ELECTRA

CIGRE's Digital magazine

ELECTRA N°336
October 2024

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Editorial by Konstantin O. Papailiou, new President of CIGRE

By Konstantin O. Papailiou
President of CIGRE

Dear CIGRE Colleagues,

Twenty years ago, in 2004, the Olympic Games came back to Athens, where they had been held in 1896 for the first time after an initiative of a French nobleman and his Greek friend; I had then the chance to serve as one of the many volunteers. This year the Games took place in Paris, coinciding with the 50th Session of CIGRE; I got again a chance to serve as a volunteer, this time as the President of CIGRE.

Olympic Games and CIGRE have many things in common: Both thrive for excellence, are inclusive, connect people, meet at great places, and are fun. Also new records were set during the Games in Paris and our Session. We have had the largest number of registrations (4,575), papers (1,200), exhibitors (315) and visitors (11,000).

Evidently such a huge success does not come out of the blue. It is the result of hard work and excellent management by the CIGRE officers and the Central Office team. For this I would like to thank from heart my good friends, immediate past President Michel Augonnet, VP Technical Marcio Szechtman, VP Finance and Marketing Mike Heyeck, and Secretary General Philippe Adam. They managed the impossible! Not only they have steered with a steady hand, together with another good friend, past President Rob Stephen, CIGRE through the pandemic, at the same time they have prepared a future oriented strategic plan, improved our financial situation and attracted a great number of new members; we will soon be exceeding the 20,000 mark!

I have been fortunate enough to serve CIGRE for quite a long time. Starting as WG member, then Secretary and WG Convenor, the highlight of my CIGRE career – until now – has been my tenure as SC Chairman for SC B2 (Overhead Lines) from 2010 to 2016. And now I am getting a huge chance to serve as President!

It is my honour and privilege to be at the helm of an organisation, which is to use an Olympic term, in top form. And my challenge will be to continue, together with the new VP Technical Rannveig Loken, VP Marketing and Finance Mike Heyeck who stays on board, and evidently with our Secretary General Philippe Adam, the CIGRE success story.

Here are some of the issues on which I would like to focus:

- **National Committees**: The National Committees are the backbone of CIGRE, as they interact directly with our members. Supporting them in their activities, e.g. by providing technical expertise, but also liaison with other NCs, is crucial. My plan is to visit each NC and formulate an action plan for their further development and progress.
- **Voice of CIGRE**: In a media dominated world, CIGRE's advice should be heard and valued by decision makers. As it is impartial, inclusive and not profit-driven, it

must become a "one-stop-shop" for unbiased information in the field of electrical networks from end-to-end. I plan to personally visit key persons in industry, academia and government agencies and present them the benefits of CIGRE.

- **CIGRE Seniors**: Keeping in mind the shortage of talent our branch is facing, increased participation of our NGN and WiE will play a crucial role toward our goal, i.e. sustainable and affordable energy for all. But at the same time, we cannot afford to lose the talent of our highly qualified experts, who are finishing their term as WG members, Convenors, SC Chairs, after having greatly contributed to the legacy of CIGRE. My plan is to create for them the LGN (Legacy Generation Network), so that they can continue to serve CIGRE as advisors, tutors or mentors.

As I settle into my new role, I look forward to hearing from you and am open to ideas and suggestions that will ensure CIGRE's continued development.

Thank you all for the confidence you entrust me,

Konstantin O. Papailiou

High Voltage Direct Current Transmission Lines and Impact on Human Health

The possible health effects of electric and magnetic fields produced by high voltage alternating current power lines have been the subject of a large international research effort over the last 40 years. Overall, the results have been reassuring. No particular health effect has been reported as likely to occur at field levels below the current exposure limits. Few concerns about the possible effects of static electric and magnetic fields produced by high-voltage DC power lines (HVDC) have been expressed. This article summarizes the relevant characteristics of HVDC power lines to human exposure. It explains why the particular environment around an HVDC power line is not expected to impact human health.

M. Plante M.D., Hydro-Québec (CA), M.B. Barbieri Eng., Universitad national de la Plata (AR), J.A. Bulcao M.D., Medical Advisor (BR), P.A. Cabanes M.D., EDF (FR), F. Deschamps Eng., RTE (FR), S. Jackson M.D., EDF-Energy (UK), L. Korpinen Dr. Tech., M.D., Elenhe Ky (FI), I. Magne Ph.D., EDF (FR), S. Nakasono Ph.D., Central Research Institute of Electric Power Industry (JP), D.H. Nguyen Eng., Hydro-Québec (CA), G. Ostiguy M.D., Hydro-Québec (CA), D. Stunder Ph.D., Amprion GmbH (DE), H. Tripp Ph.D., National Grid (UK)

Static magnetic field

The electric and magnetic fields produced by a DC line are static. The intensity of the fields measured 1 m above ground usually falls within the range of the natural fields that exist at the surface of the Earth.

The Earth magnetic field varies from 35 microteslas (µT) at the Equator to about 70 µT in polar regions. The ground-level field beneath the HVDC line will be the vector sum of the Earth's magnetic field and the field produced by the line. The total magnetic field is higher than the natural field when both components point in the same direction and lower when they are in opposite directions. The line creates a local distortion of the natural geomagnetic field which is limited to a few tens of meters from the centerline. In the case of an underground DC line, magnetic field strength can reach occasionally 100 µT due to the proximity of the cables, and attention should be paid to the field level at the height of 10 cm above the ground to avoid interference with cardiac implants (worst case scenario of a person with a cardiac implant lying on the ground). The recommended limit to avoid interference is 500 µT.

The human body is transparent to the magnetic field since it does not naturally contain metals in a significant amount reacting with such fields. The body can be exposed to very high levels of static magnetic fields with no observed harmful effects. Medical imaging equipment (MRI) produces static magnetic fields of roughly 2 T, which is 40,000 times stronger than the Earth's magnetic field. Widespread use of imaging equipment over the past three decades and research to ensure their safety has not revealed any harmful effects if metallic implants reacting to magnetic fields are avoided. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) recommends a field limit value of 2 T for worker exposure and 0,4 T for public exposure. These values are thousands of times higher than typical magnetic fields level produced by an HVDC line.

Static electric field

There is a static electric field everywhere on the surface of the Earth with an intensity of about 100 V/m. The intensity shows diurnal and seasonal fluctuations in a range of intensities between 50 and 300 V/m nearly 90% of the time. When a thunderstorm approaches, the electric field reaches much higher values, on the order of 10 kV/m to 20 kV/m at ground level.

The level of electric field produced by HVDC lines depends on several factors including the voltage of the line, the height of the conductors above the ground, the spatial configuration of the conductors, and atmospheric conditions. The electric field reaches a few kV/m under the conductors. It decreases rapidly with distance and generally reaches a value close to the natural level within a hundred meters from the center of the line.

Corona discharges (spontaneous micro-discharges at the surface of the conductors) ionize air molecules. In the case of an HVDC line, ions of opposite polarity to the conductor are immediately attracted by the electrostatic force, and the ion of the same polarity is repelled by following the electric field lines and the wind. Air ions are a natural phenomenon generated by various atmospheric and natural events. Air ion concentrations near ground level vary over a wide range. Fair weather values over land are typically in the range of 500 to 1000 ions/cm3 but can easily vary from 200 to 3000 ions/cm3 of both polarities. Reported values of air ions concentration under an HVDC line vary according to the intensity of the corona discharges, and atmospheric and wind conditions. Air ion concentrations are typically below 10,000 ions per cm3 and rarely exceed a few tens of thousands of ions per cm3. From a toxicological or physical perspective, there is no scientific basis to suspect that air ions would have significant physiological or pathological effects. A comprehensive review of experimental data has concluded that neither positive nor negative ion exposure appears to have any clear physiological effects or potential for toxicity.

There are no known harmful effects from exposure to the static electric field. When a person's body is exposed to a static field and the person is well grounded (for example, bare feet on a wet floor), the body cannot accumulate electric charges and remains at the same electric potential as the floor. If this person is well insulated from the ground (for example, shoes with insulating soles), electric charges can accumulate and cause a rise in the electric potential of the body. The phenomenon is slow because it is the electric charges present in minute quantities in the air that allow this accumulation.

There have been relatively few experimental studies on the effects of static electric fields in humans. The interaction of a static electric field with the human body is limited to the surface of the skin and physical considerations preclude the possibility of any direct effect on internal physiology. A systematic review of the biological effects of exposure to static electric fields in humans and vertebrates was published in 2017. The review did not find evidence that static electric fields have adverse biological effects on humans and animals. There was clear evidence that humans and animals can perceive the presence of a static electric field at sufficiently high levels. The data strongly supports the role of superficial sensory stimulation of hair and skin as the basis for perception of the field as well as reported indirect behavioral and physiological responses.

Experimental data showed that the presence of ions lowers the threshold of perception of static electric fields. However, electric field and ion currents levels measured under existing lines up to 600 kV/m suggest that the probability for a person to experience some type of subtle sensory perception is low.

In conclusion, static electric and magnetic fields produced by the HVDC line are safe and there is no scientific evidence that they pose a risk to human health.

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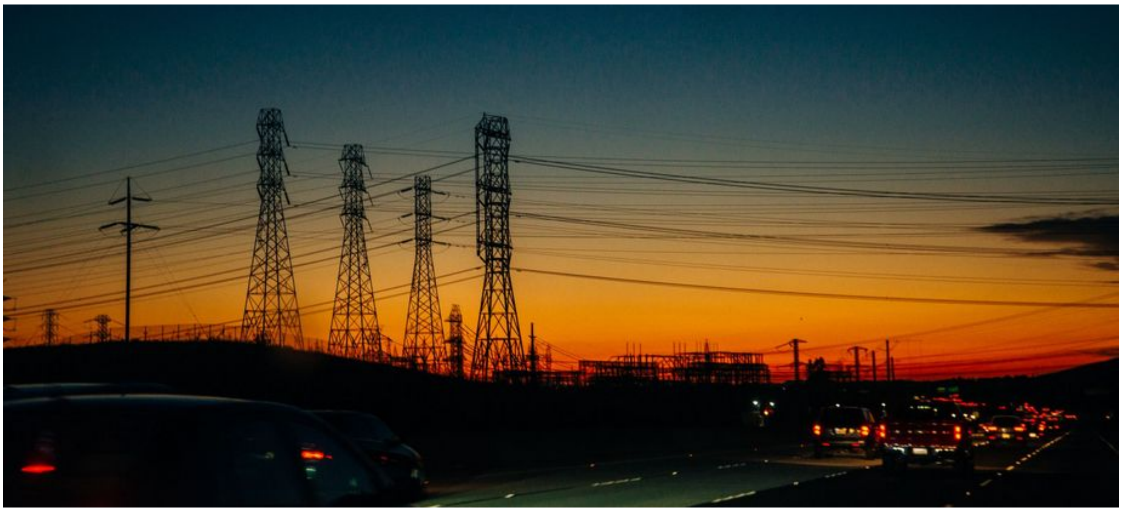
Implementation of the IEC 61850 standard in Colombia - Requirements and challenges in the implementation of digital substations

Working group B.5.8 of CIGRE Colombia presents an analysis of the current status of Digital Substations (DS) in the companies of the Colombian electricity sector, including requirements and challenges throughout the implementation process. In the technical report, the working group analyses the country's progress with experiences acquired in the implementation of DSs through the digitisation of protection and control systems, or digitisation in its entirety, including TCs and TP yard equipment, and socialises them with the CIGRE community, academia and industry, exposing implementation and validation strategies developed in utilities for the correct and adequate planning, design, operation and commissioning of this type of system, considering compliance with the international standard IEC 61850.



By Gómez-Luna Eduardo [1], Tobar-Rosero Oscar Andrés [2], Piñeros-Saldarriaga Juan Fernando [3], Hernández-Fúquene Fabio [4], Quintero-Pineda Mónica [5], Castillo-Bautista Wilson [6], Molina-Castro Juan David [7], Giraldo-Arenas Cristóbal Marino [8]

1. Universidad del Valle, Grupo GRALTA - 2. Universidad Nacional de Colombia, LACI - 3. XM S.A. E.S.P, 4. HART, Energy & Control Consulting - 5. Empresas Públicas de Medellín, Electric Power Generation, Transmission and Distribution Projects - 6. ISA Interconexión Eléctrica, Substation Automation System, S.A. E.S.P - 7. Colombia Inteligente - 8. CELSIA, Transmission and Distribution Maintenance, S.A. E.S.P.

Digital substations use the benefits of protection, control and communication technologies, eliminating electrical connections between power equipment and protection and control equipment, creating safer, more flexible, efficient and reliable working environments, reducing the costs of construction, land, engineering, commissioning, operation, maintenance and scalability [1]-[3].

As evidenced in this research, in the country, its implementation is being carried out in stages, from the conventional to the digital, which is why in this **Working Group of CIGRE Colombia B5.8**, we are working to unify criteria, experiences and success stories, to provide valuable information for the industry to minimise time, costs and risks, to achieve correct and adequate planning, design, operation and commissioning of such systems and achieve the digitisation of assets and information in a substation.

In this process, some standards support interoperability between devices from different suppliers, standardising communication and information management aspects and criteria for designing, operating and maintaining a substation under a technological architecture [4]-[11].

The activities developed by Colombia Inteligente indicate that although the objective of the process of digitalisation of electrical substations is to reach a 100% digital substation, it is essential to consider levels of digitalisation, given the existence of conventional assets or the requirement of functionalities by type of substation. According to what is described in Colombia Inteligente (2019), intermediate implementation steps are identified, such as Level I with the application of the station bus (IEDs that comply with protection, automation and control functionalities), Level II with the implementation of the process bus with digital signals and subsequently digitising the analogue signals through the use of specialised Merging Units (Level III); finally, in Level IV, the analogue signals are digitised directly in the device using non-conventional instrumentation transformers (Fig. 1).

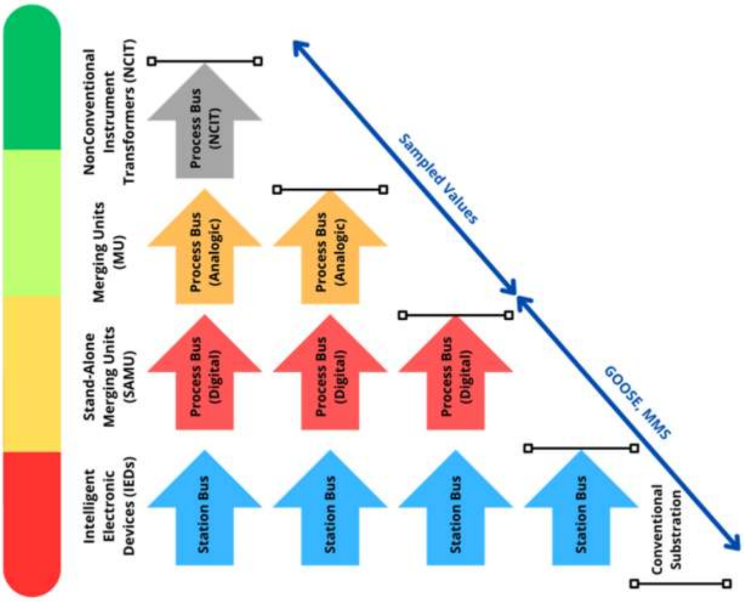


Figure 1 - Levels of digitisation in substations Source: Taken from Colombia Inteligente (2019)

In general, business experiences in Colombia focus on station bus applications (Level I) with several operational substations and some pilot projects in process bus with digital signals (Level II). Also, the working group report compiles some of the lessons learned in the country, which were identified through the implementation of station bus projects and research on process bus pilot projects [7].

Finally, collecting lessons learned also allowed the identification of gaps in the digitalisation of substations. Through the collaborative discussion of different actors, actions were established to close the gaps and promote the development of digital substations in the country [7].

Methodology - Sectoral research in Colombia

Despite the IEC 61850 standard being in existence for over 15 years, Colombia has seen relatively few successful total digital substation implementations compared to its global counterparts. This necessitates thoroughly examining the experiences and challenges encountered by stakeholders in the Colombian electricity sector to pinpoint the hurdles inhibiting the shift from traditional to digital substations.

An elaborate survey comprising approximately 20 targeted questions was disseminated among industry experts and leaders adept in DS technologies to gather insights. A diverse pool of respondents contributed their perspectives, including network operators, consultants, integrators, manufacturers, academics, and governmental bodies.

The survey's findings facilitate an evaluation of Colombia's progress toward digital substation integration, spotlighting the sector's specific requirements, challenges, and needs by the IEC 61850 standard. The research culminates in actionable recommendations and identifies critical factors for industry entities to aid in the digital transition, ensuring technological advancement and knowledge assimilation.

— Results

The following are some of the results obtained from the closed questions posed in the sector research:

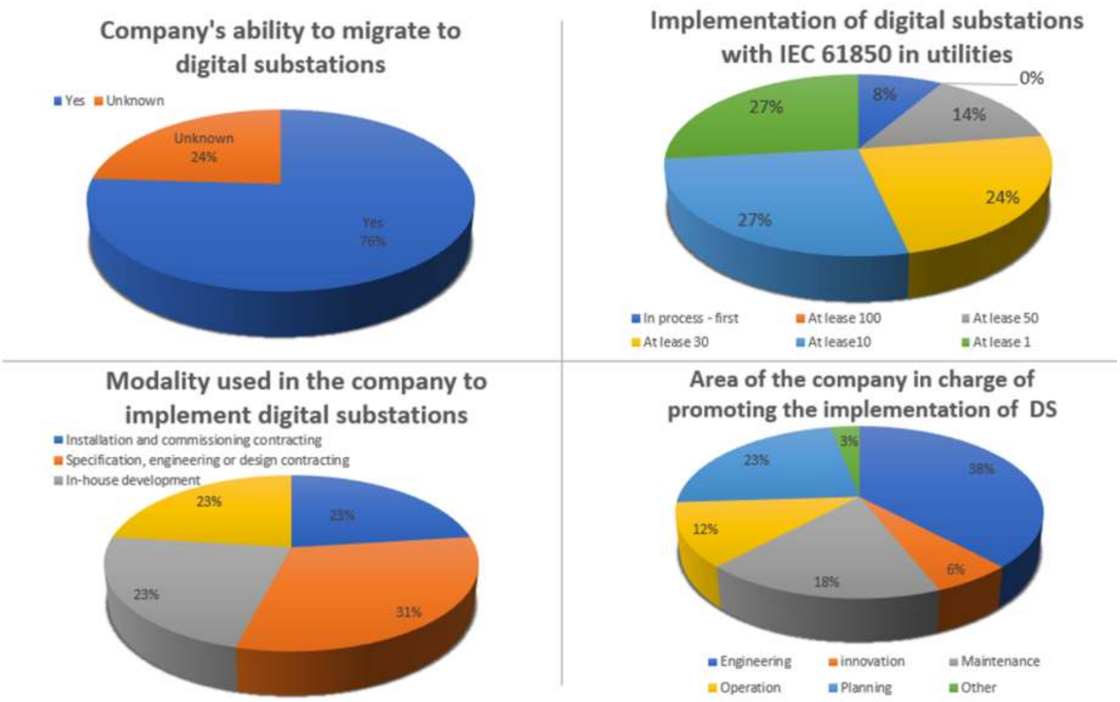


Figure 2 - Results from the survey in sectorial research

Company vision

Closed question	Result
Company investment in substation digitisation	more than 83% Yes
Expectations of implementation in digital substations	59% SB and 29% PB.
The company has implementation guidelines	more than 53% Yes
Benefits in Asset Management from DS (CREG 015 -local normative)	53% Yes
Benefits of digital twins for DS validation	63%.Yes
Equipment used in DS	MUs, IEDs, Gateway, Redbox, Switches, GPS, NCIT, etc.

Challenges

Technical and technological challenges faced when implementing a digital substation:	
1. low knowledge of the technology	5. Current regulations in the country
2. Technology still under development	6. High Cost
3. Testing and laboratories	7. Availability and traceability of information
4. Openness to change of new technology	8. Difficulty in implementing practical and functional designs

In a particular case, 75% of respondents stated that the regulatory challenges are mainly oriented towards the conventional regulatory scheme, operational integration and digital culture.

Success factors in the implementation of digital substations

- 20%: Training and coaching operation and maintenance personnel in equipment assembly, regulations and standards to strengthen their knowledge and technological skills.
- 20% Standardisation of communications architecture and substation designs is very much in line with what is being sought in terms of technology integration.
- 20% Interoperability between the different technologies, obtained through the standardisation of communication protocols, to achieve an adequate and lasting technological integration.
- 13%: Reduction in the size of substations (equipment, cabling and control rooms), which is being sought in companies and especially in urban areas where it is difficult to obtain land to locate substations in areas of high development.
- 13%: Change management and the support of top management in implementing new technologies.
- 14% did not establish specific success factors and found specific benefits in improved communications, protocols, etc.

Other Challenges

- Significant risks are evident from the point of view of cybersecurity, the degree of maturity of the technology and the lack of standardisation and normalisation of automation and telecommunications equipment in the country.
- Fear of change on the part of technical staff - technical and occupational risks.
- Interoperability risk, mostly with multi-vendor systems.
- Convincing end-customers of the technology's performance.
- Cost of integration by different manufacturers.

- Adopt and use laboratories commensurate with current infrastructure, technology and knowledge for technology validation and FAT testing.

Conclusions

Our study offers a snapshot of Colombia's electrical sector's current state regarding adopting digital substations. It reveals progress and challenges in deploying the IEC 61850 standard, highlighting technical, economic, and regulatory aspects from diverse industry perspectives, including academia, consultants, suppliers, manufacturers, and network operators.

A noticeable gap between academia and industry was identified, especially in the education and implementation of digital substations. Bridging this gap requires aligning academic curricula with industry demands to equip new engineers with the broad, in-depth knowledge necessary for swift and effective industry integration.

Professionals must possess comprehensive knowledge, extending beyond core electrical engineering to include data networks, telecommunications, programming, systems, and cybersecurity to facilitate digital substation modernisation effectively.

Technologically, the appropriateness of implementing the process bus across transmission, generation, and distribution networks warrants validation. While its benefits for distribution networks may not seem cost-effective, other factors like asset monitoring and management should be considered.

Advancing knowledge about current electrical sector trends is crucial, as well as setting best practices for automating substations, thus enhancing Colombian companies' service quality and reliability for their clients.

The evolution of the IEC 61850 standard has been pivotal for digital substations, ensuring interoperability and data exchange between equipment. Although widely adopted for station bus applications, deploying the process bus section of the standard remains a challenge for the Colombian electrical sector.

The standard's implementation signifies a challenge in human capital management, requiring knowledge beyond the standard itself. Networking, synchronisation, cybersecurity, and network digitalisation are gaining importance, calling for expanding the knowledge base among professionals designing and commissioning these substations.

Significant progress in digital substation implementation hinges on creating Constructive Units (CCUU) that incorporate new elements to justify investment through tariffs, as done with conventional substations, justified as service quality improvements and real-time monitoring.

Colombia must prepare to adopt laboratories meeting the demands of Digital Substations using digital twins for planning, designing, and validating integrated new technologies, reducing risks, time, and costs for any DS implementation.

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GLOBAL CONNECTIONS

Powering the Future with electrons and molecules: Sector Integration in the Netherlands

In the CIGRE strategy sector integration has been highlighted as a strategical building block for shaping the power system of the future. This article wants to share the importance of sector integration as an obvious strategy in the energy vision of the Netherlands, given the geographical and demographical situation of this country.
The Netherlands has set ambitious targets for reducing greenhouse gas emissions, as part of the country's Climate Agreement. The objective is to reduce greenhouse gas emissions by 55% by 2030 compared to the levels in 1990, and to achieve a 95% reduction in greenhouse gas emissions by 2050, compared to the same levels in 1990.

By Diana VAN DEN HEUVEL
Chair CIGRE National Committee of the Netherlands

The unique geographical location of the country, with the North Sea on its doorstep, presents an excellent opportunity for achieving the targets of 48-92 GW wind production, 100-183 GW sun production, and 16-45 GW hydrogen production in 2050 via an integral connection of offshore and onshore energy infrastructure.

However, production of offshore sustainable energy poses challenges for the transportation and distribution onshore due to the country's high population density.

— Limited space for expansion of infrastructure

With a population density of around 508 people per square kilometre, making the Netherlands as one of the most densely populated countries in Europe, expansion of onshore infrastructure presents additional challenges as the existing infrastructures of electricity, gas, heat, and CO2 will not suffice. Next to expansion of these existing infrastructures, also new infrastructure must be constructed for hydrogen and EV charging.

Netbeheer Nederland's Integral Infrastructural Exploration 2030-2050 provides several scenarios that demonstrate, no matter which scenario, how the Dutch energy transition is an infrastructural energy transition, mainly driven by electrification and hydrogen (Figure 1).

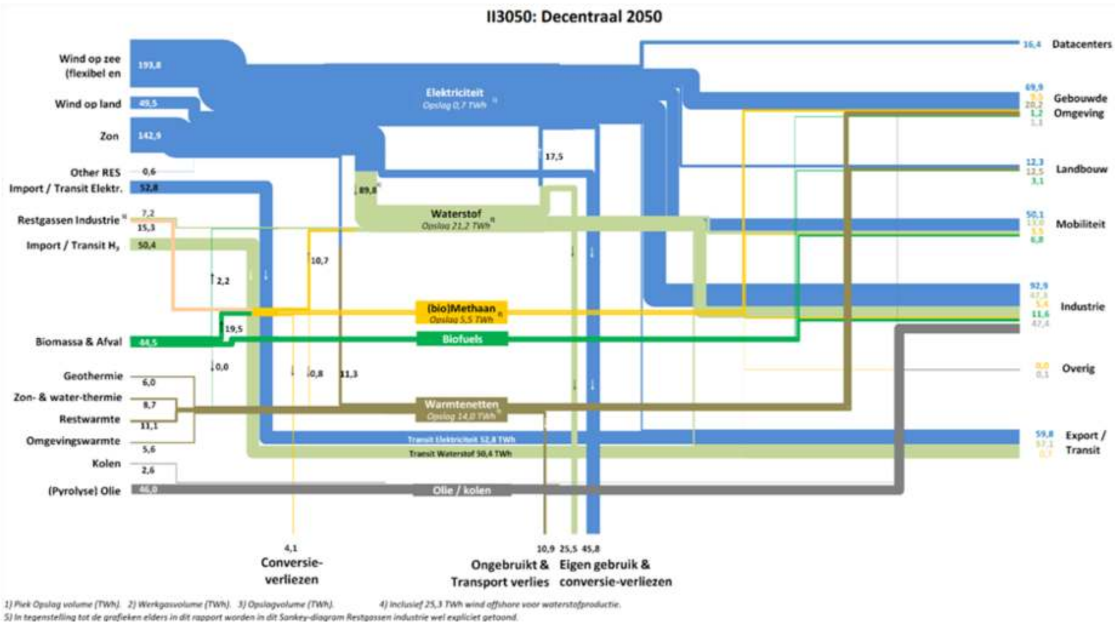

Figure 1 - Infrastructural driven energy transition [1]

Electrification alone will have a huge infrastructural impact, meaning that for transportation of renewable wind energy produced by approximately 1,700 wind turbines in 2030 multiple 380 kilovolt (kV) high-voltage stations must be built, each station being as large as twelve football fields. And by 2050, one in three streets in the Netherlands will be dug up to lay cables for green electricity, 50,000 new neighbourhood stations will be installed, and 100,000 kilometres of underground cables will be laid. To accommodate the conversion of renewable wind energy into hydrogen and transportation to the industrial clusters 1,200 kilometre of hydrogen infrastructure need to be built, although, due to the phase out of natural gas 85% of the existing gas infrastructure can be used for hydrogen transportation.

