rods are essential for adequate lightning protection [2,3]. However, many lightning accidents occur at wind turbine blades. To understand better, based on a thorough review of the various methods for safeguarding wind turbines against lightning strikes, our investigation model is suggested to comprise several vital elements, as shown in Figure 1 [4,5].

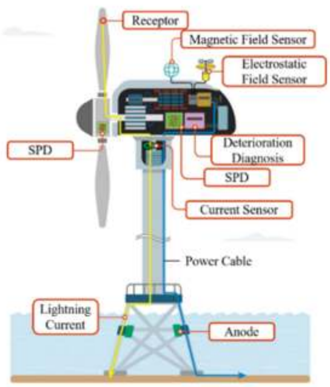

Figure 1 - Wind turbine model for lightning protection

Lightning protection simulation

Our investigation focused on the characteristics of positive-polarity lightning strikes on wind turbine blades. A reduced-scale blade was installed and compared, followed by a multi-physics simulation using the commercial program COMSOL in two steps.

First, the electrostatic field for the objects was calculated: the top electrode was biased with 20 kV at a 30cm distance from the receptor. Second, the transport of ions was simulated to move the ions in free space.

In Figure 2, our simulation shows that positive ion clouds are formed around the blade receptor against the positive-polarity lightning leader coming from the discharging electrode to the ground as the induced voltage was higher than the corona onset voltage, where the unit of the electrons and positive ion concentration is mol/m3. This might affect the propagation of the positive-polarity lightning leader, for which relevant experiments would be required.

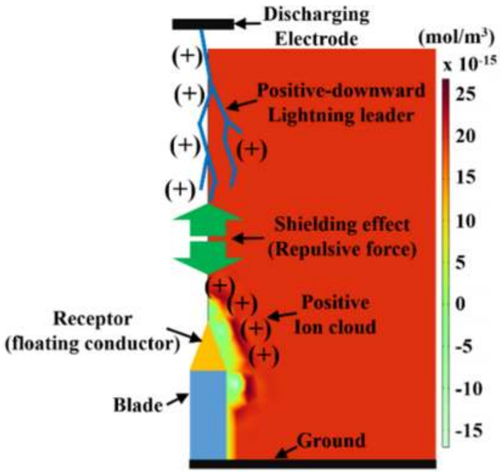

Figure 2 - Simulated space charge distribution by positive-polarity-lightning-leader

Experiments and discussion

The receptor and grounding conductor inside the blade were electrically grounded in the lightning attachment experiment. Lightning discharges were captured through long exposures of a high-resolution camera. The length of the reduced model of the wind turbine blade was 1.2 m with a receptor at its end, and then it was put under the discharging electrode at a 1.5m distance, as shown in Figure 3(a). The receptor was connected to the ground system. The distance between the top electrode and the blade's tip was 1.5 m, and the blade was isolated from the metal ground. For this work, switching impulse voltage (+ 709.2 kV, 250 μs ± 20%, 2,500 μs ± 60%) was applied to the discharging electrode.

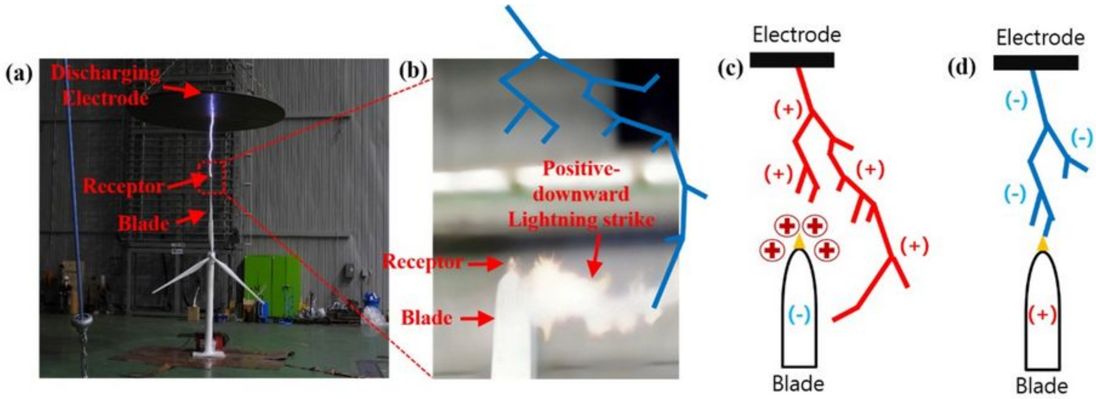

Figure 3 - (a) Photograph of lightning attachment experiment - (b) Magnified image of the positive-polarity-lightning strike - Schematic description of lightning leader propagation: (c) Positive-polarity and (d) Negative-polarity

The positive-polarity lightning strike shows curved propagation, as in Figure 3(b). This implies that the presence of the receptor demonstrated an unexpected role in directly turning the attachment of positive-polarity switching impulses lightning on the blade. In Figure 3(c), positive-polarity lightning attachment does not reach directly to the receptor but to the blade surface, causing significant damage. This differs from the general awareness that lightning strikes typically attach to the nearest conductor along their path, as shown in Figure 3(d). Accordingly, it has been proven that lightning accidents have occurred despite installing receptors for lightning protection during winter.

Based on our simulation and experimental findings, it could be assumed that the damage on the blade resulted from the propagation of positive-polarity lightning leaders generating positive ions from the receptor, as shown in Figure 2. It could be pointed out that positive ions congregate around the receptor, forming a positive-ion cloud and repelling the positive-polarity lightning leader, therefore causing the attachment of lightning leader to non-conductive surfaces where the relative presence of positive ions is very low enough to do a role.

Conclusion

The characteristics of positive-polarity lightning strikes have been investigated through experiments and simulations. According to the experimental findings, positive-polarity lightning strikes did not attach to the receptor positioned at the blade's end but to the blade's surface. This occurrence is believed to be caused by the displacement of the positive downward lightning leader due to the positive ion clouds formed around the blade receptor, as shown by simulation results, leading to lightning attachment at unintended sites. Consequently, the wind turbine blade receptor has demonstrated an unexpected role when positive-polarity lightning strikes occur. These findings are anticipated to contribute to analysing the causes of positive-polarity lightning accidents commonly observed during the winter season in East Asia.

To better understand the positive-lightning mechanism, the electric and magnetic fields will soon be measured, and current sensors will also be installed at offshore wind power sites in South Korea. Moreover, a novel receptor utterly different from the conventional configuration at the blade's end will be required for the future development of positive-polarity lightning protection measures.

Acknowledgment

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TECHNOLOGY E2E

Dealing with interactions in modern power electronics dominated power systems

We are experiencing a unique time in history whereby, driven by climate change, most governments have committed to reduce carbon emissions and many aim to reach Net Zero within the next couple of decades. These ambitious and binding goals require, amongst many other measures, the replacement of fossil fuel generation with carbon-free renewable generation. Underpinning this unprecedented transition is the use of Power Electronic Interfaced Devices (PEIDs), not only on the generation and demand sides, but also integrated as system assets, such as FACTS and HVDC systems.

**By Chandana Karawita (Convener of CIGRE JWG C4/B4.52), Łukasz Kocewiak (Convener of WG C4.49), Marta Val Escudero (SC C4 Chair)
and Genevieve Lietz (SC C4 Secretary)**

Introduction

The dynamic behaviour of PEIDs, and the ways that they interact with the rest of the power system, are more complex than conventional generators, and less understood. PEIDs can bring significant benefits to power systems, but their controls can also introduce harmful interactions if not considered carefully. Recent incidents worldwide have exhibited unwanted oscillatory behaviour of PEIDs that have caused loss of supply, economic costs and blackouts. Therefore, the transition to a clean energy future necessitates a detailed understanding of these increasingly complex interactions in modern power systems.

Within the remit of SC C4, two Working Groups (WGs) were created to better understand interactions in PEID-dominated systems and advanced methods of analysis: JWG C4/B4.52 and WG C4.49. Both WGs have completed their tasks and delivered two excellent Technical Brochures: TB 909 and TB 928.

Dealing with Sub-Synchronous Oscillations (JWG C4/B4.52)

Subsynchronous oscillations (SSO) have been identified as a major concern in modern power systems. Conventionally, large thermal generating units such as nuclear and steam turbine plants were identified as vulnerable for SSO. This was mainly due to the torsional interactions with the long shafts of the devices. The recent field experiences and the research have shown that there is a significant risk of SSO associated with other generator types and power electronic based devices such as renewable generation, HVDC and FACTs.

JWG C4/B4.52 (Guidelines for Sub-synchronous Oscillation Studies in Power Electronics Dominated Power Systems) has investigated sub-synchronous oscillations (SSO) in modern power systems and the outcome has been published in TB 909. Considering current industry needs, the TB provides a general guideline for understanding relevant SSO phenomenon, study methodology, mitigation/prevention techniques and protection mechanisms.

Classification of SSO

Having reviewed recent SSO events and keeping in-line with a recent classification proposed by the IEEE, an extended classification of SSO is proposed in TB 909, as shown in Figure 1.

SSO is divided into two main categories: Sub-synchronous Resonance (SSR) and Power Electronic Device Interactions (PEDI). SSR is further divided into Electrical and Torsional. This is to differentiate between the SSR that is purely electrical, where torsional systems are not involved, and those where a torsional system is involved. The Electrical type SSR could be due to resonance in the network when there are series compensation devices present, or it could be due to the negative resistance offered by a generator at a network resonance frequency. In both cases shaft systems are not involved. The Torsional type SSR is divided into three types: Shaft Torque Amplification, Torsional Interactions with the Network (TI-N) and Torsional Interactions with another Device (TI-D). The new category of SSO introduced in this TB is the PEDI. This category includes control interactions of two types: Control Interactions with the Network (CI-N) and Control Interactions with another Device (CI-D).

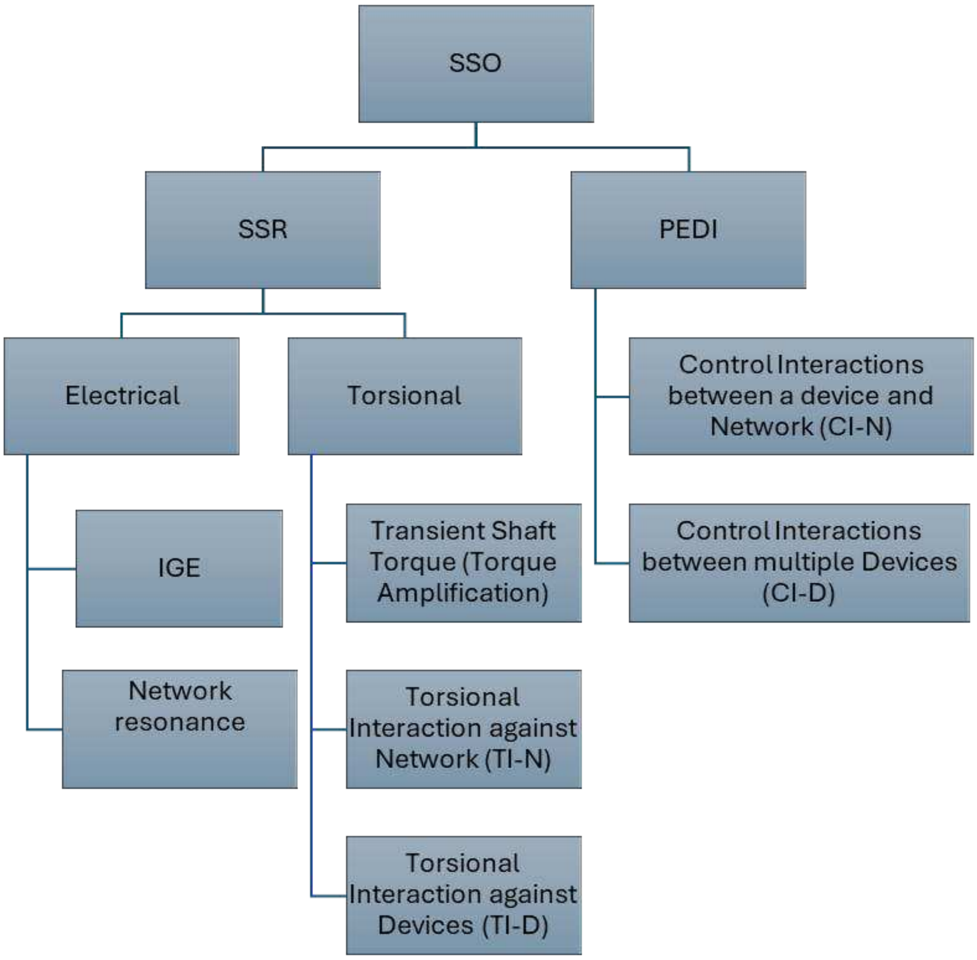

Figure 1 - New classification of SSO

Systematic Approach for Analyzing SSO Issues

TB 909 proposes a systematic approach to investigate and resolve SSO issues in power systems. The proposed SSO study procedure has been divided into four sections:

1. Screening of Potential SSO Risk

When a new project is planned or an existing SSO issue is analysed, the first step is to perform screening studies. At this stage, the possible SSO phenomenon is not clearly identified; devices contributing to the SSO are unknown; many operating scenarios and contingencies need to be considered; and detailed simulation models may not be available. Therefore, the main objective of screening studies is to evaluate the SSO risk while allowing false alarms and avoiding false dismissals. The TB presents an overview of the different methods available for screening the potential risk of various SSO types. The methodology and theoretical background of each method is explained along with the limitations, assumptions, modeling requirements and evaluation criteria. The TB also provides the reader with practical advice regarding the use of each screening method together with guidelines for the interpretation of results.

2. Detailed Evaluation of SSO

The detailed study procedures include electromagnetic transient (EMT) simulations and small-signal stability analysis (eigen analysis). EMT simulation is the most popular study procedure due to its flexibility, such as the use of black-boxed device models. However, the root cause of SSO phenomenon is difficult to determine by inspection of time-domain simulation plots. In contrast, the eigen analysis (frequency domain) provides more insight into SSO phenomenon. The oscillations and damping in the entire study case can be identified from the eigenvalues and the devices contributing to the oscillations can be evaluated using eigen properties such as participation factors and mode shapes. TB 909 provides clear guidelines for conducting these analyses.

3. SSO Mitigation and Prevention

Once detailed studies have confirmed the risk of SSO, suitable mitigation measures need to be implemented. The TB identifies and describes a range of mitigation options. Some mitigation measures can be used as short-term temporary measures until a permanent solution is implemented.

4. Monitoring and Protection Mechanisms for SSO

In addition to the mitigation measures, suitable backup protection mechanisms need to be implemented to ultimately avoid damage to devices. Furthermore, power systems are rapidly evolving, and their dynamic behavior may change unknowingly. This means that great attention must be paid to the behavior of all devices involved, and sophisticated condition monitoring is therefore needed.

The TB also provides a review of industry practices for SSO evaluation and reported SSO issues. In summary, TB 909 provides a general guideline for SSO studies in power electronic dominated power systems.

— Multi-frequency stability of PEIDs (WG C4.49)

WG C4.49 (Multi-frequency Stability of Converter-based Modern Power Systems) has examined new forms of instability and interactions driven by power electronic converters in modern power systems over a wide range of frequencies. The outcomes of the WG have been published in TB 928.

The TB presents an overview, status and outline of oscillatory instability and interaction analysis in converter-based systems. It covers definitions, classification, literature review and industry experience, including state-of-the-art stability and interaction analysis in power systems dominated by converters. The TB elaborates on small-signal instability phenomena, consolidates definitions, and explains available methods for analyses with their advantages and disadvantages to provide a common understanding for academia and industry. General guidelines for studies are provided, considering available information at different stages of an asset's lifetime, as well as choice of tools and mitigation methods. A new benchmark system has been developed by the WG to aid academia and industry in the analysis of multi-frequency stability.

Overview of instability phenomena and frequency range

In PEID-dominated power systems, the small-signal dynamics of converters can introduce negative damping in different frequency ranges, the severity of which depends on the controller types, the topologies, and the power system conditions. The root cause is the interaction of a converter controller (or several) with a grid resonance. Figure 2 shows the indicative frequency range considered for multi-frequency stability of power electronic control systems. It covers oscillations within the sub-synchronous (i.e. below the fundamental frequency) and harmonic (super-synchronous) frequency ranges.

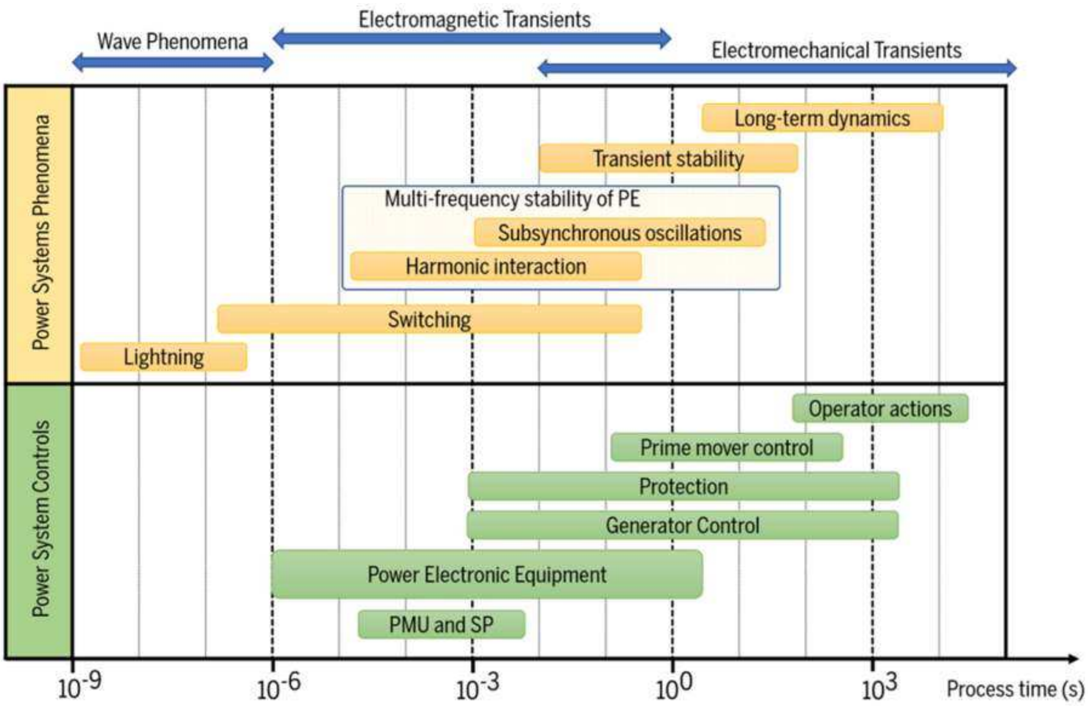

Figure 2 - Typical time frame for various dynamic phenomena in power systems

Stability analysis process for converter-based power systems

Figure 3 shows the proposed stability analysis workflow which can be easily adapted to any power system with a high level of PEID penetration such as photovoltaic power plants or wind power plants.

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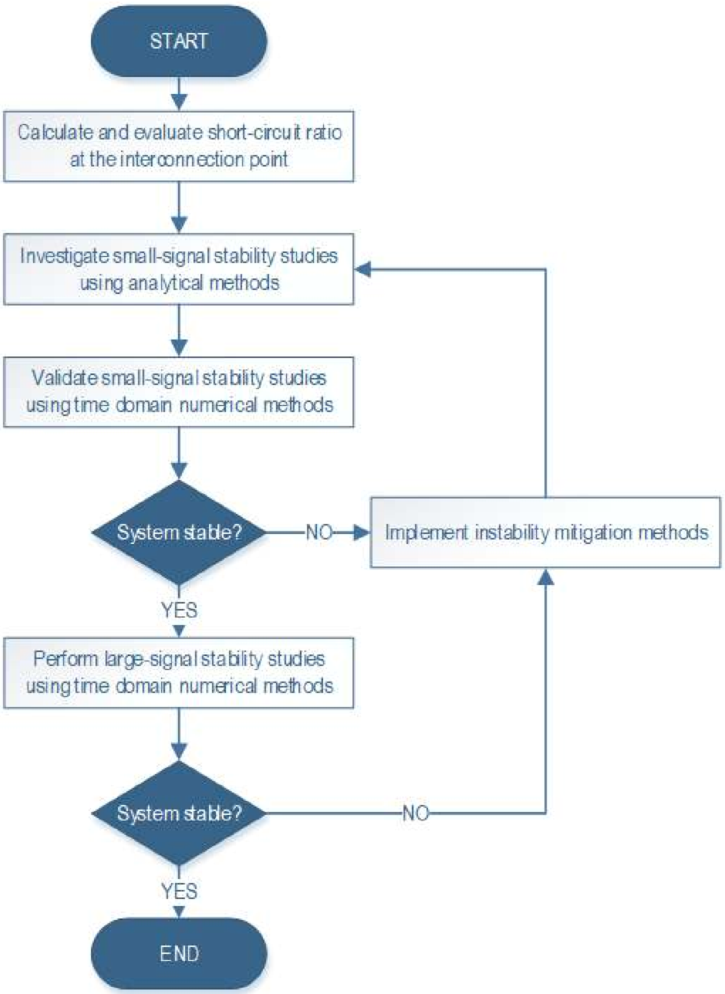

Figure 3 - Proposed stability analysis workflow for converter-based power systems

Step 1: Consider the short-circuit ratio (SCR). SCR is an indicator of p.u. impedance at fundamental frequency, and therefore does not consider resonances that may be present in the grid. However, it is indicative of how "strong" the network is at the point of interconnection and can be used (with caution) for an initial screening. Low SCR indicates possible stability challenges for grid-following converters due to weak grid connections. A high SCR can indicate challenges for converters with grid-forming control.

Step 2: Investigate small-signal stability. Small-signal stability is a necessary but not sufficient condition for entire system stability (small and larger disturbances). However, any system unable to withstand small-signal disturbances will not be able to operate in a stable manner. Thus, the first and principal task is to perform small-signal studies to investigate power system stability under a range of operating conditions. Various analytical methods are presented and discussed in the TB. These methods can yield insights into the nature of potential instability and enable optimised mitigation methods to be determined. Analytical methods are based on linearisation around a specific operating point. Therefore, multiple operating points, and therefore multiple linearised representations, are required to gain an understanding of the system's behaviour as a whole.

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Step 3: Validate small-signal stability studies. The linearisation conducted in Step 2 is a necessary simplification for analytical methods. Therefore, it is important to perform validation using a non-linear method, such as time-domain numerical simulations using detailed models of the power electronic converters with their controls.

Step 4: Perform large-signal stability studies. Power systems should remain stable not only when affected by small-signal disturbances but also by large-signal disturbances such as voltage drop and excessive inrush current due to transients, symmetrical and asymmetrical faults, frequency variation and phase jumps due to imbalance between power production and consumption, excessive harmonic distortion from power electronics or transformer energisation. Guidelines for conducting time-domain simulation analysis are included in the TB.

Step 5: Implement mitigation methods. If any possibly unstable events are identified in the previous steps, there is a need to apply suitable instability mitigation measures. There are multiple ways to avoid unstable operation, especially because, in comparison to classical power system components, converter systems are flexible due to their control and are therefore capable of changing their behaviour. However, any mitigation measure comes with a cost and impact of asset operational philosophy. Figure 4 provides an overview of various mitigation options, which are described and discussed in detail in TB 928.