It goes without saying that sector integration of this magnitude must be coordinated, and this is done in the Multi-Year Infrastructure Energy and Climate Program, a national collaboration between the Dutch government, industry, DSOs and TSO.

Collaboration however doesn't stop at the borders. To increase reliability of electricity supply interconnection capacity with the neighbouring countries like the UK, Belgium, Germany, Denmark, and Norway must increase two and a half to three and a half times (Figure 2).

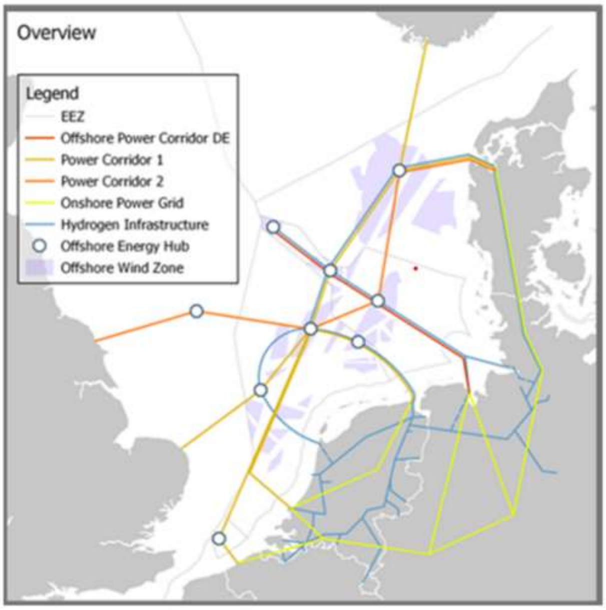

Figure 2 - Sector integration of wind, electricity and hydrogen offshore and onshore [1]

Moreover, sector integration brings efficiency, acceleration, and cost reduction as aimed for example in the plans for the Delta Rhine Corridor (Figure 3 brown route), which will connect the ports of Rotterdam and Antwerp to major industrial centres in the Netherlands, Belgium, and Germany with a 270-kilometre corridor for hydrogen-en CO_2 pipelines and 3 2GW DC cables to transport renewable offshore wind electricity.

Figure 3 - Overview MIEK projects [2]

Demand-Supply of the industry: an indispensable piece of the puzzle

In 2021, 31% of the total amount of greenhouse gases in the Netherlands was emitted by industry and has been reduced from 53,6Mton in 2021 to 47,8 Mton in 2023. Within industry, the chemical industry is the largest polluter, with 29% of total industrial emissions.

Sector integration with the industry, especially in the chemical industry, plays a crucial role in the reduction of green house gases, in particular the demand-supply especially of the production of synthetic fuels using sustainable energy. Synthetic fuels are produced by reacting hydrogen with other molecules, commonly CO2. Limited manufacturing of synthetic products using sustainable energy leads to more structural transport of this sustainable electricity abroad. Thus, it requires considerably more electricity infrastructure. Additionally, clarification of demand-supply of synthetic products is also decisive for the future development of the CO2 infrastructure as a shift of the industry towards production of synthetic products would lead to a substantial demand and utilization of CO2. Storage of CO2 will become even more crucial. For example, the project Aramis alone will realise an annual storage of 5 CO2 Mton per year, with a further growth to 12 and ultimately 22 Mton per year. The CO2 network of the future (Figure 4) plays an important role in facilitating the CO2 reduction targets of the Dutch industry.

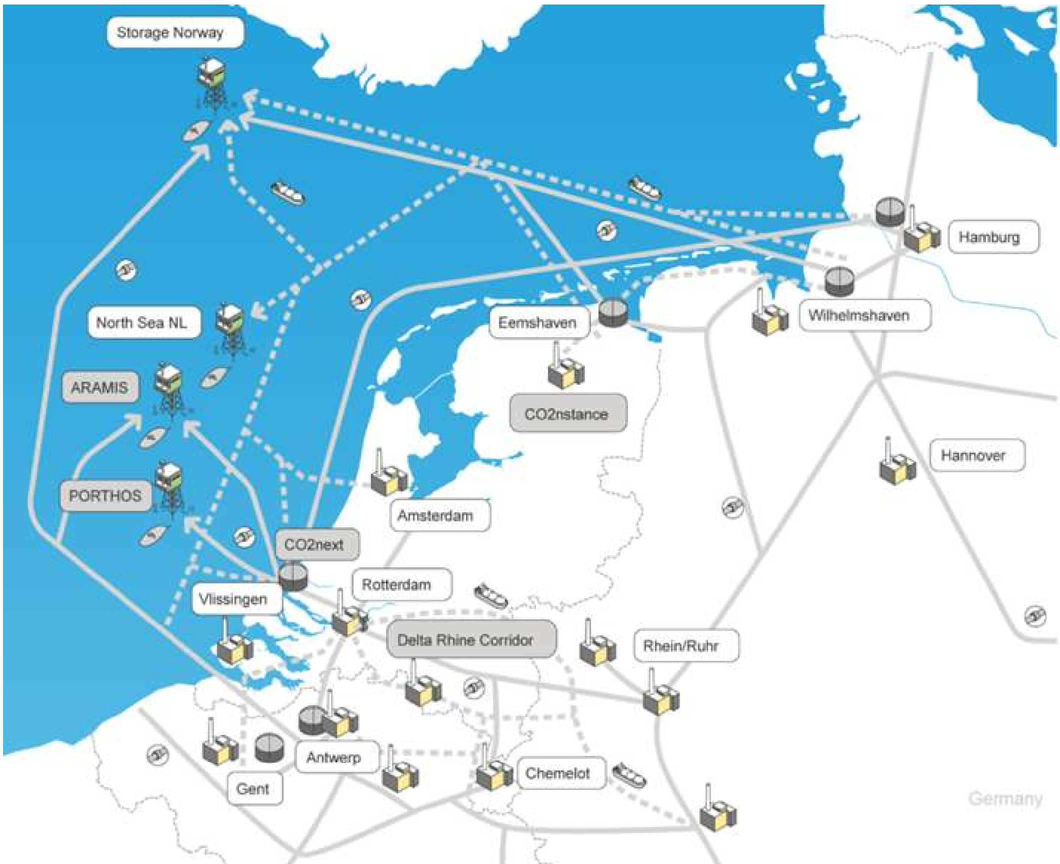

Figure 4 - CO_2 infrastructure of the future [1]

Conclusion

The Dutch energy transition could not happen without sector integration and a coordinated approach of offshore and onshore infrastructural developments which need to be aligned between energy demand and supply stakeholders. In this jigsaw puzzle every piece needs to fit at the right time in the right place, nationally and internationally making it a transformation that is unprecedented.

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About the Author

*In former leading roles in Eneco, a leading sustainable energy company in the Netherlands, **Diana van den Heuvel** shaped the energy liberalization. As a corporate account director in Siemens Energy, she leads the strategical development of key accounts in the energy transition. In her additional role as member of the Dutch Research Council, one of the most important science funding bodies in the Netherlands for quality and innovation she approves funding for innovation projects for SMEs.*

As Chair of Women in Energy Netherlands and Chair of Women Engineers of the Royal Dutch Institute of Engineers she represents and promotes diversity and inclusion.

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Out with the Old and in with the New

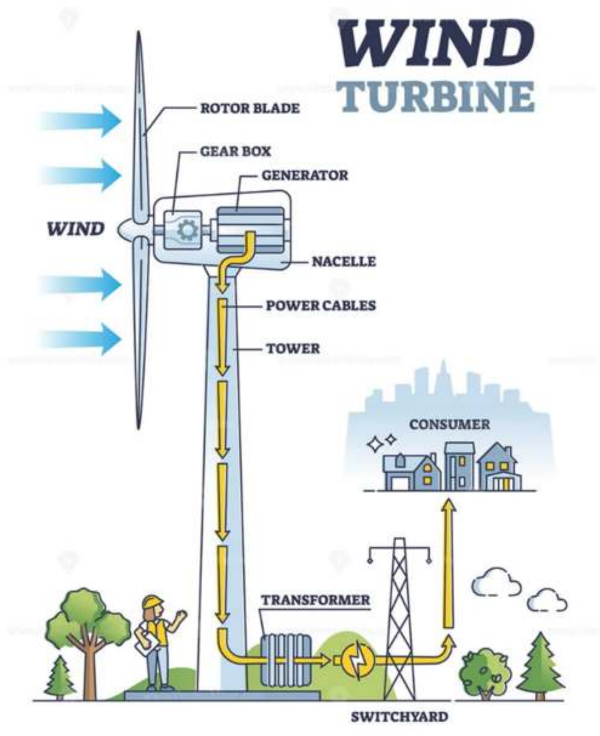
Study Committee A2 branches into new transformer applications.

Don't worry, traditional transformers – aren't going anywhere. They are just transforming… and so is Study Committee A2.

By Tara-lee MacArthur and Peter Werle

As we start to see a lot of new applications for transformers due to the worldwide energy transition process.

It starts with the massive expansion of photovoltaic and wind energy plants, thus today an additional installed energy capacity of around 2.500 GW worldwide has been reached. Therefore, additional new transformers have been installed in a range of 1 million pieces worldwide. Most of them acting as generator step up transformers (GSUs).



These transformers differ from conventional GSU transformers because they have significantly lower power ratings (typically <10 MVA in contrast to >100 MVA) and significantly lower operating voltages (medium voltage area). Therefore, these transformers are designated as Lower Voltage Generator Step-Up Transformers (LV-GSUs) as they are more like distribution transformers. Moreover, usually these LV-GSUs are in comparison to conventional GSUs highly stressed by fluctuating loads and in addition by harmonics, because they are often fed by inverter-systems instead of generator sets. Therefore, the design and the insulating system of these LV-GSUs differ significantly compared to the conventional ones. In comparison to large GSUs the small units can be designed as dry type transformer insulated by epoxy resin. In case of liquid insulated systems, alternative liquids like natural or synthetic esters in combination with thermally upgraded or even aramid paper are often used, which is unusual for conventional GSUs. Of course, the cost-price of the LV-GSUs is much lower compared to conventional ones, but the importance is similar, because a failure led to a power interruption and in case of off-shore systems the installation/repair/exchange is extremely costly.

In the last decade several failures on such LV-GSUs have been reported, leading to the assumption that they are less reliable than the conventional large GSUs. Therefore CIGRE has started the working group WG A2.68 with the goal to better estimate the failure rate, the reliability and failure root causes of these LV-GSUs. Based on such a study, it would be possible to determine failure rates of such transformers and therefore also to compare the reliability of different insulating systems. This will allow to recommend certain design parameters or improved testing for future applications and might trigger additional working groups if specific failure root causes can be identified more often than other ones.

This is important because today only approx. 10% of the transformers needed for the energy transition are installed, thus millions of transformers for such and similar applications are required in the future. For example, charging stations for E-mobility as well as Battery Energy Storage System require also special transformers with high fluctuating loads. Furthermore, many transformers will also be used in the future in the field of fuel cell energy supply, which may also have certain similarities to the LV-GSUs.

The trend to lower voltage applications can also be seen in the increasing use of “electronic transformers”. These transformers should be called *Power Electronic Inverters (PEI) or Power Electronic Converters (PEC)*, because the term “transformer” is already taken and clearly defined in various standards. Furthermore, these applications become more and more important, so that these components should also have its own name.

As a result of the energy transition, many conventional GSUs were taken out of service as a result of the phase-out of coal or nuclear power, but instead thousands of new LV-GSUs are installed, thus there are many new challenges in the transformer sector that require innovative solutions and new technologies. This can only be solved with the help of increasing engineering capacity, whereby experienced and young professionals must exchange ideas in committees such as CIGRE. The CIGRE Study Committee for Transformers (SC A2) therefore calls on young professionals to connect with CIGRE to jointly realize the electrical energy system of the future.

We envision that we will always need transformers and that we will keep adapting for new applications in the future.

Thumbnail credit: SimonSkafar on iStock

Lifelong Supervision and Management of Substations and the Digital Twin Concept

Substations are important for the proper operation of electrical grids and must provide their functionality over many decades. To achieve this goal a suitable concept for lifelong supervision and management (LLSM) of substations is needed [1]. Ideally it should provide real-time awareness of the status and reliable predictions, such that proper actions for maintenance, operation or management can be done.

by Nicolaie Fantana

Convener CIGRE JWG B3.D2.62, Consultant, Germany

Introduction

A systematical approach that can combine substation life data, and knowledge and provide a framework for situational awareness and improve lifelong management possibilities for substations is provided by the digital twin (DT) concept.

Technological advances like modern smart and affordable sensors, fast communication, mobile devices, IoT, computational possibilities, knowledge on physical phenomena are strong enablers and the basis to implement such a concept with reasonable and justifiable effort and costs.

This article intends to present the DT concept with focus on substation assets and supervision and management and to create a common understanding for substation engineers.

Lifelong Aspects and Challenges

Installed equipment in substations is typically heterogeneous, of various ages in stages of their lives, with of miscellaneous brands, builds, and technologies, and with different life expectations, failure modes, and robustness. Economic, technical, environmental, and regulatory constraints require quick and effective operation, maintenance and management responses.

The aim of a LLSM strategy for substations is keep them operational by:

- achieving detailed and well-informed substation and equipment situational awareness, in real-time or near-time in terms of status, condition, risk, and capabilities.
- supporting timely and optimized operational and maintenance decisions, avoiding unplanned outages, forecasting evolution, and predicting potential

failure or events, thereby ensuring reliability and safety.
- allowing cost-efficient and environmentally conscious asset management.

The main challenges to achieve these goals result from aspects related to:

1. Complexity and heterogeneity of the substations and equipment installed in terms of technologies, ages, sizes, materials, and brands. Also, small distribution substations are very numerous and often distributed over large areas.
2. Fast reaction time required by events and the rapid changes in the smart grid operations due to distributed energy resources, power flows, events, and power quality expectations.
3. Long life of substation equipment assets, requiring management over decades and much shorter lives of sensors and automation equipment.
4. Life data availability, implying to have sufficient, relevant, and reliable and accessible data for equipment and substations, over lifetime: real-time, near-time, event data and historical data.
5. Knowledge of installed equipment functioning details, failure modes, materials, short and long-term degradation phenomena, is essential and should be available in usable form and validated for proper use.

Towards a Lifelong Supervision and Management Strategy

The main prerequisites to implement a LLSM strategy for substations and their equipment are:

- **Availability of lifetime data**, of sufficient technical and economic relevance, quality, completeness, timeliness, and accuracy. The data needs to be stored in digital format and in systems that allow fetching and use on demand.
- **The knowledge** of substation, equipment, parts, and materials reflecting their behavior, aging, short and long-term degradation, and failure modes. Knowledge needs to continuously evolve since new materials, and designs occur.
- **An integrated, systematic, and structured concept** covering lifelong aspects, linking, and describing interactions of the real-world substations, their operations, and activities, with the digital world of data and knowledge and with decisions and actions. These requirements can be provided by the DT concept, which is a representation of real equipment and phenomena from the physical world, and which integrates equipment and virtual digital layers.

Availability of lifetime data needs systematic data collection. Typical equipment and substation life data categories of interest for LLSM are shown in Figure 1. The operational life of an equipment is indicated by the vertical dotted lines. Besides, there is data from design, calculations, CAD, BIM, manufacturing process and testing. Also, data from postmortem analysis may exist.

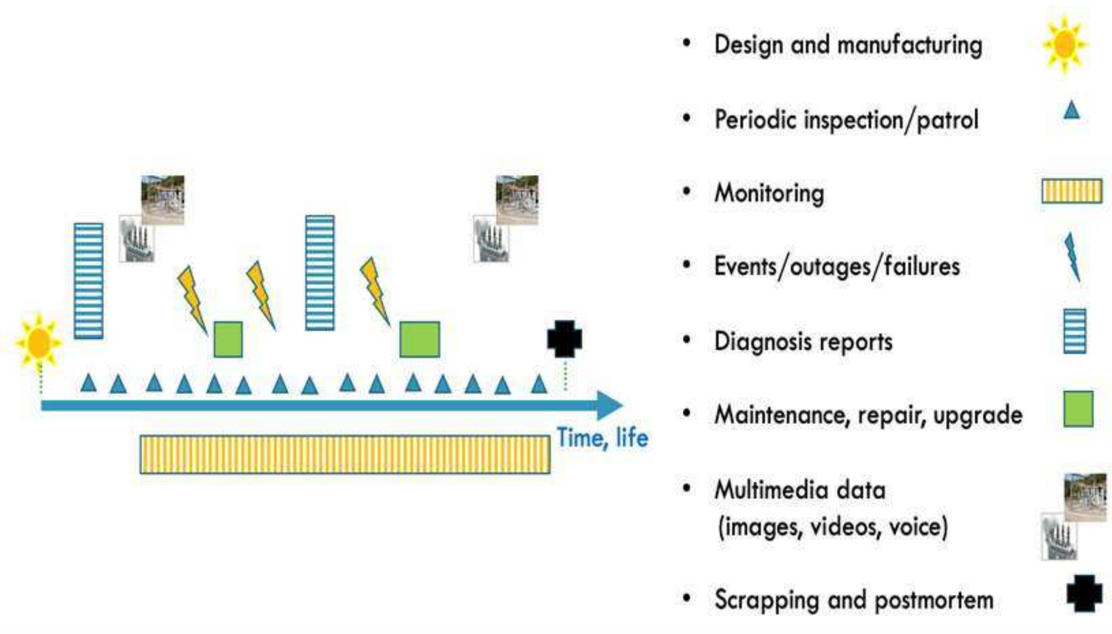


Figure 1 - Equipment data categories over lifetime real-world and with a focus on asset supervision, management, and life events

Lifetime data collection is increasingly affordable due to the advances in sensor technologies, microelectronics, and ICT. Sensors built-in or retrofitted to the equipment, IoT smart sensors and WSN and mobile devices worn by substation staff collect alpha-numeric and increasingly multimedia data during on-site activities. Cloud or enterprise storage capabilities ensure safe data storage and handling.

These may result in huge data amount over lifetime, which require increased effort and costs for cleaning, validating, storing, fetching, and managing data.

A key aspect of lifetime data collection is to ensure the data is relevant, accurate, valid, and trustworthy, which is related to both technical aspects and security challenges and not only storage and handling. The OT and IT views need to be combined to mitigate this, for example considering what data is collected, what is relevant and should be kept and stored and for how long.

Lifetime data for substations must be considered in a holistic context of operation, maintenance, and asset management and should be guided by engineering knowledge on substation and lifetime behavior, ITC, and security and economic aspects.

The knowledge especially related to how to describe, and formalize usable computational models for substations, equipment, parts, or subsystems is important but also challenging. Knowledge needs to evolve due to changes in grid, materials, designs or stresses.

Main difficulties arise also due to long-time phenomena, complex and concurrent stresses, the diversity of materials, the evolving design of equipment and devices.

The supporting concept needs to be: based on data and knowledge, be systematic and structured, offer an integrated holistic view for LLSM of substations and their installed equipment and allow to act, decide, control, and manage the substation and their equipment. The DT concept is well suited and responds to the needs of substation LLSM.

DT Concept for Lifelong Supervision and Management of Substations

The "DT" is almost a buzzword, but often means different things or is used differently by authors. For clarification: a twin is "something containing or consisting of two matching or corresponding parts" [2], while digital implies that one of the two matching parts is described by bits and bytes and software. The DT concept as presented in this paper focuses on assets, and addresses substation lifetime engineering and management needs and is aligned with the original DT concept as used by Grieves [3].

The goal of the DT concept is to support business by supporting lifelong efficient, cost-effective operation, maintenance, and asset management decisions for sustainable operation and qualitative energy delivery.

The DT concept usable for substation supervision and management, consists of the real-world objects, their digital representation in the virtual world by data and modeling software, and interactions between these two, implying collection of real-world data for digital use and applying information and control actions to the real-world entities.

The digital representation in the virtual world contains all relevant details of the substation and equipment, parts or devices installed, their operational status, capabilities, and condition at a certain time instant and situation in the grid, and the status of ongoing physical change processes. Figure 2 shows a general view of the DT concept usable for substation LLSM.

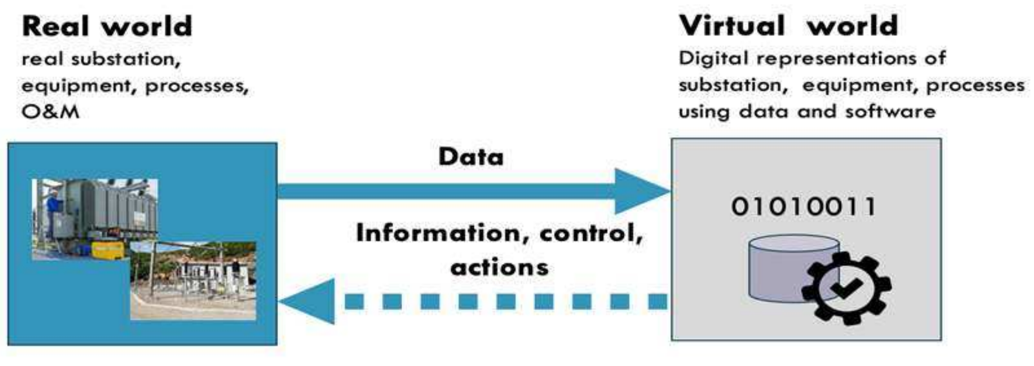


Figure 2 - General view of the DT concept usable for substations LLSM

In more detail, representation of real-world entities in the virtual world is shown in Figure 3 with a focus on the needs and common reasoning of a substation and IT engineers from utilities. Arrows are showing the corresponding representations as follows:

- **Substation, equipment, materials, and parts** installed in the real world – need to be represented in the digital world by data continuously collected over life and kept up to date. The data should be as complete and detailed as possible with all construction and design details, operation, events, maintenance, changes, updates, upgrades, etc.
- **Operational status** in the real world – the representation contains current values known at a certain time instant from operation in the grid such as currents, voltages, loading, temperatures, mechanical or chemical aspects, humidity, partial discharge, data from sensors and monitoring systems, details on status of the equipment on or offline, details on harmonics, or power flow, etc. Operational status may refer to situations in the substation regarding weather phenomena, human intervention, catastrophic conditions, intrusion, etc.
- **The real-world processes** and changes over lifetime are complex, due to multi-physics and concurrent phenomena, during normal operation or events. Thermal, electrical, chemical/biological, and mechanical stress factors act on real equipment over their life. In the virtual world these change processes can be described by any type of model implemented in software.

These models can be for example any mathematical input-output algorithm or software construct that can describe causal dependencies and phenomena. They can be static or dynamic, and evolving and self-learning. Such models can use known physical and chemical dependencies, formulas, or equations, but also models based on statistics. Also, such models can be data-driven and can use AI and machine learning or any combination of those.

The implemented models in the virtual world reflect the status of knowledge and digital processing technology at a certain moment in time and evolve with field experience, research results and data processing capabilities. The virtual world twin is not merely the representation of the real world, since it may contain additional calculated data, Figure 3. The calculation possibilities are practically unlimited.

One such example is "virtual sensors" i.e. the estimation of physical values at locations in equipment. Other calculations, such as simulations and what-if scenarios, health indices etc., help to understand the present situation or predict possible outcomes. Also, CAD or BIM models are used e.g. to virtually navigate a substation, for activities planning, training, etc.

Such calculations or applications are not the "DT," as sometimes named, but are just part of the DT concept which offers data and models and a framework to build on and work with.

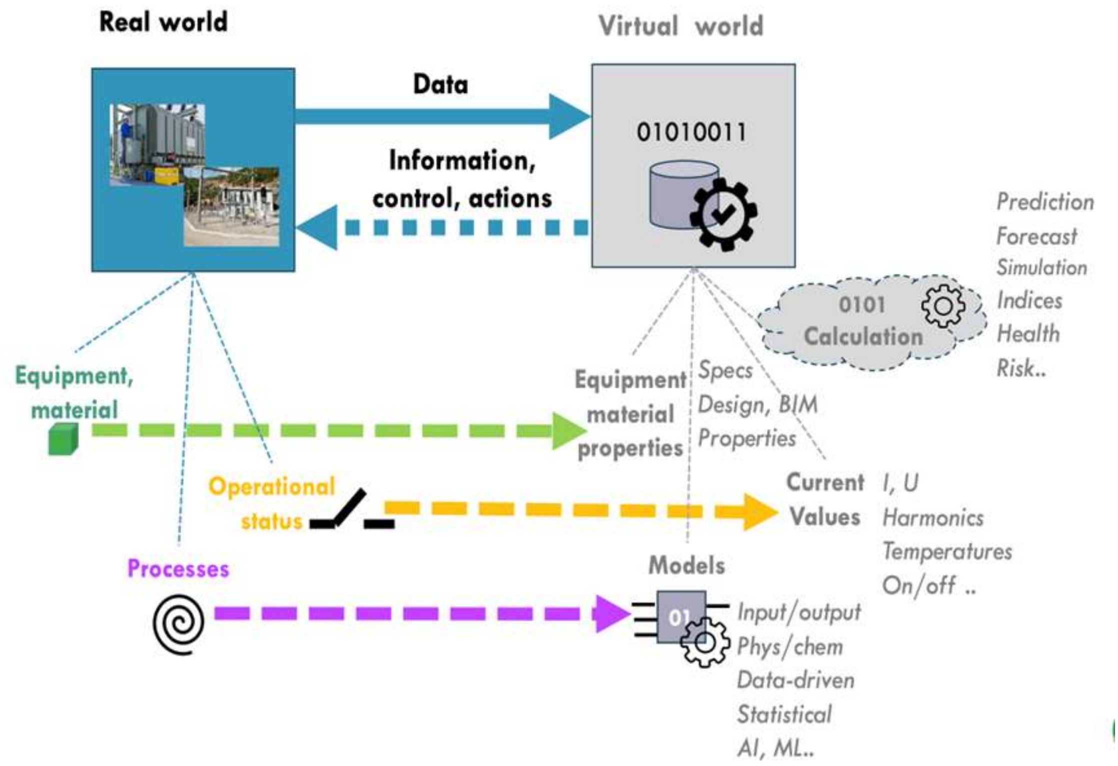


Figure 3 - Details of the DT concept usable for substation LLSM and digital representation of real-world entities in the virtual world

The DT concept is more complex since it is: holistic, integrative, and dynamic:

- It is holistic by providing from the beginning a place for all available and future to be added, data and interactions,
- It is integrative by integrating all available data in a common framework with knowledge models and algorithms, and very importantly,
- it is dynamic since it is continuously changing, by collecting data, updating knowledge, adding calculations results, enabling learning and supporting actions.

Figure 4 presents a generic and schematic view of the data collection and flow, as a key interaction in DT concept. The data collection process is evolving over time, involving learning. It is influenced by what was learned from real-life situations, actions, and decisions. Shown also in Figure 4 are calculations results. The data stored is accessible.to software applications or to humans.

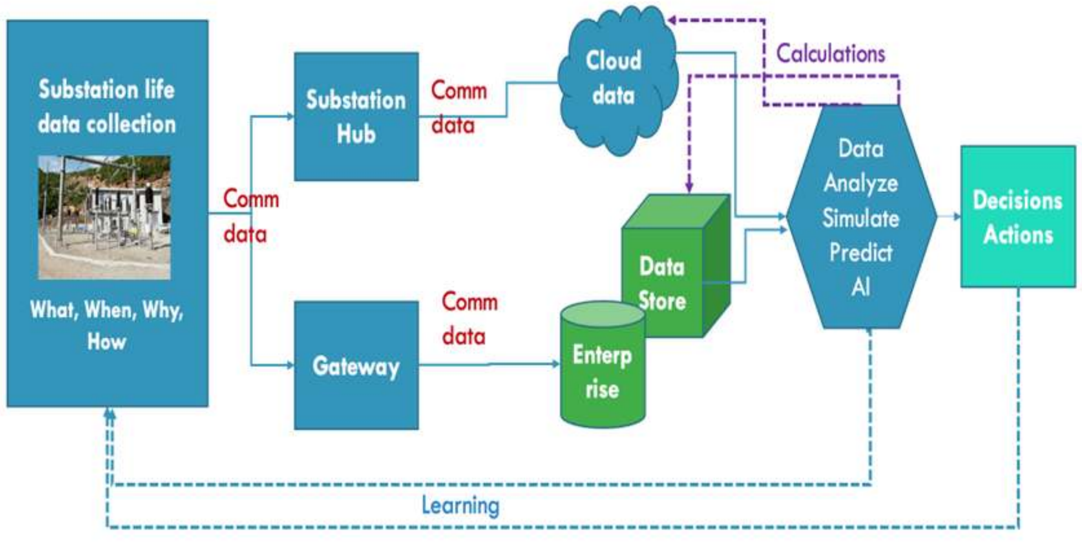


Figure 4 - Data flow representation involving collection, storage, calculations, and learning usable for substation LLSM

Conclusion and Outlook

Lifelong supervision and management of substations is strongly supported by the DT concept, which offers a systematic, holistic, integrative, dynamic framework to support substation management, enabling improved real-time or near-time awareness in terms of condition, risk, capabilities, and hazards. The needed data collection benefits from advances in sensors, engineering knowledge, advances in information and communication technologies.

Challenges exist and are related to the amount, quality, and handling of data over decades, the required knowledge, models and applications and to the cost and effort to implement and maintain, the ITC systems and human support, still interest in DT is increasing.

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Thumbnail credit: metamorworks on iStock

The Mentor and the Mentee: A little philosophy, lots of practical advice

Over the course of a half-century of globe-trotting in the power business I have come to view mentoring as a potentially life- and career-enhancing practice for those who embrace it. The order in which I list the potential benefits of mentoring is intentional: your career is part of your life, not the other way around. Enhance the life, enhance the career. Ipso facto.

By John D. McDonald
IEEE Life Fellow, Member National Academy of Engineering, CIGRE Honorary Member, Founder/CEO, JDM Associates, LLC, Duluth, GA, USA

Finding the right mentor can provide a student, a young professional, even a mid-career veteran with invaluable strategic guidance and tactical advice that enriches lives and advances careers. These benefits flow both ways. Serving as a mentor, in turn, can bring unexpected rewards to the mentor's personal and professional life.

Let's articulate the key takeaway here at the outset: a student learns the science of engineering in school, but the application of that science – the art of engineering – is crucial and that primarily occurs through working with experienced, knowledgeable professionals in the field. That, in a nutshell, is the value of mentoring to students and young professionals.

In this article, I'll share some of my own experiences and lessons learned in the often-informal realm of mentoring, while providing a few best practices for students and young professionals that may be of practical benefit to them.

(If readers are interested in more detail than this article provides, see the IEEE-HKN Series Career Conversations Episode 2, "**Effective Mentorship**," and/or a videotaped seminar I gave at Purdue University, "**Key Insights into Career Management & Building and Leading a Volunteer Organization**").

Serendipity strikes

My own experience may run counter to my thesis here, but it illustrates the role of pure luck, one of life's unexpected gifts. Although the proper outlook and adherence to best practices by would-be mentees will bear fruit, I have to acknowledge that if serendipity enters the picture, seize the day!

In my own case, I had the good fortune to have an early mentor who literally plucked me from obscurity as a freshman at Purdue University in 1969 and set me on a lifelong professional trajectory. I was enrolled in the university's Electrical Engineering honors program. Out of the blue, Ahmed H. El-Abiad, an Egyptian professor at Purdue, called me to his office. He told me (he did not ask), "I will be your major professor. You will specialize in power. You'll start graduate school in three years and graduate with a master's in five years with a BSEE, MSEE and a thesis." Age 18, I had no idea at the time that this gentleman had co-written (with G.W. Stagg) Computer Methods in Power System Analysis in 1968, a book that revolutionised our industry. To this day I don't know what he saw in me, but my whole career was mapped out in that meeting. (He soon told me to join IEEE, which I did in 1971, and the same year I was inducted into IEEE's Eta Kappa Nu (HKN), the Institute's honor society.)

Imagine my good fortune that a brilliant would-be mentor reached out in this assertive manner! I acknowledge that my case is unusual, probably rare. In ensuring years I have had many opportunities to mentor students and young professionals, so let's review the outlook and steps that can be of practical benefit to mentor-seekers.

Take the initiative

Initiating a mentoring relationship is the primary responsibility of the individual who can benefit. The mentee must drive the process, yet approach the search from an organic standpoint. Finding an influential mentor should be a natural result of the mentee's networking, participation in pan-industry organizations, and drive to better themselves through career advancement. Would-be mentors need to be open to genuinely interested individuals. Would-be mentees should not be afraid to ask for guidance from someone they respect and "click" with.

In life, the best things happen when you're not specifically looking for them. Get involved in activities outside of your school or company. Participate in extracurricular activities, volunteer to take leadership positions, expand your network. You'll run into experienced people – maybe in your local IEEE chapter – and you'll find someone you have an easy chemistry with, someone with the knowledge and experience you need. It should happen naturally. In my experience, many relationships begin in person or via a social media platform such as LinkedIn. Research the backgrounds and bailiwicks of people you meet. Trust your instincts. You'll meet people who can help you.

— Networking

Networking is a two-way street. Always be ready to offer value to others in a selfless way. When you need help, ask for it. Those you have helped will return the favor. Just being ready to assist others will make it easier to ask for assistance when you need it. Pay attention to your personal relationships, stay in touch with people you meet. LinkedIn is a simple, easy way to maintain contacts. This will be personally satisfying and professionally advantageous. Every job I've had in my career stemmed from the contacts in my network.

Social media, if used properly, is a branding and communication tool. LinkedIn offers the opportunity to continually update your accomplishments and reflect endorsements from colleagues, while making it easy for others to find you. Twitter offers a real-time chance to tout your upcoming talks and articles and to comment on industry news as a thought leader. (As long as you know what you're talking about!)

Keep the majority of your social media strictly professional. Facebook is a good place to post family-related matters outside your professional life. But even then, maintain decorum – posting photos of your crazy night at a fraternity party will never benefit you and could deter a diligent HR person from asking you in for an interview.

Think of social media as a global stage for putting your best foot forward.

— Your first job

Life is full of contradictions, which will become apparent in my advice for a graduate's first job. Be determined to provide value, to do more than expected for your company. If the work situation is less than ideal, don't let it affect your attitude. No one is indispensable. Yet you must not be naïve. You may think your company has a plan for you, that it is looking out for you. That is possible. But typically, you drive your own success. First jobs rarely offer a long-term opportunity, if you carefully cultivate your value.

Strive to become a "depth" person rather than a "surface person." Take advantage of all training opportunities. Your company, its clients, and the outside world will quickly discern whether you understand the technology, the business case, and the industry's multifaceted culture.

Speaking of the business case, early in your career may be the best time to seek a Masters of Business Administration (MBA). I see many engineers held back in their quest for advancement and influence because they don't know how to build a business case for a technology solution. Fairly early in my career, I earned an MBA at the University of California-Berkeley and that has paid dividends in my professional life.

This is also a time to join outside organizations such as CIGRE, IEEE, and volunteer for industry efforts and activities outside your company.

In finding your way forward, becoming a “depth person,” pursuing further education, and volunteering for industry responsibilities outside your company, a mentor can be an invaluable sounding board and provide a broader perspective that will open your eyes to opportunities.

— Internal vs. external focus

I advocate that a young professional in their first job should develop both an internal focus and an external focus.

Internally, apart from your day-to-day responsibilities and assignments, learn what makes your company tick. Where does it fit in the industry ecosystem? What is its unique value proposition? What is its culture? Who are your competitors? Where do you fit in this picture?

Your manager should not be your mentor – managers focus more on transactional matters than on the strategic outlook you seek. Managers are primarily aligned with their company’s trajectory, as they should be. However, it would be difficult for a person with a laser focus on business success at one company to provide the broader perspectives you seek. You will find your mentor in your ever-expanding network of colleagues outside your shop.

You must avoid what I call the “microwave mentality” that expects everything to happen instantly. In my generation, jobs were expected to be maintained for a minimum of three to four years. Today, I advocate a minimum of two years. This gives you time to understand your company, your work, your colleagues, and your networking will be more meaningful and longer-lasting. A minimum, two-year tenure promotes being a “depth person” and not a “surface person” who is constantly jumping from one lily pad to the next.

To be valuable to your company and true to your own potential, you must balance your internal, corporate responsibilities with a foot solidly planted in the outside world. Keep apprised of industry trends, events, and news. Keep an eye on the standards development process so that your own work is up-to-date and relevant. Get involved in CIGRE, IEEE or other organisation’s committees, which form to solve pan-industry challenges. Develop your own viewpoint and be able to articulate it, which is the core of thought leadership. Offer to speak, write articles or champion a peer. Seeking a mentor does not preclude offering others your own valuable experiences and insights.

— The outside world

Whenever possible, seek assignments outside your home country. In becoming a “depth person,” you will need to understand regional differences in technology, standards, policy, and business cases. International work and travel will broaden your outlook and make you sensitive to nuances in cultural differences. A mentor is invaluable in this respect. Your mentor may emerge on an international stage. Facetime, Zoom and other platforms make the Earth flat! You may find a mentor who lives on another continent.

— Managing the mentor relationship

At this point, it should be obvious that understanding the value of a mentor and finding the right one is not a goal in itself. Rather, it is likely to be the outcome of other best practices for life enrichment and career advancement that will make the mentor connection happen in an organic way. That typically results in the best fit. You will hit it off with someone whose ideas inspire you, whose trajectory captures your own aspirations, whose personality easily meshes with your own.

Mark my words: once you find this person, you have a new set of responsibilities. This relationship is not about technical training. It is about developing a broader outlook, a strategic approach to life and work, about developing opportunities, both for yourself and for others.

You should be in regular contact with your mentor via an agreed schedule. Put thought and effort into each meeting. Don't wing it. A mentor appreciates a mentee who has emailed ahead the topics they wish to discuss. This shows initiative and – this is critical – it shows respect for your mentor's time and for their commitment to the mentoring process. I often ask my mentees to view an online talk I gave in a joint program presented by the IEEE Dielectrics and Electrical Insulation Society (DEIS) Young Professionals and CIGRE United States National Committee (USNC), "Key Insights to Career Management." This program is likely to provide a mentee with pertinent questions for their mentor meetings.

The whole process, as noted, must be driven by the mentee. If you're looking to glad hand a seasoned professional for a reference on your CV, you have utterly failed to understand the mentoring opportunity.

— The work/life balance

So, you have focused on your job responsibilities while planting your feet in the larger, outside world. What's left? Making time for your family and friends outside of work.

Working hard is expected and every project will land you in the office on the occasional weekend, sometimes a few in a row, when it's "all hands-on deck." But as a mentor, I say: make time for your personal life. The efficient use of time and knowing how to use the on/off button is important. Be available to your spouse, your children. To the extent possible, attend family events. If you are traveling and cannot be there in person, Facetime is your friend.

— Being a mentor

Let's finish with the other side of the coin: being a mentor. It would seem inevitable that over the course of being mentored and later in your career, the mentee will find themselves approached to mentor others. It's never too early to start and it's easy to imagine a mid-career professional actually engaged in both the mentor and the mentee role.

I've been asked, "What skills should a good mentor have?"

Take a genuine interest in anyone who shows you a genuine interest in your strategic guidance on broadening their outlook and shaping their own trajectory. Ask questions and listen. Don't talk about yourself, unless it supports a larger point.

Schedule regular sessions with your mentee, but be flexible. In my case, I may have monthly meetings scheduled with a mentee, but suddenly they have a pressing issue at hand and need to talk. If your mentee is on another continent, hone your time zone math.

Your charges need to know how to apply the art of the science of engineering, yet their needs for guidance on career strategy may come with difficult tactical decisions they want to discuss as well. Lead them to their own conclusions by asking them to weigh the variables, prioritize the outcomes. Counsel the mentee on making rational, thoughtful, deliberate decisions after weighing pros and cons. A lot of trust is required on both sides.

Various companies I have worked for set up their own, in-house mentoring programs. Organizations such as the IEEE PES and IEEE-HKN do as well. I have been involved in both, but I also find that my most satisfying mentoring opportunities have evolved informally, based on the looser approach to career advancement best practices outlined in this article.

I should add that, initially, I expected mentoring relationships to last a couple years at most. And I found, to my surprise and continuing delight, that some have spanned nearly a decade and multiple continents.

The concept of "reverse mentoring," where both parties are expected to share their knowledge, is an intriguing one. In my experience, a mentee familiarized me with emerging blogging platforms as I took up the practice of regular, public thought leadership. No matter how smart you think you are, it's a time-saver to have someone simply share the how-to aspects of the latest technology that otherwise might escape you.

On a practical note, starting a reverse mentoring program within a company or organisation requires a thoughtful approach and a careful presentation on expectations. The recent grad might be intimidated at the prospect of teaching a seasoned professional something the latter doesn't know. Likewise, that seasoned pro might balk at learning from a freshly minted graduate. Set expectations accordingly.

— The rewards

The potential benefits of mentoring to the mentee should be obvious. Life enhancement. Career advancement. (Remember that sequence!) In my own case, it gave me a technology focus that provided a trajectory for my entire career. But the rewards for the mentor are many. It's an act of giving back, of altruism. It is deeply satisfying to see young people, with thoughtful strategic guidance, make strides in their lives and professional work as a result. Young people are enthusiastic, energetic, idealistic, hard-working, and at the threshold of a lifetime of adventure and achievement. Having a hand in facilitating their success as an IEEE Life Fellow has provided me with a deep satisfaction that makes the time and effort worthwhile.

Banner & thumbnail credit: Jacob Wackerhausen on iStock

Building Trust

The following article is based on a longer and more in-depth examination of Trust in relationships. Our intent is to expand on the topic of trust in a way that allows the readers to reflect on ways in which they might be able to build trust more quickly and more reliably in relationships.

By Stewart Ramsay, Vanry Associates

Habits and beliefs about trust

You might view trust from a perspective that is very definitive — one way or the other. Many of us tend to see trust as a personal trait or characteristic of another. We view our assessment of trust as the truth about another person, or something that we have to test or that they have to prove. We tend not to look at ourselves and instead accept our assessments of the other person as fact. We believe or know that trust is important, yet we allow it to stay in the background rather than deliberately build and strengthen it.

A useful interpretation of trust

We suggest that trust is an assessment or opinion that we each make about someone or something

- It is not fact — rather it is a view that we formulate and hold

- Your trust of others is based on an assessment formed with thoughtfulness and supported by evidence
- Others' trust in you is based on a grounded assessment they make of you, that you have influenced or impacted through your actions and behaviours

From Stephen Covey's book *The Speed of Trust*

"Trust is the one thing that changes everything".
Lack of trusting produces significant human and financial waste.

↑ Trust = ↑ Speed ↓ Cost
↓ Trust = ↓ Speed ↑ Cost

A grounded assessment of trust should include consideration of the following:

- What concern are you trying to take care of by making this assessment?
- Is it domain specific or is it all-encompassing?
- What timeframe is involved?
- What standards are you applying and are they shared by others?
- What facts or assertions do you have in support of your view?
- What new action can you take as a result of this assessment?

Trust is an attitude that we have towards people whom we hope will be trustworthy, where trustworthiness is a property, not an attitude. Trust and trust worthiness are therefore distinct although, ideally, those whom we trust will be trust worthy, and those who are trustworthy will be trusted. For trust to be warranted (i.e. plausible) in a relatonship, the parties to that relationship must have attitudes toward one another that permit trust. Moreover, for trust to be warranted (i.e. well-grounded), both parties must be trustworthy.

Trusting requires that we can, 1) be vulnerable to others (vulnerable to betrayal in particular); 2) think well of others, at least in certain domains; and 3) be optimistic that they are, or at least will be, competent in certain respects.

CAROLYN MCLEOD
"Trust", The Stanford Encyclopedia of Philosophy (Fall 2015 Edition), Edward N. Zalta (ed.)

— Typical concerns related to building trust

You might wish to:

- **Strengthen relationships** personally, professionally, or even with yourself

- **Coordinate action** more effectively with others
- **Build your dignity** — specifically through self-declarations about who you say you are
- **Enhance your public identity** and specifically your reputation. The view that others hold of you as a person or as an organization, often referred to as 'trustworthy'

— Trust is...

About changing a relationship with others and ourselves for the better — something which:

- We create, build and sustain with our declarations, commitments, promises, emotions and sense of integrity
- Resides internally in you versus externally in someone else
- Is created and bestowed by human effort and intent in a social practice with others — rather than being simply there
- Is generated through human effort and intent; it is always dynamic and flexible; never solid and never gone

Trust is often implicit in the relationship

- Mostly in the background of the relationship and assumed
- We become more aware of trust when there is a significant change in its status

If trust in a relationship is strong, then that trust may be extended to another by correlation or association

- For example, you refer a friend to your accountant and then your friend — based on the strength of their trust in you — hires the accountant
- If this type of trust is present it can be leveraged to accelerate alignment amongst teams and expedite coordination of workflow(s)

— Trust is not...

There are things that trust, or trusting is not:

- To be taken for granted
- There from the beginning
- A matter of good luck
- Familiarity with someone
- Simply reliability or predictability (more below)
- Following rules
- Only about the individual, independent of the culture and social situation
- A quality embedded in another person that is either there or not that makes the person trustworthy or not
- A general feeling or vague idea we have about someone or a situation, such as thinking 'I feel I can trust her'

One common misconception about trusting people is to equate trust with reliability

- i.e. "I can trust him if he behaves in predictable and hopefully positive ways"

People are ever changing and ever growing, adapting and learning therefore trust amongst humans is not as simple as trusting something tangible

- We can have confidence in that which is reliable, i.e. we are confident the sun will rise and set daily

But trust is <u>not</u> about predictability

- While we often predict what people will do, this is not the same as trust
- Trust is relevant in the face of unpredictability
- Predictability and probability are secondary to mutual expectations, responses and commitments

— Common barriers to trust

Some of the more common, significant barriers to trust, or trusting are:

- **Lying** which always destroys trust, whereas telling the truth builds it
- **Cordial hypocrisy** — a pretence, pretending that trust in a particular relationship is higher than it actually is
- **Cynicism** is an attitude, or mood, that refuses to trust — it is a closed door
- **Denial** is a stronger obstacle to trusting than distrust
- **Selfishness** is incongruent with trusting
- **Naivety** where we expect to receive more trust than we are willing to give

"Cordial hypocrisy: the strong tendency of people in organizations, because of loyalty of fear, to pretend that there is trust when there is none, being polite in the name of harmony when cynicism and distrust are active poisons, eating away at the very existence of the organisations."

FERNANDO FLORES AND ROBERT C. SOLOMONS
"Building trust: In Business, Politics, Relationships, and Life (2003"

— Types of trust

Basic trust

- Basic trust (*named by Erik Erikson, psychiatrist*) begins without thought or reflection in infancy and provides a general orientation to the world, later developing into a set of attitudes and practices that become established in childhood
- For adults, basic trust is the belief in the overall moral order of things

Simple trust

- An extension of basic trust, simple trust is trust that remains unthinking and unreflective in us as mature adults

- Trust that is not given, is taken for granted and goes unchallenged
- The attitude is one of assumption, not a decision based on deliberation, having considered the ethics or evidence within a situation
- Because it exists by automatic assumption about the way things are, it was never given by choice and therefore cannot be recovered if lost or betrayed.

Blind trust

- Denial is the primary strategy of blind trust
  - Blind trust is evident when someone has been presented with evidence for distrust, and not only rejects it, but denies its existence
  - It is essentially self-deceptive

Self-trust

- This is the first place to focus as self-trust is required for the practice of building trust with others
- The ability to trust oneself wisely and authentically, including our motives and cognitive integrity
- Remaining open to self-reflection and self-scrutiny
- Includes healthy skepticism, requiring we trust our self-critical abilities

Authentic trust

Trusting another is a choice, a decision, made authentically and willingly, given and bestowed on another

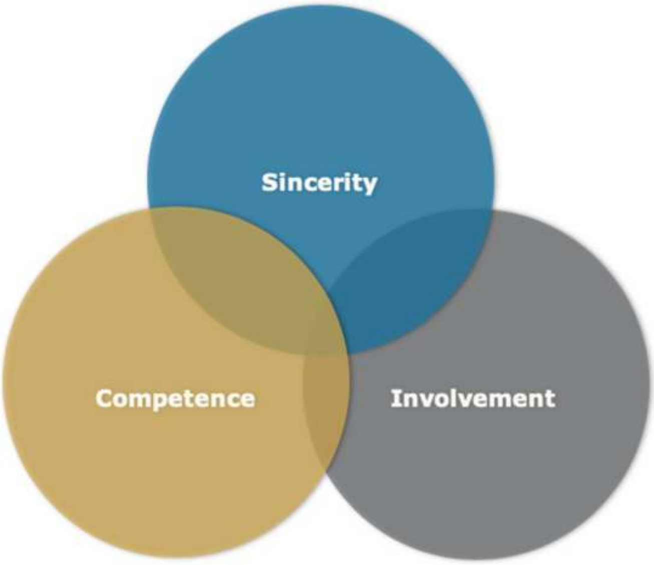
- Authentic trust is a relevant aspect in all relationships: yourself, others, groups, organizations, the market and society
- Authentic trusting opens the space for more freedom in inventing a future together
- In addition to being a declaration, authentic trusting is also a set of assessments and competencies, an emotional skill, and a dominant mood
- Self-trust is the foundation on which authentic trust is built
- Authentic trust enfolds and accepts distrust, disappointments and betrayals as part of the landscape of trusting and chooses to continue trusting in the relationship to some extent
- Authentic trust is always conditional, focused, qualified and therefore limited, knowing and accepting the associated risks and liabilities of the situation

High trusting relationships add value to both the human experience of the relationship itself, as well as the results the relationship produces

Low trust acts as a kind of tax in which human suffering occurs, along with inefficiency and ineffectiveness in producing results

— Three elements of trust

Trust is a composite of three equally important elements — sincerity, competence and involvement



Making useful assessments about another person's trustworthiness requires thoughtful consideration:

What particular standards are you applying to another person when making this judgment? What standards have you applied for sincerity; for competence; for involvement? Have these standards been shared, discussed and mutually agreed to? Many trust issues occur when standards are not discussed or are unrealistic for the situation or area. What concrete observations, facts or evidence can you offer to support your judgments?

Sincerity

Sincerity is about genuinely demonstrating consistency between what you say and what you do

- You align your actions with what you say
- You honour your commitments and promises (including promises others hear that you may not have intended)
- You don't operate with hidden agendas or ulterior motives

We each choose our own starting point about the sincerity of others

- The assessments are not the truth; they reside in you about others and in others about you

Sincerity, if damaged, is often very difficult to rebuild

- It is also the most binary of the three elements of trust, leaving us either open or closed to trusting another person

Tips for assessing sincerity

When you judge another person's **sincerity**, it is your assessment of how coherent this person is about their intent and word.

- It is important to notice the personal standards you are choosing to use when you declare a person has, or hasn't, met your expectations for wether they "mean what they say".
  → Sometimes your standards for success of your expectations, while perhaps appropriate for you, are not appropriate for the circumstance.

- It is critical to reflect carefully as to wether or not you are deliberaly choosing your standards for assessing the other person's consistency or not.
  → Further complicating this is the fact that your standards and expectations are learned, or unconsciously adopted, earlier in your life.

- Are you expecting what is reasonable from this person under the circumstances?
  → Are you setting the bar too high? Or too low?
  → Could you be setting the other person up to fail?

Competence

This is about being able to demonstrate that you have the ability and capability to deliver in specific areas

- It is a view held by another (or by you about the other person) that you deliver consistently, repeatedly and on time
- It is a view held by another that you are 'count-on-able' — you know how to deal with the situation and that if you don't know how they can be sure you will get the help you need
- It is a grounded assessment about a specific domain and is not about you, or another person, as a whole
- It is situational, you may trust someone to care for your children, or make the presentation to the board of directors, while not trusting them to do brain surgery on you because you don't see that they have any experience in brain surgery.

Breaking promises, missing deadlines and not being able to deliver consistently all have a negative impact on assessments of competence

Tips for assessing competency

When you judge another person's **competence**, it is your assessment about the likelihood that they will actually be able to carry out the commitment they're making.

- How would you define this area of competence? What is it? What is it not?

- What expectations or personal standards do you have in this area?

- What do you actually think competency looks like? What does 'sufficiently competent' look like?
  → Are you expecting this person to behave like they have a PhD in this area (when they don't)?
  → Are you expecting this person to be performing equivalent to a kindergarten student when they have had 20 years of experience in the area in question?
  → What is reasonable under the circumstances?

- Now, what do I think this person is capable of compared to my standards?

Involvment

This is about you being mindful of and tuned to what is important to the other person, both for a particular workflow and more broadly

- They know that in a meeting, you will speak for them and address an issue in the way that they would want it addressed
- Your actions are fully consistent, whether or not you are in their presence
- You remain strongly connected to them over time
- You are committed to continuing to take care of what's important to them over the duration of what you are involved in together

Tips for assessing involvment

When you judge another person's **involvment**, it is your assessment of the extent to which that person is aware of what really matters to you and to what extent they will take into account

- What are the personal standards you are choosing to use for such terms as fully consistent, strongly connected or care?

- What does sufficient involvment look like to you? Are these reasonable standards in these circumstances?

- Other questions you miht ask:
  → Have I taken the time to show the other person what matters to me?
  → Am I expecting them to read my mind?

- Are your expectations of this other person reasonable?
  → Are they too low?
  → Or so high that no one could satisfy them?

Rebuilding trust

In authentic trust, you should expect that there will be let-downs, disappointments, rejections, or betrayals and that such breaches of trust might change your relationship with another. Depending on the extent and magnitude of the betrayal, the relationship might not return to its previous level of trust. However, there is always the possibility the relationship can be reinvented or rebuilt.

Rebuilding authentic trust requires practices in:

- **Bringing a mood of hope**
  - Having a positive outlook on the future sets the mood for rebuilding trust
  - Resignation is looking backward and is not a supportive mood for rebuilding trust

- **Forgiveness**
  - Forgiveness is a social or spiritual practice in response to betrayal, rejection, being offended, hurt or misunderstood
  - Involves a series of actions, not simply a state of mind
  - Might require healing, time or assistance from others to work through

There are two alternatives to forgiveness that are consistent with authentic trust:

- **Compensation** — something awarded to someone as a recompense for loss, injury, or suffering
- **Genuine empathy** — with the ability to understand and share the feelings of another we build some ground on which to move forward and negotiate future interactions

There are two alternatives to the practice of forgiveness — **neither of which are consistent with authentic trust**:

- **Revenge** — the action of inflicting hurt or harm on someone for an injury or wrong suffered at their hands
- **Resentment** — a feeling of bitterness or indignation at a circumstance, action, or person

Using authentic trust to deal with disappointments or betrayals

Level 1: 'Things didn't work out'

- No one's fault — simply part of everyday living
- Acceptance is easy in these situations

Level 2: 'Mistakes'

- Mistakes may be disappointing and if frequently made, very irritating
- Some mistakes are attributable to a person; other times it is not clear
- Authentic trust works through this, versus writing off the relationship (trust does not equal reliability)

Level 3: Disappointments due to 'fate'

- No one person is to blame, and it is just part of what happened, e.g. accidents
- Acceptance is the authentic trust orientation in such cases

Level 4: Breaches of trust — blameworthy actions

- Requires an apology — a sincere statement of an intention to redeem oneself and the beginning of a conversation
- Beware of excuses offered instead of an apology

Level 5: Indifference

- A lack of sufficient caring in the relationship — may range from simple inattention to intentional and shameful disregard
- Requires an explicit conversation, perhaps an apology (if authentic) and negotiation on how to go forward with this relationship

Level 6: Insincerity

- Making insincere requests, offers, promises, commitments, apologies
- As above, explicit conversations are needed for mutual understanding and moving ahead

Level 7: Lying, wholesale insincerity

- Some of us tell small lies (aka white lies) for the sake of protecting other's feelings — we might not see this as a short-sighted view of caring
- We may also tell lies to protect ourselves from consequences of our actions
- The philosopher Immanuel Kant offered the view that lying is a violation of the humanity of the person lied to and a denial of their dignity (links to legitimacy)

Level 8: Reneging on promises or breaches of contract

- Promises and commitments can be successfully re-negotiated
- This breach is more related to never intending to fulfill or deliver, rather than changing circumstances, more like an intentional lie

— Becoming more trustworthy ourselves

In *The Speed of Trust*, Stephen Covey proposes a set of 13 behaviours you can do to become 'trustworthy' in the view of others and to help build and repair others trust in you — all of which are congruent with authentic trust.