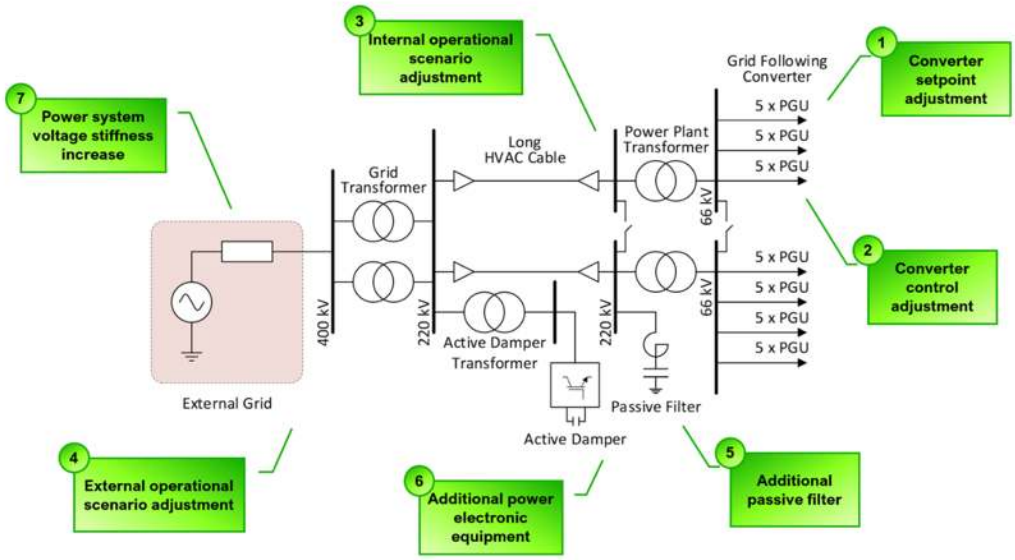

Figure 4 - Mitigation methods

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Energizing the Future: The Evolution of Smart and Eco-Friendly T&D Equipment

The evolution of power systems is being driven by a global shift towards renewable energy sources and the need for greater resilience in the face of changing demand patterns and climate-related challenges.

by Nenad Uzelac, A3 Chair, G&W Electric, USA
& Frank Richter, A3 Secretary, 50 Hertz, Germany

The traditional power grid was designed for a one-way flow of electricity from centralized power plants, which predominantly used fossil fuels, to consumers. This system is now being transformed into a more dynamic, interconnected network to accommodate energy transition – the shift from non-renewable sources like coal and natural gas to renewable sources like wind, solar, and hydroelectric power.

Medium Voltage padmount switch

Renewable energy sources, while sustainable and beneficial for the environment, introduce variability and intermittency in power generation. Unlike traditional power plants that can adjust output as needed, renewable sources depend on conditions like wind speed and sunlight availability, which can change rapidly. This means the modern grid must be highly adaptable and resilient to ensure a constant balance between supply and demand.

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Moreover, the concept of energy resilience has become a priority. Power systems now need to withstand and quickly recover from disruptions, such as severe weather events intensified by climate change. This includes the ability to isolate problems and re-route power, as well as the integration of local energy storage solutions that can provide backup power and help balance the grid.

In this evolving scenario, the equipment that underpins the transmission and distribution (T&D) of electricity—such as switchgear—must evolve as well. It's no longer just about switching on and off the flow of power; it's about being intelligent, adaptable, and environmentally friendly. Switchgear today must manage two-way power flows, incorporate renewable energy inputs, and communicate with the grid to respond to fluctuations in real-time. These systems are crucial for maintaining stability and ensuring that electricity is always available, even as generation and consumption patterns change.

Offshore platform

CIGRE Study Committee A3 is at the forefront of this evolution. We are deeply involved in all facets of high-voltage T&D equipment, tackling technical aspects, design, manufacturing, testing, and standardization. With an eye on the advancing landscape, our research is focused on the following key areas.

_ The digitalization of high-voltage systems and switchgear: (digital twin, sensors)

First and foremost, digitalization is one of the most important trends in switchgear technology. Digital switchgear can provide real-time data about the system that can be used for predictive maintenance, reducing downtime, and improving efficiency.

The integration of digital technology enables better monitoring and control, which reduces energy consumption and increases the longevity of the switchgear. Digitalization encompasses the following areas:

1. Data collection: This is the first step in which data is collected from various sources. In the case of monitoring systems, this could be data on system performance, user behavior, environmental conditions, etc. Data collection requires modern sensors that do not degrade the reliability of the equipment and are suitable for high voltage applications.
2. Data processing: In this step, the data is cleaned and converted into an analyzable format. This may also include the integration of data from different sources.
3. Data storage: The processed data is then stored in a database or data warehouse. This often raises the question of where this data is stored - in an external company or in an in-house infrastructure.
4. Data analysis: This is where the actual analysis of the data takes place. Various statistical methods and machine learning algorithms can be used to identify patterns and trends in the data. This can be a descriptive analysis (e.g. calculation of average values), a predictive analysis (e.g. prediction of future trends) or a prescriptive analysis (e.g. recommendation of measures based on the data).
5. Data visualization: The results of the analysis are often visualized using graphs, charts, and other visual tools. This makes it easier to understand and communicate the results.
6. Decision making: Finally, the results of the data analysis are used for decision making. This may involve making changes to improve system performance, identifying opportunities for cost savings, etc.

— Green technology

With growing environmental awareness, there is a trend towards more environmentally friendly switchgear. This includes the use of alternative gases to SF_6, which is a potent greenhouse gas. Examples include Fluornitries and different Natural Origin Gases such as technical air, CO_2, as well as use of Vacuum Interrupters both for Medium and High voltage applications. The use of recyclable materials in the construction of switchgear is another green initiative. This not only reduces the environmental impact at the end of the switchgear's life but also supports the circular economy.

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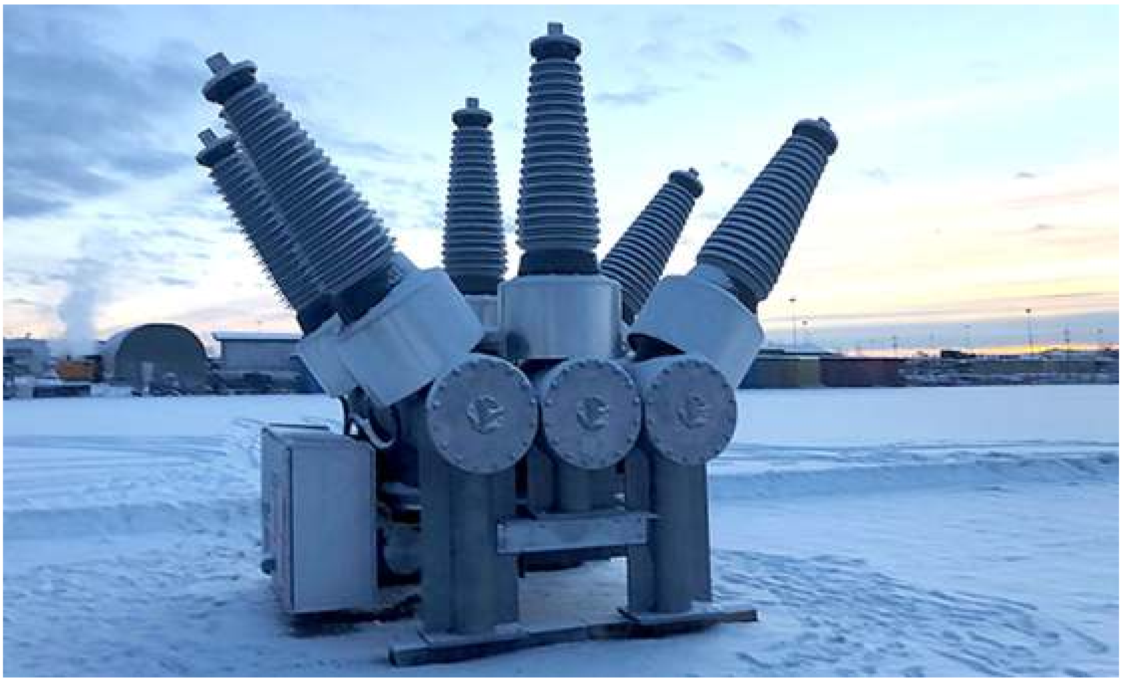

145kV High voltage SF6-free switchgear

Compact design and offshore use

The need for space-saving solutions has led to the development of more compact, modular switchgear concepts. These designs not only save space, but also enable faster installation and lower maintenance costs. An increased use of electrical switchgear that is specifically designed for use in offshore applications, such as offshore oil and gas platforms, offshore wind farms, or marine vessels is being observed. These switchgears are crucial for the safe and efficient operation of electrical equipment in these challenging environments. Features and requirements of offshore switchgear include a robust and durable design. Offshore switchgear must be able to withstand harsh environmental conditions such as high humidity, saltwater, and high winds. This often means they are made from corrosion-resistant materials and are sealed to prevent the ingress of water.

Offshore wind tower switch

— Intelligent electronic devices (IEDs)

(IEDs) have become a cornerstone in modern switchgear systems. These sophisticated devices are equipped with computing power and communication technologies that allow for real-time data processing and interaction with other grid components. This interaction facilitates advanced monitoring capabilities, control functions, and a high level of automation. IEDs can make quick decisions based on the data they receive, such as adjusting protection settings or re-routing power flows, which is vital in dynamic grid environments with fluctuating renewable energy inputs. Their role is pivotal in enhancing the operational intelligence of switchgear, thus optimizing grid performance and reliability.

— Improved safety features

Safety is paramount in the design of contemporary switchgear. Advances in this domain have led to the integration of features like internal arc fault protection, which significantly mitigates risks to both personnel and equipment. Internal arc faults, which can result from equipment failure or external factors, are among the most hazardous incidents that can occur in electrical systems. Modern switchgear designs aim to contain and extinguish these arcs quickly, minimizing the potential for injury and damage. These systems can also isolate the affected section of the grid to prevent the fault from impacting overall grid stability.

— Energy storage

The rise of renewable energy has warranted the development of switchgear that can seamlessly integrate energy storage solutions, such as batteries, into the grid. Energy storage plays a crucial role in balancing the intermittency of renewables by storing excess energy when supply exceeds demand and releasing it when the opposite is true. Suitable switchgear for energy storage must be capable of handling the rapid charge and discharge cycles, as well as maintaining efficiency over a wide range of operating conditions. The switchgear must also protect the storage devices, which are sensitive to electrical anomalies.

Improving Resilience

Advanced T&D equipment plays a significant role in enhancing this resilience (grid's ability to prevent, withstand, and quickly recover from disruptions) . For instance, modern switchgear now comes with features that enable it to detect and isolate faults automatically, preventing them from cascading through the system. Smart T&D devices also contribute to grid stability by managing fluctuations in power generation and load, thereby maintaining a steady supply of electricity. Furthermore, by facilitating the integration of distributed energy resources and microgrids, these systems can ensure that even if one part of the grid goes down, others can operate independently without disruption. This compartmentalization of the grid into more manageable sections, each capable of 'islanding' or operating in isolation, is a key strategy in building a more resilient power infrastructure.

Aftermath of the storm

Predictive maintenance

The advent of the Internet of Things (IoT) and Artificial Intelligence (AI) has transformed maintenance practices. Predictive maintenance leverages the connectivity of IoT and the analytical power of AI to anticipate potential issues before they escalate into serious problems. By analyzing data trends and performance metrics, predictive models can forecast equipment failures and allow for timely interventions. This proactive approach extends the life of the equipment, reduces

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maintenance costs, and increases system uptime, ensuring that the grid is more reliable and efficient. Remember, the goal of these trends is still to develop switchgear that is safe, reliable, efficient and sustainable!

As we navigate the complexities of a changing energy system, the work of CIGRE Study Committee A3 becomes increasingly important. We're responding to new challenges with thoughtful research into digital technologies, eco-friendly materials, and compact, resilient designs, we're contributing to a grid that's not just smart, but also sustainable and reliable.

Our journey toward improved T&D Equipment is ongoing. By integrating advances like predictive maintenance and intelligent electronic devices, we're helping to lay the foundation for a stable and resilient power network.

It's a shared mission to ensure that our power grid can support the energy demands of today and adapt to those of tomorrow. And as we make progress, step by step, we're helping to light up the future in a way that's responsible and sustainable.

Effective Meetings

Application of foundational competence

By David Hawkins & Mikel Vanry

On Meetings in general

By the time you have become a leader, you have spent a significant portion of your working life in meetings

Leaders can usually distinguish between useful meetings and ineffectual ones. Most have strong ideas about how to prepare for and run a good meeting. However, for reasons both obvious and obscure, when leaders meet, the quality and value of their meetings is often less than satisfying to many of the attendees.

The pace and volume of the work that leaders are faced with may explain part of this. They know they should prepare for meetings but do not. They know how to manage a meeting but are concerned about how that behavior may be interpreted by their colleagues.

In additionl, thos people who are used to **leading** meetings successfully don't always make a conscious transition to being an equally effective **follower** when someone else is leading the meeting.

Meetings are how executives get a fair chunk of their work done

In meetings, many different kinds of projects and issues get taken care of, often at the same time. Not all of what is being taken care of is necessarily obvious.

Effective meeting practices can only be successfully designed if we acknowledge the fact that at this level of organizational life each player can only succeed in "getting their work done" if they can navigate in matters of relationship.

- Many initiatives will depend on the willing and effective support of colleagues and staff in other functions of the organization
- Each will be dependent on the willing and effective implementation of their intent by their own staff
- Senior level initiatives are often characterized by significant involvement or dependence on external parties, such as regulators, politicians, suppliers, investors and customers; each requiring their own relationships

One useful way of thinking about what takes place in meetings is to see it as a collection of successful, bright and ambitious individuals, each trying to take care of two key variables at the same time: getting "work" accomplished and navigating the relationship landscape.

On ways to improve Meetings

From this perspective, it is possible to see the techniques for creating better meetings as a means for executives to take care, simultaneously, of both these objectives: getting the tangible "work" done and navigating in regard to relationships

In the following pages we explore techniques for creating better meetings:

- Reframing Meetings
- Meeting Design
- Meeting Roles
- Meeting Preparation
- Meeting Ground Rules

Many of these techniques work by separating elements that would otherwise be mixed together and are therefore more difficult to manage.

Reframing Meetings: From an event people show up for; to a shared commitment to produce a result and build relationships

Sometimes meetings show up like this:

- Someone sends out an invitation for a meeting, and the invitees routinely accept the invite out of duty
- An agenda may be sent out for the meeting, but it is quickly scanned and filed for use during the meeting
- People show up to meetings with varying degrees of preparation; some have done work in advance; others show up and "wing it"
- People have different views of what is important to discuss in the meeting
- There may be confusion about who called the meeting in the first place

- People behave in the meeting as they see fit, in response to the discussion that arises in the meeting, in order to take care of what is important to them
- Meetings rehash the same topics, with little or no resolution of issues
- Relationships amongst the attendees are diminished or damaged

We suggest that the biggest improvement to meetings can arise from starting to think of all meetings as:

"A shared **commitment** by all participants to achieve a result defined by the person who has requested the meeting, while building or maintaining sufficient relationships among the participants."

The implications of this view are:

- One person needs to define the result they wish and request a meeting to produce that result. We call this person the "Customer" for the meeting, and their intended result becomes the purpose of the meeting
- The Customer needs to negotiate with the other people in the meeting their agreement to produce the intended result. We call these other people the "**Performers**" for the meeting
- The achievement of the agreed result and the maintenance or improvement of relationships are the ultimate test of the success of the meeting and the standard by which the behavior of each attendee is judged

Each meeting is a Workflow between Customer and Performers, where the concerns of all are addressed.

Meeting design: All aspects of a meeting need to be considered and deliberately chosen in order to improve the success of a meeting

What are the relevant design aspects of a meeting?

Purpose and Outcomes (WHY)

- Overall purpose and specific outcomes for the meeting

Roles and Attendees (WHO)

- Customers and what is important to them
- Performers, their roles, and what is important to them
- Facilitation role, techniques and tools

Facilities and Material (WHERE)

- Place, setting, room and furniture, including light, view, noise and temperature
- Reference material to be used in the meeting
- Presentation and remote video facilities

Standards for Effective Mood and Behavior (HOW)

- Guidelines or rules for behavior during the meeting
- Expectations for mood of participants
- Preparation by all attendees for the meeting

- Anticipation of issues and breakdowns and how to address them

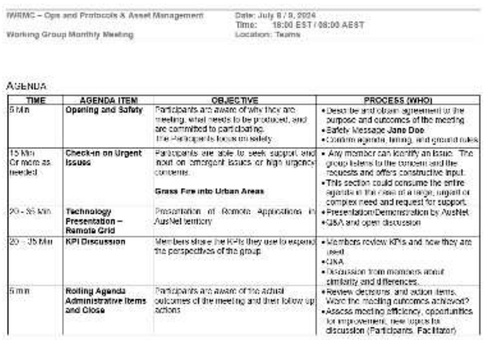
Agenda - the steps or procedure that will be used to achieve the outcomes and purpose (WHEN)

Documentation of meeting discussion and results (WHAT)

The amount of attention given to each of these aspects needs to be determined based on the nature of the meeting, how many people will be attending, the familiarity of the attendees with effective meeting practices, and if external parties will be present.

- Larger meetings require increased attention to design in order to not waste many people's time
- Meetings to address emotionally charged topics require careful design and preparation
- If attendees have good, effective meeting habits and attitudes, less design is required
- If attendees have poor meeting habits, more design is required
- If attendees have existing and sufficient relationships, less design and preparation is required
- If attendees have insufficient or new relationships, much more design and preparation is required
- Meetings including external parties require careful design and preparation

Vanry has prepared a generic meeting design document that can be used as a reference and template for effective meetings.


IWRMC – Ops and Protocols & Asset Management
Working Group Monthly Meeting

Date: July 8 / 9, 2024
Time: 18:00 EST / 08:00 AEST
Location: Teams

AGENDA

TIME	AGENDA ITEM	OBJECTIVE	PROCESS (WHO)
5 Min	**Opening and Safety**	Participants are aware of why they are meeting, what needs to be produced, and are committed to participating. The Participants focus on safety	• Describe and obtain agreement to the purpose and outcomes of the meeting • Safety Message **Jane Doe** • Confirm agenda, timing, and ground rules
15 Min Or more as needed	**Check-in on Urgent Issues**	Participants are able to seek support and input on emergent issues or high urgency concerns. **Grass Fire into Urban Areas**	• Any member can identify an issue. The group listens to the concern and the requests and offers constructive input. • This section could consume the entire agenda in the case of a large, urgent or complex need and request for support.
20 - 35 Min	**Technology Presentation – Remote Grid**	Presentation of Remote Applications in AusNet territory	• Presentation/Demonstration by AusNet • Q&A and open discussion
20 – 35 Min	**KPI Discussion**	Members share the KPIs they use to expand the perspectives of the group	• Members review KPIs and how they are used • Q&A • Discussion from members about similarity and differences.
5 min	**Rolling Agenda Administrative Items and Close**	Participants are aware of the actual outcomes of the meeting and their follow up actions	• Review decisions and action items. Were the meeting outcomes achieved? • Assess meeting efficiency, opportunities for improvement, new topics for discussion (Participants, Facilitator)

Template for effective meetings
PDF - 110 KB

Meeting roles: Increasing clarity about roles is one of the easiest (and most neglected) ways of improving the quality of a meeting

What are meeting roles and why are they important?

- Meeting roles are the identities that some of the meeting attendees take on for the duration of that meeting
- These roles help meeting attendees achieve their goals by explicitly separating matters of protocol from, say, matters of priority, by clarifying and identifying who can formally be relied upon for which responses and behavior

The key roles to keep clear about in order to have a successful meeting are:

- Customer
- Performers
- Facilitator

Meeting Customer:

- The customer is the person whose needs and concerns call for the meeting and define the purpose of the meeting
- The key accountability of the Customer is to ensure that all Performers understand the meeting Purpose and are willing and able to participate in its creation

Meeting Performers

- Performers are the people who take action before, during and after the meeting
- The key accountability of the Performers is to achieve the agreed meeting Purpose

Meeting Facilitator

- The Facilitator concentrates on the design and implementation of the meeting process, not its content
- The key accountability of the Facilitator is to make the best use of the contributions of the Customer and Performers and to minimize waste in their interactions
- Other aspects of meeting process management, such as timekeeping and note taking, may be negotiated and taken on by other attendees

Advertising, continue reading below

Meeting Preparation: Properly preparing for a meeting is another frequently neglected component to meeting success

The meeting Customer will benefit by ensuring that appropriate meeting attendees are committed to the purpose of the meeting and that they have what they need to be successful; after all, the Customer is the main beneficiary of the meeting

Most meetings are initiated by the Customer (or their delegate) by issuing a meeting invitation

- This invitation should be considered to truly be an invitation; a request to attend that can be accepted, declined, or negotiated
- Commitments are created though explicit or implicit negotiation and informed acceptance of the invitation by the attendee. Commitments are not established by the mere issuance of a meeting invitation
- In cases where effective meeting practices are not the cultural norm, care must be taken by the Customer to ensure attendees are truly committed to the purpose of the meeting. This may involve conversations with individual attendees in advance of the meeting

Any required preparation to be done in advance of the meeting by the attendees should also be requested, negotiated, and committed

- Commitments are established through negotiation and an informed acceptance by the attendee of the Customer's request to prepare for the meeting; commitments are not established by merely documenting requested preparation in the agenda

An effective process of ensuring adequate preparation for a meeting is:

- The Customer and/or Facilitator creates a written design for the meeting, documenting the proposed Purpose, Outcomes, Roles, Preparation, Ground Rules and Agenda for the meeting
- The suitability of proposed meeting attendees, location, timing, duration, facilities and setting are reviewed by the Customer and/or Facilitator
- A timely invitation is sent out by the Customer to prospective attendees with the meeting design document
- Attendance and preparation is then negotiated between the Customer and attendees as appropriate given the degree of familiarity of the attendees with effective meeting practices

Establishing ground rules is likely to be the least understood component for successful meetings

Most of us have some personal rules that we've learned over the years that help us compensate for aspects of our temperament which may, left to themselves, interfere with our most successful functioning. Possible examples:

- Some people work on themselves to speak less and listen more
- Others, to speak more (or to speak at different moments, or....)
- Others work to remember to let the other attendees show their cards before they jump in...

There is often also a collection of “ad hoc” rules that group members follow. These rules are generally not discussed, but simply understood. Possible examples:

- Never make a decision if we are in any doubt
- What doesn’t get done in this meeting can always be taken up in another meeting
- Above all else, make sure your point of view gets heard

Groups that are very high-functioning often work out an explicit set of rules-of-play (ground rules) and establish agreed-to practices for how to keep each other on track when they see the rules being broken

Examples of possible ground rules:

- Disagree with the idea, not the person
- In difficult moments, paraphrase the other person’s comments before you dive in and respond
- Delay contributing thoughts that may be off-the-subject until after the agreed-upon process has been completed
- Develop and examine the rationales underlying different positions in order to find ways to reconcile them, as opposed to planting the flag for a particular position
- Be concerned for inclusion. Who else needs to know about this? Who else’s opinion/point of view may need to be represented here?
- Each of us will approach our meetings together in a mood of engagement, openness and hope

Suggestions for next steps

All meetings are an opportunity for attendees to strengthen their relationships with one another in addition to getting things done

In this spirit, we suggest the following steps:

- Take some time to review the various possibilities for improving meetings set out in this article
- Reflect on the particular frustrations (if any) you experience in meetings
- Pay attention to meetings you are currently leading, or participating in, based on this material - what do you see differently that you may not have before?
- Identify and make some small and specific changes to your leadership or participation in one or more meetings
- Utilize the Vanry generic meeting design template in preparing for one or more of your meetings
- Notice any improvements to the effectiveness of the meetings you attend in getting things done and building relationships
- And repeat all the above

Banner & thumbnail credit: SolStock on iStock

CIGRE China - May 2024 China Day Event at the CIGRE Steering Committee Meeting

On May 27th-31st, 2024, the CIGRE Steering Committee Meeting was held in Shenzhen. During the meeting, a splendid China Day with the theme "De-carbonization and Digitization Enabling a New Power System" highlighted the energy transition in China.

By Dr. Jianbin FAN, Secretary General, CIGRE China National Committee

Shenzhen - China
27-31 May 2024

The National Day Event is a unique event set up by the CIGRE Steering Committee for the conference's host country. This China Day Event featured a themed technical exhibition and a keynote session. Thirteen members of the CIGRE Steering Committee and more than 150 representatives from China's energy industry attended the event.

The event was first opened by speeches from the Vice Mayor of Shenzhen Government, Mr. Jintao DAI, President of China Southern Power Grid (CSG), Mr. Chaoyang QIAN, and Secretary General of Chinese Society for Electrical Engineering (CSEE), Mr. Lianjun SHI to welcome all the guests and cherish the precious opportunity to have in-depth discussion and exchanges between experts from different parties. The speeches were followed by videos introducing three significant event organizers, including CIGRE, CIGRE Chinese NC (CSEE), and CSG. The event was moderated by Dr. Jianbin FAN, Deputy Secretary General of CSEE and member of the CIGRE Steering Committee.

The second part of the event was a keynote session that showcased ten keynotes delivered by leading experts from different energy industry sectors.

CIGRE President Michel Augonnet started the session with a keynote, "CIGRE and the Energy Transition." He reviewed CIGRE's history, development, and future vision, shared the challenges faced in energy transition and the legacy and revolution of the power systems, and finally introduced CIGRE's contributions through best practices, operational experiences, and technical innovations.