Behaviour	How to improve
Talk Straight	Be honest. Tell the truth. Let people know where you stand. Use simple language. Call things as they are. Demonstrate integrity. Don’t manipulate people nor distort facts. Don’t spin the truth. Don’t leave false impressions.
Demonstrate Respect	Genuinely care for others. Show you care. Respect the dignity of every person and every role. Treat everyone with respect, especially those who can’t do anything for you. Show kindness in the little things. Don’t fake caring. Don’t attempt to be “efficient” with people.
Create Transparency	Tell the truth in a way people can verify. Get real and genuine. Be open and authentic. Err on the side of disclosure. Operate on the premise of, “What you see is what you get.” Don’t have hidden agendas. Don’t hide information.
Right Wrongs	Make things right when you’re wrong. Apologize quickly. Make restitution where possible. Practice “service recoveries.” Demonstrate personal humility. Don’t cover things up. Don’t let personal pride get in the way of doing the right thing.
Show Loyalty	Give credit to others. Speak about people as if they were present. Represent others who aren’t there to speak for themselves. Don’t badmouth others behind their backs. Don’t disclose others’ private information.
Deliver Results	Establish a track record of results. Get the right things done. Make things happen. Accomplish what you’re hired to do. Be on time and within budget. Don’t over-promise and under-deliver. Don’t make excuses for not delivering.
Get Better	Continuously improve. Increase your capabilities. Be a constant learner. Develop feedback systems—both formal and informal. Act upon the feedback you receive. Thank people for feedback. Don’t consider yourself above feedback. Don’t assume your knowledge and skills will be sufficient for tomorrow’s challenges.

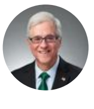
Behaviour	How to improve
Confront Reality	Take issues head on, even the “un-discussables.” Address the tough stuff directly. Acknowledge the unsaid. Lead courageously in conversation. Remove the “sword from their hands.” Don’t skirt the real issues. Don’t bury your head in the sand.
Clarify Expectations	Disclose and reveal expectations. Discuss them. Validate them. Renegotiate them if needed and possible. Don’t violate expectations. Don’t assume that expectations are clear or shared.

Trust is crucial in our ability to work together effectively. It takes work and focus, like anything of value. If we want to build and maintain trusting relationships, or trust in transactions, then we need to plan for it and ensure that we are including actions and approaches to build and maintain trust.

Banner & thumbnail credit: StudioM1 on iStock

An exciting new era ahead for the energy transition as the CIGRE 2024 Paris Session breaks records

The 2024 Paris Session (August 25-30) broke every record in CIGRE's 103 years. It is not only testimony for CIGRE, but also to Paris, the City of Lights. The Paris Session occurred between the Summer Olympics and the Paralympics. While concerned at first, registrations, exhibitions, and visitors exceeded every expectation. Every day the exhibition was bustling, meeting rooms filled, and poster sessions were well attended.



By Michael HEYECK

CIGRE VP Finance & Treasurer

— CIGRE 2024 Paris Session breaks records

4,575
Delegates

11,000
participants

1,200
papers selected

99
countries

We registered 4,575 delegates, 20% more than the previous record in 2018. With the many exhibitors, visitors, members of Study Committees and Working Groups who met during the event, more than 11,000 participants mingled at the Palais des Congrès de Paris, with an average of 5,000 per day. One of the reasons for this record turnout was certainly the number of reports on papers selected: 1,200, 50% more than in previous years.

Certainly, our signature biennial event in Paris attracts many across the world. Delegates came from 99 countries, but with visitors and others, the number of countries represented was higher. This was our 50th Paris Session with an established and storied continuity of 103 years.

An event of this magnitude does not come without a lot of work. The CIGRE Central Office geared up for months to make sure everything was well choreographed. The Exhibition Team was also outstanding selling every square meter. If you were there, you noticed we opened the spacious lobby for registrations and security filling every square meter across three levels above.

We also acknowledge **the architects of the technical program**, i.e., the Study Committees coordinated by the Technical Council, and with the unconditional support of the leadership team and the Steering Committee. Thanks also to the many reviewers who contributed to the quality of the papers.

Certainly, CIGRE's foundation is well supported by thousands of volunteers sharing knowledge and benchmarking best practices for the energy transition. Their efforts, whether in Paris or from home from contributions made, helped broaden CIGRE to its technology end-to-end (E2E) focus for sustainable electricity for all. Many new entrants, beyond traditional grid players, were noted in contributions and exhibits from the grid to all facets at the grid's edge.

The Opening Ceremony commenced with CIGRE President Michel AUGONNET about CIGRE's state of the association. The keynote address was provided by Mr. Keisuke SADAMORI, Director of Energy Markets and Security at the International Energy Agency (IEA), He spoke on the integration of renewable energy and its implications for network security and energy markets worldwide.

Since the CIGRE Paris Session is 16 conference threads aligning with our 16 Study Committee domains, at the Opening Ceremony, Technical Council Chair, Marcio SZECHTMAN, presented the week's program displaying the integrated nature of CIGRE's technical domains across the energy transition.

If you visit [CIGRE.org](https://www.cigre.org), you will see the energy transition "doors" that notes how each of the 16 Study Committees work on each facet of the energy transition. They are Digitization, Storage, Grids & Flexibility, Sustainability & Climate, Solar PV & Wind, Hydrogen, Consumers, Prosumers, & Electric Vehicles, and Sector Integration.

At the Opening Ceremony, as is our CIGRE tradition, we acknowledge our finest volunteers with awards. Our top award is the CIGRE Medal, and we awarded two, **Dr. Mladen KEZUNOVIC**, and **Prof. Ja-Yoon KOO**. We also awarded 25 of our members for CIGRE Fellow, CIGRE Honorary, Women in Energy, and Next Generation Network awards.

Apart from the opening panels on Monday, including the highly attended workshop on Large Disturbances, it was the poster sessions that attracted the most participants, between 1,100 and 1,600, during five days.

Opening Panel

Poster session

Do you want to see more records? Mark your calendars for CIGRE 2026 Paris Session, August 23-28, 2026. Will we break records again? Count on it!

— CIGRE transitions well for the new era ahead

During this Session, the Administrative Council of CIGRE elected a new President, **Konstantin PAPAILIOU**, and a new Technical Council Chair, **Rannveig LOKEN** who is the first woman to be elected to this position in the history of CIGRE. I was unanimously reappointed as Treasurer of CIGRE for an extended mandate for the next two years.

In the last four years, who knew we would endure the pandemic? CIGRE remained relevant and grew in members, technical publications, and finances the past four years due to our technical foundation broadening to the energy transition, our digital platform to share knowledge with the world for power system expertise, and our thousands of volunteers. We created a new strategic plan recently for the energy transition to a horizon of 2030, updating the prior 2018 plan.

The two officers that ended their terms at this Paris Session are CIGRE President **Michel AUGONNET**, and Technical Council Chair, **Marcio SZECHTMAN**.

Michel’s visionary guidance has been instrumental in navigating CIGRE through dynamic times, fostering innovation, collaboration, and growth. His commitment to our mission has left a lasting impact on the global power systems community. Prior to this four-year term, Michel served as Treasurer in the prior four years.

Marcio's tenure as Technical Council Chair has been equally remarkable. His expertise and passion for advancing technical excellence have propelled our initiatives forward, ensuring that CIGRE continues to be at the forefront of industry developments. Marcio volunteered his time as Technical Council Chair for the last six years.

We are thrilled to welcome Konstantin PAPAILIOU as the new President of CIGRE. With his experience and commitment to our goals, we are excited to see how he will steer our organization into new horizons. He is committed to engagement with National Committees and the CIGRE Strategic Plan.

A special congratulations to Rannveig LOKEN, who has made history as the first woman to be named Chair of the CIGRE Technical Council. This is a landmark moment for our community, reflecting our commitment to diversity and inclusivity, and we are eager to see the fresh perspectives and innovative ideas she will bring to the table.

As for me, I will help provide continuity to our new, but well experienced CIGRE leaders as CIGRE VP Finance and Treasurer. As convener of the approved CIGRE Strategic Plan, I will help the leadership team grow CIGRE for the betterment of society in the energy transition.

There is one team of excellence I would like to acknowledge once again. Our **CIGRE Central Office Team** works tirelessly for CIGRE – for you. Their leader, **Philippe ADAM**, CIGRE Secretary General, steeped in CIGRE history and contributions, is our constant for CIGRE leadership and growth.

2024 Outgoing Study Committees Chairs

We asked our outgoing Study Committee Chairs to share their reflection about their experience within the Study Committees and give us their expections for the future. Here's their feedback.

_ Study Committee A1: Power generation and Electromechanical energy conversion

It has been both challenging and rewarding to chair CIGRE SC A1 over the last four years. This would not be possible without the dedication, commitment and combined expertise of the whole CIGRE community. Thank-you all for your support.

KEVIN MAYOR

Reflections as SC A1 Chair (2020-2024) on four years of A1 achievements

- As part of the CIGRE 2030 Strategic Plan, SC A1 proposed a change of name from “Rotating Electrical Machines” to “Power generation and electromechanical energy conversion”. This will enable SC A1 to better serve the evolving technical landscape covered by rotating machines, driven by the energy transition.
- The SC A1 Strategic Plan and Action Plan were updated in 2024 to reflect the recent SC name change, update the scope definition and define a forward-looking action plan to address the CIGRE 2030 Strategic Plan and Energy Transition.
- A Newsletter was established to keep the SC community better informed of CIGRE activities related to A1.
- 2023 saw the return of the odd-year face.to-face SC meetings following the disruption created by the CORONA-19 pandemic. The event, held in Kyoto, Japan, was a great success. Thanks to all involved.
- A1 published 7 technical brochures, submitted 1 CSE paper and presented 7 tutorials on a variety of topics.
- SC A1 has seen an increase in the number of papers related to wind turbines, and this year one paper on generators for marine applications.

Future challenges and expectations for SC A1

The future challenges for SC A1 are driven by three main developments:

The Energy Transition

As the energy transition continues to evolve, SC A1 needs to adapt broaden its appeal to a wider community. In 2023, the first step in this adaptation was to change the name of the SC to "Power Generation and Electromechanical Energy Conversion" and revise the scope definition to visibly encompass more alternative technologies to encourage the participation of the related communities. In the coming years SC A1 needs to build on this to continue to attract younger, diverse talent and bring new perspectives to the work of SC A1.

Operational and business environment

The quality of CIGRE work relies heavily on the responses to questionnaires circulated amongst the Regular and Observer members for completion by experts in their countries. Increased competition and focus on intellectual property driven by market globalisation and the break-up of large utilities into independent business, has meant that it is increasingly difficult to get detailed responses on specific topics. SC A1 must adapt to this changing business environment.

Technology trends

SC A1 needs to continue to identify technology trends and changes to the operational duty and load profile of both new and installed machines to ensure the technical directions and SC structure are relevant and attractive to the engineering and broader community engaged in the production and consumption of electricity. Current trends are driven by economic pressure to achieve greater capacity for peaking power, increased energy production from existing power plant, extension of service life, and changes in power system performance/regulation requirements.

— Study Committee A3: T&D equipment

"Alone we are smart, together we are brilliant"
I extend my deepest gratitude to all A3 active Working Group Members, Conveners, Advisory Groups, liaisons, paper authors, contributors, reviewers, presenters, special reporters, and NC representatives. Collective efforts have driven significant progress in our field. A huge THANK YOU goes to A3 Secretary Frank Richter for his major contribution and tireless support throughout this time.

NENAD UZELAC

Reflection on Chairing A3

It has been an incredible honor to chair the CIGRE A3 Study Committee (SC) over the past six years. Working with such dedicated experts from around the world across all 16 committees has been a truly enriching experience. I've grown not only as a technical expert but also as a person.

CIGRE is more than an organization; it feels like a family where we collaborate, overcome challenges, and push the boundaries of our industry. The past few years, especially through the challenges of COVID-19, tested our resilience. Yet, we endured and continued to achieve great things together, demonstrating the strength of our community. During those times, I often recalled Nietzsche's wise words: "What doesn't kill us makes us stronger."

Reflecting on these years, I am proud of our dedication and deliverables. A3 has actively participated in 10 events (conferences, symposiums, colloquiums), revised more than 300 technical papers, organized 6 strategic advisory meetings, established 15 WGs and JWGs, disbanded 11, published 5 Technical Brochures alone and 5 with other SCs (with an additional 4 to be published this year). We have also held 22 tutorials and 4 webinars, contributed to 3 Green Books, created the Utility Advisory Board, established a liaison with IEC TC 38, strengthened our relationship with IEEE, included NGN in our SC work, continued to work virtually during COVID (remember the 2020 and 2021 virtual Paris sessions?), re-energized the A3 community post-COVID, and last but not least, fostered strong collaboration with other SCs the Central Office

In closing, I am deeply grateful for the opportunity to have led such a dynamic and resilient committee. As I step down from this role, I remain confident in the bright future ahead for the entire CIGRE community. I am committed to continuing my contributions to the Power Sector and supporting CIGRE in the years to come. I also look forward to witnessing the future path of A3 and playing a meaningful role in the broader mission of our beloved Study Committee

Future Challenges

As the global energy landscape shifts toward **sustainability**, the CIGRE A3 Study Committee is addressing critical challenges in transmission and distribution (T&D) equipment. Our work aligns with the **CIGRE 2030 Strategic Plan**, guiding our efforts in the energy transition.

A key challenge is integrating **renewable energy sources** into the grid. As we move away from fossil fuels, the variability of renewables like wind and solar requires T&D equipment to evolve. We must innovate smart, adaptable switchgear to handle two-way power flows and respond in real-time.

Enhancing **grid resilience** is another critical focus. With increasing climate-related disruptions and security threats, robust and resilient T&D infrastructure is essential. The A3 Study Committee is advancing equipment that can withstand and quickly recover from these challenges.

Digitalization is transforming the grid. We are committed to developing digital switchgear and intelligent electronic devices (IEDs) for real-time monitoring, data analysis, and automated decision-making, optimizing grid performance and reliability.

Reducing the **environmental impact** remains a top priority. Lowering greenhouse gas emissions through alternatives to SF6 and adopting eco-friendly materials will significantly reduce the carbon footprint of T&D equipment.

As these challenges grow more complex, **collaboration** is key. We must work closely with other CIGRE Study Committees and external organizations, such as IEEE PES and IEC, to share knowledge and drive innovation across our industry.

We are also committed to **inclusion** by actively engaging young engineers through **NGN** and promoting female engineers through the **Women in Energy** initiative. These efforts are crucial for fostering diverse perspectives and ensuring continued growth in our field.

Last but not least, I am honored to pass the baton to our **new A3 Chair**, **Nicola Gariboldi**. With his experience, vision, and energy, I am confident that under Nicola's leadership, A3 will continue to evolve, tackling the critical challenges of our time and further increasing our contribution to the power industry!

Study Committee B3 : Substations and electrical installations

It has been an honour to work with you over the past six years and I am truly grateful for this opportunity. We are a family that has been through the best of times and the challenging times together. Thank you for the best moments of my life!

KOJI KAWAKITA

Reflections on SC B3 (2018-2024) achievements

B3 published a number of publications in the last six years.

- 19 Technical Brochures
- 5 CSE papers
- 5 Future Connections articles
- 1 End-to-end article for ELECTRA
- 1 reference paper for ELECTRA jointly with B1 and B2

B3 organised and supported Symposia, Colloquia and NC Conferences

- Led 2019 Chengdu Symposium and 2022 Kyoto Symposium
- Organised 2021 A2&B3 Joint Colloquium in Bucharest, Romania and 2023 B3&A3 Joint Colloquium in Birmingham, UK

- Supported 2021 Slovenia Symposium, 2023 Cairns Symposium, 2019 CIGRE-IEC Colloquium on EHV &UHV (AC&DC), 2018 CIGRE Workspot, Brazil NC, 2019/2021/2023 CIGRE CMDM, Romania NC and 2021/2022 CIGRE GCC Power, and online NC events.

B3 also supported CIGRE TC Africa Project and participated in the 2023 CIGRE-UMEME academy seminar in Tanzania in March 2024.

B3 established 13 WGs/JWGs and delivered 31 tutorials, 2 webinars and 3 workshops.

Future challenges and expectations for SC B3

To support the realisation of a sustainable society with energy transition, substations' research & development continues to advance in new technologies and applications that offer substation owners and operators the flexibility, security and stability they need to continue to expand their systems efficiently and environmentally friendly. These activities must align with and anticipate the "CIGRE 2023 Strategic Plan - Entering CIGRE's 2nd Century - Horizon 2030".

The challenges mentioned above have resulted in several new initiatives:

- Dealing with the increased impact on substation design and new applications to support energy transitions such as integrating renewable energy resources, energy storage systems and other installations.
- Mitigating environmental, health, safety and security impacts, including the reduction of Green House Gas emissions and the substation carbon footprint
- Substation design, operation and maintenance, resilience against natural disasters and threats (terrorism, epidemic, physical/cyber, etc.)
- Optimising substation asset intervention (retrofit, uprating, upgrading, renewal, extensions).
- Increased substation operational efficiency and availability.
- Integration of intelligence for digitalisation.
- New set of skills for new technologies, knowledge transfer, and high standards of education are needed in developing engineering skills.

Study Committee B5: Protection and automation

I have had the honour to work with the SC B5 community as the secretary for 6 years and as the Chair for 6 years. In CIGRE we have unbiased technical discussions, share knowledge, and get friends across the world. CIGRE is part of my passion and is an important part of my life.

RANNVEIG S. J. LØKEN

Reflections as SC B5 Chair (2018-2024) on six years of B5 achievements

CIGRE Technical Council have worked closely with CIGRE Steering Committee and CIGRE central office to develop the "CIGRE 2023 Strategic Plan & Horizon 2030: Entering our Second Century with Renewed Vision". This work has been important for CIGRE's relevance in the Energy Transition attracting new entries in our End-to-End (E2E) scope.

CIGRE have a variety of stakholders and there are different expectations in terms of "produced documents". SC B5 worked to diversify the publications, complementing the 16 traditional Technical Brochures with Green Books ("IEC 61850 Principles and Applications to Electric Power Systems", and one chapter in "Electricity Supply Systems of the Future"), reference papers, newsletters, tutorials, and webinars. SC B5 also formed 22 SC B5 led WGs/JWGs.

SC B5 organised the SC B5 Colloquium in Tromsø Norway in 2019. The pandemic accelerated many changes, including the way of working within CIGRE. SC B5 supported the CIGRE e-Session 2020 and the Virtual Centennial Session 2021.

The Technical Organizing Committee (TOC) for the 2021 Hybrid Symposium in Ljubljana was co-chaired between SC B5 and SC B1. SC B5 was also part of TOC for 2019 Chengdu Symposium, and the 2023 Cairns Symposium.

All achievements are the consequence of the long-term vision of past B5 Chairs and are the results of passionate work done by a large community of people who share their unbiased technical knowledge.

Future challenges and expectations for SC B5

SC B5 strategic plan focuses on providing key technical information related to protection, automation and control system to executives, regulators, policy makers and technology innovators. It also focuses on understanding and influencing the development of new technology and practices for all voltages and systems.

One of the important topics for SC B5 to address is protection related challenges in network with low-inertia and low fault-current levels. This topic includes grid protection impacts of increasing inverter-based resources, impact of inverter-based resources on distance protection, modelling of inverters for protection coordination studies, impact of inverter-based resources on transient stability and consequences for protection performance requirements, impact of decreasing grid inertia on transient stability and consequences for protection performance requirements.

Process bus-based substations is also an important topic for SC B5. There is an increasing number of developments and projects of process bus related solutions, both real-world implementations, and findings from laboratory or university studies. The prominence of discussions surrounding centralized, virtualized, and wide-area protection, automation and control applications indicates a significant trend. Specifically, the adoption of the IEC 61850 standard plays an important role in enabling these applications, with the necessary technology infrastructure already established.

The best and more important asset of CIGRE and of SC B5 are people. SC B5 needs to maintain the spirit and the willingness to contribute of its many experts and to give value to the many who are contributing, but also to attract and include more people from countries across the world.

Study Committee C2: Power system operation and control

Yes, it is an honor to conclude a four-year cycle as Chair of CIGRE SC C2 alongside the Secretary of SC C2, Mr. Flavio Alves. A journey of learning, challenges and hard work. A vision of pride in what the group of SC C2 Members was able to build. May the future steps of SC C2 be increasingly grandiose and full of content for humanity.

JAYME DARRIBA MACÊDO

Outgoing Chair Experience and Main CIGRE roles

With the ongoing support of C2 Secretary, all C2 members, SAG experts and WG convenors, the following results were achieved:

- 8 Technical Brochures were published
- 6 new Working Groups were launched
- 9 Tutorials and webinars were delivered at different events
- Co-led the Technical Organizing Committee for the 2023 CIGRE Cairns International Symposium
- Participation in 2021 Centennial Session, 2022 and 2024 CIGRE Session and 2022 Kyoto Symposium
- We disseminated information about the Africa Initiative among C2 members.

Future challenges and expectations for SC C2

Challenges: Significant reduction in load, from the perspective of the bulk system. Large demand ramps. Great variability in demand. Understanding the variability of new resources better, making optimal use of energy storage new possibilities, and making better use of dispatchable resources, are challenges whose solutions are always evolving.

To be replaced by the new Chairperson is to hand over responsibility to someone who will lead the group, guide the development of new knowledge, support the industry and suppliers, and seek the continued success of the operation of power systems in their mission.

How to improve the forecast of the shape of demand curves and their values, for the next day and for future periods?

How to obtain more flexibility from dispatchable supply sources to ensure demand is met with all the variability involved?

What new technologies are available or will need to be developed to provide answers to these challenges?

What new equipment will be the technical answers with compatible costs for system operation and control

Hydrogen? Batteries? Demand response? Flexible gas supply? Pumped storage plants? Interconnections? Something new not listed here? What is the optimal mix of these possibilities that will make up the best solution to the challenge of maintaining an operationally reliable system?

These are the "first steps" because we will remain in a time of rapid changes to be experienced by societies that consume electricity.

Study Committee C5: Electricity Markets and Regulation

My term of six years has been a challenge with the changes to the industry as technology and government policies changed. Covid created its own issues but the work of CIGRE continued. It was a fabulous opportunity to coordinate the work of the SC during the Sessions and Symposiums, as well the working groups that have covered a diverse range of topics as CIGRE.

ALEX CRUICKSHANK

Outgoing Chair Experience and Main roles

Study Committee C5 has published or participated in the publication of a range of publication during the last six years:

- Nine Technical Brochures (one with another SC), dealing with topics such as emissions pricing, market development with new technologies and interactions between TSO and DSO.
- Two books: SC C5 contributed to the markets chapter of "A handbook of Powers Systems", 2021, edited by K. Papailiou and provided Electricity Markets and Regulation chapter of the Technical Council Green Book "Electricity Supply Systems of the Future", 2020

SC C5, in addition to the normal Paris Sessions and the Centennial Session:

- Participated in the 2019 CIGRE Canada Conference "Innovation at the heart of power grid transformation" in Montreal
- Co-chaired, with SC C2, the 2023 CIGRE Cairns Symposium "The End to End Electricity System: transition, development and integration".

Personally, I have had the opportunity to contribute to

- the ELECTRA Editorial Board, which has been a fabulous opportunity to see the operation of Electra and the range of topics that are covered, and
- the reviews of the approach to papers for the CIGRE Session and Symposiums, which has led to a dramatic increase in participation by authors and an increase in the quality of papers being discussed.

Experience Summary

The nature of the industry is changing but market and regulatory principles remain the same. With new technologies entering and becoming dominant, the market and regulatory rules that had been applied to the old technologies need to be reconsidered in light of the different characteristics of the new technologies.

In addition, the requirements community and government expectations on our industry have changed from when the existing markets were developed both in relation to issues of transition and customer expectations. These changes require refocusing the markets and regulatory approaches, particularly in the areas of system security and power quality.

SC C5 has been at the forefront of the changes with revisions to markets, changes to regulation and imposition of economic distortions to meet the requirements. The study committee will need to analyse and report on:

- the best economic and market thinking to ensure that the changes to the markets increase their efficiencies and
- Efficient regulatory approaches for pricing, access and system security,

to support the industry in achieving the optimal financial and economic outcomes for the communities that we serve.

The issues currently being addressed by SC C5 intersect with other study committees, particularly SCs C1, C2 and C6. This requires careful coordination and joint efforts to optimise to work of CIGRE.

CIGRE Medal 2024: Ja-Yoon Koo

Prof. Koo was awarded the CIGRE Medal this year, in recognition of his outstanding contribution to the development of CIGRE. We publish his speech here, as well as his interview on CIGRE TV at the bottom of the article.

In a world that is rapidly evolving, the importance of collaboration between industries, universities, and research institutions cannot be overstated, especially in fields as crucial as power engineering. Speaking to the CIGRE Family, I am grateful for the opportunity to share some thoughts on the future of this vital industry and to express my deep appreciation for the honor bestowed upon me with the CIGRE Medal.

As I watch the Paris 2024 Olympics unfold in a spectacular display along the river, I'm reminded of the grandeur of human achievement, both in athletics and in the technological advancements that have shaped the world we live in. CIGRE, too, has been a driving force behind such achievements in the energy sector, and I want to commend the Central Office for its remarkable preparation of the 2024 CIGRE Session, despite the enormous pressure of the upcoming Olympic and Paralympic Games.

Reflecting on my own journey, it has taken me forty years of dedication and perseverance to stand here and offer my sincere thanks to the CIGRE Family for this honor. My involvement with CIGRE began as a postdoctoral researcher at the EDF

Research Center during the 1984 CIGRE Session, and over the decades, I have witnessed the incredible impact that this organization has had on both industry and academia.

The CIGRE Medal represents not only a personal achievement but also a testament to the fruitful collaboration between the Korean industrial sector and the global CIGRE community over the past forty years. This cooperation has been key to numerous advancements, and I believe it holds even more potential for the future.

CIGRE NGN: Discussion with Genesis Alvarez

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!

CIGRE NGN United States

Master of Science in Electrical Engineering (May 2019) and a Bachelor of Science in Electrical Engineering (May 2017)

Engineer III for the Electric Transmission Strategic Initiatives group

WG B4.83 Flexible AC Transmission Systems (FACTS) Controller's commissioning, compliance testing, and model validation tests

What lead you to your present career or job?

Genesis: While pursuing my master's degree at Virginia Tech, I had an internship at Dominion Energy. During my internship, I designed and modeled a 34.5 kV microgrid (MG) using Real-Time Simulator Computer-Aided Design (RSCAD). A microgrid is a small-scale network of distributed energy resources and loads that can operate independently or in conjunction with the main power grid. It typically serves a specific area, such as a neighborhood, campus, military base, or industrial facility. My project's objective was to design and model the MG, including the diesel generator, PV arrays, load, and batteries, in order to analyze the feasibility of the MG. I conducted two case studies: the first studied synchronization of the microgrid with the main grid, while the second studied battery storage to assist frequency regulation of an islanded MG. When I graduated, I started working at Dominion and continued to work on the microgrid project.

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

G.: Currently I am working on two projects of interest: One is what we call a Substation Automated Training Simulator. This project creates a realistic training environment for technicians and engineers, allowing them to simulate real-world errors encountered in the field. The training helps minimize human performance errors. The project's main focus is to provide a flexible and realistic training program, all while avoiding the risks associated with high-level voltage.

Another project I am working on is the Locks Microgrid Pilot Project in Virginia. It will have a large battery storage capacity and generate power from roof-top solar, ground-mounted solar, and solar carports. The campus will be a learning lab for tomorrow's engineers. They will be able to study how technology can support critical load centers in the future.

What has been the biggest challenge with your work?

G.: My main challenge has been to adapt to and implement cutting-edge technology, specifically constructing a microgrid without prior field experience. I have had modeling experience with RTDS and OPAL-RT, but the construction aspect is new. Fortunately, I am collaborating with a team of experienced engineers across various fields to integrate this new technology.

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

G.: I recognize that maintaining a healthy work-life balance can be difficult at times, especially for me, because both my husband and I work for the same company. We have started to set boundaries. For example, we avoid discussing work-related matters during dinner or while we are on vacation.

How did you get involved in CIGRE?

G.: I first got involved with CIGRE in 2018. When I interned at Dominion Energy, I was required to submit a paper to the CIGRE Grid of The Future Conference. Then, I became involved with the Next Generation Network (NGN) because a colleague, who was previously on the NGN board, recommended that I join.

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

G.: CIGRE is a global community where power system professionals collaborate. It includes committees like Women in Energy and Next Generation Network, which I find extremely valuable. These groups facilitate connections between women, young professionals, and industry experts. CIGRE's various working groups unite members to create industry-wide best practices and standards, enhancing the power sector as a whole.

Why would you recommend CIGRE membership to others?

G.: The CIGRE membership is highly beneficial, offering members access to exclusive publications, industry insights through the ELECTRA journal, growth opportunities for young professionals, and a global network for collaboration. It's a gateway to professional development and industry connection in the power system sector. For instance, during the Grid of the Future conference, I met a microgrids subject matter expert who provided valuable insights on effective grounding techniques within the microgrid system. Additionally, he introduced me to his colleague who works as a consultant engineer. Impressed by the consultant's expertise, our team decided to hire him to assist with the microgrid project.

Where do you see yourself in 15 years?

G.: I envision myself deeply engaged with innovative technology within the power sector over the next decade and a half. My goal is to expand my expertise in inverter-based systems and contribute to global communities by spearheading renewable energy projects in emerging nations. I aspire to ascend to a leadership position, where I can inspire and guide future women engineers in this industry.

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

G.: My bucket list is:

- **Professional Advancement**: Achieve the milestone of earning my Professional Engineering License.
- **Philanthropic Endeavor**: Collaborate with a charitable group dedicated to implementing solar solutions in developing nations.
- **Mentorship Role**: Leave a lasting mark by guiding and supporting other woman within the industry.
- **Global Exploration**: Embark on a journey across various states and nations to gain insights into diverse renewable energy projects.
- **Leadership**: Ascend to a position of influence within the power sector.

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

G.: I would like to see significant increase in the number of women in the power industry, as well as a general increase in diversity. A surge of women will make the industry dynamic and more fair, paving the way for a more equitable future. Diversity in general is crucial for fostering innovation, ensuring representation, enhancing performance, and promoting inclusion. Diverse teams bring varied perspectives that lead to breakthroughs in technology, better customer understanding, and excellent team performance. By prioritizing diversity, the power industry not only stays dynamic and relevant but also serves as a role model for other industries.

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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**.*

SC C4

Power System Technical Performance

Marta Val Escudero, Chair & Genevieve Lietz, Secretary

— Overview of Study Committee C4

Study Committee (SC) C4's main mission is to facilitate and promote the progress of power systems engineering and the international exchange of information and knowledge in the field of system technical performance and to add value to this information and knowledge by means of gathering state-of-the-art practices from around the world and developing recommendations. The main approach is through the formation of working groups (WGs) and the publication of CIGRE technical brochures (TBs); some recent examples are provided at the end of this brief report. The other approach is through sponsoring and promoting colloquia around the world which focus on the key technical challenges in modern power systems that relate to system technical performance.

The scope of SC C4 is the development and review of methods and tools for analysis related to power systems, with particular reference to dynamic and transient conditions and to the interaction between the power system and each of the following: (i) its apparatus/sub-systems; (ii) external causes of stress; and (iii) other installations. Specific issues related to the design and manufacturing of components and apparatus are not within the scope of SC C4, nor are those specifically related to planning, operation and control, apart from cases in which a component, apparatus, or subsystem behaviour depends on, or significantly interacts with, the performance of the nearby power system.

The SC C4 scope covers system technical performance phenomena that range from nanoseconds to hours, which includes everything from lightning, switching, power quality, electromagnetic compatibility and electromagnetic interference (EMC/EMI) and insulation coordination to power system stability, modelling and long-term system dynamics.

As the scope is quite broad and covers all aspects of the technical performance of large power systems, further work was carried out to better explain the timeframe of various phenomena. This work is regularly revised, and the timeframes of various current phenomena are given in Figure 1. The output of this work is included as an appendix in the SC C4 strategic plan.

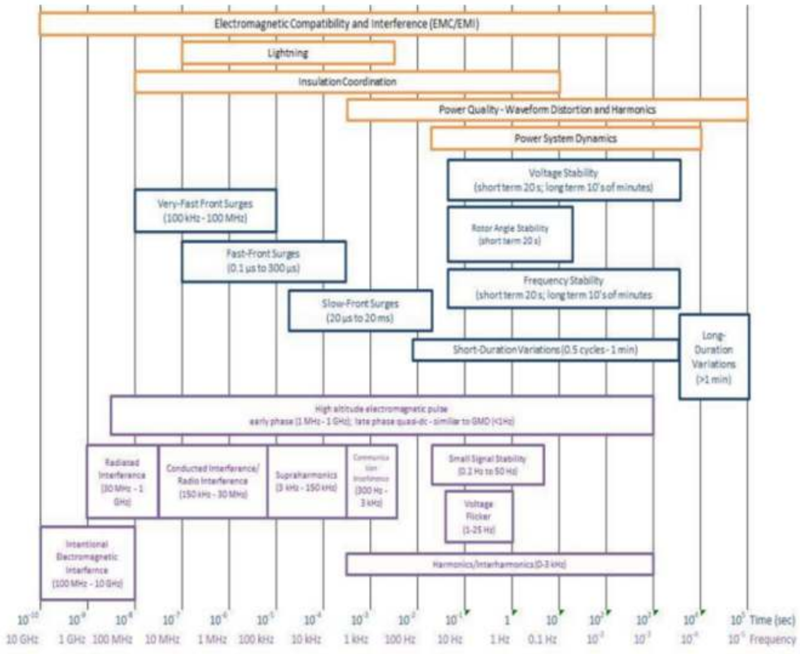


Figure 1 - Range of phenomena investigated by SC C4

Due to its wide remit, SC C4 alone cannot investigate power system technical performance issues without a solid understanding of the equipment itself, its performance, system planning and operational issues and environmental factors that may play a role in system performance. This leads to close cooperation between SC C4 and other CIGRE SCs that deal with equipment, system planning and operations, distribution networks, materials and testing, and environmental aspects of the power system. The close cooperation can be seen from the establishment of a formal liaison member between the following SCs and SC C4: SC A2, SC B4 and SC C2, and several joint working groups (JWGs). Furthermore, nomination and establishment of liaison members from other SCs in SC C4's WGs and vice versa also adds to the close collaboration between SC C4 and other SCs. At the time of writing, there are 14 JWGs with SCs A1, A3, B1, B2, B4, B5, C1 and C2. Furthermore, two SC C4 WGs are joint with CIRED on issues related to distribution networks. There are also two JWGs between SC C2 and IEEE owing to the increasing cooperation between the two organisations. SC C4 also has formal liaisons with the IEC TC 77 (on EMC) and the International Special Committee on Radio Interference (CISPR), and liaisons with the Global Power System Transformation Consortium (G-PST) and the IEEE.

SC C4 Structure and Strategic Direction

SC C4 is composed of 27 regular members, 3 additional regular members, 1 regular NGN member, 1 regular WiE member and 9 observer members, together with a Chair and a Secretary representing 35 countries. SC C4 presently consists of 41 WGs performing highly technical work aligned with the strategic fields of SC C4. These WGs are composed of hundreds of individual technical experts from around the world, some serving in more than one WG.

There are also three advisory groups (AGs) within SC C4. AG C4.1 is a group of experts that consults on the strategic directions for SC C4 and includes liaisons with IEC, IEEE, G-PST, SC A2, SC B4 and SC C2. AG C4.2 on Customers reviews and prioritises the composition of target groups and identifies improvements and opportunities for communication of the SC target groups. AG C4.3 on Tutorials and Conferences coordinates SC C4's activities with respect to colloquia and tutorials.

The SC C4 annual meeting in 2024 took place during the CIGRE Session in Paris, France.

— Main Technical Areas of Activity in SC C4

Below is a brief summary of WG activities in the main technical directions within SC C4. A complete list of all active SC C4 WGs with their annual reports is available in the SC C4 KMS space.

Power Systems Dynamic Performance Models and Numerical Analysis

The subject of system dynamics and the overall system performance in terms of various stability parameters is gaining significant attention due to the energy transition bringing increased connection of power electronic based devices. This trend is obvious from the number of WGs covering this technical direction, with a total of fifteen WGs examining many important issues of present and future concerns for power system dynamics and analysis. These include:

- Development of grid forming converters for secure and reliable operation of future electricity systems (**JWG B4/C4.93**)
- Power system resilience (**WG C4.47** and **JWG C1/C4.46**)
- Review of advancements in synchrophasor measurement applications (**JWG C4/C2.62/IEEE**)
- Impact of low inertia networks on protection and control (**JWG B5/C4.61**)
- Wind generators and frequency-active power control of power systems (**JWG A1/C4.52**)
- Protection roadmap for low inertia and low fault current networks (**JWG B5/C4.79**)
- Guidelines for sub-synchronous oscillation studies in power electronics dominated power systems (**JWG C4/B4.52**)
- Benchmarking of simulation models for control interaction in meshed AC networks with multiple converters (**JWG B4/C4.97**)
- Small signal stability analysis in inverter-based resource dominated power systems (**WG C4.71**)
- Evaluation of voltage stability assessment methodologies in transmission systems (**JWG C4/C2.58/IEEE**)
- Generic EMT-type modelling of inverter-based resources for long-term planning studies (**WG C4.60**)
- Application of real-time digital simulation in power systems (**WG C4.64**)
- Developments in large city and metropolitan areas incorporating new generation, grid and information technologies (**JWG C1/C4.36**)
- Line and cable models for steady-state and transient studies (**WG C4.74**)
- Best practices for individual and collective conformity assessment of inverter-based resources during their lifetime (**WG C4.77**)

These WGs are investigating challenging technical issues associated with modelling, simulation and dynamic performance assessment of power systems around the world. The ever-increasing penetration of renewable energy sources within the generation mix is driving the formation of more WGs in this area due to the need to understand the level of technical performance issues facing the grid of the future.

Power Quality

Currently there are five WGs concentrating on power quality related issues of present and future power systems. Work in most of the WGs is at an advanced stage. The work of WG C4.40 is very important in this area as it is trying to revise the relevant IEC Technical Reports, i.e. IEC 61000-3-6, 61000-3-7, 61000-3-13 and 61000-3-14. C4.51 is addressing traction supply points and the impact these points may have on the wider system with respect to power quality. WG C4.63 looking at harmonic power quality standards and approaches from a comparative viewpoint and has issued a questionnaire to National Committees to gather information. WG C4.65 is addressing the specification, validation and application of harmonic models for inverter-based resources and has formed a liaison with the IEEE Task Force on Harmonic Modelling.

Electromagnetic Compatibility and Electromagnetic Interference (EMC/EMI)

Electromagnetic Compatibility and Electromagnetic Interference (EMC/EMI) issues addressed by SC C4 cover emission and immunity problems resulting from disturbances that are not addressed under the subject of power quality. These include disturbances produced by the electrical power system as well as disturbances of external origin able to interfere with the electrical power system. Such disturbances can affect the integrated system performance by electrical conduction (electrical contact), induction (electric or magnetic fields) or radiation (high-frequency electromagnetic field). Health effects related to low-frequency electromagnetic field (EMF) are excluded, whilst intentional electromagnetic interference (IEMI) is instead included.

There are five active WGs within SC C4 that can be classified as being related to EMC. WG C4.44 is focusing on EMC for large photovoltaic systems and its work is at an advanced stage. Two further WGs include C4.54, which is looking at the protection of HV power network control electronics from the high-altitude electromagnetic pulse (HEMP), and C4.55, which is examining EMC related very-fast transients in gas-insulated substations. WG C4.68 is working on identifying EMC issues in modern and future power systems building on the work that was achieved a few years ago by the now disbanded WG C4.24. JWG C4/B4.72 is looking into lightning- and switching-induced electromagnetic compatibility (EMC) issues in DC power systems and new emerging power electronics-based DC equipment.

Lightning

Lightning is one of the most important natural phenomena that impacts and interacts with the electric power network necessitating advanced knowledge of lightning current parameters. There are presently ten WGs investigating various aspects of lightning. WG C4.36 is looking at lightning parameters and engineering consequences for wind turbines WG C4.43 is well advanced in its work reviewing lightning protection design schemes for structures from the viewpoint of avoiding physical damage and overvoltages that could generate flashover at electric apparatus and lines and investigating the applicability of these schemes to nuclear power plants. Two other WGs include WG C4.57, which is looking specifically at formulating guidelines for the estimation of lightning performance of distribution lines; and JWG B2/C4.76, which is concentrating on lightning and grounding considerations during rebuilding or refurbishment of overhead lines for both AC and DC. WG C4.59 is addressing real-time lightning protection in relation to the networks of the future where digitisation is heavily in use. Three further WGs include WG C4.61 investigating lightning transient sensing and monitoring, WG C4.66 researching new concepts for analysis of multiphase back-flashover phenomena, and WG C4.67 investigating the lightning protection of hybrid overhead lines. Two WGs, WG C4.69 and WG C4.70, are looking at quantifying the lightning response of tower-footing electrodes of overhead transmission lines in terms of measurement methods, and the application of space-based lightning detection in power systems, respectively.

Insulation Coordination

There are six active WGs within the technical direction of insulation coordination. Two WGs concentrate on overvoltage related issues. WG C4.76 is addressing overvoltage protection in switching inductive devices with vacuum circuit breakers and JWG B4/B1/C4.73 is addressing surge and extended overvoltage testing of HVDC cable systems with a goal to produce recommendations on methods for determining lightning levels in mixed OHL-cable systems. These are complemented by JWG B1/C4.69, which is investigating the development of insulation coordination recommendations on AC cable systems. WG C4.50 is investigating the evaluation of transient performance of grounding systems in substations. Three WGs investigate additional aspects related to insulation coordination: WG C4.43 deals with insulation coordination of HVDC overhead lines, JWG C4/A3/B2/B4.75 aims to create guidelines for the creation of pollution maps for outdoor insulation coordination purposes and WG C4.76 (mentioned above).

— Newly Formed Working Groups

Two new WGs have been established since September 2023:

- **C4.77**: Best Practices for Individual and Collective Conformity Assessment
- **B4/C4.103**: AC Network Equivalents for HVDC and FACTS Project Studies

CIGRE active Working Groups / Call for experts

Publications

Technical Brochures

The following three Technical Brochures have been published since September 2023 as a result of work done by SC C4 WGs and JWGs:

TB 928 - Multi-Frequency Stability of Converter-based Modern Power Systems - WG C4.49

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

TB 921 - Applying Low-Residual-Voltage Surge Arresters to Suppress Overvoltages in UHV AC Systems - JWG C4/A3.53

Six further Technical Brochures are expected to be finalised and submitted for publication before the end of 2024:

- **JWG C4/C2.58/IEEE**: Evaluation of Voltage Stability Assessment Methodologies in Transmission Systems
- **WG C4.61**: Lightning transient sensing, monitoring and application in electric power systems
- **JWG C4.42/CIRED**: Continuous assessment of low-order harmonic emissions from customer installations
- **WG C4.59**: Real-time Lightning Protection of the Electricity Supply Systems of the Future
- **JWG B4/B1/C4.73**: Surge and Extended Overvoltage Testing of HVDC Cable Systems
- **JWG B1/C4.69**: Recommendations for the Insulation Coordination on AC Cable Systems

Green Books

SC C4 recently finished a new Green Book on "Power system dynamic modelling and analysis in evolving networks", co-edited by Dr Babak Badrzadeh and Dr Zia Emin. Various chapters within the book were led by SC C4 experts. This Green Book provides information about all aspects of contemporary power system dynamic modelling and analysis in a rapidly changing power system with increasing uptake of inverter-based resources. It also provides a comparison of changes occurring in conventional power systems with a dominance of synchronous generators, and an evolving power system with a high share of grid-connected and distributed inverter-based resources. Topics addressed include dynamic phenomena experienced, analysis methods and simulation tools required, and enablers to achieve this. The Green Book was launched at the 2024 CIGRE Paris Session with an accompanying SC C4 Workshop.

Tutorials and Conferences

Since September 2023, SC C4 has supported the following eventS:

- Sendai Colloquium (October 2023): SC C4 had two paper sessions and two tutorials.
- Suzhou CIGRE ICLPS-SIPDA (October 2023)
- CIGRE 2024 Paris Session (August 2024): SC C4 had a General Discussion Meeting, poster session, a tutorial and two workshops:
  - The General Discussion Session was moderated by Special Reporters Torsten Lund, Antti Harjula, Patricio Munhoz-Rojas, Tim Browne, Angelica Rocha and Lukas Schwalt, who were supported by Marta Val Escudero;
  - The tutorial entitled “EMC issues in modern and future power systems” was organised by WG C4.68 (Patricio Munhoz-Rojas);
  - The Workshop on the SC C4 Green Book “Power system dynamic modelling and analysis in evolving networks” (see Figure 2) was organized by Babak Badrzadeh, Zia Emin, Marta Val Escudero, Genevieve Lietz, Julia Matevosyan, David Jacobson, Nilesh Modi and Deepak Ramasubramanian;
  - The Joint C4/C1 Workshop on "Resilience by design" was organised by Emanuele Ciapessoni and Mathaios Panteli; and
  - The poster session was convened by Papiya Dattaray and Manual Martinez.

Figure 2 - Green Book Authors (L-R, front) at the workshop: Jean Mahseredjian, Udaya Annakkage, Yicheng Liao, Nilesh Modi, Babak Badrzadeh, Ismail Ibrahim, David Jacobson, Gabriel Miguel Gomez Guerreiro, (L-R, back): Julia Matevosyan, Deepak Ramasubramanian, Marta Val Escudero and Torsten Lund

Upcoming events in 2025:

- Trondheim (Norway) Symposium, May 2025
- Montreal (Canada) Symposium, September 2025

The following webinars were presented, and the associated recordings can be accessed **soon** at eCIGRE:

- WG C4.49: "Multi-frequency Oscillations in Power Electronic Based Energy Systems". Presenters: Łukasz Kocewiak, Christoph Buchhagen, Xiongfei Wang, Mats Larsson, Ramón Manuel Blasco Giménez and Yin Sun.
- JWG C4/B4.52: "Guidelines for Sub-synchronous Oscillation Studies in Power Electronics Dominated Power Systems". Presenters: Chandana Karawita, Udaya Annakkage, Olli-Pekka Janhunen and Anuradha Dissanayaka.
- WG C4.46: "Evaluation of Temporary Overvoltages in Power Systems due to Low Order Harmonic Resonances". Presenters: Filipe Miguel Faria da Silva, Konstantinos Velitsikakis, Oscar Lennerhag, Chris Liberty Skovgaard and Julien Michel.
- JWG C4/A3.53: "Advanced metal-oxide varistors for surge arresters with better protection properties". Presenter: Jinliang He.
- Joint NGN-C4 webinar: "Hosting Capacity for Modern Power Systems". Presenters: Rafael S. Salles, Tais T. de Oliveira and Math Bollen.
- JWG C4/C2.58/IEEE: "Evaluation of Voltage Stability Assessment Methodologies in Transmission Systems". Presenter: Udaya Annakkage.

— Awards

The following individuals associated with significant contributions to SC C4 work were recognised with various CIGRE awards :

- CIGRE Technical Council Award: Dr Babak Badrzadeh (AU)
- CIGRE Women in Energy Award: Angelica Rocha (BR)
- CIGRE Fellow Award: Professor Jinliang He (CN)

Figure 3 - Award recipients (L-R): Babak Badrzadeh (TC Award), Angelica Rocha (WiE Award) and Jinliang He (Fellow Award)

- CIGRE Distinguished Member Award: Sarath PERERA (AU)
- CIGRE Distinguished Member Award: Andrew HALLEY (AU)
- CIGRE Distinguished Member Award: Don GEDDEY (AU)
- CIGRE Distinguished Member Award: William CHISHOLM (CA)
- CIGRE Distinguished Member Award: Božidar FILIPOVIĆ GRČIĆ (CR)
- CIGRE Distinguished Member Award: Filipe FARIA DA SILVA (DK)
- CIGRE Distinguished Member Award: Manuel MARTINEZ DURO (FR)
- CIGRE Distinguished Member Award: Stanislav UTTS (RU)

Figure 5 - Distinguished Member Award recipients

— Contact

[Contact of the Chair and/or the Secretary of the Study Committee](#) →

SC C5

Electricity markets and regulation

Yannick Phulpin, Chair, & Anthony Giacomoni, Secretary

— Introduction

Wholesale and retail electricity markets, like the objectives of the entities and systems that those markets serve, continue to evolve. Internationally, markets have developed and have successfully provided economic signals that support the development and operation of wholesale electricity. The success of those markets has allowed for the recognition, development and successful implementation of new technologies and solutions for supplying and purchasing electricity. This success has brought new demands on those markets. Market-based approaches have also been challenged by sudden changes in external factors (for example, the impacts of the energy transition, weather events and commodity prices).

Study Committee C5 is expanding its focus to report on and discuss the regulatory and market issues associated with the changing electric power industry, which include emerging technologies and services in generation, storage, transmission and distribution, and electricity demand management. It also includes perspectives on the integration of other energy vectors (H2, PtoX) in the value chain. SC C5 members provide needed insight to the wide variety of market and regulatory requirements involved with providing reliable energy with the changes in energy policy, technology development, consumer choice, and climate conditions.

Moreover, the changing landscape of behind-the-meter supply and the growing recognition for different levels of reliability and flexibility provides changes in industry requirements and consequent changes in market designs and regulations to properly incentivise the providers and consumers.

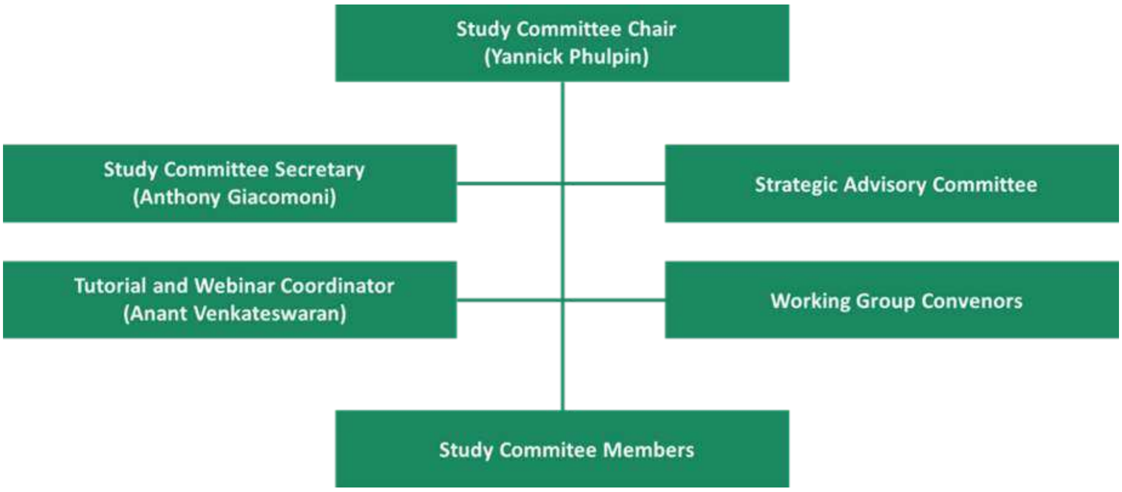
— Scope of work

The scope of the Study Committee is to analyse

- the impacts on the planning and operation of electric power systems of:
  - different market approaches and solutions
  - new structures, institutions, actors and stakeholders
- Industry practices and standards in terms of certification of origin, for electricity and other energy sources
- the role of competition and regulation in improving end-to-end efficiency of the electric power system.

— Structure of SC C5

The Chairmanship of the study committee changed in August 2024 at the Paris Session. The new Chairman, Yannick Phulpin, has developed a new structure, which is shown overleaf.



SC C5 membership

The current membership of the study committee is available **here**. The Study Committee has 32 regular members, 4 regular additional members and 8 observers. Together, the members and observers represent 40 different countries.

WG membership

The Working Group membership and demographics are examined in March of each year. The report for 2024 noted that the Study Committee had 6 Working Groups (6 at the time of this report). There were 108 members in the Working Groups. The WG members were spread across 31 countries. Our Working Groups had 17% female membership and a handful of NGN members.

Principal areas of interest

The study committee focuses on three key areas

- **Market structures and products**: Market design, physical & financial markets and their interaction, isolated and interconnected systems, interactions with Hydrogen systems.
- **Market approaches and tools**: Demand & price forecasting, financial risk management, demand management and active customer integration, integration of blockchain technologies.
- **Regulations**: Regulatory objectives, regulatory approaches, transmission pricing, ancillary service pricing, reliability and economics).

In addition, the Study Committee is interested in:

- Changes in regulatory roles and jurisdiction related to the interaction between the transmission system and the distribution system.
- The role of retail and wholesale markets, including: the integration and coordination of distributed energy resources; the impact on wholesale market price formation caused by non-wholesale market participants; the need for and development of distribution service providers.
- The impact of emerging technologies on system operations.
- Market clearing procedures, techniques and principles used to take advantage of the flexibility of aggregating large numbers of end-users.
- Potential market rule changes to address changes in traditional ancillary service products.

— Areas of attention

The current areas of attention, which are reflected in the current Working Groups, are listed below.

Demand side developments and their integration into existing market structures

Innovative DR mechanisms and EV charge/discharge solutions have become a priority in the transition to low carbon energies. The WGs focus on the role of transmission system operators (TSOs) and distribution system operators (DSOs) in managing DR and EV services (e.g. operational time frames, service procurement mechanisms, payment methods, and activation of such services) and on the development of market-based approached for the management of these services (time frame, bid structure, and pricing mechanisms).

- **WG C5.31** - Wholesale and Retail Electricity Cost Impact of Flexible Demand Response
- **WG C5.34** - Electric vehicle charge/discharge flexibility in wholesale energy markets

Market Drivers and development in markets

The purposes for market changes, the initiators of those changes, the processes for selecting a proposed change and the success of changes in meeting their objectives.

- **JWG C5/C6.29** - New Electricity Markets, Local Energy Communities

Sector integration for renewable gas — primarily Hydrogen

Approaches to integrate Hydrogen solutions in electricity markets, particularly the development of markets and regulations relating to renewable hydrogens, and possibly related renewable gases.