Chief Scientist of CSG and member of the Chinese Academy of Engineering, Dr. Hong RAO, shared the keynote "CSG Promotes the Construction of New Type of Power Systems through Technology Innovation." He pictured CSG's strategic initiatives to operate the regional grid with more than 80% non-fossil energy and achieve over 75% electricity in terminal consumption by 2060. As a key to realizing these operations, CSG's previous and continuous practices and innovation based on a complicated AC&DC bulk power system were introduced.

Then, CIGRE Vice-President Technical Marcio Szechtman addressed "Challenges for the Technical Council," examining the challenges during the energy transition's pivotal phase. He spotlighted the impact on the electric power industry, emphasizing digitalization, renewable energy cost reductions, the ESG framework, and data management. The presentation also gave a complete review of CIGRE's organizational structure, strategic plan updates, study committee scope, and focus from a technical perspective.

The last speaker at the keynote morning session was Mr. Javier Iglesias, a member of the CIGRE Steering Committee representing the Spanish National Committee, who gave a presentation entitled "Challenges for Electric Grid Development." His speech outlined the rapid growth of renewables and the world's escalating reliance on electricity. He stressed the necessity for substantial grid investments and upgrades to meet future demands and critical challenges, including aging infrastructure, permitting delays, supply chain constraints, and workforce shortages. He also called for coordinated efforts, innovative solutions, and strategic planning to enhance grid efficiency and resilience, ensuring a transition towards net zero.

At the beginning of the keynote afternoon session, Mr. Xipeng CAI from CSG Electric Power Research Institute delivered the keynote "Research on Key Technologies for Large Scale Clean Energy Scale Transmission." His presentation showcased the development of HVDC technology within CSG and the support of VSC-HVDC technology for large-scale clean energy transmission. Mr. CAI also highlighted several innovative schemes for VSC-HVDC design in future engineering applications to transmit clean energy from the far west area and the offshore.

David Sun, the CEO of Huawei Electric Power Digitalization BU, opened the discussion with a keynote, "Thrive with Digital, Driving Intelligent Electric Power." He stressed the significance of digitalization and intelligence in propelling the electric power sector forward. David outlined the "33 Model" for digital transformation, encompassing three innovation dimensions and three objectives to be safe, green, and efficient as a new power system.

The afternoon session also included sharing from the CIGRE NGN group in China. Dr. Yishen WANG from State Grid Corporation of China (SGCC) illuminated "Intelligent Computing Enabled the Intelligentization of the Power Grids." His keynote showcased the role of intelligent computing in the smart grid revolution, underscored the development of large power industry models and AI for Science (AI4S) applications in power systems, emphasizing the imperative integration of AI with traditional grid operations to tackle challenges in renewable integration, grid stability, and decision-making.

Dr. Zhujun YU from BYD Energy Storage shared a presentation entitled "Research and Application of LFP Energy Storage Battery Technology" that spotlighted BYD's Blade Battery. She introduced the safety and technical characteristics of BYD's Blade Battery, such as reduced thermal runaway temperature and a unique winding electrode structure that mitigates lithium plating risk. Her keynote triggered the discussion on battery's structural strength, space utilization, and service life advantages, along with BYD's milestones in energy storage systems and applications.

Advertising, continue reading below

Mr. Chaolin HE, Vice Director of CSG Digital Grid Technology (Guangdong), presented "Connect the World by Power IoT," concentrating on the development of the Power Harmony Unified IoT Operating System. The presentation explored the background, necessity, and evolution of this power industry-specific IoT OS, introducing its core values and contributions to the power sector's digital transformation and ecosystem development.

At last, the keynote session was wrapped up with Dr. Yan LI from Shenzhen Power Supply diving into "Exploration and Practice of Source-grid-load-storage Interactive Technology in Urban Power Grid." She explained the approach to examine the demand and framework for urban power grid interaction among sources, grids, loads, and storage. The challenges and impact of distributed renewable energy integration and electric vehicle growth in China were deliberated, showcasing Shenzhen Power Supply's innovation and management of sustainable development and the aggregation of flexible resources.

Aside from the keynote session, a technical exhibition with the same theme was displayed at the event site with support from CIGRE NGN groups in China. Young CIGRE members were passionate about demonstrating the latest technical breakthroughs and thinking for grid de-carbonization and digitization in areas such as HVDC transmission, power equipment, power system operation and simulation, and power supply etc.

This China Day event has been a great success in convening diversified participants, including CIGRE Steering Committee members, representatives from leading Chinese utilities, academicians, scholars, and manufacturers. Together, they shared innovative thinking and engineering experiences and engaged in profound exchanges and discussions on the challenges and opportunities within future energy transition, thus achieving fruitful conference outcomes. The meetings and events have also promoted CIGRE in China, attracting potential members from different sectors and ages.

CIGRE President, Michel Augonnet, remarked about the impressive progress by China in the energy transition and also noted the contributions by many young in their careers helping to lead energy transition progress in China.

Thumbnail & banner credit: Vincent Chan on Unsplash

CIGRE NGN: Discussion with Kurtis Martin-Sturmey

CIGRE would like to introduce a new section in Life of the Association: Interviews from Women in Engineering and Next Generation Network. A lot of focus is given to senior CIGRE members and these interviews will present younger members and let them explain what CIGRE means to them. These Q&A interviews are short but allow us to have a new, younger perspective on CIGRE membership; they tell us what interests them in their work, as well as what their projects and goals are. These are the voices of our industry's future. Please share with young people on your teams and encourage their membership in CIGRE!

BASc in Engineering Science – Energy Systems Engineering, 2014, 11 years

Current position: Manager, Asset Management & Performance at BBA ; Member of NGN CIGRE Canada;

CIGRE WG B3.61 : Risk and asset health based decision making in existing substations

What lead you to your present career or job?

Kurtis: I've been interested in the energy industry since high school since our entire economy and quality of life is dependent on affordable and reliable access to power. There are always interesting new problems to solve in the industry.

What are you working on now that would interest ELECTRA readers?

K.: My main focus has been forecasting the impacts of electrification on transmission and distribution networks. Some of the biggest impacts will occur on the last mile of the distribution system including single-phase laterals, distribution transformers, and secondary services.

What has been the biggest challenge with your work?

K.: When trying to forecast impacts of electric vehicles and heating electrification, there's lots of unknowns with respect to how these technologies can be deployed at scale, how regulatory and government incentives will affect the growth profile, and what the diversity factors will look like at different levels of the electricity network. More studies are needed.

What has been your biggest challenge balancing work and personal life?

K.: As someone coming up in the next generation, I don't mind putting in the extra work now to succeed in the future. The most important things are not to compromise sleep and to make time for physical activity on a regular basis.

How did you get involved in CIGRE?

K.: I started out in CIGRE as an NGN member of the C1.38 Working Group. I then learned that Canada didn't officially have its own NGN group and teamed up with some colleagues to found it. That was 6 years ago, and we've grown quite a lot since then. I'm really proud of the team.

What do you feel is CIGRE's 'added value'?

K.: It's easy to get stuck in a bubble, whether it's your own department, company, or even your own country. Collaborating with people internationally through organizations like CIGRE allows one to continually test and refine their own ideas and likewise benefit from others' ideas.

Why would you recommend CIGRE membership to others?

K.: CIGRE membership provides a portal to cutting-edge development across the industry, whether you are participating directly in the Working Groups with colleagues across the globe or benefitting from the publications once they're available.

Advertising, continue reading below

Where do you see yourself in 15 years?

K.: Who can say where the path of life will take us; for me, it's hard to imagine a future where I'm not engaged in solving tough problems.

Do you have one major goal or do you have a bucket list? Are you willing to share this information?

K.: There's a lot to experience on this beautiful planet. Patagonia is a place I definitely want to visit.

What would you like to see change in our industry in the future?

K.: It's hard to generalize the industry as a whole, but one common thread I could attribute to our industry is that we've focused on expanding the grid, while putting both R&D and asset renewal on back burners. We need more R&D to achieve the grid of the future and we need a more pragmatic approach to asset renewal to keep the grid reliable.

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*If you are a WiE or NGN member and wish to be featured in an upcoming ELECTRA edition, please contact **ELECTRA Editorial Team**. If you are reading these and wish to join CIGRE, please **visit this page**.*

CIGRE International Symposium Montreal 2025 - Call for papers

Grid Enhancement, Strategic Planning, Technological Innovation and Climatic Adaptation for Resilient Future Energy Systems

Hosted by the Canadian National Committee

Symposium Theme

The 2025 International CIGRE Symposium in Montreal will bring together international, regional, and local key players in the electric power systems sector: **business leaders**, **system operators**, **manufacturers**, **engineers**, **scientists**, **policymakers**, **regulators**, and **academics**.

PS1: System Enhancement, markets and regulation

- Energy sector integration for efficient decarbonization
- Power system dynamics and interaction
- Renewable energy, DER, microgrids, EV, storage
- Power systems with high percentage of renewables
- Electrical installations on offshore and artificial Islands
- Large-scale renewable energy integration, transmission and regional Interconnection
- DC applications in distribution and transmission: onshore and offshore
- Substations, switchgears, MV and HV Equipment
- Increase transfer capacity

PS2: Application of technologies, information technology (IT) and artificial intelligence (IA)

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- Innovative approaches on system design, construction, monitoring and maintenance
- Power quality performance
- Experiences with communication and cyber security in HVDC/FACTS systems
- Innovations and development of technologies, IT and AI tools for operation and maintenance

PS3: Climate change and extreme weather events

- Identification, risk assessment and management for extreme weather events and increasing temperatures
- Managing assets for power systems and industry as climate changes
- Evolution of industry standards
- Development and deployment of equipment suitable for extreme weather events

PS4: EHV & UHV AC and DC

- Insulation coordination
- Design of UHV/EHV AC and DC equipment
- Factory and field testing of UHV equipment
- Large projects based on UHV and EHV

Participating Study Committees

- **A1 -** Power generation & electromechanical energy conversion
- **A2 -** Power transformers & reactors
- **A3** - Transmission and distribution equipment
- **B2** - Overhead lines
- **B3** - Substations and electrical installations
- **B4** - DC systems and power electronics
- **C1** - Power system development & economics
- **C3** - Power system sustainability and environmental performance
- **C6** - Active distribution systems and distributed energy resources

The **6th International Colloquium on EHV and UHV AC&DC** in association with IEC will also be part of the Symposium.

ENGLISH VERSION - Call for Papers
PDF - 1.26 MB

VERSION FRANÇAISE - Appel à communications
PDF - 1.29 MB

— Papers publication

Papers will be available to download one month in advance of the symposium for registered participants. One month after the symposium, papers will be available on eCIGRE free of charge for CIGRE members. The CIGRE Science & Engineering (CSE) journal will publish the best papers selected from the symposium. The Technical Committee of the Symposium will produce a summary report of the symposium for publication in ELECTRA.

— Submission of synopses

The quality of the papers is initially assessed on the basis of a synopsis. To this end, the synopsis must summarize the results and advances that will be described in the paper. A synopsis that only describes the context of the research will be rejected.

Study Committees involved in the symposium will manage the process of full Papers review with a Peer Review Panel composed by experts. The papers from other Study Committees will be reviewed by Canadian experts. Authors may be asked to make changes or adjustments to their papers. Final acceptance or non-acceptance is duly notified to authors.

Participants wishing to present and publish papers should submit synopses by following the instructions **on website**, where the synopses and paper templates are also available. All synopses, papers, and presentations must be in English or in French and English. Please note that at least one author must present the paper at the symposium.

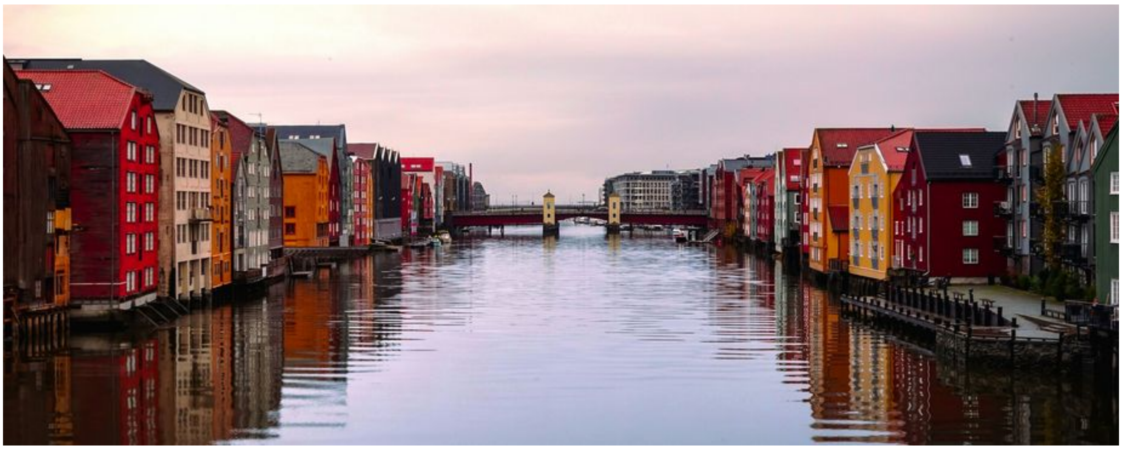
Deadlines

- Opening of the upload for abstracts: **September 10, 2024**
- Deadline for Synopses (English or English+French): **November 27, 2024**
- Selection of synopses by SCs and information to authors: **January 25, 2025**
- Deadline for full papers: **April 25, 2025**
- Opening of registrations: **Spring 2025**
- Feedback to authors of full papers: **June 13, 2025**
- Final papers: **July 11, 2025**

The full program will be available closer to the symposium on the **Canadian National Committee website** ***(coming soon)***.

CIGRE International Symposium Trondheim 2025 - Call for papers

Changes needed in the Power System for the Energy Transition



Hosted by the Nordic Regional Council of CIGRE (NRCC)

Symposium theme

The CIGRE NRCC 2025 symposium in Trondheim will be on the theme: Changes Needed in The Power System - for the Energy Transition. This will be divided into two topic streams:

PS1: Integration of renewable energy resources to the grid

- Environmentally friendly power grid and its equipment
- New applications and technologies applied to AC and DC onshore and offshore grid
- AC and DC onshore and offshore grid
- AC grid development, protection of the future meshed AC and DC system
- Sector integration including hydrogen, EV, energy hubs, DER
- Services/operation applied to AC and DC onshore and offshore grid
- Monitoring the system applied to AC and DC onshore and offshore grid
- Maintenance and Services applied to AC and DC onshore and offshore grid

PS2: Technologies supporting the power grid for energy transition to carbon neutral energy production

- Requirements for power grid and its equipment
- Inverter based control interacting with existing system and Converter stability issues (resonance stability, converter driven stability)

- Coordination between AC and DC networks
- Grid forming
- Multivendor interoperability
- New modelling tools
- Planning and operation of lower inertia system
- System analysis (technical)
- Black start and resilience aspects including DER integration
- Optimize and increase the capacity of the energy transmission network
- Reliability and security – critical infrastructure

Participating Study Committees

- **A3** - Transmission and distribution equipment
- **B1** - Insulated cables (co-lead)
- **B2** - Overhead lines
- **B3** - Substations and electrical installations
- **B4** - DC systems and power electronics
- **B5** - Protection and automation
- **C2** - Power system operation and control
- **C3** - Power system sustainability and environmental performance
- **C4** - Power system technical performance (co-lead)
- **C6** - Active distribution systems and distributed energy resources
- **D2** - Information systems telecommunications and cybersecurity

Download the Call for Papers (June update)


cigre NRCC | Symposium 2025 Trondheim, Norway

Call for Papers

CHANGES NEEDED IN THE POWER SYSTEM for the Energy Transition

International Symposium hosted by the Nordic Regional Council of CIGRE (NRCC) in Trondheim, Norway on May 12–15, 2025

Participating CIGRE Study Committees (SC): SC A3 Transmission and distribution equipment, **SC B1 Insulated cables (co-lead)**, SC B2 Overhead lines, SC B3 Substations and electrical installations, SC B4 DC systems and power electronics, SC B5 Protection and automation, SC C2 Power system operation and control, SC C3 Power system sustainability and environmental performance, **SC C4 Power system technical performance (co-lead)**, SC C6 Active distribution systems and distributed energy resources, SC D2 Information systems telecommunications and cybersecurity.

SYMPOSIUM THEME

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- Maintenance and Services applied to AC and DC onshore and offshore grid

PS2: Technologies supporting the power grid for energy transition to carbon neutral energy production
- Requirements for power grid and its equipment
- Inverter based control interacting with existing system and Converter stability issues (resonance stability, converter driven stability)
- Coordination between AC and DC networks
- Grid forming
- Multivendor interoperability
- New modelling tools
- Planning and operation of lower inertia system
- System analysis (technical)
- Black start and resilience aspects including DER integration
- Optimize and increase the capacity of the energy transmission network
- Reliability and security – critical infrastructure

Trondheim Symposium 2025 - Call for papers
PDF - 219 KB

Paper publication

Papers will be available to download one month in advance of the symposium for registered participants as described in the webpage.

One month after the symposium, CIGRE members can download, and other can purchase papers on eCIGRE.

CIGRE Science & Engineering (CSE) journal will publish the best papers selected from the symposium.
The Symposium Technical Committee will produce a summary report of the symposium for publication in ELECTRA.

Submission of synopses

Participants wishing to present and publish papers should submit synopses by following the instructions on the Symposium website, where the synopses and paper templates are also available. All synopses, papers, and presentations must be in English. Please note that at least one author should present the paper at the symposium.

Authors should note the following deadlines:

- Registration starts: **June 1, 2024**
- Deadline for Synopses in ConfTool: ***New deadline (June update)*** **September 12, 2024**
- Selection of synopses by SCs and information to authors: **October 7, 2024**
- Deadline for full papers: **February 3, 2025**
- Acceptance and other feedback to authors of full papers: **March 3, 2025**
- Final papers to ConfTool: **April 7, 2025**

Registration information will be available from the **Symposium website**.

Thumbnail & banner credit: Photo by Louis Droege on Unsplash

5th SEERC Conference Sarajevo 2025 - Call for papers

The presiding country of SEERC for the period 2023-2025, NC CIGRE of Bosnia and Herzegovina welcomes you to the 5th SEERC Conference!

Hosted by the South-East European Regional Council of CIGRE

The South-East European Regional Council of CIGRE (SEERC) is hosting the 5th SEERC Conference to bring together experts in electric power systems and electricity markets. The goal is to accelerate decarbonization and support the transition to future energy systems. The conference will cover advanced technologies in electric power systems and regional innovations in renewable energy. Additionally, a special history panel will examine the electrification history of the SEERC region, emphasizing the importance of historical context for future developments.

All Study Committees of CIGRE (A1, A2, A3, B1, B2, B3, B4, B5, C1, C2, C3, C4, C5, C6, D1, D2) are addressed.

— Conference topics

The conference topics are focused on accelerated decarbonization and steady transition to the future power systems.

1. Increasing energy efficiency of existing facilities and increasing renewable energy capacities

Technologies to improve energy efficiency and encourage the adoption of renewable energy sources and decreased emissions of greenhouse gases; presenting interesting projects. Advantages of energy efficiency, including diminished energy expenditures, and enhanced energy dependability, energy audits, regulations, energy management systems. Renewable energy technologies, economic and environmental benefits of solar, wind, hydropower, and geothermal technology; regulatory frameworks for funding; collaborations between the public and private sectors.

2. New technologies and methodologies for accelerated decarbonization and digitalization of electric power systems

Advanced renewable energy integration and storage solutions. Internet of things, machine learning and smart grid technologies (artificial intelligence, sensor integration and predictive maintenance) . Citizen's initiatives (energy communities, prosumers, e-mobility).

3. Development of the electricity market balancing and dynamic regulation

Integration of national balancing markets in Europe, harmonization of requirements for Balancing Service Providers. Opening of ancillary service markets to distributed energy resources and TSO/DSO cooperation. Storage device evolution, technical & economic performances, short/medium term measures for balancing the grid and managing the electric system in the long term.

4. Resilience issues of the electric power systems

The impact of climate change on the electric power infrastructure and the functioning of the electric power system. Electric power system adaptation concepts, strategies and innovative solutions to increase operational resilience. Electric power system security and resilience against cyber threats.

5th SEERC CONFERENCE

Call for Papers

Sarajevo, Bosnia and Herzegovina, 4th – 5th June 2025

OBJECTIVES & THEMES

The South-East European Regional Council of CIGRE (SEERC) is hosting the 5th conference to bring together experts in electric power systems and electricity markets. The goal is to accelerate decarbonization and support the transition to future energy systems.

The conference will cover advanced technologies in electric power systems and regional innovations in renewable energy. Additionally, a special history panel will examine the electrification history of the SEERC region, emphasizing the importance of historical context for future developments.

CONFERENCE VENUE

Sarajevo, the capital of Bosnia and Herzegovina, is renowned for its rich cultural diversity and historic landmarks. It serves as the political, economic, and cultural hub of the country, offering a picturesque setting with stunning architecture, and scenic landscapes surrounded by mountains. The conference will take place at the Hotel Hills Thermal & Spa Resort Sarajevo.

CONFERENCE TOPICS

1. Increasing energy efficiency of existing facilities and increasing renewable energy capacities

Technologies to improve energy efficiency and encourage the adoption of renewable energy sources and decreased emissions of greenhouse gases; presenting interesting projects.

- Advantages of energy efficiency, including diminished energy expenditures, and enhanced energy dependability, energy audits, regulations, energy management systems.
- Renewable energy technologies, economic and environmental benefits of solar, wind, hydropower, and geothermal technology; regulatory frameworks for funding; collaborations between the public and private sectors.

2. New technologies and methodologies for accelerated decarbonization and digitalization of electric power systems

- Advanced renewable energy integration and storage solutions, internet of things, machine learning and smart grid technologies (artificial intelligence, sensor integration and predictive maintenance).
- Citizen's initiatives (energy communities, prosumers, e-mobility).

3. Development of the electricity market balancing and dynamic regulation

- Integration of national balancing markets in Europe, harmonization of requirements for Balancing Service Providers.
- Opening of ancillary service markets to distributed energy resources and TSO/DSO cooperation.
- Storage device evolution, technical & economic performances, short/medium term measures for balancing the grid and managing the electric system in the long term.

5th SEERC Conference 2025 - Call for papers
PDF - 1.27 MB

Submission guidelines

- Synopses should be 300 words or less and must provide a clear overview of the research objectives, methodology, and key findings.
- Full papers should be in English, between 5,000 to 8,000 words (including references), adhering to the prescribed formatting guidelines.
- Accepted papers will be presented during dedicated sessions and included in the conference proceedings.
- Selected papers will receive awards and be published in the journal B&H Electrical Engineering.

Important dates:

- Synopses Submission: **October 31, 2024**
- Notification of Synopses Acceptance: **December 15, 2024**
- Full Paper Submission: **February 28, 2025**
- Notification of Paper Acceptance: **March 31, 2025**

Submission and information on the **Conference website**.