- **JWG C5/C1.35** - Integration of Hydrogen in Electricity Markets and Sector Regulation

Environmental Regulation in the Electricity Sector

A variety of regulatory or market-based approaches are implemented to manage environmental constraints, such as reductions in greenhouse gas emissions.

- **JWG C5/C1.36** - Certification of electricity used to produce hydrogen

Sector regulation to support investment

Regulatory approaches to foster efficient investment in network assets.

- **WG C5.37** - Regulatory framework on modernization and extension of useful life of transmission & distribution assets

CIGRE active Working Groups / Call for experts

— 2024 Paris Session

Group Discussion Meeting

The Preferential Subjects of the 2024 CIGRE Session attracted papers that cover the analysis of the impacts on the planning and operation of electric power systems of different market approaches and solutions. This includes new structures, institutions, actors and stakeholders as well as the role of competition and regulation in improving end-to-end efficiency of the electric power systems. SC C5 had 57 papers from 20 countries.

The Discussion Group Meeting was chaired by the Study Committee Chairman, Alex Cruickshank, with Albert Moser, Samir C. Saxena, and A. Venkateswaran as Special Reporters, Yannick Phulpin as SC C5 Secretary, and Anthony Giacomoni as incoming SC C5 Secretary. In total, there were 29 prepared contributions and a handful of spontaneous contributions that triggered timely and lively discussions.

Large Disturbance Workshop

The Study Committee convened a workshop, in conjunction with SC C2 to examine large disturbances in energy markets and systems. The Large Disturbance workshop has been convened by CIGRE during the Paris Session for many years and recently has included market disturbances. In total more than 770 people attended the workshop.

Other Workshops

The Study Committee organized three additional workshops:

- a workshop on Consumer-Energy Resources, co-organized with SC C6 and D2, which attracted more than 180 participants;
- a workshop on Hydrogen development, co-organized with SC C1, which attracted more than 200 participants;
- a workshop on the development of retail competition, which attracted more than 90 participants.

Tutorials

The Study Committee organized one tutorial: WG C5.34 presented a tutorial based on the integration of electric vehicles into electricity markets. This tutorial attracted more than 330 participants.

— Topics of current and recent Working Groups

JWG C5/C6.29 - New Electricity Markets, Local Energy Communities

Today it becomes more and more efficient to develop local energy systems based on distributed energy resources (DER) allowing customers to become energy suppliers. Adding locally batteries to dispersed generators, stationary or within electric vehicles, allows for a group of citizens or more generally for any group of consumers, to settle their own local structure for their supply of electricity, becoming a local energy community (LEC). With the digitalization of the economy and some specific tools such as block chain, each member of this group may organize easily its local market. Depending on national regulation, LEC can or not own and/or operate the network, or even target to be physically balanced, enabling islanded operation. As underlined by the recent Clean Energy Package in the EU, regulation is under development for LEC.

This JWG will liaise with parallel **JWG D2/C6.47** "Advanced Consumer-Side Energy-Resource Management Systems".

WG C5.31 - Wholesale and Retail Electricity Cost Impact of Flexible Demand Response

The study aims to provide an international view of the connection between retail programs/rate structures to costs incurred in the provision of electric service that may be impacted by flexible demand response (DR). Demand response (DR) includes all forms of demand-side response, which refers to a change in load coordinated with system or market needs. The change in load behind the utility meter of the customer can stem from end-use equipment, storage, PV, and other forms of distributed generation.

The study also aims to analyse the methods applied in practice to either directly or indirectly reduce costs, by service territory, in both regulated and competitive market environments. Introductory background on the functions that flexible DR supports and how it is factored into system planning and/or operations will be addressed at a high-level to provide context for presentation of findings by service territory.

The study will also identify and clarify terminology, in order to assist data collection and presentation of findings with consistency to support ready comparison of findings across service territories.

WG C5.34 - Summary of current uses of electric vehicle charge/discharge flexibility in wholesale energy markets and reliable grid operations

This Working Group will summarize the current uses of Electric Vehicles and EV charging networks in the operations and market optimization of the wholesale power grid. The evaluation will summarize the locations, purposes/services/pricing, participant roles, requisite technology and requisite regulatory frameworks of current uses of EVs in wholesale grids. The final report will provide insight into both the common and bespoke elements of current integrations providing a framework for assessing potential future standardization of EV integration. The final report will also identify areas of need for future assessment for successful standardization of EV integration.

JWG C5/C1.35 - Integration of hydrogen in electricity markets and sector regulation

This Working Group will gather information about grid connection to hydrogen technology resources and new initiatives for analysing the effect on electricity markets such as capacity markets, day-ahead markets as well as market coupling on commodity markets: natural gas prices in spot and forward markets. In addition, this group will gather hydrogen related information and analyse regulation issues in various countries and continents which currently are established or are planned for the future.

JWG C5/C1.36 - Certification of the electricity used to produce hydrogen

The Working Group will recommend attributes that are considered to define hydrogen as green and will also structure the parameters that need to be certified so that it is possible to verify if hydrogen is green or if it has a greenhouse gas emission content.

WG C5.37 - Regulatory framework on modernization and extension of useful life of transmission & distribution assets

The Working Group aims to capture different regulations applied worldwide for modernization and extension of useful life of transmission assets, from generation to distribution connection points to assess how regulators balance the costs and benefits of augmentation and refurbishments for grid users.

Latest publications for 2023 and 2024

Technical Brochures

The Study Committee published two Technical Brochures:

- TB 897 - Carbon Pricing in Wholesale Electricity Markets - WG C5.32
- TB 893 - Trading Electricity with Blockchain Systems - WG C5.33

Articles in CIGRE newsletters and Electra

In addition to the two Technical Brochure summaries, the Study Committee contributed five articles for Future Connections and ELECTRA:

- "Restoration of cyclone damage in rural Western Australia through long-term, off-grid supply", by Jacinda Papps
- "VPP Market Participation in the NEM", by Mitch O'Neil
- "Cairns Symposium was a blast", by Alex Cruickshank — report on the CIGRE Cairns Symposium
- "Renewable gases to decarbonise the power system", by Snow and Harris
- "Operating a 2GW power system on 100% distributed resources", by Jenny Riesz

Pending Technical Brochures for 2024/25

Five Working Groups expect to complete their work and publish technical brochures in the coming 12 months:

- Wholesale and Retail Electricity Cost Impact of Flexible Demand Response
- New Electricity Markets, Local Energy Communities
- Summary of current uses of electric vehicle charge/discharge flexibility in wholesale energy markets and reliable grid operations
- Integration of hydrogen in electricity markets and sector regulation
- Certification of the electricity used to produce hydrogen

Pending Study Committee C5 meetings

- 2025 - Montreal, Canada - **CIGRE Symposium**, September
- 2026 - Paris, France – **CIGRE Session**, August

Contact

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

SC C6

Active distribution systems and distributed energy resources

Kurt Dedekind, Chair, & Evert De Haan, Secretary

Introduction

The energy transition is in full flight, and the C6 related activities form part of shaping the destiny of this new energy future that we are currently witnessing.

A measure of the success of our contributions within the C6 working activities, is the progress that is shown towards meeting the universal Sustainable Development Goal (SDG7). Whilst significant progress has been made towards improved energy efficiency worldwide, the access to electricity remains out of reach to 675 million people. Despite advancement being made across the indicators, the current pace of delivery is not sufficient to achieve the 2030 targets.

Whilst the uptake of renewable energy has grown in the last decade, efforts must be scaled up to increase the share of renewables in the total energy mix to meet the decarbonisation targets that have been agreed upon internationally. If the world is to be on track to limit the temperature rise to less than 1.5°C, the share of renewable energy must increase substantially. (In the electricity sector, renewable energy would need to increase to 60-65 percent of all electricity generation by 2050 to meet these goals.)

Decarbonisation gives rise to the adoption of Distributed Energy Resources (DER). The C6 Study Committee activities provide the framework for managing the increased uncertainty and variability associated with the introduction of larger percentages of DER. The outcomes are geared towards providing the world at large access to electricity, whilst ensuring a more reliable, sustainable, and resilient network. This naturally needs to also remain affordable to permit access to electricity to all users.

Technology advances have also introduced measures to manage the variability and flexibility requirements associated with an increased penetration of DER in distribution systems. This implies that greater synergy is required to manage the interfaces between the Generators, the Distribution System Operators, and the Customer to ensure a balanced outcome.

Background and Scope of SC C6 Activities

Over the last decade, there has been an increased focus on distributed energy resources (DER) deployed in distribution systems. DER includes distributed generation, which in turn includes conventional systems (diesel engines, gas turbines, CHP), renewable resources (wind and solar based generation), energy storage systems (battery energy, thermal and inertial storage), and demand response methods (controllable and curtailable loads). Transportation, technology changes and electrification trends have also introduced further disruptors that have altered the distribution landscape.

Increased levels of DER penetration have impacted the planning requirements and the associated operations of distribution systems. The variability associated with the integration of DER into distribution systems, has required increased visibility and controllability of these systems at local and grid level. It has also required the DSO to respond to an increased flexibility required from the System Operator to balance, and to meet the ancillary services to manage and coordinate the distribution grids. Advanced operating systems are required to ensure that the interface between the System Operator and the DSO, and in turn between the DSO and the customer, can respond to the dynamic requirements of the grid and the energy system as a whole. Distribution system reliability and resilience, together with grid stability, are core to such operational interfaces.

As DER displaces part or all the central generation, the DSOs play an increasing role in the dispatch of generation in its interface with the Transmission System Operator (TSO). Increasing consumer involvement in demand-side management options, including market response and pricing signals, has ushered in new requirements for the DSO. The advent of Electric Transportation, Multi-Energy Systems and Power to X has introduced a series of additional planning and operational requirements for the distribution systems. Customer behaviour is also shaping the direction of new and additional electrification requirements. Access to data requires additional data centres, financial investment is attracting a need for bitcoin mining and many of these practices are shaping the evolution of the distribution networks.

This evolution of electricity grids is also driven by new technologies, including the digitalisation of grid control and management, which brings significant benefits whilst disrupting conventional approaches. Furthermore, it is challenged by societal and environmental concerns and pressures and includes decarbonisation and energy sustainability measures whilst encouraging a move away from fossil fuel use. In addition, there is a trend towards deregulation of the electricity markets, and requirements for increased resilience and reliability of the energy supply. Finally, DER deployment can be an approach that will facilitate rural and remote community electrification.

Distributed energy resources and active distribution systems can therefore contribute to key elements of the CIGRE technical direction, which include (a) innovative solutions for DER and distribution technology deployment, (which includes the interface with the prosumer); (b) new approaches to configure, plan and operate new and reinforced distribution systems for enhanced reliability and resilience; (c) rural electrification, islanded power systems and individual customer off-grid systems and solutions; (d) energy efficiency and demand side management solutions.

The complexity associated with the management of DER which include technologies mentioned above, are displayed in Figure 1. These assets and resources are the key drivers for deploying active distribution systems. They are increasingly included in the planning and operation of distribution systems. They make distribution grids more controllable and responsive, enhance the role of the Distribution System Operator (DSO) and enable consumer participation in electricity markets.

Aggregators, energy communities and virtual power plants interface between the customer and the DSO and the market to achieve the required flexibility to manage the distribution networks. DER, as it displaces part of the central generation, has an increasing impact on central power generation dispatch and the consequential impact on the operation and stability of transmission systems. Ancillary services are increasingly thus also able to be provided from these platforms to the System Operators to ensure overall grid stability.

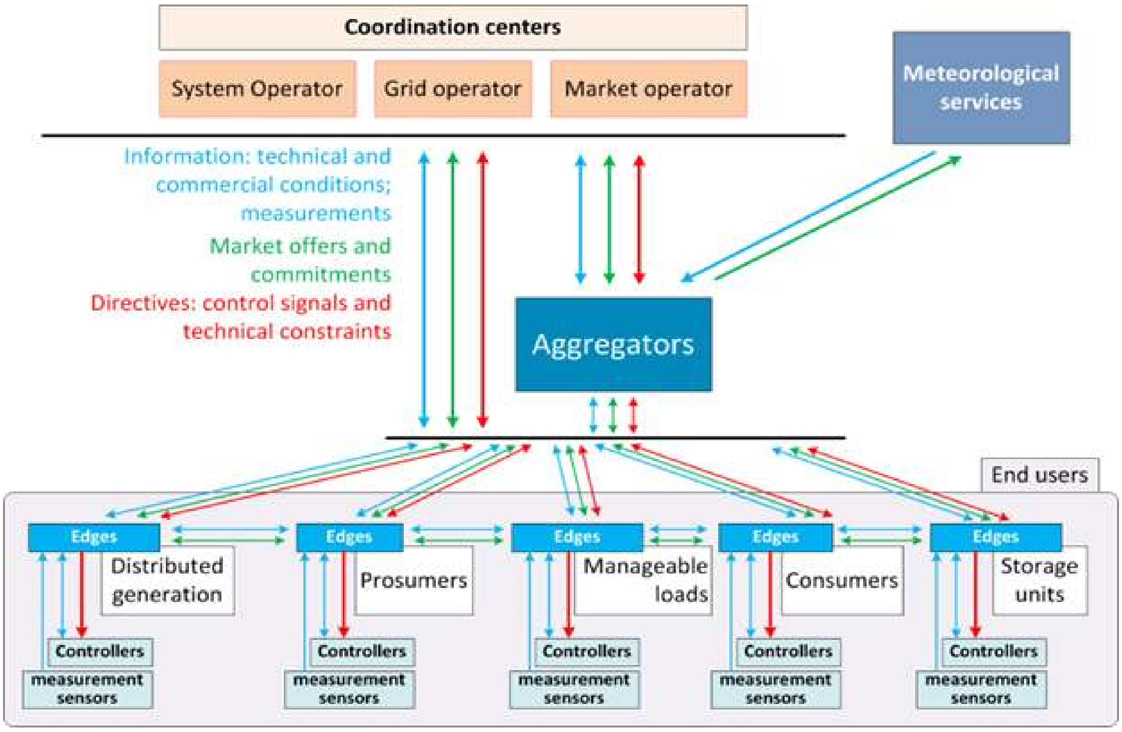


Figure 1 – Distributed Energy Resources (DER) – Information interactions between DER and DSO

Distributed generation, an element in the DER asset base, includes generation from renewable energy resources, which in practice are predominantly solar and wind power. These resources are variable and intermittent in nature and need to be balanced to provide dispatchable power to the grid. The flexibility of these operations can be managed using electricity storage (batteries) and demand response mechanisms. Distributed generation assets may also export power into the grid. The aggregation of DER is thus an effective way of managing many DERs, including smaller solar panels and battery energy storage systems at residential, small industrial and commercial levels. Concepts and tools such as microgrids, virtual power plants (VPP), as denoted in Figure 2, or software platforms such as DER management systems (DERMS) can thus aggregate and manage DER over a wider area as part of an active distribution system.

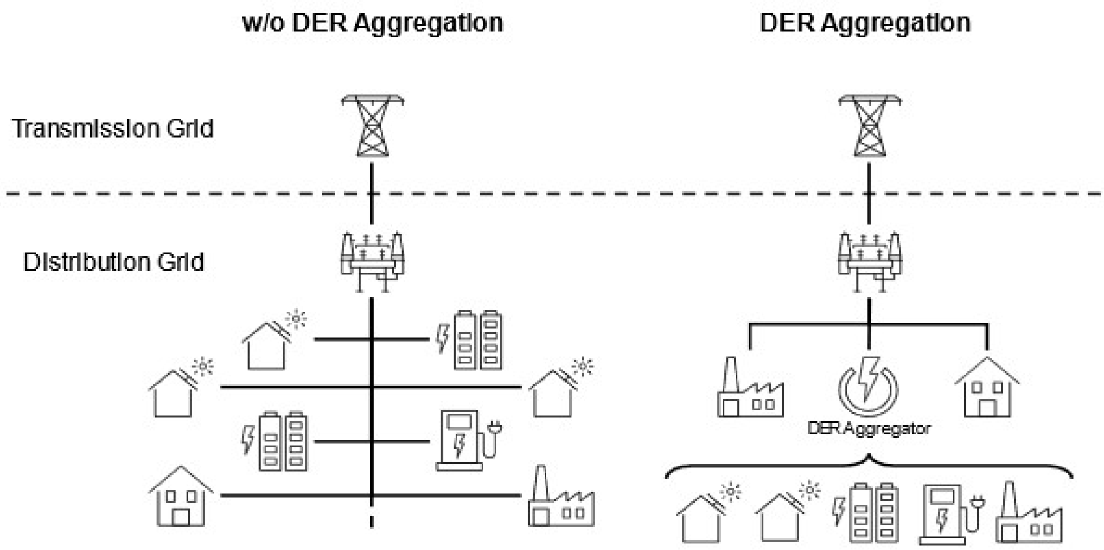


Figure 2 – DER deployment and aggregation – active distribution systems

SC C6 Mission and Scope

The activities of SC C6 are mainly concerned with the technology, the deployment of distributed energy resources (DER) and the impact of these on distribution grids. The SC C6 working groups are thus structured by using building blocks shown in Figure 3 as a platform for its activities:

The activities are principally concerned with the assessment of the technical impacts and requirements which a more widespread adoption of distributed energy resources (DER) including renewable generation units, storage applications and customer integration that could impose on the structure and operation of the whole energy system.

In parallel, the Study Committee should assess the degree to which such solutions are likely to be adopted in the short, medium, and long term. The practical importance and timing of the related technical impacts and requirements should also be assessed.

Through its work the Study Committee strives to objectively analyse the implications of DER and distribution technologies to become an internationally recognized forum on this evolving subject. Thus, the following topics are in the focus of SC C6:

- **Technology, integration and operation of distributed energy resources and the associated active distribution systems** - Analysis of the different approaches and solutions and to assist various players in distribution systems to make DER more controllable, visible, and responsive (active distribution systems with enabled customer involvement) and enhance the role of the Distribution System Operator (DSO) and its Distribution Management System (DMS).
- **Technological field of activity** - Innovative equipment and systems for DER and distribution technology deployment; customer integration and empowerment; enabling technologies for DER integration and application; storage technologies and multi-energy technologies, electric transportation, rural electrification, and off-grid systems.

- **Distributed generation**, from conventional (diesel, gas turbines, CHP) to renewable resource (wind and solar) based generation, **energy storage systems** (battery energy storage, thermal and inertial storage), and **demand response strategies** (controllable and curtailable loads).

Applications of interest may be reflected as:

- **Enabling technologies for renewable and distributed energy resource integration and application**: active network management, microgrids, virtual power plants, distribution management systems (ADMS, DERMS), DER monitoring and control, aggregation systems, platforms, blockchain applications
- **Innovative solutions for DER and distribution technology deployment**: smart inverters and power electronic interfaces and interconnection device applications, MV/LV DC supply systems, distribution system modernization
- **Storage technologies**: deployment of various storage technologies such as electrochemical electric battery energy storage systems, flywheels, flow batteries, and new storage technologies, hydropower, hydrogen, multi-energy solutions (with thermal storage), power2X applications (power to heat, power to gas ...), electric vehicles.
- **New approaches to configure new distribution systems for enhanced reliability and resilience**: islandable grid-connected microgrids, power exchange between microgrids, meshed grids, MV and LV DC considerations.
- **New approaches to determine the impact and plan and operate distribution systems in the context of a wide deployment of DER**, including the analysis of hosting capacity, network stability and protection requirements
- **Consumer integration and empowerment**: Demand side integration and participation, demand response, load management, smart load, new customer sectors such as electric vehicles, smart home, and smart meter applications with impact on distribution systems.
- **Smart cities**: integrated distribution system technologies, power, control and information and communication technology deployment for flexibility, integration of multi-energy systems.
- **Rural Electrification**, islanded power systems and individual customer off-grid systems and solutions

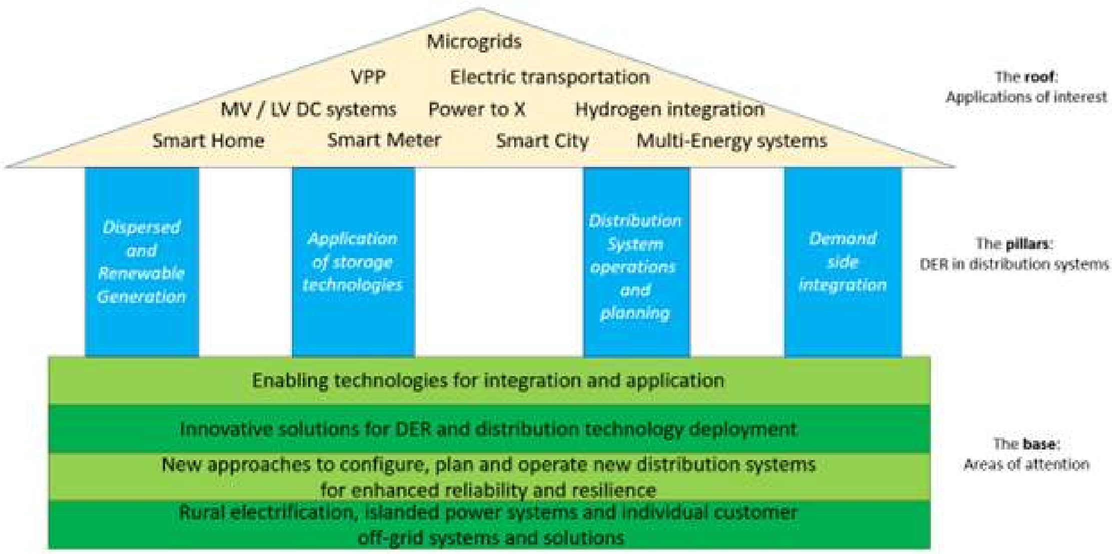


Figure 3 – Elements and building blocks of SC C6 technical activity

Structure and Membership

The SC is composed of 33 regular members, 4 additional regular members, 9 observer members, an NGN and a WiE member, and a Chair, Secretary and Communications Officer. Represented are 42 countries.

The membership includes stakeholders that have an interest in the topics covered by the Study Committee work. They include distribution planning and operations engineers and system operators, power system planning consultants, technology providers, manufacturers, applied information and communication technology experts, and researchers from academia and government laboratories. These stakeholders contribute to the effective collaboration platforms that shape the outcomes of the Working Groups

The Study Committee also collaborates through joint working groups (JWG) with other Study Committees, including SC B4 – *HVDC and Power Electronics*, SC C1 – *System Development and Economics*, SC C2 – *System Operation and Control*, SC C4 – *System Technical Performance*, SC C5 – *Electricity Markets and Regulation*, and SC D2 – *Information systems and telecommunication*.

Advisory Groups in C6 assist with the strategic direction setting and functioning of the Study Committee activities. The Advisory Group activities (AG) include:

- AG 01 – Strategy.
- AG 02 – Quality control of brochures and paper reviews.
- AG 03 – Delivery of Tutorials.
- AG 04 – Women in Energy
- AG 05 – NGN co-ordination
- AG 06 – Communication
- AG 07 – Rural Electrification (with a close link to the Africa Working Group)

The composition of the WG activities and the strategic support provided by the respective Advisory Groups is portrayed in Figure 4.

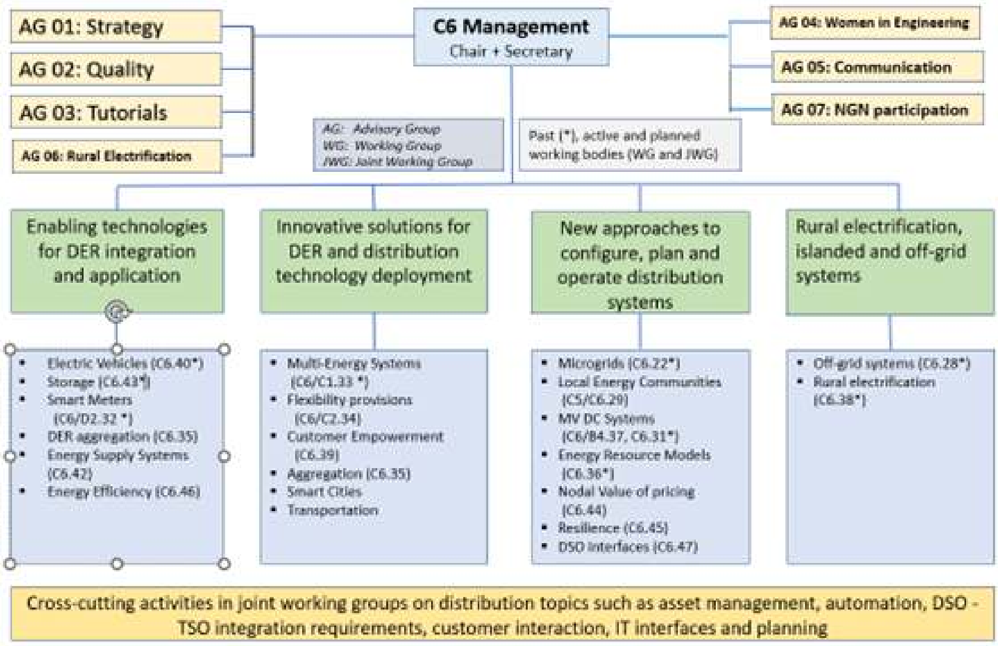


Figure 4 – Structure of SC C6 and associated technical activity

Current Technical Activities of SC C6 Working Groups

Current technical activities are addressed in the active working groups listed in Table 1. These cover the elements of the SC C6 technical activities structured in Figure 4, and with references to Figure 3 and the list in the Table 1. They include the following focus areas:

1. **Drivers for DER deployment and integration in distribution systems** (areas of attention) – covered in WG C6.38 (rural electrification), JWG C6/C2.34 (DER flexibility provision), JWG C1/C6.37/CIRED (investment decision under uncertainty), JWG C1/C6.42 (planning for high levels of DER), WG C6.36 (DER models for impact studies), WG C6.43 (Aggregation of battery energy storage and distributed energy resources (DER), including solar PV), WG C6.45 (The Impact of DER on the Resilience of Distribution Networks)
2. **Enabling DER technologies (pillars for DER)** – covered in JWG C6/C1.33 (multi-energy systems, as generation), WG C6.40 (electric vehicles as DER, as storage), JWG D2/C6.47 (Advanced consumer side energy resource management systems), WG C6.39 (customer empowerment and demand response).
3. **Innovative solutions for DER and distribution system technologies and deployment** (applications) – covered in JWG C6/C1.33 (multi-energy systems), JWG C5/C6.29 (local energy communities participating in markets), WG C6.39 (customer empowerment), WG C6.35 (DER aggregation platforms), JWG C6/B4.37 (medium voltage DC distribution systems), WG C6.42 (Electric Transportation Energy Supply Systems), WG C6.44 (Nodal Value of Distributed Renewable Energy Generation).

WG	Title of the Working Group	Approval	Convenor
JWG C6/C2.34	Flexibility provision from distributed energy resources	2018	P. Mancarella (Australia)
WG C6.35	DER aggregation platforms for the provision of flexibility services	2018	A. Oudalov (Switzerland)
WG C6.39	Distribution customer empowerment	2018	M. Ross (Canada)
WG C6.40	Electric Vehicles as Distributed Energy Resource (DER) systems	2019	J. P. Lopes (Portugal)
WG C6.42	Electric Transportation Energy Supply Systems	2020	M. Albano (UK)
WG C6.44	Nodal Value of Distributed Renewable Energy Generation	2021	K. Reiche (Germany)
WG C6.45	The Impact of DER on the Resilience of Distribution Networks	2022	N. Faarooqui Usman (New Zealand)
WG C6.46	Energy Efficiency in Distribution Systems	2023	A. Pandarum (South Africa)
WG C6.47	DSO - Customer interfaces for efficient system operation	2023	D. Eghbal (Australia)
JWG C1/C6.42	Planning tools and methods for systems facing high levels of distributed energy resources	2019	C. Higgins (UK)
JWG C5/C6.29	New markets, local energy communities	2019	A. Taccoen (France)

Table 1 – List of active SC C6 (Joint) Working Groups

Scope of Active Working and Joint Working Groups

JWG C6/C2.34 – Flexibility provision from distributed energy resources – The scope of the WG is to analyse, assess and promote the role and potential of distributed energy resources (DER) in providing ancillary services, particularly flexibility, and participating in balancing market and whole-system operation. It will review drivers and new requirements for flexibility at different stages of power system planning and operation at different levels of the power system, from the whole-system to the local network, with a focus on DER based on intermittent renewables and compile information on the potential of DER and multi-energy coupling to provide flexibility over different time scales, and in different forms, including generation (inverter interfaced), energy storage (batteries, thermal storage, e-vehicles, gas infrastructure), demand response (industrial installations, individual buildings or district energy systems), and flexible assets (transformer tap changers and voltage regulators, dynamic thermal rating) and operations (active power control of renewable energy, TSO - DSO coordination). The WG analyses the contribution of DER to operational and planning flexibility in transmission and distribution networks in current and future power systems, considering market structures, in providing multiple services of their choice to TSOs or DSOs, facilitated by new actors (aggregators) and grid architectures (interconnections, microgrids, virtual power plants, and energy hubs interlinkage, among which Vehicle to Grid (V2G) and Power to Gas (P2G). It will identify and discuss experiences and case studies and explore new business cases for emerging technologies and new market models. Finally, it will provide recommendations and guidelines regarding commercial, regulatory and policy changes required to exploit the flexibility provided by DER.

WG C6.35 – DER aggregation platforms for the provision of flexibility services – The objectives of this WG are to collect and analyse information on technical, economic, and regulatory aspects of DER aggregation and to analyse methods for integrating aggregated resources into network planning and operation. Economically attractive DER aggregation approaches, classified according to contracted customers and services offered, as well as aggregator interaction with other major stakeholders such as participation in ancillary services markets, including frequency regulation, capacity and energy markets, bilateral agreements with distribution network operators. Services covered include voltage support, congestion management, black start and restoration and services to end-users and customers, including backup power. The WG will review of aggregation technologies including DERMS (Distributed energy resource management system), VPP (virtual power plant), and microgrids, considering among others the role of ICT and forecasting, trading, and scheduling optimization and analyse the technological improvements that will allow DER aggregation to move to the next level of controllability and flexibility. Experiences, case studies, regulatory and business model trends will be analysed providing guidelines and existing practices, techno-economic challenges, and solutions for the deployment of DER aggregation platforms.

WG C6.39 – Distribution customer empowerment – The scope of this WG is to study the contributions to the operation of distribution systems that can be made by customers through the deployment of DER on their premises, supported by modern control and communication systems. Customer empowerment approaches include providing them the information required to understand their impact in better managing their consumption and the tools available to implement this management in a manner agreed with the distribution system operator. Load shifting and levelling are some of the tools. The WG will explore and elaborate the general context for customer engagement and empowerment opportunities, distribution utility interests, expectations, and requirements in-regard to the consumer. It will analyse the sensing, communication and control infrastructure required, and the implementation of customer empowerment and interaction with stakeholders. It will perform a review of current and planned practices and approaches to empower customers and the available power, control and communications and analyse experiences and examples of deployments and case studies. Guidelines and existing practices, techno-economic challenges and present and future solutions are provided.

WG C6.40 – Electric Vehicles as Distributed Energy Resource (DER) systems – The electric vehicle (EV) battery and its charging system, with or without the addition of a stationary battery, can therefore be used in almost the same manner and with almost the same potential benefits as any BESS type DER. Some of the benefits include demand response management (load shifting and load smoothing), distribution grid resilience enhancement (building back-up power supply, local grid support, enhanced hosting capacity and stability, contribution for islanding operation and black start in microgrids), renewable energy system balancing (solar PV), and ancillary services to the transmission system, particularly when aggregated, for purposes such as ramping and frequency support. This WG deals with the EV charging systems and infrastructure as a key distribution grid enabling technology. The EV battery and charging system technologies are presented from the distribution grid perspective, and the control systems required to enable the multiple benefits these systems can provide are described.

WG C6.42 – Electric Transportation Energy Supply Systems – The scope of this working group is the study of the available electric transportation energy sources and supply systems from perspectives related to the relative costs of the equipment, which include capital and operating costs, volume, weight and installation requirements, reliability, availability and maintainability considerations, and the recharging infrastructure requirements and deployment considerations. The energy supply systems to the transportation systems include batteries, hydrogen fuel cells, and electrochemical supercapacitors. Environmental impact, life expectancy and life cycle considerations are covered. The study proposes a comparative evaluation, including technical and economic considerations, of on-board energy supply systems and of the recharging infrastructure. For the on-board energy supply systems, power and energy considerations, range and losses, operating temperatures and environment, safety, security, and risk mitigation are considered. For the stationary installation, the reuse of existing infrastructure and impact on the existing infrastructures (electric power grid, energy supply infrastructures) are considered.

WG C6.44 – Nodal Value of Distributed Renewable Energy Generation – The objective of the WG is to document, discuss and analyse in practical terms how the variable renewable energy (VRE) nodal value concept can be applied more broadly and systematically by public and private power sector planners (and investors). This would allow for the joint optimization for distribution systems and generation expansion of the scaling up of distributed VRE investments, in different countries and energy system contexts. The practical issues and implications of applying the VRE nodal value concept are developed. Issues addressed include: (a) typical economic benefits, directly through reduced distribution losses, and indirectly in terms of providing ancillary services; (b) relevance of VRE nodal value analysis in VRE expansion planning and policies, particularly in weak power grids; (c) integration of the nodal value analysis in other power sector planning methods and procedures; (d) determination of minimum standards for data, modelling and cost benefit analysis information needed to generate robust results, to be used by practitioners and policy makers.

WG C6.45 - The Impact of DER on the Resilience of Distribution Networks - With increased probability and severity of extreme weather events, resilience of the energy system has become a key concern to system operators. Processes before, during and after an event will need to be elaborated upon. Hardening of existing infrastructure should be revisited under the scenario of extreme weather events and global warming. Vulnerability to failure of the upstream network shall be analysed. Distributed Energy Resource integration may enhance and complement existing resilience practices. With electricity becoming the backbone of the entire energy system, and where an increase of decentralized renewable generation of electricity with highly automated operation, cyber security will become an increased risk to manage. Strengthening the inverter-based energy system will be a third element requiring further investigation. This working group will focus on how to increase resilience in local and regional energy systems via increased DER integration.

WG C6.46 – Energy Efficiency in Distribution Systems - The potential for energy efficiency measures to address economic growth, facilitate a sustainable and secure energy future, together with a positive impact on the environment is well known. Energy efficiency can however have a pronounced impact in developing and developed countries where the need for access to electricity, and where electrification growth is affecting these requirements. Utilities are battling to keep up with the demand for electricity, grid capacity is becoming constrained, and the capital to expand the availability of energy and improve the quality of supply is scarce. Energy efficiency in electrical systems thus promotes a host of beneficial characteristics that may ultimately assist with the achievement of the Sustainable Development Goals (SDG), whilst also improving environmental and climate outcomes, health, gender equity and associated economic opportunities. The working group will thus evaluate energy efficiency measures in electrical networks, the associated impact of the implementation of such programs on power systems and associated customer behaviour.

WG C6.47 – DSO-customer interfaces for efficient system operations - Where DSOs used to design their networks for rather predictable loads and have the required reinforcements in place on time, the world could not be(come) more different. The climate issues (and transition to renewables) force customers to go about their energy use in a different manner, resulting in (rapid) increases in electrical loads (e.g., electric heating and mobility) and generation (e.g., solar and wind) on the distribution networks. The natural reflex for DSOs might be to ramp up their grid reinforcement efforts to support the electrification. However, shortages in staff and materials do not always allow for timely reinforcement and significant grid reinforcement increases the electricity price for customers. Furthermore, low-capacity factors for certain use cases (e.g., for PV) raises the question whether all reinforcements would be cost effective. These developments require the DSOs to grow into their system operator role. Increasingly, the DSO can (due to increased integration of DERs) and needs to (due to capacity constraints) unlock and orchestrate the customer-side flexibility capabilities. It requires increased communication with the customers on the state of the grid and the behaviour that is expected from the customer. Communication between the DSO and the customer requires a defined interface – an interface that goes beyond the capabilities of the regular (smart) energy meter. The working group is to investigate the requirements for communication, data exchange, visibility and controllability between a customer and its DSO. These requirements will be translated to (high level) design considerations for such an interface. Note that different design choices may be made for different types of customers and include the role of aggregators. These design considerations will help move towards international best practices and standards for information exchange between DSOs and customers.

JWG C5/C6.29 – New electricity markets, Local Energy Communities (LEC) – The WG will provide a worldwide overview of DER technology applied in LEC, the planning and operation of DER, and the development of LEC. The regulatory framework will be addressed. The aim is to understand how members of a LEC can be market actors, and how the LEC can itself be a market actor. The following topics are addressed: (a) definition of LEC (differences to microgrids, virtual power plants or net-zero communities) and of DER technology; (b) role of the regulator, local legislations as well as business cases within the internal organization of the LEC; (c) mechanisms for consumers entering and leaving a LEC; (d) options for an LEC being locally responsible for the balance between generation and demand; (e) interfaces as well as relation and required exchange of data between a LEC and the DSO; (f) competition between suppliers within a LEC.

JWG C1.C6.42 – Planning tools and methods for systems facing high levels of distributed energy resources – The JWG will identify the impact of a large deployment of DER at the distribution level and repercussions on the transmission grid as well as methods of aggregating DER and of determining the benefits of aggregating DER at the distribution and transmission levels. It will identify the tools required to analyse the impact of individual and aggregated DER on the distribution and the transmission systems and investigate the potential of co-simulation tools allowing the analysis of the impact of DER installed at the distribution level on the transmission grid considering static and dynamic aspects. Planning and operation tools required at the distribution and at the transmission levels to consider the impact of a wide deployment of DER will evaluate the impact on reliability and resilience. The economic aspects associated with the generation of power and increased reliability and resilience will be analysed. A survey for distribution and transmission utilities will provide present practices and additional needs, with a focus on known techniques, valuing DER and customer flexibility; practices and techniques in developing scenarios and tools to adapt to uncertainty, and commonly used tools, methods, and data.

WGs led by other SCs – with C6 liaisons and contributions: (a) **WG C5.31 – Wholesale and Retail Electricity Cost Impact of Flexible Demand Response**; (b) **WG C2.40 – TSO-DSO Interaction**; (c) **JWG C1/C4.36 – Review of Large City & Metropolitan Area power system development trends considering new generation, grid and information technologies**.

CIGRE active Working Groups / Call for experts

— Recently Published Technical Brochures

The following Technical Brochures have been published since 2023.

TB 906 - Distributed Energy Resource Benchmark Models for Quasi-Static Time-Series Power Flow Simulations - WG C6.36

Given the continuing evolution of DER technologies and applications, modelling these technologies poses a significant challenge when performing distribution system planning studies. Inconsistent terminology, multiple representations of specific DER types, and other issues arise as a result. This brochure presents a framework along with initial benchmark models developed by the CIGRE C6.36 working group for quasi-static time-series (QSTS) power flow simulations. These benchmark models are intended to be a common reference to understand and verify the performance of existing models as well as support standardization within the industry.

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

Electricity transmission and distribution investment decisions are transforming due to increasing uncertainties in various parameters, driven by factors such as evolving electricity market frameworks. Notable uncertainties include the rising penetration of renewable energy sources (RES) and distributed energy resources (DER) in response to carbon neutrality targets, climate change impacts on operational planning (e.g., hydrology), and the dynamics of variable renewable energy (VRE) like wind and solar photovoltaic. Economic uncertainties, electrification of load and transport, and recent global events, such as the Covid-19 pandemic, further contribute to the complexity.

The report delves into transmission and distribution network planning methodologies under increasing energy scenario uncertainty, drawing on experiences from Portugal, Germany, and Italy. Case studies from Europe, Sweden, France, and Chile analyse investment decision-making processes and coordination between ISO/TSO and DSO. Key learnings and recommendations for optimal investment decisions in the face of uncertainties include recognizing the impact of separate legal entities on decision-making, emphasizing the need for stronger integration among ISOs, TSOs, and DSOs, and highlighting the importance of comprehensive expansion plans that consider mutual interactions between transmission and distribution systems.

[TB 929 - Advanced Consumer Side Energy Resource Management Systems - JWG D2/C6.47]

This Technical Brochure addresses the technological challenges and economic consequences arising from the massive penetration of distributed energy resources (DERs) at consumers' side in power distribution grids. It provides an overview and recommendations on how to use existing and new types of information and telecommunication technologies to improve the integration of DERs by actively engaging them in energy flexibility markets. The presented materials also open further horizons for the development of a digital platform approach for the technical and economic rationalization of solutions aimed at efficient and cost-effective integration of DERs.

[TB 932 - Aggregation of Battery Energy Storage and Distributed Energy Resources - WG C6.43]

BESS are key enablers for the implementation of active distribution system functions by providing a range of grid services at the distribution level. This TB describes these grid support services, distributed BESS aggregation approaches, BESS operating constraints in terms of battery technology, weight, maintenance, and coordination with other controllers and regulatory and legal frameworks for BESS grid service delivery, regulatory and market considerations.

— Involvement in recent Conferences

Cairns Symposium September 2023

The Symposium in Cairns was supported by SC C6, where international C6 members joined the local C6 members to participate in the event.

- 11 Papers submitted for the Symposium under the C6 banner were integrated into the regional program of the CIDER (Committee for the Integration of DER) event.
- 19 papers were presented in three sessions as part of the C6 series of presentations. Broadly the following themes were accommodated during these sessions.
    - Active network management techniques for distribution systems
    - The customer interface and its impact on distribution operations

  - Managing the network with hybrid solutions and other power electronic devices

Paris Conference August 2024

The bi-annual Conference in Paris 2024 attracted a number of C6 members and delegates that attended the event. A very full C6 program of events featured the following outcomes.

- 78 papers were accepted as part of the Conference proceedings, including 5 papers from NGN members.
- 72 Poster were presented in two sessions.
- 37 Formal contributions were made at the Group Discussion Meeting with several spontaneous contributions. The following themes were presented as preferential topics:
  - Flexibility Management in Distribution Networks
  - Power Electronic based Solutions for Smart Distribution Systems
  - Rural, Islanded and Industrial Electrification Standards, Practices and Technology Options
- A Tutorial was presented on Battery Energy Storage Systems
- A joint workshop was held with the D2 and C5 colleagues with the title of "Consumer-Side Energy Resource Management - Market, Control and Information Systems Perspectives"

— New directions and conclusion

Study Committee C6 has sustained, during this reporting year 2023-2024, its efforts to create new WGs and extend its activities to new types of DER and new areas of DER applications...

Other issues proposed by SC C6 member proposed for future activities will focus on the following challenges in active distribution systems, addressed with the help of other interested study committees:

The following topics for new Working Groups were suggested:

- **Grid forming capabilities** - TSOs would like DER units to be grid forming, where from the DSO point of view this might not be the preferred solution. Several technical, regulatory and market-related elements may have to be considered.
- **DSO operational planning** - DSO operational planning practices as a topic that would focus on the day-ahead / week ahead domain. Methodologies and tools that shape these requirements might be relevant to such a Working Group. This could be seen as an update of the work of Working Group C6.19, culminating with the publication of TB 591.
- **TSO/DSO coordination** - coordination between TSOs and DSOs and to include power system operational control (e.g. on data exchange). This closely relates to the C2 activities.
- **Behind-the-meter device management** – The interface between a customer/home energy management system and the DSO. This includes the dispatch of the DER given various network and market signals. In this context, a local energy system might be seen as a customer as well.

- **Rural electrification** - Rural electrification and how local industry and technical capability tie into the requirement to accelerate the rural electrification. Technical Brochure (TB 835, published in 2021) may be referenced with the last mile aspect deserving more attention.
- **Hosting capacity** - Related to the diminishing hosting capacity due to increased DER penetration and electrification requirement. European Regulators want the DSOs to produce appropriate heatmaps, but the definition of hosting capacity and the way to perform the calculations are unclear. The questions are also: Hosting capacity for what? ...and, ...What load profiles should be taken into account in calculating it? When putting this into practice questions pertaining to the purpose of the heatmap, and the level of accuracy and dynamic modelling that will be required to achieve these outcomes. The previous TB 586 was published in 2014. Currently hosting capacity is often seen as something for the planning domain rather than the operational domain, while it holds for both.
- **Commissioning requirements of DER assets** - Commissioning of certain distribution assets. This should include regulatory, statutory and visibility and controllability requirements.
- **(Future) requirements for DERMS** - DERMS requirements, e.g. probabilistic calculations. Published experiences on how you put these IT/OT assets into operation.
- **Dynamic simulation technologies** - The DSO will need more simulation systems for e.g. earthing, wind energy calculations and more. The number of nodes in a distribution system is huge and the question is how you are able to perform these calculations. It is also of importance that both the system models and modelling concepts are unpaked as part of this activity.
- **Dynamic operating envelopes** - The concept of dynamic operating envelopes as a way to manage customer behaviour. A Technical Brochure would go into the definition of these envelopes and how they are to be used.
- **Low-voltage DC** - Exploring the concept of low-voltage direct-current networks. The grid topologies may be different from the topologies used in AC grids.
- **Customer intake and assets loading of distribution networks** - The risk encountered when considering a customer request for (additional) contracted capacity. As the industry is both looking at thermal loading of assets rather than nominal loading (pushing assets to their limits) and congestion management (changing the load profiles), the asset overload risk is increased. The question is how far you go and how to value this risk in the customer intake and network planning stage.
- **Fairness** – the position of the customer in MV and LV network determines the quality of supply. This is unfair by nature and the question is how to resolve this?
- **Model accuracy vs. data quality** – Increasingly accurate models... but is there a natural limit based on data quality. At some point, making the models more accurate is not effective.
- **Interoperability** - Creating a system where the different DER vendors can work together. This requires interoperability of control and standardisation of interfaces.

These outcomes must be viewed within a perspective in which the energy transition is evolving. These include...

- There is a need to develop an appreciation for the integration of new technologies. Applications such as Battery Storage solutions, invertor management and DC applications are avenues that will have to be explored further.
- New customer behaviour patterns are shaping the technology options, information exchange platforms and network operations of the future. Energy

Efficiency measures, EV adoption and Demand Response options are shaping the discourse of such a future engagement.
- Electrification growth will spurn a range of challenges to existing network capacity, notably in dense urban environments.
- Energy security will play an increasingly important role, as both resilience and reliability measures will become key focus areas for the sustainability of the industry.
- The move towards the decarbonisation net-zero targets will require greater flexibility management to cope with the uncertainties of existing energy supplies, and the variability associated with renewable energy integration.

The increased integration of DER into networks is adding layers of complexity in the management and modelling of network behaviours and is introducing challenges for both the network service provider, aggregators, and customers. It is apparent that SC C6 continues to scan the environment to look at technology offerings that are shaping the "how" of this energy transition. In similar vein, the varied facets of DER integration are challenging both the approach to the engineering behaviour required to manage the increased flexibility dictated by these new technologies and accompanying customer behaviour. It is thus evident that SC C6 needs to be adaptive to the requirements that shape both the energy transition and associated value chain.

SC C6 continues to publish technical brochures and produce tutorials that focus on knowledge dissemination related to the transition to the future power systems with a high penetration of DER and the potential for decarbonization. The preferential topics of the CIGRE symposia and session in which SC C6 is involved reflect these trends and initiatives. Future working group terms of reference and session preferential topics will integrate the topics and considerations proposed above. Technologies and solutions are available especially in the form of different storage and intelligent electrification systems, including MVDC systems, and increased consumer integration, coupled with conventional infrastructure strengthening measures can cater for the expected energy transition. Their application will however mainly be driven by the cost or the value of the benefits they provide for different stakeholders. The benefits realised are also dependant on the regulatory regimes and associated political to move towards a de-carbonised and sustainable future.

The key impact will be the ability to learn from the lessons from across the globe, and to ensure that the collaboration within platforms such as CIGRE, in fact enable such a transition towards an energy-secured future.

— Acknowledgements

The SC C6 Chair would like to acknowledge the active participation, contributions and support of all dedicated individuals that contributed to the achievements of SC C6 in this reporting period, including working group and joint working groups convenors, and SC members, reviewers of abstracts, papers and CSE articles, observers, and experts. It also wishes to recognize the contributions and support it received from other SCs in developing and promoting the potential of distributed energy resources to implement active distribution systems and provide services to transmission systems.

— Contact

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

TB 937 WG A2.64

Condition of cellulose insulation in oil immersed transformers after factory acceptance test

Due to the large magnitude of the investments involved, in particular for large power transformers, it is of vital interest to ensure that the buyer gets a transformer that is fit for service. There are, however, no agreements or guidelines of what shall be expected from a new transformer in terms of solid insulation properties. The purpose of this brochure is to provide the industry with a guide for checking material properties of cellulose insulation at the point when the transformer leaves the factory that is relevant for problem free and long future operation of the transformer.

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Introduction

Currently, the condition of the solid (cellulose) insulation in a transformer when it leaves the factory is not clearly defined in international standards. It is generally agreed that the insulation shall be new and dry, but there are no numerical limits in the standards, either concerning DP (minimum or average) or concerning remaining moisture (maximum water content). It is common practice to set an initial DP, the DP_0 (the DP after successful factory acceptance test (FAT)) in the range of 800 - 1000. Such values, however, are based on practice rather than on numerical calculations and they are often not accompanied by a moisture content value. In addition, compensation for not meeting DP_0 minimum limits could become a point of dissention between transformer supplier and buyer.

It has to be recognised that the precise determination of the DP and of moisture content of the insulation, even under controlled conditions at the transformer factory, is technically challenging and requires specific expertise. When the transformer leaves the factory, the DP_0, and particularly the moisture content, can vary substantially within the whole insulation system. The wide range of these variations is mainly due to the different types of insulation (from very thin paper to very thick, laminated solid pressboard plates) and to the complex active part construction and conditioning (drying) of power transformers.

Power transformer active parts are processed at intermediate manufacturing stages and there is no uniformity in the final processing during vapor phase drying (VP), or other drying methods, and final oil filling process before testing and hence DP_0 values when measured will show different results.

The present report covers the selection of relevant acceptance parameters, simulations of the relative influence of these parameters and suggested acceptance criteria. It also covers how to measure these parameters. Focus has been to define parameters that are relevant in terms of a direct effect on the transformer insulation lifetime, that are measurable and where achievable limits can be defined and set.

In this study, the effect of the combination of the DP_0 and the initial moisture content of the solid insulation on expected lifetime was investigated in detail, considering specifically the different temperature regimes (conductor paper wrap at the hotspot versus thick laminated pressboard typically at the top and bottom of windings). The brochure provides models for simulating these effects. The determination of the moisture level at delivery is based on the average moisture content of the total insulation. Methods for evaluation of the average moisture are presented. Simulations, as presented in the brochure, are very useful for studying the effect of moisture and DP_0 on the insulation lifetime as well as for defining acceptance limits for these parameters.

Multiple drying processes can sometimes be required, for example following manufacturing or factory acceptance test problems. This issue has been thoroughly investigated by various simulations, including the differentiation of thermally upgraded versus standard Kraft paper and various factory climatic conditions.

The brochure also provides instructions for both the measurement and interpretation of DP_0 and moisture content. The recommendations and conclusions in this brochure are based on the assumption that DP can be properly measured and that the issues with new, dried paper not dissolving can be resolved.

Results, examples

As an example, it was found that the impact of moisture (fractions of a percentage point of water in the solid insulation per weight) on expected insulation lifetime is more pronounced than the value of DP_0. For instance, “dry” paper with “low” DP_0 (900 DP with moisture content of 0.3 %) has longer calculated life expectancy than “wet” paper with “high” DP_0 (1100 DP with moisture content of 0.6 %).

The marginal influence of initial DP_0 can be illustrated by considering a reduction of initial DP_0 from 1000 to 900:

- It causes a reduction of transformer insulation lifetime of about 3 %
- It can be compensated by just slightly reducing the moisture content of the solid transformer insulation, a relative moisture reduction of about 3 percent (for

example 0.485 % instead of 0.5 %)
- It can be compensated in service by an operational temperature reduction of about 0.4 °C (for thermally upgraded paper (TUP), less for Kraft)

The manufacturing process of power transformers requires several intermediate drying steps, such as winding sizing, active part drying and final vacuum phase. After oil filling, the transformer is sometimes submitted to a temperature rise test. The brochure includes both simulations and measurements of the impact of these factory steps on the DP. The drying of the active part (usually with vapor phase process) has the largest impact, while the influence of temperature rise tests is negligible. As an example, Fig. 1 shows the simulated effect of VP drying on a 50 MVAR transformer with Kraft paper.

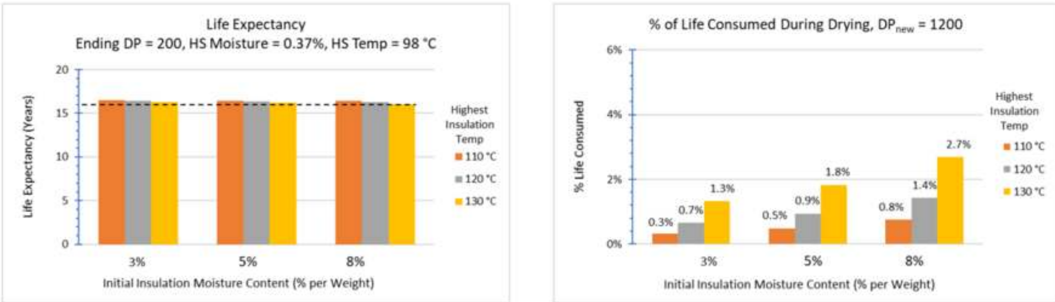
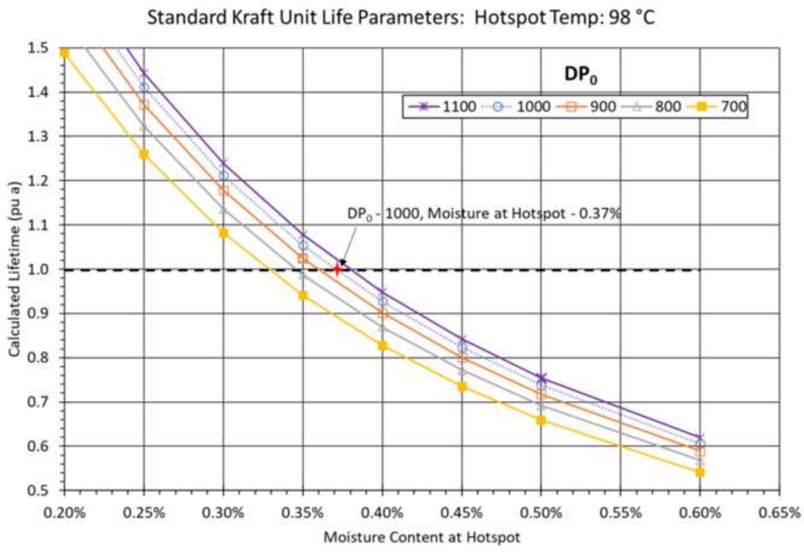


Figure 1 - Sensitivity of DP and Ageing to Initial insulation moisture and temperature – Unit 1, 50 MVA (Kraft Paper)

Figure 2 summarizes the simulated sensitivity of life expectancy of standard Kraft and TUP to DP_0, moisture content and temperature at the hotspot. It is observed that the effect of small changes in initial moisture content on lifetime of the insulation is more significant than changes in DP_0. For example, “dry” insulation with “low” DP_0 (900 DP_0 with moisture content of 0.3 %) has longer calculated life expectancy than “wet” insulation with “high” starting DP_0 (1100 DP_0 with moisture content of 0.6 %).