Advertising, continue reading below

Introducing six new Study Committee Chairs

_ SC A1 - Power generation and electromechanical energy conversion

Howard Sedding

Summary of experience within CIGRE

- Active participation in CIGRE since 1990; SC A1 & D1
- Co-authored/presented 12 papers at CIGRE general sessions and colloquia
- Contributed to several A1 and D1 WGs
- Canadian Regular member of A1 (2006 – 14)
- SC A1 Special Reporter (2016 – present)

Summary of Professional Experience

- Qualitrol – Iris Power, Insulation Engineer (2015 – present)
- Ontario Hydro/Kinectrics, various positions; research engineer to department manager (1988 – 2014)
- Worked on rotating machine testing and condition monitoring
- Participated in several IEEE & IEC WGs developing standards in rotating machines manufacture, operation & maintenance

_ SC A3 - Transmission and distribution equipment

Nicola Gariboldi

Summary of Experience within CIGRE

- Convener JWG A3.43 - Tools for lifecycle management of T&D switchgear based on data from condition monitoring systems
- Member WG A3.39 - Application and field experience with Metal Oxide Surge Arresters
- Member JWG A3.32 - Non-intrusive methods for condition assessment of distribution and transmission switchgears
- Member WG A3.19 - Line fault phenomena and their implications for3-phase short- and long-line fault clearing
- A3 Special Reporter CIGRE Sessions 2020, 2021, 2022

Summary of Professional Experience

- From 2016 Qualitrol LLC: Director FS Europe - Technical Application Specialist for Breaker monitoring.
- 2013-2016 ABB Wettingen (CH): Technology Manager Surge Arrester development
- 2001-2013 ABB Baden (CH): Project Manager High Voltage Interrupter development
- 1996-2001 ABB Lodi (IT): responsible of R&D dep. for GIS and Circuit Breaker Testing
- 1995 Passoni & Villa (IT): respondible of High Voltage Laboratory
- 1991-1994 ABB Bergamo (IT): Short Circuit Lab eng. MV LV power tests

— SC B3 - Substations and electrical installations

Mark McVey

Summary of Experience within CIGRE

- 2003-2007 Corresponding B3.03 (300) Guidelines to An Optimal Approach AIS
- 2007-2020 WG Member and Contributing Author Brochure: 300,439,532,624 and 660
- Convener Brochure 613 AIS Design for Severe Climate Conditions
- Convener Brochure 805 Guidelines for Safe Work Methods in Substations
- Special Reporter B3 2013 Extreme Weather/Seismic Auckland Symposium
- Special Reporter B3 2018, 2020, 2021 and 2022 Paris Symposium
- B3 AA3 Advisor all Air Insulated Substation brochures and activities 2019 to current (2023)
- The CIGRE Distinguished Member Award B3 2022 Paris
- The CIGRE Technical Council Award B3 2018 Paris
- U.S. National Committee of CIGRE Attwood Associates Award 2018

Summary of Professional Experience

- BS EE Virginia Tech University 1982
- 40 years Electric Utility, 38 Years Dominion Energy
- Principal Engineer, Operations Engineering, Substation Engineering, Operations and Division Operation Supervisor, Field Engineer Control Operations, Associate Engineer

— SC B5 - Protection and automation

Volker Leitloff

Summary of Experience within CIGRE

- Member of B5 SAG and convenor of B5 TM51 since 2007
- 2004-2012 French Member of CIGRE Study Committee B5
- Convenor of WG B5.06 (Maintenance Strategies for DSAS) 2008 - 2011
- Special Reporter (SC B5 colloquium 2009, & 2017)
- Secretary of WG B5.43, WG B5.53 & WG B5.69 (ongoing)
- Numerous papers and prepared contributions, mainly in B5 sessions

Summary of Professional Experience

- PhD Thesis (1991-1994) on neutral grounding of MV networks
- 1994-99 EDF R&D – Research engineer in the field of protection & control
- 2000-02 EDF R&D – Research group leader "Transformer and Network Technologies"
- Since 2003 Rte – Protection and control expert, PACS projects
- Since 2017: chair of IEC TC38 (Instrument Transformers)
- Since 2018: Convenor of IEC TC95 WG2 (Digitally interfaced protections)

— SC C2 - Power system operation and control

Dr. Renuka Chatterjee

Summary of Experience within CIGRE

- CIGRE Member since 2017
- C2.B4 38 JWG Technical Brochure Key contributor and Chapter 2 lead.
- SC C2 Participant since 2017 and part of SC C2 advisory group
- Reviewer: Papers/proposals for SC C2 (complete as required and provide feedback)
- Presenter: 2018 Large Disturbances Workshop, Topic = USA: Hurricanes Harvey and Irma
- 2020 CIGRE Special Reporter for PS2
- 2020 CIGRE Technical Council Award

Summary of Professional Experience

- 23 years of experience in various leadership roles in System Operations, Market Operations and Planning with MISO (Midcontinent Independent System Operator, Inc.), a large Regional Transmission Organization in the USA
- Current Position: Vice President, Operations

— SC C5 - Electricity markets and regulation

Yannick Phulpin

Summary of Experience within CIGRE

- SC C5 Secretary since 2018
- Member of the SC C5 Strategic Advisory Group since 2019
- Co-author of the Greenbook “Electricity Supply Systems of the Future” – 2020

Summary of Professional Experience

- 2021 - : EDF (FR) Head of power systems studies
- 2015-2021 : EDF (FR) Expert in European electricity markets & regulation
- 2011-2015 : EDF (FR) R&D Expert in power system operation and markets
- 2011 : INESCTEC (PT) Senior Expert in power system operation
- 2004-2010 : CentraleSupélec (FR) Assistant Professor in power systems
- 2005-2008 : Georgia Tech (USA) PhD in power system operation

— SC Chairs 2024 Composition

A1	Howard SEDDING (CA) – Utility and Consultant
A2	Pascal MUELLER (CH) - Utility
A3	Nicola GARIBOLDI (IT) - Manufacturer
B1	Geir Clasen (NO) - Manufacturer
B2	Pierre Van Dyke (CA) – Research Institute
B3	Mark McVey (US) - Utility
B4	Johanne HU (CA) - Consultant
B5	Volker LEITLOFF (FR) - TSO
C1	Antonio ILICETO (IT) – Utility and TSO
C2	Dr. Renuka CHATTERJEE (US) - TSO
C3	Maria MERCEDES Vasquez (ES) - Utility
C4	Marta Val Escudero (IE) - TSO
C5	Yannick PHULPIN (FR) - Utility
C6	Kurt Dedekind (ZA) - Utility
D1	Simon Suttton (UK) - Manufacturer
D2	Victor Tan (AU) - Consultant

Thumbnail credit: Hilch on iStock

CIGRE General Assembly 2024 Report

In accordance with the French Legislation on French Associations, every year in the first semester, CIGRE must hold an annual Ordinary General Assembly to approve the accounts of the previous year.

Article disponible en français ici.

The agenda of the Ordinary General Assembly was:

- **Resolution 1**: Approval of CIGRE annual 2023 accounts;
- **Resolution 2**: Approval of the allocation of CIGRE 2023 annual result;
- **Resolution 3**: Approval of the Administrative Council Membership for 2024-2026;
- **Resolution 4**: Approval of the membership fees for 2025-2026.

Extraordinary General Assembly resolution:

- **Resolution 5**: Approval of the revision of the statutes

The results of the Ordinary and Extraordinary General Assemblies are as follows:

Invited Members

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6715
Individual members I (incl. Honorary)

570
Individual Members II

924
Collective Members I

123
Collective Members II

12913
Equivalent member number

Participation

Individual members I (incl. Honorary)	757	11.27%
Individual members II	26	4.56%
Collective members I	50	5.41%
Collective members II	9	7.32%
Equivalent member number	1097	8.50%

Results (% Invited members)

Equivalent votes	**Yes**		**No**		**Abstention**	
	Number	%	Number	%	Number	%
Resolution 1	1058.5	8.20%	1	0.01%	37.5	0.29%
Resolution 2	1064.5	8.24%	2	0.02%	30.5	0.24%
Resolution 3	1073	8.31%	3	0.02%	21	0.16%
Resolution 4	1015	7.86%	34.5	0.27%	47.5	0.37%
Resolution 5	1013.5	7.85%	8.5	0.07%	75	0.58%

Results (% Expressed votes)

Equivalent votes	**Yes**		**No**		**Abstention**	
	Number	%	Number	%	Number	%
Resolution 1	1058.5	96.49%	1	0.09%	37.5	3.42%
Resolution 2	1064.5	97.04%	2	0.18%	30.5	2.78%
Resolution 3	1073	97.81%	3	0.27%	21	1.91%
Resolution 4	1015	92.53%	34.5	3.14%	47.5	4.33%
Resolution 5	1013.5	92.39%	8.5	0.77%	75	6.84%

The results were elaborated and checked under the scrutiny of CIGRE statutory auditor and CIGRE Central Office staff.

Résultats de l'Assemblée Générale CIGRE 2024

Conformément à la législation française sur les associations, le CIGRE doit tenir chaque année, au premier semestre, une assemblée générale ordinaire pour approuver les comptes de l'année précédente.

L'ordre du jour de l'Assemblée Générale Ordinaire était le suivant :

- **Resolution 1**: Approbation des comptes annuels 2023 du CIGRE ;
- **Resolution 2**: Approbation de l'affectation du résultat annuel de CIGRE 2023 ;
- **Resolution 3**: Approbation de la composition du Conseil d'Administration pour 2024-2026 ;
- **Resolution 4**: Approbation des cotisations des Membres pour 2025-2026.

Résolution de l'Assemblée Générale Extraordinaire :

- **Resolution 5**: Approbation de la résolution des statuts.

Les résultats de l'Assemblée Générale Ordinaire et Extraordinaire sont les suivants :

— Membres Invités

6715
Membres individuels I (y c. d'Honneur)

570
Membres individuels II

924
Membres Collectifs I

123
Membres Collectifs II

12913
Nombre de membres équivalents

— Participation

Membres individuels I (y c. d'Honneur)	757	11.27%
Membres individuels II	26	4.56%
Membres Collectifs I	50	5.41%
Membres Collectifs II	9	7.32%
Nombre de membres équivalents	1097	8.50%

— Résultats (% Membres invités)

Equivalent votes	Oui		Non		Abstention	
	Nombre	%	Nombre	%	Nombre	%
Résolution 1	1058.5	8.20%	1	0.01%	37.5	0.29%
Résolution 2	1064.5	8.24%	2	0.02%	30.5	0.24%
Résolution 3	1073	8.31%	3	0.02%	21	0.16%
Résolution 4	1015	7.86%	34.5	0.27%	47.5	0.37%
Résolution 5	1013.5	7.85%	8.5	0.07%	75	0.58%

Résultats (% Votes exprimés)

Votes équivalents	Oui		Non		Abstention	
	Nombre	%	Nombre	%	Nombre	%
Résolution 1	1058.5	96.49%	1	0.09%	37.5	3.42%
Résolution 2	1064.5	97.04%	2	0.18%	30.5	2.78%
Résolution 3	1073	97.81%	3	0.27%	21	1.91%
Résolution 4	1015	92.53%	34.5	3.14%	47.5	4.33%
Résolution 5	1013.5	92.39%	8.5	0.77%	75	6.84%

Les résultats ont été élaborés et vérifiés sous le contrôle du commissaire aux comptes du CIGRE et du personnel du Bureau Central du CIGRE.

CIGRE Medal 2024 Recipients

Every Session year, the "CIGRE Medal" is granted to maximum two members of CIGRE, in recognition of an oustanding contribution to the development of CIGRE (either administrative or technical achievement).

Mladen KEZUNOVIC

United States

In recognition of his outstanding contribution to the activities of the Association, as convener within Study Committee B5 Working Groups and serving as Special Reporter in national and international conferences since 1986. He also led several educational activities in "Protection & Automation".

Ja-Yoon KOO

South Korea

In recognition of his outstanding contribution to the activities of the Association, as Chairman of the Korean National Committee and an active member of CIGRE Administrative Council. He aligned with CIGRE's strategic goals to grow the next generation of CIGRE by fostering active engagement among Korea and other Asian countries.

CIGRE grants 7 kinds of distinctions in recognition of the services rendered by members. More information on **cigre.org**.

CIGRE Fellows 2024 Recipients

The "CIGRE Fellow" award is attributed for active participation in the activities of the technical work of the Study Committees and for providing a lead technical role in the Study Committees (maximum five awards every two years).

The Recipients 2024 are:

Jinliang HE

China

In acknowledgement of his active participation to the activities of the Association as convenor of C4.26, C4/A3.53 & C4.61 and for his contributions to lightning and overvoltage protection technologies of power systems.

Monique KRIEG-WEZELENBURG

Netherlands

In acknowledgement of her active participation to the activities of the Association on a national and international level, within Study Committee A1 as convener of WG A1.39 and Chair of the Advisory Group A1.01.

Pierre MIREBEAU

France

In acknowledgement of his active participation to the activities of the Association, as liaison member of IEC TC 20 to CIGRE B1 from 2014 to 2020 & as convener of Working Groups B1.25, B1.88, B1/B3.49, B1/B3.33.

Ulf MÖBERG

Sweden

In acknowledgement of his active participation to the activities of the Association as member of the Administrative Council from 2015 to 2022 and represented the Administrative Council at the Technical Council from 2017 to 2019.

Eduardo Marcio TEIXEIRA NERY

Brasil

In acknowledgement of his active participation in the activities of the Association since 1974. He held leadership positions in SC Protection and Automation, SC Future Systems, and the Brazilian National Committee.

CIGRE grants 7 kinds of distinctions in recognition of the services rendered by members. More information on **cigre.org**.

CIGRE Honorary Members 2024

Every Session year the "Honorary Member" award is granted to maximum ten members who have proven participation in CIGRE technical activities in a leadership role of CIGRE, and for members whose service of CIGRE has been judged exceptional.

The CIGRE Honorary Members are:

Ralf PIETSCH

Germany

In recognition of his outstanding contribution to the activities of the Association, as Chair of Study Committee D1 "Materials and emerging test techniques" from 2016 to 2022.

Alex CRUICKSHANK

Australia

In recognition of his outstanding contribution to the activities of the Association, as Chairman of Study Committee C5 "Electricity markets and regulation" from 2018 to 2024.

Jayme DARRIBA MACEDO

Brasil

In recognition of his outstanding contribution to the activities of the Association, as Chairman of Study Committee C2 "Power system operation and control" from 2020 to 2024.

Saulo José NASCIMENTO CISNEIROS

Brasil

In recognition of his outstanding contribution to the activities of the Association, as Special Reporter in the 2006 Paris Session, and Chair of the Brazilian National Committee and member of the Administrative Council from 2019 to 2023.

Goran SLIPAC

Croatia

In recognition of his outstanding contribution to the activities of the Association, as Chair of Croatian National Committee and member of the CIGRE Administrative Council since 2019.

Ivanka ATASANOVA-HOEHLEIN

Germany

In recognition of her outstanding contribution to the activities of the Association, within Study Committee D1 as a member of several Working Groups and convenor of the Tutorial Advisory Group since 2002.

Akihiko Yokoyama

Japan

In recognition of his outstanding contribution to the activities of the Association, as Chairman of Japan National Committee and as member of the Administrative Council and of the Steering Committee from 2014 to 2020.

Koji KAWAKITA

Japan

In recognition of his outstanding contribution to the activities of the Association, as Chairman of Study Committee B3 "Substations and electrical installations" from 2018 to 2024.

Rannveig LØKEN

Norway

In recognition of her outstanding contribution to the activities of the Association, as Chairman of Study Committee B5 "Protection and automation" from 2018 to 2024 and as the Chair of the Norwegian National Committee, member of the Administrative Council.

Nenad UZELAC

United States

In recognition of his outstanding contribution to the activities of the Association, as Chair of Study Committee A3 "Transmission and distribution equipment" from 2018 to 2024.

CIGRE grants 7 kinds of distinctions in recognition of the services rendered by members. More information on cigre.org.

CIGRE Women in Energy Award 2024

This award is intended to recognize active contribution to the activities of the Association, and to the promotion of Women in Energy within CIGRE at a national and global level.

The Recipients of WiE Award in 2024 are






Angélica DA COSTA OLIVEIRA ROCHA	Brasil
Jessica LAU	United States
Tara-Lee McARTHUR	Australia
Maja MUFTIĆ DEDOVIĆ	Bosnia & Herzegovia
Cécile ROZE	France
Sophia Abena TIJANI	Ghana

CIGRE grants 7 kinds of distinctions in recognition of the services rendered by members. More information on cigre.org.

Next Generation Network Significant Contribution Award 2024

This award is intended to recognize outstanding contributions of NGN members to CIGRE activities

The 2024 CIGRE Awards recipients are:





Phillip COUGHLAN	Australia
Aditie GARG	India
Bogdan LEU	Romania
Gen LI	Denmark
Laetitia MAUGAIN	France

CIGRE grants 7 kinds of distinctions in recognition of the services rendered by members. More information on cigre.org.

SC C1

Power system development and economics

By Antonio Iliceto, Chair, & Peter Roddy, Secretary

Overview

The Paris Agreement and climate neutrality goals for 2050 or thereabouts are driving energy transition planning in most countries worldwide. Renewable energy-dominated 2050 power systems, which serve e-mobility, heat pump and electrified industrial loads that are much higher than today, are already becoming routine study subjects in planning. Therefore, power system development, investment analysis and asset management, i.e., the Study Committee (SC) C1 scope, are at the heart of planning for and managing this enormous transition that the entire world must go through together, at the same time, with the same goals and challenges. As one example, because of this common global climate and energy transition challenge, cooperation in a global electricity network seems increasingly desirable, and SC C1 is finalising its highly successful first global grid feasibility study in a follow-up working group (WG C1.44).

Together with other SCs, SC C1 has described the role of system development and economics in the CIGRE Green Book future "Electricity Supply Systems of the Future". Uncertainties play a key role in planning for 2050 climate neutrality, concerning future cost reductions in photovoltaic cells, onshore and offshore wind energy, electric vehicles, batteries, electrolysers, UHV transmission technology, EHV cables, and HVDC systems. The only certainty is the world's climate neutrality goal to be attained: whatever scenarios we analyse and however strongly they diverge from each other over coming decades, the goal remains a climate-neutral energy system by mid-century. At least with respect to greenhouse gas emissions, the scenarios need to converge by about 2050 towards zero, even if the exact mix of locally and globally traded electricity, of electric vs. hydrogen-based transport, of thermal or hydrogen-based seasonal storage, of nuclear vs. renewable generation will differ by scenario.

The mission and 2023 progress of SC C1 is very much in line with this important role of power system development & economics for the world's climate neutrality goals, i.e., to support electricity system planners and asset managers worldwide in anticipating and successfully managing system changes to address emerging needs, opportunities and uncertainties while respecting multiple constraints, starting from reliability of supply and security of operations. SC C1 aims to provide particularly strong value with its recommendations on methods and descriptions of practices during the ongoing electricity system paradigm shift, brought about by the swift introduction of CO2-free renewable energy sources aided by rapid evolution in generation patterns and economics, and also by digitalisation, demand response, and in social, environmental and regulatory frameworks and expectations.

The specific perspective of SC C1 is to show how this paradigm shift can be managed while emphasising the integrating role of the transmission and distribution networks for the entire system which also includes generation, demand and storage. The system needs to be: planned to deal with the changes; built taking into account economic and public acceptance challenges; and well maintained. Making the most of the change implies supporting customers' and market participants' desire to implement innovative solutions and emphasising opportunities – along with risks – which the changes bring. It also implies anticipating, integrating and supporting progress. Opportunities for improvement relate to e.g., customer empowerment, increased penetration of distributed generation, closer transmission-distribution cooperation, new technologies, and efficiency and sustainability improvements.

The scope of SC C1 work generally includes descriptions of state-of-the-art applied methods and practices for system planning, economics, and asset management. To provide value to SC C1's target audience, the drivers of the ongoing paradigm shift need to also partly drive the methods and practices that SC C1 recommends: smart grids and demand-side response; energy-efficient electrification of heating and transport; generation cost structure changes (from Capex+Opex to Capex only), especially for renewable and variable distributed generation; energy storage and sector coupling options; sustainability policies (e.g. CO_2), as well as evolving regulation; and electricity market development and integration.

SC C1 Organisation

The four main areas covered by SC C1 are:

- Grid planning
- System economics and business investment
- Interconnections and Energy Sector Integration
- Asset management

Each area is covered by an C1 member acting as Advisor, and all of them are gathered in a Strategic Advisory Group (SAG), which supports the Chair, Antonio Iliceto (IT), together with the Secretary Peter Roddy (UK).

The main sections of this Annual Report describe how SC C1 and its Working Groups (WGs) have addressed in 2023 the effects and the management of the paradigm shifts in each area.

SC C1 now meets twice per year; once in person and one remotely:

- Remotely: 15 March 2023 (43 attendees)
- In-person at the Cairns Symposium: 7 September 2023 (22 in person plus 32who joined remotely)

At our Plenary Session in Cairns, attended by 90 delegates, 25 papers were presented over four sequences, each allowing ample time for discussion. C1 also delivered a well-received Tutorial on hydrogen, attended by over 100 delegates. The kick-off meeting on WG C1.50 (Global sustainable energy system coupling electricity and hydrogen) was also held, taking advantage of the large number of technical experts present in Cairns.

Following further refinement of their scope in Cairns, the Terms of Reference of the following WGs were agreed by Technical Council late 2023/early 2024:

- **WG C1/B4.49**: Offshore transmission planning
- **WG C1.50**: Global sustainable energy system coupling electricity and hydrogen.
- **WG C1.51**: The potential roles of energy storage in electric power systems
- **WG C1.52**: Virtual Power Plants: Role & deployment in large power systems' operation and planning

Strategic Plan

The C1 Strategic Plan was published in July 2021 and updated as part of the Cigre new Strategic Plan, catering for new trends of an "End-to-End system of systems", referring to the integration of energy sectors coupled with the electricity one (mobility, heating, hydrogen); also the website description of C1 activities and workplans is being updated accordingly. Key enhancements implemented since the last revision of the plan include:

- Advanced studies on economic assessment, business models, Cost-Benefit analysis, KPI definition, optimisation metrics in the changing and complex power system
- Introduction of Hydrogen topic in WGs and papers, as well as in Cigre TC & SAG Energy Transition
- Introduction of explicit Sector Coupling topics in WGs and papers
- Advanced studies on Global Grids
- Increased emphasis on Flexibility at planning stage
- Increased emphasis on Resilience, at system level
- Increased work on TSO-DSO coordination
- Introduction of explicit / dedicated actions on sustainability of future developments

Reports issued in 2023

- **Technical Brochure 910** (WG C1.43 - Business requirements for asset performance management)
- Two Technical Brochures submitted in 2023 were published in 2024 (see later)
- Future Connections: **Africa working group initiatives**
- Two high level reviews were carried out by C1 experts on papers submitted for publication on CSE (activity on-demand)
    - **A probabilistic approach to stability analysis for boundary transfer capability assessment**
    - Defining a typical set of requirements for Asset Analytics data platforms and tools aimed at supporting Asset Management decision making processes

— Grid Planning

Overview

As highlighted in the overview, system development of a secure, sustainable and affordable power system has become central to the world's climate neutrality goals. Planning methodologies and evaluation tools continue to evolve in order to live up to the enormous climate change challenge, the many associated uncertainties, but also the great opportunities and benefits which electrification can bring in both emerging and mature economies. Sector coupling with mobility, heating/cooling, smart cities, climate-neutral industries and hydrogen are becoming increasingly important to system planners and to SC C1. There are also institutional (e.g., transmission and distribution operator cooperation) and stakeholder involvement challenges that need to be overcome to deliver the network of the future.

Recently published work

JWG C1/C4.36 reviewed large city & metropolitan area power system development trends taking into account new generation, grid and information technologies. Metropolitan areas are increasing in size, population, and surface area, and are of increasing political and economic importance. The WG considered new technologies to replace ageing assets rather than replacing assets on a like-for-like basis. This includes cross industry coordination and cooperation considerations, taking into account power flows to and from the distribution network; application of innovative measurement devices; development of electric vehicles; active and reactive power flow control technologies and their increasing automation; economic drivers for large city & metropolitan area development; large scale HV and UHV cable route penetration; rooftop PV penetration etc. Criteria and principles for large cities power system operation and development were proposed. The TB (922) was published in January 2024.

TB 922 - Review of Large City & Metropolitan Area power system development trends taking into account new generation, grid and information technologies - JWG C1/C4.36

Work in progress

JWG C6/C1.42 addresses planning tools and methods for systems facing high levels of distributed energy resources. It identifies the impact of large deployments of distributed energy resources (DER) at the distribution level and repercussions on the transmission grid, as well as the tools, methods and benefits of aggregating DER at the distribution and transmission levels. The WG investigates the potential of co-simulation tools allowing the analysis of the impact of distribution-connected DER on the transmission grid considering static and dynamic aspects. It identifies and defines the planning and operation tools required at the distribution and at the transmission levels. The WG surveys distribution and transmission utilities for present practices and additional needs focusing on already known techniques, tools, methods and data for valuing DER and customer flexibility, practices and techniques in developing scenarios, both for transmission and for distribution (where e-mobility presents large uncertainties). The TB is scheduled for publication in 2024.

The aim of **WG C1.47** (Energy Sectors Integration and impact on power grids) is to address both the technical, business, economic and regulatory issues for the developing of concrete use cases of energy systems coupling, and assess state-of-the-art research in different countries around the world. The WG will also bridge the gap between academy research and industry on the ESI to reveal the key issues that should be addressed in the future. The TB is scheduled for publication in 2024.

— System Economics & Investment

Overview

The work in this area addresses uncertainties and increasing penetration of renewable energy from the investment viewpoint. Business management involves investment decisions in all aspects of the system, including generation, transmission, distribution, storage, and demand with its flexibility. It complements grid planning with broader analyses of whether and how investments can actually be made, and infrastructure be built, in conjunction with private investors. More specifically, the work in this area describes how investment drivers and decision-making processes are changing, how to communicate with the many relevant stakeholders, and how transmission and distribution investments relate to each other.

Recently published work

JWG C1/C6/CIRED.37 describes optimal transmission and distribution investment decisions under growing uncertainty. Transmission and distribution investment decisions resulting from a planning process require new approaches to deal with growing uncertainties on many parameters incl. new market designs, high penetrations of renewable energy, demand growth and so on. The WG summarises learnings from several prior SC C1 and C6 WGs. It then investigated how transmission and distribution planning scenarios are consistently used to ensure holistic investment decisions are made by both TSOs and DSOs. This work was showcased at the e-Session in a joint workshop with C1.39. The TB (923) was published in January 2024.

TB 923 - Optimal transmission and distribution investment decisions under increasing energy scenario uncertainty - JWG C1/C6.37/CIRED

Work in progress

WG C1.23 describes transmission investment decision points and trees, by defining target networks at the end of a specified planning period to meet all the necessary criteria and requirements. To account for uncertainty, multiple potential target networks can be generated which further require a number of decision trees. This WG established if and how target networks are being used, and if they are used to generate decision trees and key decision points. In particular, it investigated processes used to determine the timelines of the decision points in the different countries and the methods used. The report has been reviewed by C1 members and awaits approval by the Chair; the Technical Brochure is due to be published ahead of the Paris Session.

WG C1.48 - the main objectives are to: (a) collect and analyse numerous studies related to technical and economic aspects of hydrogen supply chain and use, as well as supporting national policies and implementation strategies; (b) present different use cases in industry, transport, heating sectors and as energy storage and other system services including renewable electric energy supply needs, land and water requirements, and (c) recommend technology solutions for grid code compliance and to enable market-based provision of various local and system wide flexibility services by large scale electrolyser plants. Liaison experts from SC C6, B1 and C5 have been invited. The following topics will be explored and elaborated within the working group: Overview of hydrogen supply chain; Forecasting hydrogen demand and a corresponding amount of renewable electric energy supply and installed capacity; Identification and analysis of specific use cases in terms of economic value of green hydrogen; Review of technologies for scaling up electrolyser plant capacity; Evaluate a future role of green hydrogen and its derivatives; Identify region/scenario dependent optimal mix of interconnectors, storage including hydrogen and demand response; and, Overview of governmental policies and implementation strategies in different regions. The WG delivered a Tutorial at Cairns Symposium in 2023 and a further Tutorial, joint with C5, will be delivered at the Paris Session ('Role of Green H2 in the Energy Transition and its impacts across the value chain'). The TB is scheduled for publication in 2024.

Based on a thorough analysis of the outputs from WG C1.44 and WG C1.48, the main objective of **WG C1.50** is to perform a quantitative pre-feasibility study of a global power system including electricity and green hydrogen by 2050. This pre-feasibility study is exploring the economic costs and benefits of: interactions between electricity and hydrogen supply chain including production, conversion, transport, and storage; and, of electricity and H2 storage and transport between continents. Ultimately, the WG will summarise the results of its analyses, including recommendations on how and where the most important obstacles to the development of inter-continental electricity hydrogen mix power system can be addressed.

The introduction of Virtual Power Plants (VPP) can help to reinforce the flexibility and resilience of large power systems. Since inception, VPPs have gained interest worldwide, and different jurisdictions have developed their own practices, mechanisms, organization modes, and policies of VPPs; it is, therefore, important to learn from and exchange ideas with each other. **WG C1.52** aims to analyse and document the technologies, models and practices of VPPs. In addition, the influencing mechanism, economic efficiency and benefits of VPPs on power system operation and planning will be addressed. It will also compare the operation of VPPs with traditional aggregators in electricity markets.

_ Energy System Developments and Interconnections

Overview

This area of SC C1 work examines the increasing interdependence and integration faced by system developers, on top of the usual complexity already implicit in grid planning, which arises from the power grid being at the centre of the energy transition towards the climate-neutral energy system, both as a fundamental enabler and as the most impacted element. The new dimensions of system development tackled in this C1 work area are:

- higher interconnection rates between countries and systems, up to continental level and eventually to a global grid ("horizontal" interconnections); besides the traditional hurdles of realising large technical infrastructures, these cross-border links spanning several jurisdictions face further critical issues in different authorisation patterns and market regulations, assessing and allocating costs and benefits, negotiating partners' and investors' roles, and managing international implementation;
- increasing interdependence of transmission and distribution grids, which means that going beyond issues like DER, active distribution grids, radical modification of flow patterns, consumer empowerment, energy communities, planners need to look at the end-to-end electricity system, leading eventually up to a joint transmission and distribution grid planning process ("Vertical" integration); this requires also an organisational and cultural change, since one TSO interfaces often with several or many DSOs, who are themselves undergoing a deep process of modernising their practices on local system development and of evolving towards smart grid operation;
- starting integration with other energy systems ("Sector Coupling"): to achieve global climate change targets, electrification of transport, heating/cooling and industry, fed by CO2-free power generation is a very effective route; therefore several workstreams are starting, in order to assess and capture the benefits of a common planning and a synergistic operation of various energy carriers (including gases and hydrogen), exploiting their respective capacities and complementarities in storing and transporting bulk energy.

Work in progress

WG C1.33, convened by the C1 Chair, investigates interface and allocation issues in multi-party and/or cross-jurisdiction interconnections: it addresses the origination and design phase of such projects, focusing on the specific issues arising from the different rules/practices/investors' policies, to be considered at early stage for the sake of project success. The work analyses real cases to extract the drivers, rationale and criteria of such issues, as well as the solutions adopted; it also describes the business model designed for realising the interconnection project according to the specific needs, in order to infer useful guidelines for project of high complexity. Material and contents for TB has been gathered, and new fresh support from prospective CIGRE young members is helping to accomplish the drafting exercise within 2024.

WG C1.44 builds on the highly successful work of WG C1.35's global grid feasibility study, to analyse more deeply the impact of large and cheaper storage and the effect of demand response as further elements to be co-optimised together with investments in transmission and in generation, and to begin addressing the necessary trading rules for a global grid. The report has been reviewed by C1 members and awaits approval by the Chair; the Technical Brochure is due to be published in July 2024.

The scope of **WG C1.45** is twofold:

- Identification of the benefits indicators (economic, social, technical, environmental) associated with an interconnection project. In identifying benefit indicators, the various market and regulatory frameworks worldwide will be considered
- Procedure to quantify the benefit indicators and how to combine them in consistent way when they have different metrics.

The focus is on interconnection reinforcements or on building new interconnections between isolated areas, but, in general, the suggested solution(s) can also be applied to inter-area transmission reinforcements within the same jurisdiction. The concept of "interconnections" does not necessary refer to a cross-border infrastructure. The TB is scheduled for publication in 2024.

JWG C1/B4.49 aims to build on the findings of previous and ongoing working groups and projects, drawing together key issues and international experience, to provide insight into and guidelines for how offshore transmission grids can be planned, developed, deployed and operated, taking into account the purpose to be fulfilled, the limits of onshore AC grids, limited planning horizons, and technology characteristics. This will involve: reviewing existing and planned offshore transmission systems/concepts and drivers; discussing offshore transmission purposes & multi-purpose infrastructure and associated; providing an overview of offshore transmission technologies & their range of application; discussing basic offshore grid topologies, functions & associated performance; analysing the interface with onshore grids & associated impact on offshore grid design; researching and discussing offshore grid growth models; providing an overview of applicable governance & ownership frameworks and their potential impact on offshore grid design and operation; researching and discussing offshore grid planning considerations; and , exploring necessity and models for coordination of offshore grid planning.

Successfully decarbonizing the electric power system will need energy storage for a range of roles, in particular short term for grid operation and long term for system balancing. Some roles for storage are clear while others lie in the future. **WG C1.51** aims to quickly establish a reference of state-of-the-art defining the range of possibilities for energy storage in electric power systems. The working group is investigating and will report on: types of energy storage; energy storage uses in time and space; storage already available and under development; technical functions of energy storage; future needs for implementing energy storage; delineating the generation, transmission, distribution, and load management functions of energy storage; technical solutions that can reduce the need for storage; techno-economic benchmark of different storage solutions; matching storage solutions with system needs/optimal mix; and, role of storages in the flexibility mix of future energy systems.

— Asset Management

Overview

The work in this area addresses emerging issues in asset management related to operational, tactical and strategic aspects, in a context of increasing sophistication of risk and economic modelling and increasing convergence of asset management and planning data and methods. At present there are two WGs.

JWG C1/C4.46 aims to find break-even conditions between preventive, containment and restoration measures and propose guidelines for determining an optimal mix of resilience measures from diverse techniques. The proposed scope will be delivered in three distinct steps: (a) establishing current practices and standards (b) development of a gap analysis and (c) propose opportunities for improving existing planning methods and standards. Major tasks within the stepped delivery approach for the proposed WG include: Build on work done by prior WGs on power system resilience topics; Adapt and document suitable metrics to define power system resilience for interconnected electrical power networks; Review existing planning methods and standards used for power system infrastructure investments; Consider the resilience of power system equipment in view of changing climatic conditions; Investigate the most used system restart techniques; Investigate the concept of flexible grid design; Promote technical papers, technical panel sessions, and workshops on power system resilience planning for a decarbonizing energy sector. Liaison experts from SC C5 have been invited to contribute. The TB is scheduled for publication in 2024.

The intent of **JWG B2/C1.86** (Approach for Asset Management of Overhead Transmission Lines) is to recommend a consistent set of requirements for establishing AM for OHTLs, including requirements for an Asset Performance Management (APM) platform capable of extracting the data from a multitude of data sources, have functionality to process these data and generate the required information, and provide users with required outputs. The objective of the WG C1.43 (TB 910, published in 2023) is to assist utilities in identifying overall requirements for such a platform without specifically defining requirements at the asset category level. This JWG will develop a set of APM requirements specifically for OHTLs. The TB is scheduled for publication in 2024.

CIGRE active Working Groups / Call for experts

— SC C1 contributions to Technical Council

Participation at CIGRE's Technical Council has been focused on the development of new way of working in pandemic era, which has particularly affected the work of a world-wide organisation like CIGRE. Meetings, Workshop and Tutorials have suddenly switched to web-based tools, with challenging time-zones issues and lack of the networking, which is one fundamental ingredient of professional exchanges at the basis of Cigre workstyle. General Sessions have been held virtual (2020) or in broadcast style (2021), with ever challenging tools and engagements from many members. For the 2022 Session and all subsequent Symposia and Sessions, ConfTool has been utilised, and fine-tuned with contributions also from SC C1 to make it easier and more trackable the management of the scientific papers and their revision/approval process. The new peer revision process implies much higher engagement of SC members; for this reason and for fostering the creation of new WGs, SC C1 is in favour of enlarging the global number of Committee members, and will endeavour to engage them in CIGRE voluntary activities.

Consistent with its system planning-related mission, the SC C1 Chair Antonio Iliceto contributed, within the CIGRE Technical Council, in founding a Forum on Hydrogen and holding/organising 3 internal webinars, last one with the testimonial of ENTSO-E; in this thread, C1 Chair hold also a similar joint webinar for GO15. Recently, this Forum has enlarged is scope to Energy Transition, where C1 still keeps a substantial contribution role.

C1 Chair is the CIGRE liaison officer in IEC ACTAD (Advisory Committee on T&D within the IEC organisation), in which he is co-Convenor of a specific Task Force on structured exchanges on respective workplans between the two organisations. At yearly meetings (last one in New York June 2024, hosted by IEEE) he has proposed a new structure and memberships supporting the set-up for achieving the assigned goal in an efficient manner. C1 Chair is proposing to extend the same task also to IEEE, taking advantage of a new liaison officer from their side.

Regarding IEEE, after a joint meeting in Chicago, C1 is participating in a new collaboration Group, which is set up through a MoU with IEEE-PES, on which C1 Chair is also a regular co-author of technical articles; a first joint endeavour, with C1 contributions, shall be a paper on RES penetration and its consequences on power grids.

A Memorandum of Understanding (MoU) has been signed through C1 leadership with ETIP SNET (European Technology and Innovation Platform for Smart for Smart Network Energy Transition); the MoU covers cross publicisation of respective deliverables and a space in CIGRE annual events / ETIP SNET Regional Workshops.

SC C1 has a standing role in some cooperation between Technical Council and GO15, GEIDCO, IEA, World Energy Forum, Desertec Energy, Hydrogen Europe and Hydrogen MENA.

Antonio Iliceto, C1 Chair, is also the co-Convenor of the WG Initiative for Africa; this WG reports directly to the Technical Council and is in collaboration with World Bank. This initiative aims at disseminating CIGRE knowledge base and support their deployment also for rural electrification in Africa; another aim is to establish new regional Cigre Committees in the main African regions. West Africa has been established already, East Africa is next in the pipeline. The launch of Cigre Academy took place on 28 & 29 July 2023 in Tanzania and was followed by a second training program in April 2024, hosted by Dar es Salaam University, in collaboration with C6 and B3; the two Chairs attended in person and presented in a detailed way their recent and relevant work, with contributions also from C1. The topics are particularly relevant for African audience. The in-person workshops were also attended on-line by other students, scholars and utilities' engineers from the regional African footprint. The workshop was enriched with ample Q&A sessions, with facilitated networking, and it was the occasion to float, with new volunteers, the idea of setting up the East African National Committee. The workshop was opened with a patronage message by CIGRE Secretary General.

Under the guidance of Keith Bell from C1, the CIGRE policy of Tutorials has not only been updated but also widely applied in the Paris Sessions and in Symposia.

Dissemination and Keynote speeches

To disseminate the activities of CIGRE, Chair and members from SC C1 have participated and presented Keynote speeches during:

- **Symposium in Muscat**, Oman (March 2023) organised by GCC
- Tanzania (July 2023): CIGRE Capacity Building for Africa program launch

Future meetings and events

- Paris Session 2024
- Montreal, September 2025
- Jerusalem, Spring 2027 (exact date to be confirmed)

Contact

Contact of the Chair and/or the Secretary of the Study Committee →

SC C2

Power system operation and control

By Jayme Darriba Macedo, Chair, & Flavio Alves, Secretary

— Introduction

To summarize the activities and feelings of a CIGRE Study Committee during an odd year could be to focus the reports on the expectations of preparing for another CIGRE Session which, in this case, will only take place in August 2024.

But these days are definitely different!

The biggest feeling is that Power System Operation has definitely joined the highly dynamic group. It has gone from being an area where the experience accumulated over dozens of years of work is decisive for today's performance and results. Currently, it is better to look at the lessons learned from the last five or ten years than to return to old practices that have been solidified over time. What was known 30 or 20 years ago has lost its application today, not completely, of course.

We still need the experience, of course. In particular, that of professionals who experience this dynamism within Control Rooms or preparing real-time actions in advance. But the speed of change, more than ever, is requiring constant and, if possible, quick updating of knowledge.

Perhaps it would be repetitive to quote:

- the insertion of distributed energy resources, especially wind and photovoltaic resources;
- the new challenges introduced by new categories of equipment and, in this case, highlighting the performance of Inverter Based Resources about whom we learn a lot every day;
- the difficulty of forecasting the primary energy sources (wind and sun), bringing uncertainty every minute in supplying instantaneous demand;
- uncertainty regarding the behaviour of demand itself, hour-by-hour, where variability is consolidated between moments in which distributed resources cause a large reduction and others in which the reduction of these resources generates an intense need for supply from the bulk system;
- the insertion of storage resources with fast application and the challenge associated with deciding on the best way to use and charge them;
- the need for Flexibility that previously seemed limited by equipment performance and today brings other uncertainties that begin in the fuel supply chain and reach the need to establish the best possible regulation;
- new demands arising from the behaviours of social groups, which are increasingly unpredictable;
- new demands that arise as a consequence of the ertainty that environmental concerns have absolute priority;

And this list can be interrupted here as it already contains enough content to define the complexity that took over the Power System Operation and Control actions.

But it is the decision of the people who make up our Study Committee C2 to not stop generating and disseminating new knowledge that translates into the practical actions carried out and ongoing that gives life to these very successful movements of the CIGRE community.

Therefore, we can start with the highlight of the second half of 2023, which was, without a doubt, the Cairns International Symposium 2023.

There was our SC.C2, not just as a participant, but in the role of co-leader with SC.C5.

And there was no doubt about the success of the symposium due to the excellent organization, the outstanding technical content of the programming events, the sponsorship obtained, the number of participants and the impressions gathered from those who were present.

And for our SC.C2, we were assured of great success not only in the general role of co-leading the event, but also, specifically, in the opportunities to carry out:

- Technical discussion groups on 29 papers presented divided into six sessions, in each of which we had more than 100 people in the audience, of a very high technical level;
- Two Tutorials on Technical Brochures published as a result of studies by Working Groups that recently ended their activities, always in rooms whose capacity was exceeded by the number of participants;
- Hybrid technical meeting of the community of SC.C2 National Representatives;
- Representation during the CIGRE Technical Council Meeting;
- Representation during the meeting on the CIGRE Initiative for Africa;
- Organization and preparation of the Symposium Proceedings.

Truly an event that made us very proud to be a fundamental part of its realization.

But, regarding events, it is impossible not to report the intense preparation movement for CIGRE Session 2024, where, from our SC.C2 we have:

- Due to the work of the Special Reporters, review of synopses culminating in the approval of 62 full Papers to be produced for the CIGRE Session;
- After the work of our Reviewers and Special Reporters, review and approval of the 55 full papers that will integrate the technical program (Group Discussion Meeting and Poster Session) of the CIGRE Session;
- Collection and evaluation of case suggestions to be presented at the C2/C5 Large Disturbances Workshop during the event with assembly of the complete Workshop program;
- Selection and definition of the Tutorial to be presented by SC.C2 in person;
- General organization of SC.C2 activities during the CIGRE Session.

In conclusion, everything that is necessary to generate great expectations among those interested in Power System Operation and Control who will be in Paris participating in the event.

We also highlight the progress of our Working Groups. We ended 2023 with four Working Groups and two Joint Working Groups under our leadership in progress. During the first half of 2024, two of these groups closed their activities, but, in compensation, a new Working Group and a new Joint Working Group under our coordination begin their activities during this period. The dynamism and productivity of this process remain.

Furthermore, we actively participate in the production and review of technical articles published in the different CIGRE vehicles, through the invaluable collaboration of the members of our Study Committee.

Our Chair remains in the activities of the CIGRE Technical Council with in-person participation in meetings in Australia (September 2023) and Brazil (April 2024) and virtual participation in several events of this group throughout the period in question.

And we purposely left this brief report on the activities of the SC.C2 Chair until last to anticipate the announcement of excellent expectations for the future of our Study Committee as we will have, from September 2024, a new leader in our Study Committee bringing new experiences and solutions for our ever-renewing technical challenges.

May the shine of the work of our SC.C2 community be increasingly intense, always renewing the excitement to face our challenges, the true energy that moves us!

— SC C2 Mission and Scope

The scope of the SC C2 covers the technical, human resource and institutional aspects and conditions for a secure and economic system operation of power systems in a way that is in compliance with requirements for network security, against system disintegration, equipment damages and human injuries, and security of electricity supply.

Unbiased and high-quality knowledge dissemination to the power systems community by CIGRE Study Committees is a strong pillar for the development and performance of power systems, especially in the increasingly integrated environment. This applies not only to current but also to future power systems. SC C2 therefore needs to understand, use and integrate results from other Study Committees to assure that technical concepts can be applied in real-time in various contexts and implemented by the System Operators. An area which is unique for C2 is however the dependence on good performance of human resources in performing operational planning and real-time system operation. In these respects, SC C2 embraces a wide range of competence areas and interfaces to other disciplines.

The mission of SC C2 can be summarised in the following four points:

1. To facilitate and promote knowledge dissemination and worldwide collaboration in the field of system operation and control, providing adequate conditions for progress of engineering.
2. To facilitate unbiased technical information exchange, integrating solutions and recommendations for system operations issues and problems. These first two points are achieved among others by the publication of Technical Brochures and

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papers, delivering tutorials, and participating in conferences, symposia and colloquia.
3. To prepare for the foreseen future challenges by integrating and consolidating available knowledge and taking into account the usage of new and proven technologies. For example, the joint effort of several Study Committees in establishing Joint Working Groups, where different expertise and knowledge is combined, as well as in writing multi-disciplinary Reference Papers.
4. To engage and encourage young members to increase their involvement in the SC activities. By integrating them into Working Groups, a bridge between the young experts and experienced members can be built. SC C2 aims to connect, when possible, a young member to a mentor from the same SC and NC. This gives the opportunity to support the young member's development in a supervised way.

Structure

An overview of the structure of SC C2 is given in Figure 1. The SC has 27 regular members and 12 observer members, 8 active Working Groups of which 3 are Joint Working Groups with other CIGRE SCs, and 3 Advisory Groups.

The Strategic Advisory Group, consisting of the SC Chair, Secretary and other SC C2 experts, deals with SC strategy and updates the scope of the Technical Directions. The Publication Advisory Group is responsible for the revision of synopses and papers for CIGRE activities where SC C2 plays a role. The Tutorial Advisory Group (TAG) coordinates the development, planning, quality assurance and delivery of tutorials for conferences, symposia, colloquia and webinars. There are around 241 experts from 46 countries actively involved in SC C2 activities.

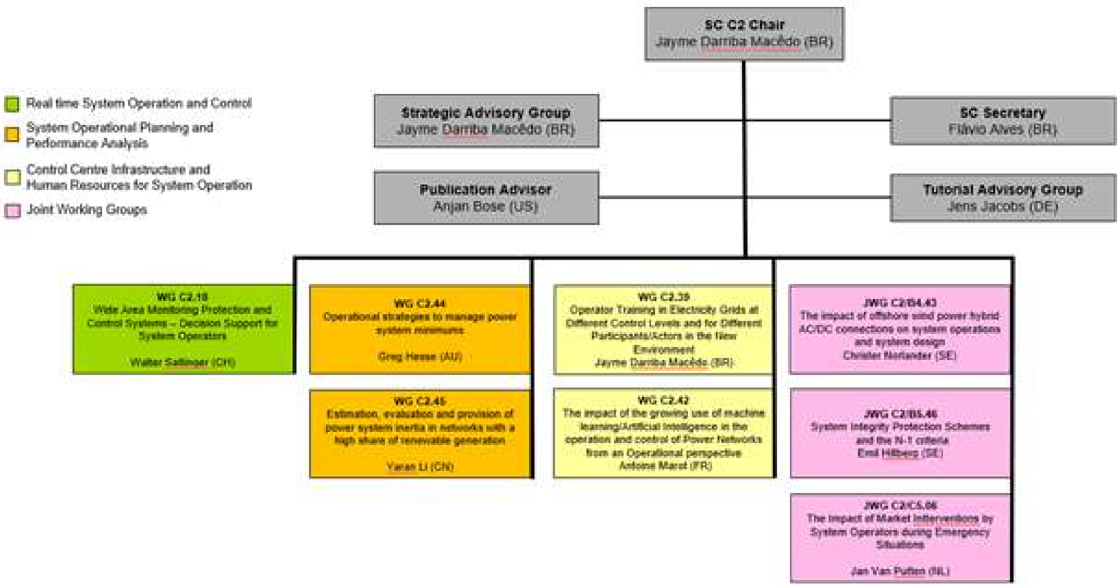

Figure 1 – Study Committee C2 Structure

Figure 2 gives an overview of the geographical distribution of SC C2 members.

Figure 2 - Geographical Distribution of SC C2 Members

— Main technical directions

SC C2 has defined three Technical Directions (TD) to address important emerging factors that will influence and define new requirements on the System Operation performance.

TD 1: Real-time System Operation and Control

- Wide area control, supervision and increased coordination: integration of regional and national grids into large control areas
- Operation and control of new technologies and system protection schemes
- Increased power system controllability, observability, flexibility and exchange of information, both at transmission and distribution level: e.g. voltage control, frequency control
- Interaction between market mechanisms and power system operation, e.g. ancillary services and congestion management
- Operational real-time security and risk assessment
- Maintaining Security of Supply, Emergency control and restoration procedures and tools
- Information and data exchange in real-time operation

The Working Group C2.18 and the Joint Working Group C2/C5.06 address topics in this TD 1.

TD 2: System Operational Planning and Performance Analysis

- Impact on system operation from new generation mix, storage and changes in electrical load behaviour
- Close to real-time operation, crucial for a successful and secure real-time operation, performed both by operational planners and control room operators
- Security assessment in Operational Planning, including coordinated activities

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- Assessment of monitoring, control and protection functionalities, including development of new operational strategies
- Emerging Operational Issues for Transmission and Distribution Interaction
- Impact assessment on integration of new technologies
- Blackout integral analysis, defence plans, resilience schemes and restoration strategy considering the evolving environment
- Reliability, network security principles and generation and transmission adequacy
- Operational requirements in Grid Codes
- Information and data exchange in the operational planning timeframes

Working Groups C2.44 and C2.45 and the Joint Working Groups C2/B4.43 and C2/B5.46 address topics in this TD 2.

TD 3: Control Centre Infrastructure and Human Resources for System Operation

- Knowledge management and Operator training
- Operator training simulator and other training tools
- Control Centres processes, methods, tools and organisation development
- Tools for decision support and situational awareness
- Integration and exchange of information in system operations and data management
- EMS/SCADA systems, specifications and experiences
- WAMS system requirements and their integration within CC
- Control Centre reliability and resilience
- Information, cyber-security and other vulnerability aspects on control centres

Working Groups C2.39 and C2.42 address topics in TD 3.

However, it is relevant to point out that some of the Working Groups touch upon more than one technical direction.

— Working Groups Report

Below a short update of the working groups active in 2023-2024 is provided.

WG C2.18: Wide Area Monitoring Protection and Control Systems – Decision Support for System Operators

In late 2023 the working group published Technical Brochure 917 “Wide Area Monitoring Protection and Control Systems - Decision Support for System Operators”, which complements the work documented in the TB 750 titled “Wide Area Monitoring Systems – Support for Control Room Applications” while describing additional developments done in the meantime in the field as well as describing more details with respect of Wide Area Monitoring including Control and Protection application tools.

The Technical Brochure is based on a pragmatic approach, starting from the different physical phenomena that require a decision by the control room staff, describing it from a scientific perspective and discussing the solutions applied by the System

Operators in real life. The document describes also the state of art of on/offline applications and tools, focusing on the interaction and integration with EMS/SCADA, including the evolving analytics/AI promising perpesctives. An important focus is dedicated to the WAM/WAMPAC system performances and cybersecurity constraints with aim to support the reader in the right selection of the proper architecture and design, considering also communication, synchronization and protocols issues.

The Working Group will deliver the tutorial "Wide Area Monitoring Protection and Control Systems - Decision Support for System Operators" during the Paris Session 2024 and will be disbanded thereafter.

WG C2.44: Operational Strategies to Manage Power System Minimum Operating Conditions

The WG was approved by the Technical Council in June 2023 and commenced its work in October 2023, following the Cairns Symposium. The WG currently comprises 22 members from 16 countries and includes 4 female members and 2 NGN members. Members come from organisation across the industry spectrum, including ISOs, TSOs, DSOs, academia and consulting.

The WG is currently holding on-line meetings every 4 to 5 weeks, with alternating times to suit members different time zones. The WG plans to meet face-to-face in conjunction with the Paris Session in late August 2024 and again in May 2025 in conjunction with the Trondheim Symposium.

The objectives of the WG are to:

- identify and articulate the key risks to the power system that arise from the emergence of minimum operating conditions such as minimum inertia, minimum system strength and minimum operational demand;
- identify gaps and improve the understanding of these minimum operating conditions; and
- propose remedial actions and strategies to manage power system operation during minimum operating conditions.

The WG has adopted an approach that separates the question of what characterises power system minimum operating conditions from the question of what consequences might flow from those minimum operating conditions. Once answers to these questions are understood we turn to the questions are how power system operators can know when potentially dangerous minimum operating conditions are present or approaching, and what strategies can be adopted to mitigate the consequences of those minimum operating conditions.

This model of the WG approach is illustrated in Figure 3.

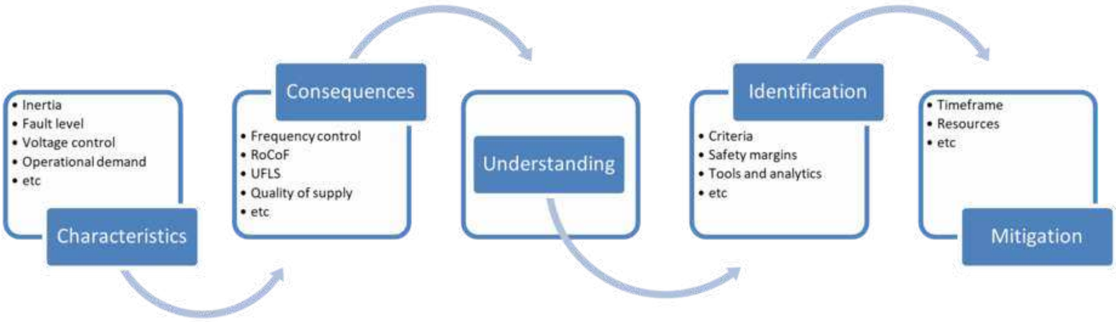

Figure 3 – Model of the Working Group approach used by WG C2.44

A survey has been developed based on the above model and will provide valuable data on the current "state of play" with respect to this subject in utilities around the world. The goal remains to publish a Technical Brochure in late 2025.

WG C2.45: Estimation, evaluation and provision of power system inertia in networks with a high share of renewable generation

The WG was approved by the Technical Council in November 2023 and had the kick-off meeting in April 2024. The WG currently comprises 26 members from 21 countries and includes 2 female members and 6 NGN members. The WG plans to meet face-to-face in conjunction with the Paris Session in late August 2024 and again in May 2025 in conjunction with the Trondheim Symposium.

The WG focus is specifically on the underlying principle of inertia response for networks with a high penetration of renewables and the effective scheme of managing the inertia from the perspective of interconnected power systems. Therefore, the purpose of this working group is to investigate new definitions for power system inertia in the current context, and then identify the methodologies and requirements to estimate, assess and improve the power system inertia, which ultimately facilitates the maintenance of frequency stability throughout the power system transformation. The WG also serve as a platform for the dissemination of innovative technologies, on-site experiences and knowledge sharing.

The WG has developed its working plan and assigned the sub-group leaders. A survey is under preparation and expected to be released in September 2024. The Technical Brochure is forecasted to be ready by Q4 2026.

WG C2.39: Operator Training in Electricity Grids at Different Control Levels and for Different Participants, Actors in the New Environment

The Working Group began its activities in September 2018, went through the difficulties of evolving the work during the 2020/2021 pandemic and, in the last year, focused its activities on preparing the final document that presents the conclusions of the work. It is the only Working Group that focuses studies on the training and technical updating of systems operation teams. Through research and subsequent

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analysis, it established the current situation and future possibilities of training processes and the tools used, especially Operator Training Simulators (OTS), considering the changes introduced by the energy transition. The final result of the work is presented in Technical Brochure 925, published through e-CIGRE in March 2024. With the presentation of the webinar on this content on July 16, 2024, the work is completed, and the Working Group will be disbanded thereafter.

WG C2.42: The impact of the growing use of ML-AI in the operation and control of power networks from an operational perspective

The WG focused on finalizing the Technical Brochure (expected to be submitted for approval in Q3 2024) organized in six chapters covering the following topics:

- Fundamentals of AI and ML
    - Taxonomy for AI in systems operations; relevance of generative AI and foundational models in system operation
- Applications and case studies
    - Overview of the current solutions from six TSOs for system operations and the main findings derived from a survey conducted within the AI/ML industrial ecosystem focused on power systems operation, highlighting various applications and use cases. Moreover, it delves into the specifics of six different use cases (see Figure 4) that range from operational planning to real-time operation scenarios.

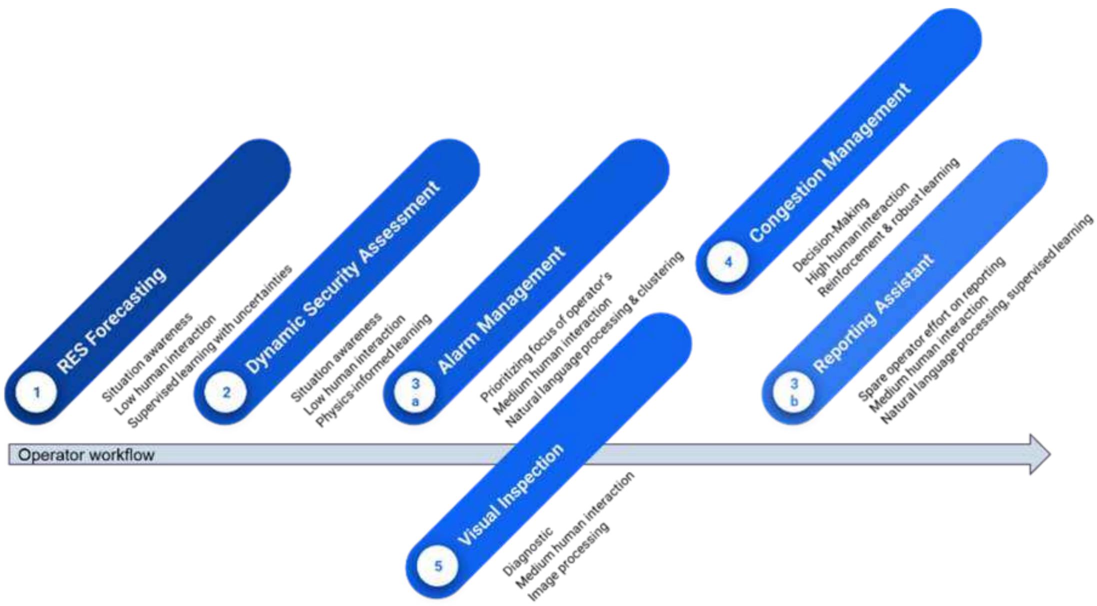

Figure 4 - Operator workflow and the distribution of the selected use cases

- Benefits of AI for flexible operations power systems
    - Discusses how AI-driven transformations culminate in the provision of enhanced flexibility (illustrated by Figure 5) for the power system operator and consequentially with the outreach on the grid reliability, efficiency, and resilience.

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Figure 5 - Flexible operator of the power system

- Challenges and risks
  - Analyze the key aspects of emerging AI regulations around the globe that will impact ML applications in the energy sector. A generic framework for assessing the regulatory risk for AI systems and exemplifying its potential application on a few selected use cases in TSO business.
- Implementation AI in TSOs
  - How to implement AI through a project in an organization and pitfalls; AI maturity levels (TRLs) and how to break them down and define them; culture needed for development, organizational perspective, and technical requirements.

Together with the Technical Brochure, the WG plans to deliver a tutorial in 4Q 2024 in Paris, supported by CIGRE France.

The Working Group has 28 experts (R&D / Academia from the AI community and power systems, system operators, industry, regulators, and policymakers for digitalization) from 19 different countries.

JWG C2/B4.43: The impact of Offshore Wind Power hybrid AC/DC connections on System Operations and System design

The JWG C2/B4.43 is made up of experts, utility representatives, consultants, suppliers/manufacturers and academics, from 17 countries. The work on the ToR started up early 2022 by TenneT NL and Svk SE, with Approval by Technical Council Chairman on July 7th of July. The start-up meeting was held during the 2022 Paris Session and the work has been based on the ToR and also on the participants' insights, experiences and projection of what the future could look like. Final TB delivery be link to CIGRE International Symposium in Trondheim Norway 12-15th of May 2025, in time for approval from C2 and B4 Chairs & by CIGRE Secretariat handled.

Specific subjects the JWG now additionally focus on in bullets below:

- TSO role – Connections to Grid on land.
- Operations of multi-terminal, multi vendors, model requirements & design.

- Collaborations by system operators – Investors and developers in design with the operational perspectives based on political & regulatory framework, considering global differences.
- Grid support due to weather dependencies, frequency & voltage profiles etc. brings focus on developments on OWP and equipment's linked to it – AC/DC and design.
- Market related areas are of course of huge impacts for decision on investments.
- Maintenance and outages with huge impact in the ongoing energy transition as together acceleration of electrifying society, are crucial challenge, Environmental aspects differ but part of judgements to be handled based on facts.
- DC breakers to be follow-up how developments take further steps forward.

JWG C2/B5.46: System Integrity Protection Schemes and the N-1 criteria

The WG was approved by the Technical Council in June 2024 and is presently accepting nominations. The kick off meeting will take place during the Paris Session 2024, in August 2024.

JWG C2/C5.06: The Impact of Electricity Market Interventions by System Operators during Emergency Situations

The JWG started its work in October 2021 and is finalizing it during summer 2024, the Technical Brochure will be delivered and it is expected it will be published later this year. Around the moment of publication a webinar will be organised.

The work focused on what happens when system operators intervene in markets in order to handle emergency situations in the power system. As input for the work the JWG relied for a large extend on the responses received following a survey that was launched. This survey responses gave interesting insights in the different approaches around the world when intervening (or not) in market processes in order to help restore the power system back to normal operating conditions. In the Technical Brochure these approaches are described. Further in the Technical Brochure an overview is presented of possible intervening actions, the impact they have (how do they support the power system) and what are the consequences (what are the consequences for market parties concerned) of such actions.

CIGRE active Working Groups / Call for experts

– Past Tutorials & Webinars

During the Cairns 2023 Symposium, on Monday, 04 September 2023, Frank Crisci, convener of WG C2.24, delivered a tutorial titled "Mitigating the risk of fire starts and the consequences of fires near overhead lines for System Operations" on behalf of SC C2. During the same event, Babak Badrzadeh, convener of WG C2.26, delivered a tutorial titled "Power system restoration accounting for a rapidly changing power system and generation mix”. As these tutorials were the last activities to be completed by WG C2.24 and WG C2.26, both Working Groups were disbanded soon after.

— Joint Technical Activities

The SC also participates in other Working Groups that are being led by other SCs. SC C2 is part of Joint Working Groups C6/C2.34, C4/C2.58/IEEE, C4/C2.62/IEEE and D2/C2.48. The SC has active liaisons in the Working Groups C1/C4.36, C6.36 and C6.40.

— Publications

The following Technical Brochures were published since July 2023:

- TB 911 - Power system restoration accounting for a rapidly changing power system and generation mix - WG C2.26
- TB 917 - Wide Area Monitoring Protection and Control Systems – Decision Support for System Operators - WG C2.18
- TB 925 - Operator training in electricity grids at different control levels and for different participants, actors in the new environment

Study Committee C2 also participated in JWG D2/C2.48 whose Technical Brochure was sent for publication in June 2024.

- TB 936 - Enhanced Information and Data Exchange to Enable Future TSO-DSO Coordination and Interoperability - JWG D2/C2.48

Study Committee C2 actively participated in the review of 3 technical papers published by CIGRE.

— Awards

Nominations for the 2024 Technical Council Award were sent to TC by SC C2 Chair.

Future Activities

The next events for SC C2 are:

- On Tuesday, 16 July 2024, Jayme Darriba Macêdo and members of Working Group C2.39 delivered **a webinar** on the content of Technical Brochure 925, the last deliverable expected from the Working Group.
- On Monday, 26 August 2024, Study Committees C1 and C2 will be in charge of the Large Disturbances Workshop, traditional event held during the last Paris Sessions. Disturbances on market and/or operation of power systems from different countries will be presented.
- On Tuesday, 27 August 2024, during the Paris Session 2024, Giorgio Giannuzzi, Cosimo Pisani, Tadeja Babnik, Douglas Wilson, Asja Deviskadic and Walter Sattinger will deliver the tutorial "Wide Area Monitoring Protection and Control Systems – Decision Support for System Operators" as the last deliverable expected from Working Group C2.18.
- On 12-15 May 2025 the **CIGRE NRCC will be held in Trondheim**, Norway, with SC B2 on lead. SC C2 is taking part in the Technical Organizing Committee.

Conclusions

It remains an absolute truth that technical innovations in Power Systems continue to emerge.

All these new developments bring complexities to the operation, in a broad context, of these systems

and, as a direct consequence, the challenges for the themes addressed by Study Committee C2 continue to grow in size and variety.

The need to update knowledge and develop new solutions to the new problems we face in our routine tasks has never been so urgent. In fact, we have never experienced such a lack of routine in the operation.

Care must be taken to develop and share new knowledge and practices so that we have more and better resources available for the actions of the Control Rooms in the search for the best result of the operation. It is necessary to take care of the training and behaviour of operation teams who experience the pressure of real-time monitoring and actions, ensuring the reliability and effectiveness of the power system.

We are experiencing a positively special moment for our Study Committe C2 and for CIGRE as a whole and we must maintain our efforts to continue providing the best solutions available or to be created.

May this be our greatest motivation!!

— Contact

Contact of the Chair and/or the Secretary of the Study Committee →

SC C3

Power system sustainability and environmental performance

By Mercedes Vazquez, Chair, & Angel Salinas, Secretary

— Overview of the Study Committee C3

SC3 was created in 2002 with the main mission to produce unbiased positions and approaches on power system environmental performance and their implication for management, construction, operation, and investment decisions. In 2019, by the approval of a new Strategic Plan, the focus of the group's activities was broadened towards a sustainability approach. The goal is to facilitate and promote the principles of sustainable development through the global exchange of information and knowledge, by synthesizing state-of-the-art practices and developing recommendations in line with global best practice.

The concept of sustainability development is a broad one. The United Nations defines it as “meeting the needs of the present without compromising the ability of future generations to meet their own needs” which necessarily involves considering the three pillars: profits, planet, and people.

SC3 activities are focused on environmental protection and dynamic equilibrium in human and natural systems.

Fortunately, sustainability concern is becoming increasingly relevant within Cigre, and many SCs are already considering the protection of the environment and people while addressing technical issues. Moreover, in the context of the current climate and environmental crisis, sustainability itself is one of the main drivers for moving towards a different and decarbonised electricity system. Therefore, sustainability is now one of the focal points for the entire CIGRE community. In this sense, good communication, cooperation, and collaborative work with other CSs is especially important for SC3.

— Highlights

The lack of face-to-face meetings during COVID 19 slowed down SC3 activities and it has been difficult to relaunch the work. The group has many new members and many WG members (including convenors) have changed jobs without producing any TB or report. During this last year, we have focused on finishing pending WG and, fortunately, some are about to present their tutorials. Besides, 4 SC3 new WG have been approved (2 of them leaded by other SC. As sustainability is a transversal issue, an increase of participation in JWG is expected in the next years)

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Workstreams

SC C3 has currently 33 regular members (including the chairman and the secretary) and 9 observers, representing 40 countries.

Currently, we have 1 Strategic Advisory Group (SAG), 1 Advisory Group on EMF, 5 ongoing Working Groups and 2 Working Groups to re-start and 3 JWG (leaded by other SC) divided over three Technical Directions.

TD1 Asset management and environment

This TD is aligned with the traditional approach of SC C3 works. It refers to the integration of power facilities into the environment, considering their entire life cycle: from the planning stage to their decommissioning (cradle to grave).

The WGs are focused on identifying the interaction between nature and infrastructure and defining tools and measures to minimise their negative impact and enhance their positive contribution. There are some active WG regarding this topic:

C3.09A: Corridor management

This WG was disbanded for a few years but TB or articles were not published. With the aim to finish the publications, the TOR of the group was reviewed, and a new version of the group (C3.09A) started to work, with some old and new members. The WG has collected information and compared regulation, procedures, methods, and best practices from different countries that apply to relations with landowners and environmental aspects of corridor management. TB is expected to be published at the end of the year and a tutorial will be presented during 2024 Paris Session.

WG C3.22: Vegetation management in substations

The main intention of the work is to identify experiences and knowledge regarding the alternatives to the use of herbicides, but the scope also includes the collection of best practices regarding types of surfaces and vegetation control in substations. The work is in progress.

JWG B1/C3 85: Environmental impact of decommissioning of underground and submarine cables

It focuses on old and new cables and is investigating the decommissioning strategy (leave it in or dig it up) and impact on environment. The work is in progress.

JWG C3.B2/24: Methods of reducing electrocution of birds from power lines

The TOR was approved in 2023 and the first meeting was expected to take place in Paris 2024. However, the convenor has changed his job position, and a new convenor will take the group. Therefore, the launch of the works will be delayed until October 2024.

Non active WG:

WG C3.14: Impact of Environmental liability on transmission and distribution activities

The aim of the WG is to create a reference document to enable T&D utilities to understand the possible impact (practical and financial) of environmental liability and to have a view on best practices regarding prevention, investigation, and remediation of environmental damage. The WG has been dismantled without publishing any work.

WG C3.17: Interactions between wildlife and emerging renewable energy sources and submarine cables

This WG was created to complete WG C3.16 work by addressing renewable projects and associated transmission systems, focusing on operational aspects, though construction impacts are also considered. As the scope of the work is still very broad, the TOR has been reviewed. The focus will be on submarine and underground cables and leave renewable projects for another possible/future WG. There was no agreement regarding the inclusion of offshore substations marine substation platforms, as the potential environmental impacts could be similar to the effects of submarine cables. The SC C3 is looking to find a new convenor to propose the updated TOR to the Technical Committee and lead the works.

TD2 Sustainability: the role of the power sector

This TD is to address the new trends in the power sector under a sustainability approach. The aim is to anticipate future challenges and their implications.

Ongoing Working Groups:

WG C3.20: Sustainable Development Goals in the electric power sector

The general aim of the WG is to develop recommendations on how the electric power sector should implement SDGs within their business strategies to reach a maximum contribution to the achievement of these goals. The work is progressing, although not as fast as expected.

WG C3.23: Eco-design methods for TSOs/DSOs under environmental transition > New: WG C3.25: Eco-desing methods for the power system

The purpose of the group is to activate and harmonize the eco-design potential for TSOs/DSOs to reduce environmental impact, given that the implementation of a systemic eco-design approach will be a key success factor to achieve our sustainable goals. As the scope of the work was very broad and the former convenor was not available anymore, the TOR was reviewed and a new version of the WG has been approved in June 2024 (with a new name). The new convenor has called for the first meeting, that will be held during Paris 2024 session.

Participation in relevant WG leaded by other SCs:

- **JWG B3/A2/A3/C3/D1.66: Guidelines for Life Cycle Assessment in Substations considering the carbon footprint evaluation**
- **JWG A2/C3.70: Life Cycle Assessment (LCA) of Transformers**

Non active Working Groups:

WG C3.12: Greenhouse Gas Emissions inventory and report for transmission system operators

The purpose of the WG was to review and recommend harmonized procedures and methods for accounting and reporting GHG emissions that can be used by TSO's worldwide, but the work of this group was temporary suspended due to a lack of members. The TOR was updated, and a new title was proposed: "Managing GHG emissions of T&D activities. Accounting, reducing & reporting progress". The SC3 is looking for a new Convenor and participants to relaunch the works.

TD3 Stakeholder engagement and public acceptance

This TD deals with other traditional issue of SC3 scope of work: people. It includes topics related to EMF (as one of the main discussion issues for stakeholders) and engagement strategies to improve infrastructure development and maintenance.

C3.AG: EMF and Human Health

The group provides CIGRE with information and advice on topics regarding EMF and all health aspects related to electrical installations and the use of wireless communication. The scope of the Advisory Group includes:

- AC Transmission line environment - 50/60 Hz Electric and magnetic fields; spark discharges
- DC Transmission line environment - Static Electric and magnetic fields; air ions
- Intermediate frequencies and radiofrequencies up to 300 GHz
- Interference with medical implants (pacemakers; cardiac defibrillators, insulin pumps etc.)

WG C3.15: Best environmental and socio-economic practices for improving public acceptance of high voltage substations

The Working Group aims to make an inventory of the best practices, options, and boundary conditions for the integration of substations in their environment. The resulting Brochure intends to be an international reference document to be used in the discussion with other stakeholders. It shall help to identify workable solutions from environmental and socio-economic perspectives and increase acceptance by local authorities. Marijke Wassens, the WG convenor, passed away. The members (with an NGN help) have been working hard this last year to collect the material and finish the Technical Brochure, that will be finished soon. The tutorial will be presented in Trondheim symposium (Norway) next spring.

Dismantled WG:

WG C3.21: Including stakeholders in the investment planning process

The goal of this group was to study the best practices of the Cigre members to improve the decision-making processes for grid development both to system operators and the public/local communities. The WG has been dismantled without any report.

CIGRE active Working Groups / Call for experts

Next Meetings and Events

- Spring 2025: **Trondheim Symposium**
- Autumn 2025: **Montreal Symposium**

Specific actions for the recruitment of young experts, Place of Women in the SC

Presentations from NGN member have been included in the last technical sessions and there are NGN members in SC C3.

Regarding the place of Women, SC C3 usually has a very significant participation men: 48% of the members are women and the two last SC C3 chair have been women.

Conclusions

CIGRE, as a global organization, must be sensitive to global sustainability issues, paying attention to social and environmental aspects.

Sustainability issues, especially those related to climate change, the circular economy, the protection of flora and fauna and social acceptance, are cross-cutting and affect many aspects of the electricity system. For this reason, although SC C3 has a key role to play, it is extremely important to work together and strengthen SC C3's collaboration with the other SCs so that these issues are increasingly integrated into the work of the CIGRE community. In this way we will be able to move towards an electricity system that is more respectful of the planet and people.

Contact

Contact of the Chair and/or the Secretary of the Study Committee →

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TB 934 **WG B4.81**

Interaction between nearby VSC-HVDC converters, FACTs devices, HV power electronic devices and conventional AC equipment

Large integration of renewable energy sources (RES) and HVDC converters in power system have resulted in displacement of conventional power generation, lower system inertia and lower short circuit capacity of the AC power system. The AC grids integrates multiple converters in the close vicinity that potentially influence each other. The interoperability and stability of the system with massive amounts of converters is regarded as a key issue in future power systems and decarbonization of the industry. In recent years large-scale integration of solar, wind and HVDC converters, have resulted in several stability problems in the power system.

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Introduction

Interactions phenomena between VSC-HVDC converters and other power electronics devices or passive HV components installed on the network, can have a wide range of frequencies: from interarea oscillations, to sub-synchronous interaction (as SSRI and SSTI) and even to high frequency interaction (between 100Hz till several kHz). In addition, interactions due to non-linear behaviour such as transformer saturation, control non-linearity, etc. can also occurs.

Various RMS and EMT simulations tools and models from the converters and passive grid components are available. Through various works it has been documented that the tools and models representing the active and passive components have a major

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influence on the study result.

This Technical Brochure (TB) focuses on the interaction between VSC-HVDC converters and the other power electronics or passive HV devices.

Chapter 1 - Background

Chapter 1 includes the motivation and needs for recommendations on analysis, modelling and mitigation of interactions between VSC-HVDC converters and with the rest of the system.

In recent years, large-scale integration of solar, wind and HVDC converters resulted in several stability problems in power systems. Identifying and de-risking these stability issues is challenging without specific guidance. Consequently, ensuring interoperability and stability in systems with a significant presence of converters is considered a major concern for future power systems and a critical challenge that must be addressed to facilitate power system decarbonization.

Additionally, the rise of power electronic equipment connected to the electric grid has led to interaction and stability issues that require adequate address. Table 1 shows the proposed classification of multi in-feed and interaction studies used through the Technical Brochure.

Multi-Infeed and Interaction Study Interaction between at least two main power electronic devices (HVDC, FACTS, Renewables, etc.)					
Control loop interaction		Interaction due to non-linear functions		Harmonic and Resonance interactio	
Near steady-state controls	**Dynamic controls**	**AC fault performance**	**Transient stress and other non-linear interaction**	**Sub-synchronous resonance**	**Harmonic emission and resonance**
•AC filter hunting •Voltage control conflicts •P/V stability	•Power oscillation •Control loop interaction •Sub-synchronous control interaction •Voltage stability	•Commutation failure •Voltage distortion •Phase imbalance •Fault recovery •Protection performance	•Load rejection •Voltage phase shift •Network switching •Transformer saturation •Insulation coordination •Transition between control modes	•Sub-synchronous torsional interaction •Sub-synchronous resonance	•Resonance effec •Harmonic emissi •Harmonic instability •Core saturation instability
•Static analysis •RMS time domain	•RMS time domain •EMT time domain •Small-signal analysis	•RMS time domain •EMT time domain	•EMT time domain	•EMT time domain •Small-signal analysis	•Harmonic analys •EMT time domai •Small-signal analysis

Table 1 - Classification of multi-infeed and interaction studies

Therefore, the main objective of the technical brochure is to provide recommendations on analysis, modelling and mitigation of interactions between VSC-HVDC converters, other converters and the grid, throughout the project lifecycle, including guidelines on screening studies and selection of the area of study.

Thus, the Technical Brochure provides recommendations on:

- Methodologies to analyse and to assess control interactions in meshed AC networks with multiple converters, including study area selection.

- Required data and modelling recommendations to analyse such interactions and verify that the models used are a valid representation of in-service behaviour.
- When to perform such studies at various life-cycle stages of a VSC-HVDC or FACTS project.
- Suitability of different studies depending on the state of a VSC-HVDC or FACTs project life cycle.
- Simulation (offline and real time) tools and models that can impact the study results.
- Confidentiality issues and model exchange for multivendor systems.
- Risk assessment and evaluation of potential solutions.

Chapter 2 - Types of models and methodologies for different interaction studies

Chapter 2 focuses on the different types of models and methodologies used to conduct interaction studies between HVDC, power electronic devices and the AC grid. These studies are essential for assessing the stability and performance of power systems, especially those incorporating large-scale renewable energy sources (RES) and High Voltage Direct Current (HVDC) converters.

Figure 1 illustrates the essential interaction phenomena provided in Table 1 and methods and tools that are typically employed for the respective studies. It must be noted, that the proposed classification is based on the collection of the best practice in the industry.

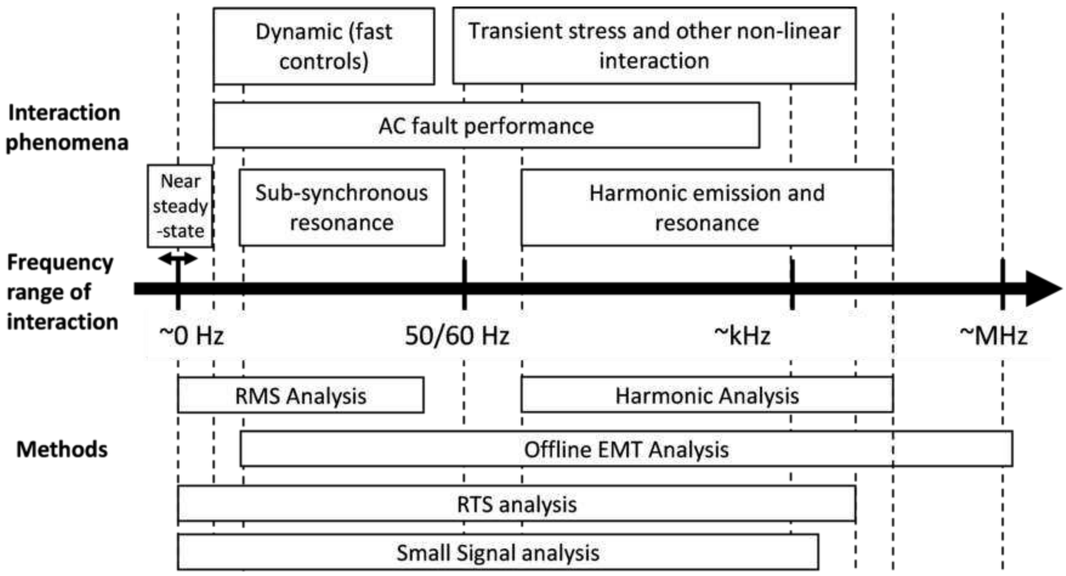

Figure 1 - Overview of methods for interaction phenomena

The chapter begins by outlining the main types of simulation tools employed in these studies: time-domain tools, small-signal analysis and harmonic emissions methods.

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Time-domain simulations are categorized into Root Mean Square (RMS) and Electro-Magnetic Transient (EMT) tools. RMS tools or phasor-domain transient (PDT) models, are utilized for system stability for large interconnected systems, including electromechanical oscillations, angle-stability of synchronous generators and frequency stability. For phenomena with frequency up to few Hz and outside the range the network's model fidelity diminishes rapidly. Conversely, EMT tools are designed for detailed transient analysis, capturing accurately the interactions that occur over shorter timescales. These EMT simulations can be performed either in real-time or offline, each offering different but complementary benefits. Real-time EMT simulations are crucial for hardware-in-the-loop testing with real C&P cubicles, whereas offline EMT simulations, despite being computationally intensive, allow for in-depth analysis of specific scenarios.

Figure 2 provides an overview of the main simulation tools that are commonly used. It shows that the load-flow tools cover a single "snapshot" on a time-domain scale, whereas the RMS provides slow dynamic in the range of few seconds and the EMT provides transient dynamics within the microseconds or milliseconds time scale.

Small-signal analysis is another methodology highlighted in this chapter. By linearizing the system around a specific operating point, this technique helps identify potential oscillatory modes and their damping characteristics, which is vital for understanding stability and control interactions. Additionally, the chapter discusses harmonic emissions analysis, which examines the harmonic distortions produced by power electronic devices and their impact on the power system.

The chapter further explores the types of models used in interaction studies in each type of tools. Each model type serves a specific purpose: EMT models offer detailed insights into transient behavior, RMS models focus on the average system behavior over longer periods, harmonic models investigate the harmonic content generated by power electronic devices, and small-signal models aid in stability analysis.

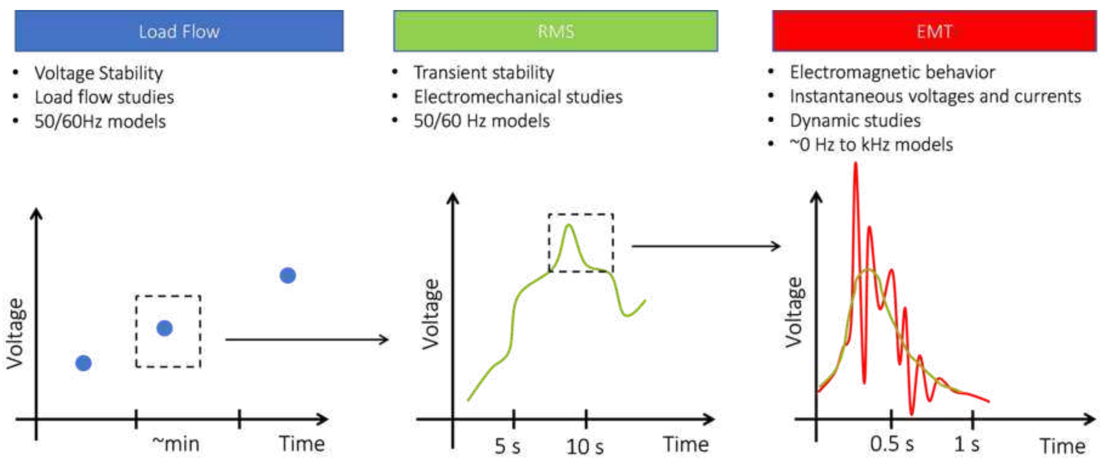

Figure 2 - Overview on type of time domain simulation tools for HVDC applications

A crucial aspect covered in this chapter is model validation. Ensuring the accuracy of models throughout the project lifecycle is paramount. Validation involves comparing model with onsite system behavior to enhance reliability. This process is essential for building confidence in the models used for studying interactions and predicting system performance accurately.

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The chapter also addresses the advantages and disadvantages of different modeling approaches. While EMT offline models provide high fidelity, they are computationally expensive. RMS models, although less detailed, are useful for transient stability studies. The chapter recommends a balanced use of these methods to achieve comprehensive analysis, emphasizing that employing complementary methods allows for cross-verification of results and thorough analysis. Also, proper model validation is highlighted as a critical step in maintaining accuracy and reliability throughout the project lifecycle.

In conclusion, this chapter provide a guideline for understanding the tools, type of models and methodologies necessary for analyzing and mitigating the interactions between HVDC, power electronic devices and the AC grid, which is crucial for the stability and performance of power systems.

Chapter 3 - Selection of the Study Area and Screening Methods

Chapter 3 focuses on selecting study area within a power network for detailed modelling and analysis, and the various screening methods used to identify this study area. This approach is necessary due to the challenges of accurately modelling large power systems with numerous power-electronic devices (PEDs).

Selecting the study area is important because it helps balance computational efficiency with simulation accuracy. Modelling the entire network in detail is often impractical due to the significant computational resources required and the unavailability of detailed and accurate models of devices connected to the network. Instead, the focus is placed on the part of the network where device interactions are most likely, known as the "study area," while the rest is represented by an equivalent network model.

The selection of the study area depends on the type of study being conducted, which can be either root mean square (RMS) studies for slow electro-mechanical phenomena or electromagnetic transient (EMT) studies for fast electromagnetic transients. With increasing complexity in modern power grids and high PED penetration, more phenomena need to be studied in the EMT domain, requiring smaller simulation time steps and longer simulation times.

Key factors in selecting the study area include network size, operating states, device details, phenomena to be studied, study types, and device sensitivity.

Screening methods are explained in Chapter 3 to help in identifying devices at risk of control interactions and determine the study area. Common screening methods include:

- Topology-based assessment: a general and obvious approach where the boundary is identified by the topology of the network, for example, where a radial connection is a sole link.
- Fault-level assessment: the short-circuit levels (SCLs) of the busbars are calculated at a PCC of interest and/or its surrounding busbars. The buses with high SCL are stronger buses and can be considered to be excluded from the study area, although not necessarily.

- Unit Interaction Factor (UIF): this calculation indicates potential interaction of a PED with the long-shaft synchronous generators in the grid under study.
- Electrical damping: a series of simulations of low-magnitude perturbations of electro-mechanical quantities to trigger the reaction of other devices in the grid under study and assess the electrical damping provided by the machine under study.
- Multi-Infeed Interaction Factor (MIIF): this calculation indicates the potential interaction of a PED with the other PEDs in the grid under study.
- Frequency scanning: this consists in a series of calculations of network impedance in points adjacent to the point of observation interest, over a certain frequency range, to indicate the risk of series and parallel resonance in the network. This should take into account the frequency-domain impedances of the PEDs and their control systems as well as for the other elements in the grid.
- Step-response calculations: this consists in a series of calculations and simulations of steps of various electrical quantities, in the points around the point of observation, with the aim to assess the impact of certain step changes on the power system.

Each of these screening methods has its strengths and limitations, especially concerning modern converter technologies. Chapter 3 provides a detailed analysis of the deficiencies associated with each method and recommends their thresholds and criteria to be customised to individually to characteristics of each network.

After selecting the study area, network reduction is necessary to extract and simplify this area from the whole network model. The reduced model should match the original model in both steady-state and dynamic behaviour within acceptable thresholds. Chapter 3 provides a brief summary for steady-state and dynamic model reductions.

In steady-state analyses, network reduction focuses on ensuring that the simplified model replicates the original network's behaviour under steady-state conditions. This involves matching parameters such as power flows, generator outputs, voltages, and short-circuit levels at all substations.

Dynamic equivalents are crucial for ensuring that the reduced model accurately mimics the original network's dynamic behaviour at substations near the study area's connection points. These retained dynamic characteristics enable accurate analysis of transient behaviours and interactions within the study area.

Chapter 4 - Risk assessment of converter interactions during the project life cycle

The chapter defines the standard life cycle stages of a converter project and identifies the issues of converter interactions that can occur at each stage. According to the stages of the converter project life cycle, the flowchart with activities consisting of interaction screening and subsequent more detailed analyses has been proposed from the general concept down to commissioning stage (Figure 3). The goal of the initial screening is to remove from the analysis the converters that are not indicating potential interactions, thus reducing the overall size of the system with the project converter unit, making the further analyses less demanding. During this process the identified converter interaction issues will require certain mitigation proposals to resolve the issues. Therefore the complexity of the analyses increases with the course of the project life cycle.

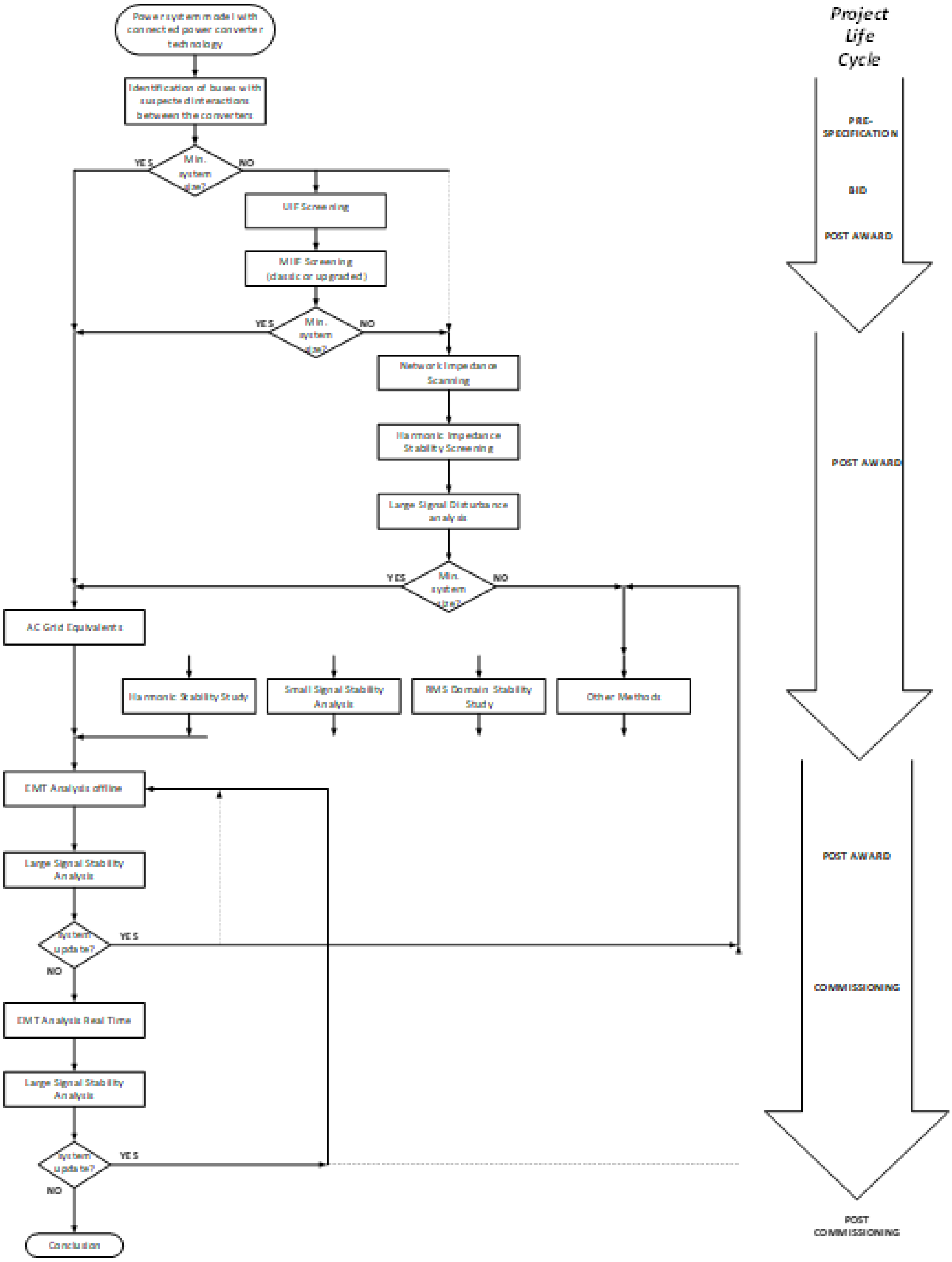

Figure 3 - Partial representation of the project life cycle flowchart including interaction analysis

For the purpose of identification and mitigation of interactions, two large tables are provided that summarize the technical aspects and practices regarding multi-infeed interactions, including the type, cause, consequence, example, analysis tool, and mitigation method of each interaction issue. These tables (Figure 4) are aligned with the converter interaction summary of Table 1, including the known (conventional) methods of analysis and proposing some new methods more relying on statistics, machine learning, AI and optimization methods.

The chapter also proposes a procedure for the verification of interaction mitigations, such as introducing new support devices, modifying existing controls and protection, and adding new operating measures and practices. For all verification procedures it is common to examine the vulnerability of the solution, replicate the original interaction problem, apply the remedial action and repeat the same event with the aim to confirm the removal of the issue. Finally, the implementation and the field testing of the found solution for the converter interaction is considered.

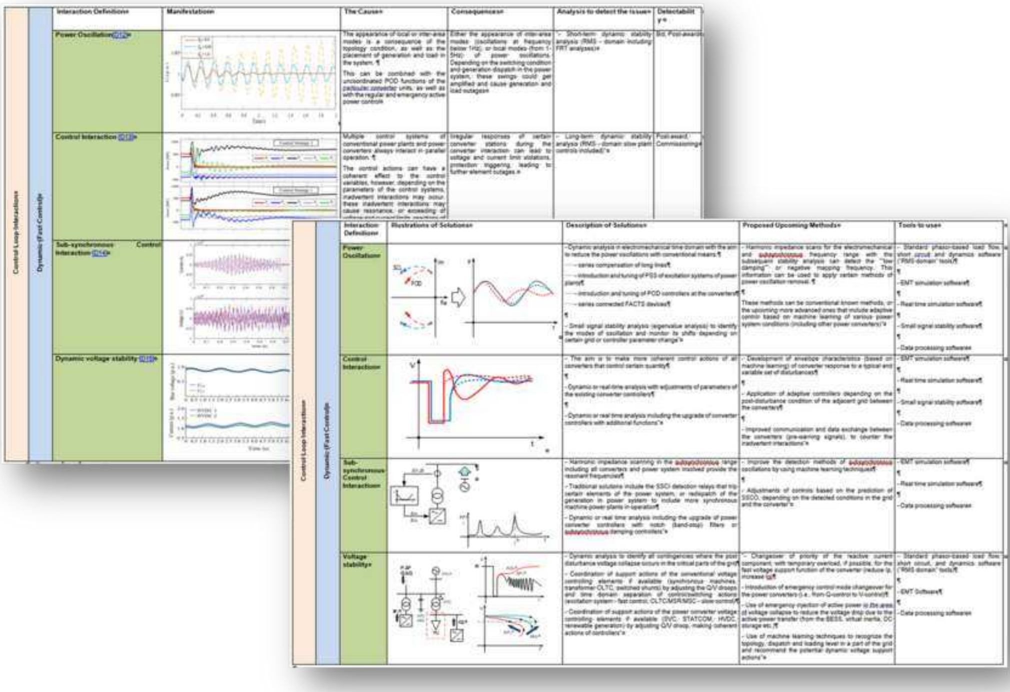

Figure 4 - Example of Identification and mitigation tables (for the known converter interaction phenomena)

The procedure of identification and resolution of unwanted converter interactions understands the necessity of having the necessary set of information and mathematical models of all converter units involved. In the market-oriented environment, with intellectual property and legal boundaries involved, the challenges of organization and mutual cooperation have been identified between the different parties (manufacturers of equipment and grid operators) involved in one project. Therefore, in the chapter these issues have been addressed with several cooperation modalities proposed, based on the full cooperation (with open data exchange), partial cooperation (black-box data exchange) or with the involvement of the third party (consultant or the grid operator). The main message that was derived in this section is that the protection of intellectual property of the converter

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manufacturers implies the limited data exchange with other parties involved, at a price of prolonged communication and increased number of iterations in the process of resolving of the converter interaction issues.

Conclusion and recommendations

This Technical Brochure has included a classification of the main interactions between VSC-HVDC converters and between VSC-HVDC converters and other power electronic devices and passive HV devices. Together with the classification, the TB included recommendations on analysis tools and methodologies, study area selection, studies at various life-cycle stages and practical issues such as confidentiality and model exchange between vendor systems and risk assessment and evaluation of potential solutions.The main recommendation would be to consider adequate interaction studies as part of the different stages of project development in order to minimise overall interaction risk and to agree to the extent and approach of such studies with the relevant stakeholders.

TB 935 WG B4.84

Feasibility study and application of electric energy storage systems embedded in HVDC and STATCOM systems

Electrical power systems are currently experiencing significant changes across all levels of generation, transmission, distribution, and demand. One of the major transitions involves the increasing penetration of renewable energy systems, energy storage assets, and advanced technologies such as Flexible AC Transmission Systems (FACTS) and High Voltage Direct Current (HVDC) links. Concurrently, there is a gradual phase-out of conventional synchronous generation (SG). These changes are transforming the power network into a power-electronics-dominated system. Future electrical transmission grids, characterized by these fundamental changes, require the development of new transmission assets with enhanced capabilities to manage the variability and uncertainty introduced by renewable energy sources.

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— Introduction

To support the modern power-electronics-dominated network, HVDC links and FACTS devices, particularly STATCOM devices, will play a crucial role. Voltage Source Converter (VSC) based HVDC with Modular Multilevel Converter (MMC) technology has emerged as the preferred solution for upcoming HVDC installations. This preference is due to their improved efficiency, scalability for high voltage levels, compatibility with XLPE cable, reduced footprint, and fast response capability.

The rapid increase in the number and size of electrical Energy Storage (ES) systems is globally driven by their ability to provide the necessary flexibility to integrate intermittent renewable energy sources. As costs decrease and technical improvements (such as energy density and safety) advance, large storage systems are being installed at both distribution and transmission levels in various countries. Integrating ES systems into HVDC or STATCOM devices is expected to introduce or enhance functionalities, providing innovative services to the network, reducing the overall cost and increasing its resilience. These services include improved fault ride-through (FRT) response, black-start capability, dynamic voltage support, (enhanced) grid-forming capacity, fast frequency support, and improved network stability.

This Technical Brochure (TB) B4.84 explores the integration of ES systems in HVDC and STATCOM systems (i.e. ES-HVDC and ES-STATCOM) that are rated in the range of few hundreds of MWs to few GWs and connected at high voltage transmission system levels.

For HVDC systems, different options exist for integrating ES systems depending on the design, requirements, specifications, and cost considerations. Table 1 illustrates the potential locations. It includes integrating ES on the AC side of the converter station, on the DC side of the converter station or into a DC network, or within the converter submodules themselves.

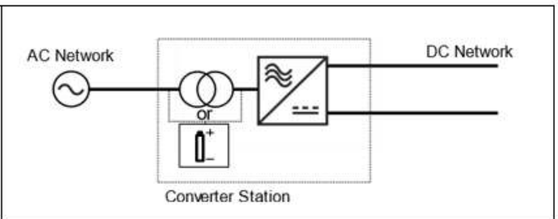
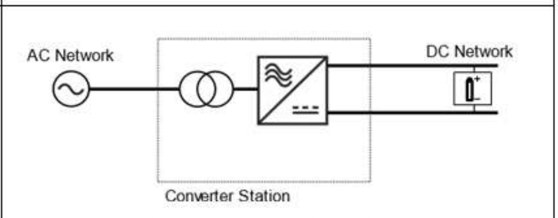
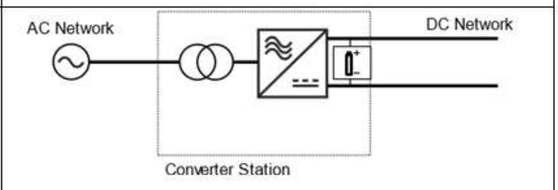
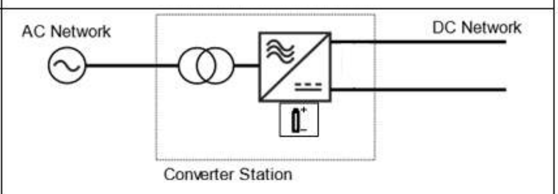
Option 1	**ES Integrated on the AC-side of a Converter Station**	
Option 2	**ES integrated into the DC network**	
Option 3	**ES Integrated on the DC Bus Inside a Converter Station**	
Option 4	**ES integrated into a Converter**	

Table 1 - ES Locations in a converter station of HVDC Link

Similarly, for STATCOM applications, ES can be integrated within the modular STATCOM system on the DC bus side or inside the valves as highlighted in Figure 1.

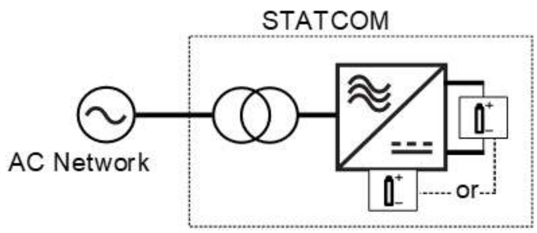


Figure 1 - ES locations in an STATCOM substation

When considering ES-HVDC, it is important to distinguish between the power transferred by the HVDC and the power provided by the ES. The rating of the ES system does not necessarily need to match the HVDC rating and can be smaller depending on the required ancillary services.

The TB presents various MMC converter topologies with embedded ES. To have a common understanding of the circuit topology, the WG has defined new symbols for different circuit structures. As an example, Figure 2 shows the symbol descriptions for MMC with half-Bridge submodules. The battery symbol refers to either supercapacitor or electrochemical battery technologies. The square box refers to ES embedded in the overall converter. Such ES can be partially or fully embedded within the valve. The circle box refers to ES embedded at the valve level. When ES is embedded in the SM, different power electronics interface circuits are feasible that is further elaborated in the TB.

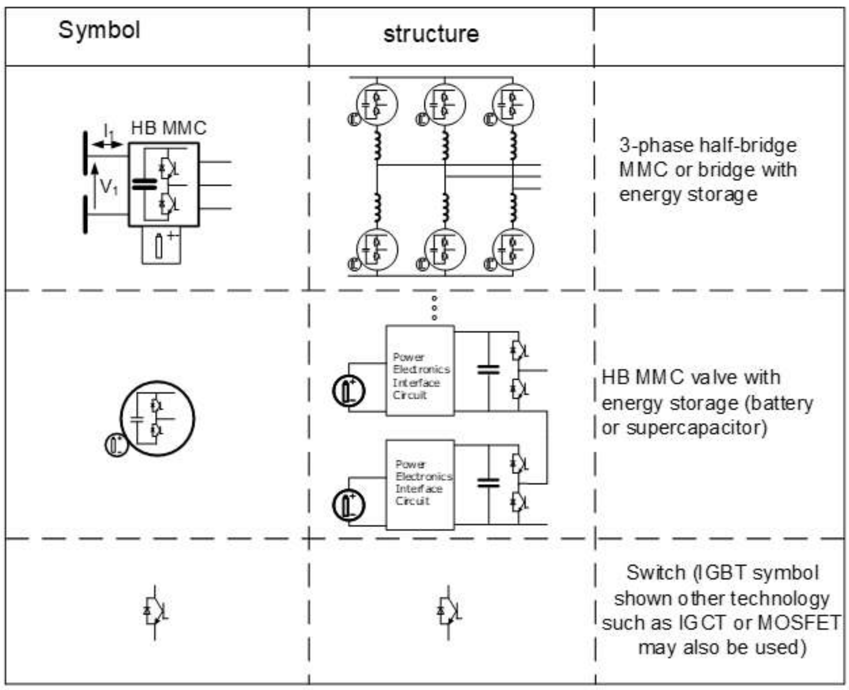


Figure 2 - Symbols definition for MMC half-bridge converter

The document aims to provide key information for power system stakeholders on the ES-HVDC and ES-STATCOM devices. It covers:

- Review of large storage systems

- Analysis and possible MMC topologies for ES integration
- Analysis of different integration options for ES in HVDC/STATCOM systems
- Overview of ancillary services and potential applications
- Benefits for future applications and conventional grid services
- Challenges of integrating ES with HVDC/STATCOM assets

The TB also provides guidelines for developing models to perform dynamic studies with embedded ES in HVDC and STATCOM and highlights several system studies where ES-HVDC can offer significant benefits for system stability.

— Background

The first chapter of the TB reviews the ES technologies with a focus on electrochemical storage and briefly describes the MMC topologies. To determine the most suitable ES technologies for the integration into HVDC and STATCOM applications, a detailed assessment of their capacity and performance is essential. Key parameters include energy density (Wh/kg or Wh/m^3), power density (W/kg or W/dm^3), efficiency and lifetime (numbers of cycles). Comparision between different types of ES shows that, presently, lithium-ion batteries, supercapacitors and hybrid solutions are the most suitable ES technologies for HVDC and STATCOM applications. This is due to ES cost reduction, reduced footprint, the ability to connect from the DC side and fast-acting ES systems with more power density. Despite the advantages of SMES and Flywheels, such as high power capacity, to date, their sizing and costs of implementation are major issues and are not considered within this TB.

— Application, benefits and motivation

This chapter reviews various aspects of transmission systems that could benefit from integrating ES with HVDC and STATCOM systems. It starts by discussing potential changes in grid codes and comparison of the expected contributions of HVDC systems, with or without ES, to ancillary services. It concludes by examining use cases where ES integration could enhance HVDC and STATCOM systems.

Depending on the application cases, ES-HVDC and ES-STATCOM systems can provide or enhance the following ancillary services:

- Synthetic inertia and Fast Frequency Reserves (FFR)
- Frequency containment reserves (FCR)
- Manual and automatic frequency restoration reserves (FRR)
- Active Power Oscillation damping (POD-P) for HVDC offshore applications
- Congestion management and investment deferral
- Black-start capability

Besides ancillary services, ES can provide a number of additional benefits such as power quality and firewall improvements (i.e. reduce disturbance that is transferred from one side of the HVDC to the other side).

With regard to possible application cases for ES-HVDC system, three different applications are identified : Point-to-point connection with weak networks, HVDC for offshore applications and DC grid systems. Figure 3 and Figure 4 illustrates the first two potential appalications.

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For Point-to-Point HVDC connections : ES-HVDC can become attractive when both sides of the HVDC are subject to a very low short-circuit level. Also, ES-HVDC would play the role of a firewall between both networks when one network is subject to Power and frequency fluctuations. Additional storages provide the ability to black-start the HVDC system without the need of a live AC system on one of the ends. ES-HVDC might provide better flexibility and higher resilience with regard to ancillary services.

For HVDC Connections to offshore wind farms (OWFs) : ES-HVDC can provide POD-P functionality and act as a firewall between offshore and onshore events. ES-HVDC can buffer and smooth power oscillations from OWFs and improving power quality. ES could replace dynamic braking systems (or DC choppers) and help avoid curtailment by storing the excess energy from OWFs.

The expected power rating of the ES for such applications is around 10-20 % of the nominal active power. It is expected that the combination or addition of several functionalities will lead to an attractive techno-economical solution for such ES-HVDC applications.

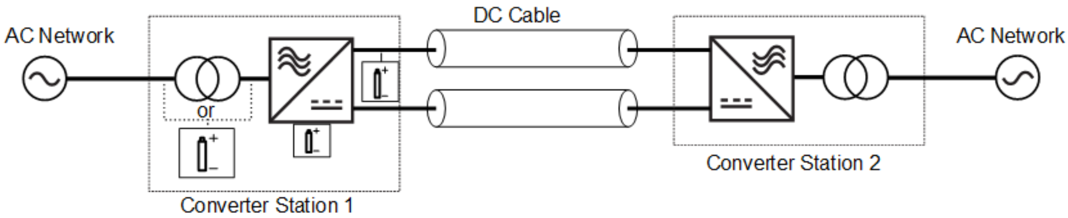

Figure 3 - ES-HVDC application for point-to-point connection with weak network

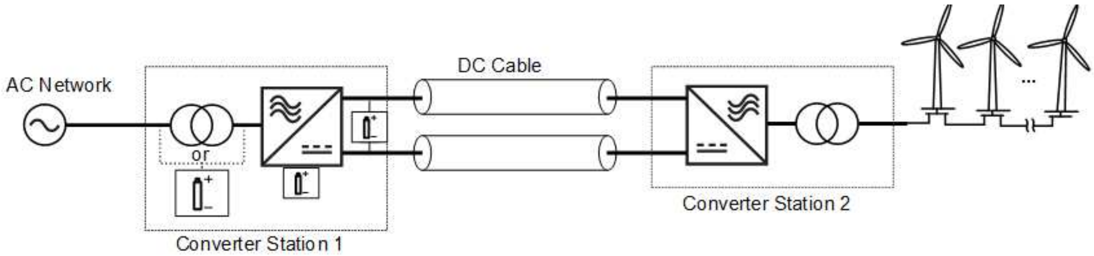

Figure 4 - ES-HVDC application for OWF connection

Power Electronic converter Interfaced energy storage technologies

This chapter of the TB details the interface of ES technologies with power electronic converters, focusing on supercapacitors and batteries. It provides a comprehensive analysis of different converter topologies used for integrating ES within the power modules.

Modular Converter Topologies for ES-STATCOM & ES-HVDC Applications

This chapter discusses different topological solutions for integrating ES within HVDC and STATCOM systems, evaluating the advantages and disadvantages of each solution. It compares various modular converter topologies and their applicability in real-world scenarios.

Challenges regarding ES-HVDC and ES-STATCOM

The integration of ES in MMCs presents both opportunities and challenges. MMC device is already a complex technology that includes several elements that need to be controlled and protected adequately. The integration of ES will introduce additional complexity to system design and operation. Also, challenges that are related to the installation of conventional ES are expected to be covered as well for the ES-STATCOM and ES-HVDC system, such as safety, permissions with regard to chemical materials, fire assessment, etc. The identified challenges are:

- Technology and market maturity: Challenges include the maturity of ES technologies, market regulations, and load cycling patterns.
- Design Integration: Integrating supercapacitors and batteries into MMCs involves significant design challenges.
- Control and Protection system design: Issues arise with embedding ES in converter valve halls and designing appropriate control and protection systems.
- Ageing and Failure Rate : Electrochemical ES components degrade over time, affecting performance. Understanding degradation kinetics is crucial for HVDC and STATCOM applications, which are designed for lifespans of 25-40 years, while ES technologies often last 5-20 years.
- Footprint and Weight Considerations: ES integration affects installation footprint and weight. Requirements vary based on the ES location and application needs, influencing the overall system design and space allocation.
- Insulation Coordination : DC-side ES integration impacts insulation coordination and current stress in converter stations and DC equipement, necessitating careful investigation to maintain equipment safety.
- MMC rating : For ES-HVDC with Option 2 to 4 (i.e., ES embedded in the MMC or at the DC side), the rating of the MMC might be impacted or the provision of the stored energy will be limited by the MMC rating. It is possible to to include HVDC overload capability or to overdesign the converter. However, such solution will increase further the overall cost of the system.
- Maintenance: procedures of HVDC and STATCOM installation and maintenance will be affected as well as service personnel needs to be trained for additional ES specific maintenance activities.
- Cost benefit analysis : Cost-effectiveness is crucial. Detailed cost-benefit analyses are needed to determine economic viability for such enhanced services.

Modeling

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For the deep understanding of the operation of the converter and its control, proper modelling is vital. Modelling and simulation of MMC with ES can be a challenging task because of the presence of numerous nonlinear devices which require small simulation time steps and advanced control system design.

Modeling of ES-STATCOM and ES-HVDC systems in electromagnetic transient (EMT) programs follows the same structure as modeling of STATCOM and HVDC systems without ES. Depending on the required precision and acceptable computational burden, four type of models with different levels of detail are elaborated in the TB. ES models can also have different levels of detail. Depending on the simulated phenomena and technology, modeling requirements in terms of level of detail are discussed and analysed in the TB.

System studies

The TB presents system-level studies of ES-HVDC and ES-STATCOM and give indication on preliminary designs of the ES system for each ancillary services. For illustration, the following subsection presents one of these examples.

ES-HVDC OWF for compensating mechanical wind power oscillations

Mechanical vibrations of wind turbines can cause power output oscillations at low frequencies (0.1 to 0.5 Hz) with magnitudes up to 3%, especially during wind gusts or after fault recovery. These oscillations are undesirable because they can amplify existing inter-area oscillations in the transmission network and can impact the power quality. ES-HVDC systems can stop propagation and smooth these oscillations, stabilizing the power injected into the grid.

The following example illustrate such phenomenon on a 1 GW HVDC-OWF (see Figure 4). Figure 5 shows the results of active power from the offshore wind, HVDC and ES respectively as well as the energy variation of the ES. At 15 s, mechanical oscillations starts and stabilize around 3% with a frequency of oscillation at 0.1 Hz. At t=50 s, the ES is activated to smooth the wind power oscillations, the wind power going through the offshore station remains oscillating with similar magnitude and frequency while the power delivered to the grid at the onshore point of common coupling is smoothed. The required peak storage power is 32 MW while the maximal energy deviation is 97 MJ. As the offshore wind farm oscillation can be considered permanent or during a long duration of time (i.e. few minutes/hours), this service can lead to cycling stress of the ES that should be considered during the design stage.

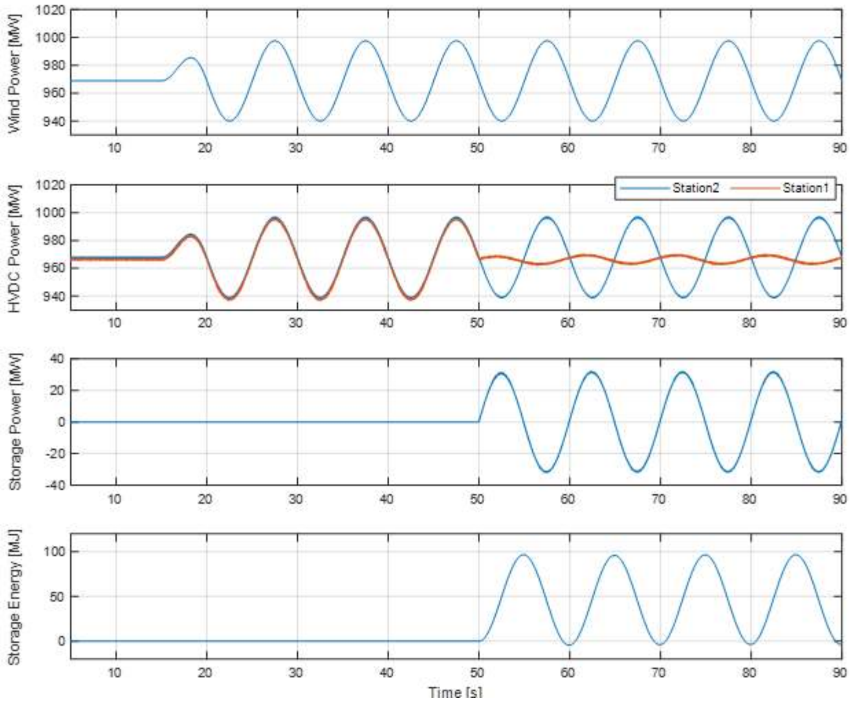

Figure 5 - Illustration of service provided by ES-HVDC with OWF which experience WTG mechanical power oscillations

Conclusion

The TB provides technical feasibility study and potential use cases for integrating ES within HVDC or STATCOM systems. The findings confirm that such integration is technologically possible and can enhance the resilience and stability of future power systems dominated by renewable energy sources and power electronics.

Up to now, the most suitable ES technologies to be integrated in the MMC are the lithium-ion batteries and supercapacitors. Also, new solutions are emerging such as hybrid solutions that can provide an optimal solution by combining these two ES technologies.

The different ways to integrate these ES within HVDC and STATCOM systems are examined and pros and cons of each integration approach are compared and elaborated within the TB.

For the use cases, the potential for providing ancillary services in HVDC point-to-point, HVDC-OWF systems and DC grid is clear, but the market for ES-HVDC is still in its early stages. As for ES-STATCOM, the market is developing and some projects are currently ongoing.

Proposed ES integration solutions and their benefits are presented, however detailed cost-benefit analyses are limited, with decisions currently based on technical needs. Further research and development are recommended in areas such as grid studies, specific cost-benefit analysis, system design impact assessments, control integration, and market development to advance the technology towards market readiness.

TB 936 JWG D2/C2.48

Enhanced Information and Data Exchange to Enable Future TSO-DSO Coordination and Interoperability

Future coordination and interaction of transmission and distribution operational procedures and planning as well as real-time tools and modelling approaches will need to be extended, modified, revised and integrated with regard to different information and data communication technologies. Whole system information and data exchange management and schemes will be required that will consider overall power system security, flexibility requirements, stability, resiliency and affordability. By way of example, appropriately detailed representation of distribution systems as required in operational procedures for transmission systems needs to be specified. However, such representations will be constrained by computationally demanding processes, intensive information and data management, data confidentiality and cybersecurity issues at both distribution and transmission system operator levels. Therefore, enhanced Information systems and data exchange is now essential with regard to enabling future transmission and distribution system interoperability, interaction and coordination.

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Introduction and scope

Overall power system operation and planning needs to change significantly at whole system levels in order to exploit the ongoing and emerging smart grid developments. The conventional approach to the operation and planning of transmission and distribution networks, as virtually separate entities with limited coordination, interaction and interoperability, is no longer applicable or practical. Especially with regard to achieving whole system flexibility as made available by vastly increasing amounts of distributed generation, renewable energy sources, active consumers and new market mechanisms.

Environmental and economic pressures are increasing on power system operation, planning and development, through the progressive evolution of smart grid functionality, as well as the vastly increasing integration of distributed energy resources as presented in the following Figure. In addition. distribution networks are transitioning towards far greater active network management and are therefore presenting significant challenges and issues with regard to conventional transmission system level operational procedures.

Overview of key challenges for future TSO-DSO coordination, interaction and interoperability

This Technical Brochure (TB) presents the research findings and outputs conducted by the CIGRE Joint Working Group (JWG) D2/C2.48 "Enhanced Information and Data Exchange to Enable Future Transmission and Distribution Interoperability". The authors cover the following topics in the six chapters of the technical brochure.

- The first Chapter provides an introduction to the technical background of enhanced and standardized information systems and data exchange in order to enable future transmission and distribution systems coordination and interoperability.
- The second Chapter presents an international survey of current practice and state-of-the-art with regard to interoperability, interaction and coordination activities between Transmission System Operators (TSOs) and Distribution System Operators (DSOs).

- The third Chapter describes relevant ongoing and future international standardization activities concerning the future development of TSO to DSO as well as DSO to TSO information and data exchange in relation to enhanced coordination, interaction and interoperability across and between systems.
- The fourth Chapter focusses on standardized approaches and methodologies that can be employed to formally define business and system Use Cases in relation to information systems and data exchange for current and future TSO-DSO interoperability and coordination.
- The fifth Chapter presents an overview of interoperability testing, compliance conformance and regulation in relation to adopting and standardizing information systems and data exchange to enable future TSO-DSO coordination, interaction and interoperability.
- The sixth Chapter summarizes the recommendations, conclusions and proposed further developments concerning the future development and standardization of TSO to DSO as well as DSO to TSO information systems and data exchange.

The TB also presents detailed accounts of the application and development of the following IEC TC57 'Power systems management and associated information exchange' WG13 'Software interfaces for operation and planning of the electric grid' international standards in relation to information systems and data exchange as associated with current and future TSO-DSO interaction, interoperability and coordination:

The ongoing adoption and development of the Common Grid Model Exchange Standard (CGMES) profile as presented is based on the existing IEC Common Information Model (CIM) standards as follows:

- IEC 61970-552: CIM XML Model Exchange Format
- IEC 61970-301: CIM Base
- IEC 61970-302: CIM for Dynamics Specification
- IEC 61970-452: CIM Static Transmission Network Model Profiles
- IEC 61970-453: Diagram Layout Profile
- IEC 61970-456: Solved Power System State Profiles
- IEC 61970-457: CIM for Dynamics Profile
- IEC 61968-4: Application integration at electric utilities – System interfaces for distribution management - Part 4: Interfaces for records and asset management

The adoption and development of the European Style Market Profile (ESMP) as presented is based on the existing IEC CIM standards as follows:

- IEC 62325-301: CIM Extensions for Markets
- IEC 62325-351: CIM European Market Model Exchange Profile
- IEC 62325-450: Profile And Context Modelling Rules
- IEC 62325-451-1: Acknowledgement Business Process and Contextual Model for CIM European Market.
- IEC 62325-451-2: Scheduling Business Process and Contextual Model for European Market.

— Conclusions and key messages

The activities of the JWG were focused on the research and development of standardized, secure and efficient information systems and data exchange mechanisms between TSOs and DSOs. The main findings include the development of novel operational and planning TSO-DSO approaches with regard to data and information exchange. Furthermore, Business Use Cases (BUCs) that specify novel TSO-DSO processes that involve exchanging and validating grid models as standardized between TSOs, DSOs and other stakeholders. The main outcomes from the formally defined and specified BUCs is specific enhancements and extensions to relevant series of standards, such as the following:

- IEC 61968: Application integration at electric utilities – System interfaces for distribution management
- IEC 61970: Energy management system application program interface
- IEC 62325: Energy market communications

More specific outcomes as presented include the CGMES based on proposed development and extensions for standardized CIM profiles, Furthermore, enhanced state of art for TSO-DSO coordination and interaction is achieved by developing and extending standardized approaches for information exchange and data communications.

It is also indicated that the same standards as developed and extended for information systems and data exchange in relation to future TSO-DSO coordination and interaction can also be adopted and applied to virtual TSO-DSO coordination and interaction potentially involving interconnected systems of digital twins.


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