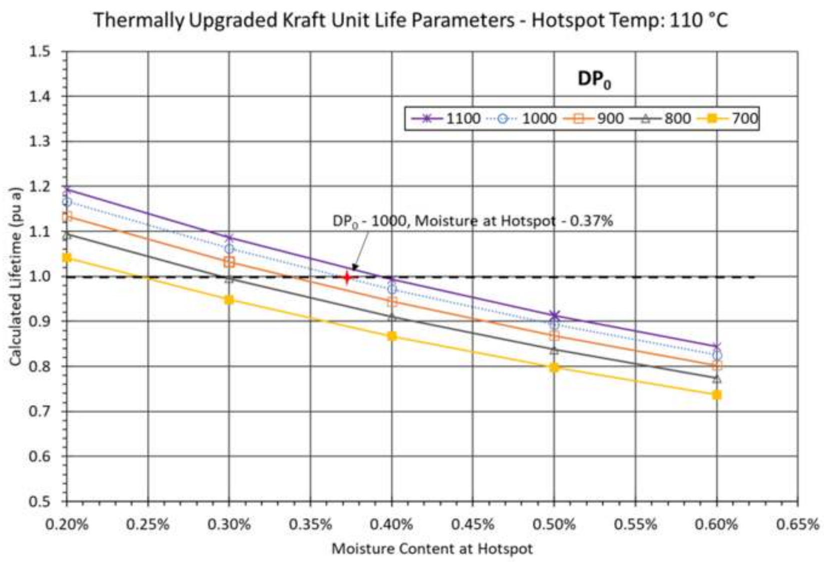


Figure 2 - Sensitivity of Expected Insulation Life to DP_0, Moisture Content and Temperature for Kraft (upper graph) and TUP (lower graph) paper

Recommended threashold values

For TUP, the moisture-DP chart in Figure 3 shows both the average moisture at the beginning and end of the specified insulation lifetime. For Kraft paper, the corresponding moisture-DP chart is shown in Figure 4. In both figures, the solid red line gives the maximum average moisture allowed in the insulation at the end of factory dryings based on the measured DP value at the end of factory dryings.

With an average moisture value of 0.5 %, a wide variation of DP-values below 1000 can be covered. Considering temperature levels with tolerances up to 2 °C below reference values, an average moisture content up to 0.8 % may also be classified as tolerable in many cases.

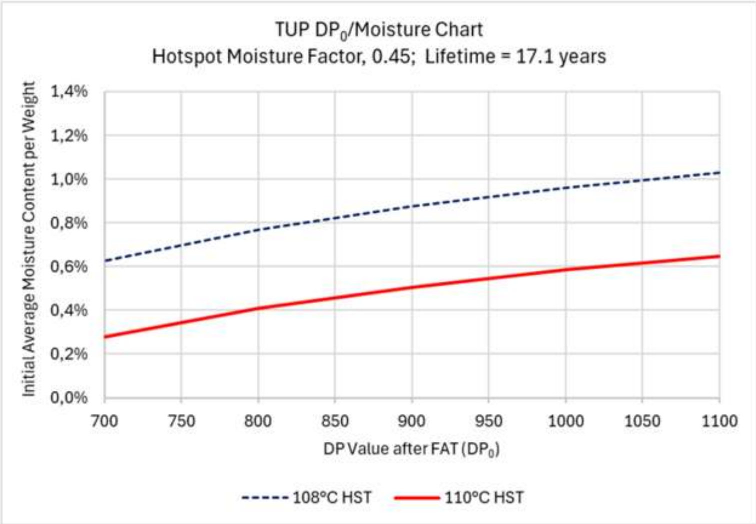


Figure 3 - Threshold Initial Moisture/DP chart for Transformers Insulated with TUP

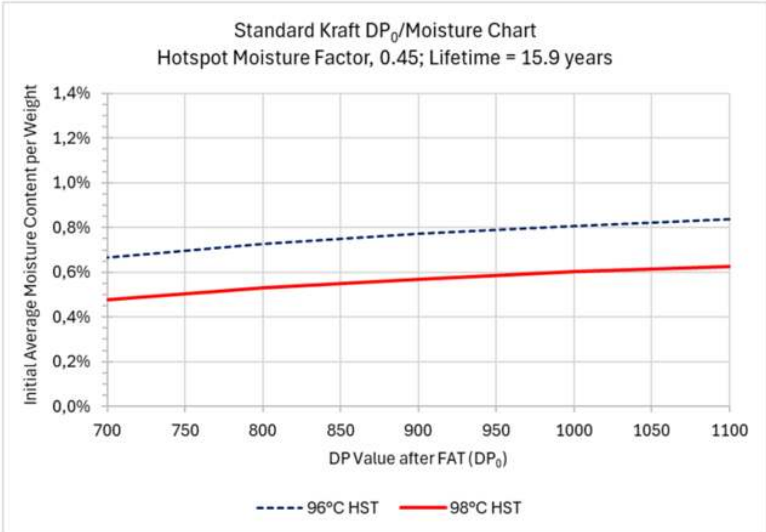


Figure 4 - Threshold Initial Moisture/DP chart for Transformers Insulated with Kraft Paper

It is recommended to evaluate a transformer after FAT by the following steps:

1. An average moisture level of 0.5% proves to be robust against wide variations of DP values. Therefore, if the average moisture is below 0.5% and DP_0 is above 800, the new transformer is in acceptable condition with respect to moisture and aging of the insulation. If this moisture level is not met or DP_0 values are below 800, then a more detailed analysis is recommended as defined below.

2. If the conditions defined in step 1) are not met, the transformer should meet the following rules:

- The average moisture must not exceed a threshold value of 0.8 %.
- The combined moisture and DP_0 limit values (the red solid lines) of the charts in Figure 3 and Figure 4 (irrespective of the hotspot factor for TUP and Kraft respectively) must be adhered to.

3. If the conditions defined in step 2) are not met, and if moisture values are below 0.8 % and provided that a hotspot temperature rise of more than 2°C below the regular threshold (i.e.< 88 K for TUP or <76 K for Kraft, assuming a 20 °C ambient temperature reference) can be demonstrated, the transformer must adhere to the dashed line of Figure 3 (HS temp 108 °C for TUP) or Figure 4 (HS temp 96 °C for Kraft).

If after Factory Acceptance Testing the transformer does not pass the acceptance criteria above, then there are two possible approaches, either modifying the transformer such that the unit now passes the acceptability criteria or providing satisfactory compensation to the buyer. Options for modifications are discussed in this brochure. In practice any specific situation may involve a combination of these two approaches.

Conclusions

The main conclusions of the brochure are, in summary:

- Any parameters to be used for acceptance criteria must be relevant in terms of a direct effect on the transformer insulation lifetime, must be measurable and limits must be achievable. Among many possible parameters, two were selected, having direct effect on transformer insulation lifetime, they are measurable and limits can be set. Moisture and DP were selected.
- Expected (shortened) insulation lifetime due to the heat impact of drying must be assessed by evaluating the DP together with the moisture content of the cellulose insulation as a value pair. These two parameters must not be assessed and specified separately.
- The importance of high DP_0, seems often to be overrated or misinterpreted by the industry, particularly because of the non-linear DP decrease with aging and because the moisture is not taken into account.
- The water content has strongest influence on the lifetime of the insulation, considerably stronger than the DP_0.
- When applying today's efficient and effective drying techniques in a well-controlled fashion, the DP of the cellulosic insulation is not affected significantly. In contrast, low remaining moisture creates an advantageous precondition for a long lifetime.
- Compensation schemes, if any, in case of discrepancies between measured and expected DP_0 and/or moisture level, should preferably be defined early in the purchasing process, i.e. as part of the specification and quotation process. Also, the validation model and acceptance criteria should be agreed in advance between supplier and buyer.

TB 938 | WG C1.44

Global Interconnected and sustainable electricity system

Following an initial pre-feasibility study on the global power grid concept, which highlighted the value of interconnections between continents for more efficient implementation of wind and solar power worldwide, an extension was carried out to consider alternative solutions such as storage and demand response. In addition, the commercial rules and governance issues of a global grid have been added to the scope.

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Summary

In 2016, CIGRE decided to launch a pre-feasibility study on the concept of a global power grid. The results published three years later in TB775 highlighted the value of an interconnection between continents for a more efficient implementation of wind and solar energy worldwide. Thanks to these encouraging results, CIGRE decided to launch a new C1.44 working group with the aim, on the one hand, of deepening and refining certain modeling hypotheses, based on feedback received from the CIGRE community, and on the other, of enriching the options for decarbonization enablers not only with more interconnections, but also with more storage and more demand response, seeking the optimal combination of these viable options. In addition, the trading rules and governance issues of a global grid have been added to the scope.

The methodology and input data are those used in the previous C1.35 study. Total electricity production in 2050 is expected to be 40,000 TWh, compared with 25,000 TWh in 2020. Decarbonization should be significant: less than 1 billion tons of CO_2, compared with 13.4 billion tons of CO_2 in 2020. Total equivalent installed capacity is 14,000 GW in 2050. With these assumptions, renewable energy resources would account for almost 60% of total energy production.

The technologies considered in this study include HVDC overhead lines as well as HVDC submarine cables for land and submarine corridors. Storage facilities were modeled in two activation categories according to their minimum time to full discharge: short-term (4 hours) and medium/long-term (48 hours). For the assessment of demand response, the potential was estimated at 10% of peak load reduction.

The study highlights the main advantage of interconnections over other solutions such as storage and demand response. It reveals the existence of two major backbone networks. The first links Europe to the Middle East and South Asia, to share Europe's high wind potential and the Middle East's high solar potential with the high level of demand in South Asia. The second links North America East to North America West, underlining the economic advantage of merging the North American zones. Several secondary "north-south" corridors are also highlighted, mainly to bring together wind from temperate zones and solar from inter-tropical zones with load centers.

The TB includes an overview of cross-border trading and regulatory practices applied throughout the world. From the perspective of building a global grid, it seems natural to leverage on existing and emerging supranational electricity power system organizations, particularly if trading rules are already in place inside within these organizations. This is the case of a broader framework which, in addition to trading rules, includes network codes, connection rules, commercial standards, regulatory frameworks, operational agreements for interconnections. In this sense, the case of Europe with ENTSO-E can be taken as a reference for its evolution towards a regional to continental power pool for the common electricity market and trade.

Finally, the document sets out key recommendations for the implementation of a global grid, including the following:

- A gradual approach to trade, from bilateral to regional, continental and global levels.
- Political support is needed to build interconnections, but also to support general trade agreements and individual trade transactions.
- Long-term power purchase agreements should be seen as means of ensuring the viability of new investments in RES, but also of interconnections where they are needed to evacuate this generation.
- Regional institutions should be encouraged and created in the form of regional energy committees or regional coordination forums.

— Scope

The central scope of this study is to extend the results of the previous WG C1.35, which was essentially solving the optimization trade-off between more transmission vs more generation, introducing also different storage options and demand response as further variables in the optimization exercise. This makes more robust and more realistic the quest for optimal investment allocation in the perspective of a potential intercontinental transmission grid; an analysis of trading rules and possible commercial arrangements, based on existing/projected use cases has also been added.

Storage options have been simulated fo short term (4 hours electrochemical batteries) and medium term (hydro pumping with 48 hours cycle). Demand response, both implicit and explicit, have been simulated as peak shaver effect. Conceptually, both elements contribute to reduce the need of new generation and of new transmission lines; the results have shown that this effects are relatively limited, and do not impair the previous conclusions that extending the grid even to intercontinental outreach is in all cases and sensitivities is still an indispensable building block for a wider optimized power system.

The study is based on a set of assumptions encompassing predicted techno-economic developments on a global scale. In the upcoming sections, these assumptions (e.g., the evolution of the electricity demand and the construction of associated time series, the clustering of regions and the selection of corresponding transmission corridors, the estimation of renewable energy potential) will be introduced and discussed.

From the very beginning, a series of limitations inherent to this approach should be mentioned. First, as the current work focuses solely on the assessment of interconnectors and the associated inter-regional power flows, transmission systems within regions are not modelled, thus potential grid reinforcements that may be necessary to accommodate incoming flows are not considered. Second, the estimated variable renewable energy potential within each macro-region may differ from the empirical values associated with locations within it, but it rather corresponds to optimistic visions of solar PV and wind potentials in each region. Also, the process of demand time series projection to 2050 builds on the premise that there will be no changes in the daily/seasonal consumption patterns, an assumption that may not hold with the electrification of other demands (e.g., residential heating via heat pumps or transportation through electric vehicles).

Description of the Technical Brochure

The Technical Brochure comprises nine chapters and four appendices.

Chapter 1 presents the objectives of the study and describes the organization of the Working Group.

Chapter 2 presents the scope and limits of the study, and the data sources used for the assumptions. It introduces the selected scenario and describes the regional model and corridors used for simulations.

Chapter 3 describes data collection.

Chapter 4 describes the technologies considered in the study.

Chapter 5 addresses cost issues, for both transmission assets and generation.

Chapter 6 describes the case studies considered.

Chapter 7 presents the simulation results. It includes the sensitivity analysis taken into consideration.

Chapter 8 addresses cross-border trade and regulatory issues.

Chapter 9 concludes the report, including recommendations.

Results of the study

The geographic model used with C1.44 increased the granularity of grid architecture from the previous C1.35 study, from 13 to 22 regions, with one electrical node per region. This coarse granularity is sufficient to provide an initial quantitative assessment of interconnection capacities and potential inter-regional power flows. Priority is given to the identification of the main electricity transmission corridors, including (i) the development of non-existing interconnectors and (ii) large capacity reinforcements (higher than 2 GW) for already existing links. Internal reinforcements are not modelled and are captured by an appropriate selection of endpoints in each region.

The different simulations carried out aim at partially replacing the use of gas (CCGT with or without CCS, and OCGT) with additional RES (wind and solar) with the support of optional solutions: either additional storage, Demand Response, interconnection between regions, or a combination of them.

Compared to the previous study, this study has limited the capacity of the corridors to 50 GW. Without this limit, the simulations would have resulted in unrealistically large corridors (up to 400 GW). Even with this limit, interconnections remain the most advantageous solution. Total interconnection capacity is 750 GW, which represents only 5% of installed generation capacity. The annual electricity transferred by these interconnections would represent 10% of the total energy produced.

The simulations assess the impact of the different solutions, and the results are compared with the reference case, which is the isolated system (no link between the 22 regions, no storage and no DR). All the solutions, alone or combined, lead to a reduction in costs and CO2 emissions.

The Table 1 summarizes the results of all simulations performed.

CASE STUDIES	INTERCO	STORAGE	DR	COST (€/MWh)	CO2 (Mt/yr)	Cost / #1	CO2 / #1	gas GW %	wind GW %	pv GW %	PHS-BESS GW %	GRID GW %
Isolated (#1)				49,0	453			2 100	5 839	3 336	158	
Isolated with STORAGE		✓		48,6	316	-1%	-30%	-30%	-6%	+43%	+444%	
Isolated with DR			✓	49,0	457	0,1%	1%	+2%	-3%	-6%	0%	
Isolated with ST and DR		✓	✓	48,7	330	-0,5%	-27%	-28%	-8%	+38%	+426%	
Interconnected only	✓			47,1	309	-4%	-32%	-47%	+24%	-14%	0%	738
Interconnected with ST and DR	✓	✓	✓	47,1	239	-4%	-47%	-56%	+16%	+8%	+274%	-15%

Table 1 - Summary of the simulations

Implementing all three solutions is the most efficient. Total costs are reduced by 4% compared with the reference scenario. CO2 emissions are reduced by almost 50%. However, implementing the interconnections alone achieves the same cost reduction (4%), with a smaller reduction in CO2 emissions (30%). The combination of storage and DR has little impact on cost reduction (0.5%). As regards the impact on production, the development of interconnections leads to a significant reduction (-47%) in gas production, mainly offset by the increase in wind generation (+24%). With the combination of the three solutions, the reduction in gas production could be even greater (-56%) but would require an increase in wind production (+16%) and considerable development of storage (+274%).

The different solutions are compared by two indicators: cost and CO2 emissions.

Thus:

- The best results are gained by the combination of the three solutions; however, the advantage is low compared to ''interconnection only'';
- ''DR only'' does not provide any improvement. In this case, the peak of demand is at noon, synchronized with the peak of PV generation. Therefore, the shift of demand (DR model) induces a reduction of PV capacity but needs additional non-intermittent generation (gas) at a later stage in the day.
- ''Storage only'' induces the replacement of gas generation by storage means and by the implementation of additional PV capacity.
- With ''interconnection only'', the gas capacity is replaced by wind capacity. The interconnections allow a larger smoothing effect of wind.

In this feasibility study, corridor capacity was limited to 50 GW, whereas no limit was set in the previous study. This limit was chosen for realistic reasons. For example, 50 GW represents about ten interconnections between two regions, which is already a large technical and social challenge to implement in three decades. Nevertheless, even with this limitation, the economic viability of interconnections is confirmed. The optimized system includes about 700 GW of cumulative interconnection capacity, corresponding to only 5% of the generation capacity and 2% of the electricity cost. The interconnections are used bi-directionally, depending on the season.

Regarding cross-border trade and regulatory issues, the document proposes key recommendations for the creation of regional, continental up to global market:

- A progressive approach to trade – from bilateral to multilateral, regional, continental up to global level – is necessary and should be followed, considering different local conditions and constraints.

- Political support is needed to build interconnections, but also to support general trade agreements and individual trade transactions.
- Commercial transactions need to be hedged against external risks: geopolitical risks, environmental risks, climate change adverse impacts risks, legal/investment risks, financial/bankability risks, technical/operational risks. Legal risk and investment protection, given the huge initial investment effort in transmission assets and new power plants, as well as stable legal framework at macro-regional level, are essential to attract private investors and promote cross-border trade.
- Long-term Power Purchase Agreements (PPAs) should be seen as a mean of ensuring the viability of new investments in RES, but also for interconnections where they are needed to evacuate this generation, so that Independent Power Producers (IPPs) in one country can also secure their investments through PPAs with suppliers across future interconnected regions.
- Regional institutions, in the form of Regional Energy Committees or Regional Coordination Forums, with close operational links to the relevant TSOs and utilities, should be promoted and created. A Regional Energy Committee or a Regional Coordination Forum should be established to propose regional agreements and to develop and implement rules and standards for cross-border electricity trade. A Regional Energy Committee or a Regional Coordination Forum should have dispute resolution capabilities, coordinate market developments and take decisions on important economic issues.
- Bilateral energy trading — The market model for energy trading and the use of transmission capacity should be as simple as possible, particularly in the early stages of interconnection operations. Initial energy trading could focus on the first interconnections with the use of bilateral contracts in the form of PPAs between generators and buyers, plus relevant arrangements for transfer capacity.
- Regional market model — The regional market model in a restructured, mature electricity system would see the coexistence of bilateral energy exchanges and short-term energy transactions on a spot market where the various market agents (sellers, purchasers, traders) operate.
- Access to the transmission grid — The transmission network should be open to connection by IPPs. Remuneration for use of the grid should be transparent, non-discriminatory and, as far as possible, stable over the time. Transmission fees should reflect costs.
- Regulatory harmonization and governance — Although some national reforms may be necessary, regional rules should minimize interference with national policies. This will allow a more harmonious development of intercontinental/interregional interconnection and continue to give national governments the freedom to define their domestic policy. In terms of governance, it is important to define common ground at regional level regarding standardization and market opening, given the differences in the maturity of electricity markets between countries. It is also necessary to establish a common definition of elements (where they exist) such as: energy transactions, supply contracts, metering, settlement, accounting and invoicing, rights and obligations.

— Further work

The dynamics and behavior of the corridor network, beyond the basic load flow, were outside the scope of this study. Thus, the electrical topology within a region was considered as a copper plate. Consequently, the individual assessment of each corridor could be relevant to characterize priority.

Trade rules and governance issues have been analyzed in a progressive approach, from bilateral to multilateral, from regional to global. This should help clarify business models for project financing.

The introduction of sectoral coupling and hydrogen into the trade-off equation could be relevant, as hydrogen is expected to play a role in long-term storage and as a long-term energy carrier. Heat, transport, etc. could also contribute to a broad sectoral coupling. This question could be addressed by a new working group.

Finally, the question of which interconnection could kick-start the process remains open. Clearly, the most important conditions are a solid climate of cooperation, mutual trust and strong socio-political support.

TECHNICAL BROCHURE

TB 939 | **WG A2.62**

Analysis of AC Transformer Reliability

The reliability of the global power transformer fleet was reviewed again, continuing CIGRE's long legacy of surveying started forty years ago. As technology and working practices are updated it is important to periodically review reliability and how it is changing. More than 425,000 transformer years of operation collected, there were 1,204 major failures and 1,916 retirements from 66 utilities in 27 different countries. In addition to retirements and major failures, the age distribution was also analysed. As a result of increased emphasis on improving reliability over the life cycle, the failure rate has now fallen by more than half since the last Working Group. For all major failures, the hazard curve was fairly random with a slow increase with age. Failures resulting in the transformer being scrapped showed a clear age-dependency. The hazard rate for scrapped units accelerated after twenty years of age.

Data was sought from new applications of transformers, such as solar and wind farms. However, as they are relatively new there has not been enough operational service-years and failures to make statistically significant conclusions. A recommendation is to continue these surveys to continue to build experience. A thorough discussion has been given on how the industry has improved the reliability of power transformers, with advice how an owner can request a quality design and maintain longevity over the long operating life of this asset class.

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Introduction and Scope

The last CIGRE international survey for transformer reliability was published in 2015 (CIGRE WG A2.37, 2015). However, it was not possible to compare failure rates because the age distribution of the investigated transformer population was not known. Consequently, a new survey of failures and retirements of power transformers and reactors operating at 100 kV and above was performed, which includes detailed information about the individual age distributions.

Key Country Updates since 2015

Reasons why reliability has improved were also explored. Power transformer reliability and maintenance strategies have evolved across various regions since the last comprehensive update in 2015. Updates gathered from ASEAN, Australia, New Zealand, North America, South Africa, and Spain show the diverse approaches and advancements made to quantify reliability and ensure the resilience and longevity of transformer fleets. In ASEAN, a shift towards proactive maintenance regimes, adoption of advanced monitoring technologies, and strategic specification improvements reflect a concerted effort to mitigate risks and enhance asset performance, particularly in the face of challenging environmental conditions. Similarly, utilities in Australia and New Zealand have made strides in data collection and analysis, leveraging collaborative efforts to gain valuable insights into failure trends and lifecycle management strategies. The emphasis on statistical calculations and comprehensive reporting underscores a commitment to informed decision-making and regulatory compliance. In North America, a steady improvement in transformer reliability over the past decade is attributed to a multifaceted approach encompassing improved maintenance practices, planned interventions, and reduced false trips. The downward trend in transformer failures underscores the effectiveness of these measures in enhancing grid resilience and operational efficiency. South Africa's experience highlights the impact of targeted modifications, such as the transition to resin-impregnated bushings, in mitigating catastrophic failures and informing future asset management strategies. In Spain, a focus on technical specification updates and maintenance enhancements underscores a proactive approach to optimising transformer performance and longevity. The integration of fibre optic temperature sensors, variable frequency power factor measurements, and advanced monitoring equipment underscores a commitment to leveraging cutting-edge technologies for real-time asset management and risk mitigation.

Collectively, these insights underscore the importance of continuous innovation, collaboration, and data-driven decision-making in ensuring the reliability, resilience, and longevity of power transformer fleets in an ever-evolving energy landscape. As utilities navigate emerging challenges and opportunities, the exchange of best practices and lessons learned will remain critical in driving ongoing improvements and advancements in transformer reliability and maintenance strategies.

Measures to Increase Reliability

Technical specifications play a crucial role in defining various aspects, including industry standards, characteristics, manufacturing requirements, and testing protocols. These specifications significantly influence transformer reliability and performance. Key areas covered include performance and service conditions, insulation levels, dielectric tests, thermal performance, and ageing considerations. Emphasis is placed on managing insulation material condition through measures like controlling moisture ingress and specifying breathing systems. By adhering to international standards and leveraging resources like the CIGRE Technical Brochure 528, stakeholders can formulate robust technical specifications tailored to their needs, ensuring transformer integrity and longevity.

Design reviews, as outlined in the CIGRE Technical Brochure 529, are pivotal for confirming that the design meets performance requirements and utilises proven materials and methodologies. Recent advancements in transformer design, particularly in dielectric, mechanical, thermal, bushing, and tap changer designs, have significantly enhanced reliability. Thermal design advancements employ simulations and temperature rise tests to optimize cooling and prevent overheating. Bushings and tap changers have also seen notable improvements, with increased reliability through synthetic insulation and vacuum-type technology, respectively. Maintenance strategies, including online monitoring, help detect issues early, reducing the risk of catastrophic failures.

A reliable production of power transformers is intricately linked to safe, clean, and efficient manufacturing processes, supported by well-trained personnel. Given their physical size, weight, and cost, power transformers require meticulous attention throughout their design, manufacturing, and testing phases. To ensure consistent reliability, adherence to audited Quality Management Systems, such as ISO9001, is essential. Manufacturing technology continues to evolve, offering superior techniques aimed at reducing production time while enhancing product quality. From core assembly to winding processes, advancements in automation and precision contribute to improved efficiency and performance. Moreover, the selection and application of insulating materials play a critical role in ensuring the longevity and operational integrity of transformers.

The deployment of new inspection and quality control technologies, both in factory assembly and on-site operations, further increase the reliability of power transformers. By leveraging tools such as PD measurement, FRA and PDC testing, manufacturers can proactively identify potential issues and ensure compliance with acceptance criteria. On-site manufacturing and testing technologies have emerged as indispensable components of transformer production, particularly for large-scale installations. These approaches not only enhance safety but also streamline logistics and mitigate risks associated with transportation. Digital innovation, such as online monitoring and remote diagnostics, offer insights into transformer performance, strengthening predictive maintenance strategies and minimizing downtime. However, these technologies must be carefully integrated and configured to maximize their effectiveness and security. Looking ahead, the power sector must embrace digital transformation across the entire lifecycle of transformers, from design and manufacturing to operation and maintenance. By leveraging cutting-edge technologies and best practices, stakeholders can ensure the resilience and reliability of power infrastructure in the face of evolving operational challenges and dynamic grid environments.

Maintenance activities conducted throughout the lifespan of a transformer play a pivotal role in ensuring its reliability and longevity. By adhering to manufacturer-recommended maintenance schedules and employing advanced testing methods, potential issues can be detected early and addressed proactively, thereby averting costly failures. In regions with ageing transformer infrastructures like North

America, there is a growing emphasis on extending transformer life through strategic refurbishments, which offer a cost-effective alternative to replacement and mitigate the risks associated with potential failures.

Interpretation of Life Data

This chapter explains the statistical methods and techniques used to analyse and model the life data of transformers, the Weibull distribution, the hazard function and the Kaplan-Meier estimator.

Methodology for Failure Data Collection

Based on the experience of working group A2.37, the decision was taken to limit the data collection to only major failures of transformers and reactors operating at 100 kV. Additionally, retirement data was also collected for this work. A transformer may be retired before it actually fails, therefore not be included in a failure list, and so the failure rate calculation may underestimate the number of transformers which have failed functionally.

In general, a major failure was defined as any situation which required the transformer to be removed from service for longer than a week for investigation, remedial work or replacement. The necessary repairs could have involved major remedial work, maybe requiring the transformer to be removed from its installation site and returned to the factory. Also, a major failure would require at least the opening of the transformer or the tap changer tank, or an exchange of the bushings. A reliable indication that the transformer condition prevents its safe operation is considered a major failure as well. In some cases, failures were assigned as major if remedial work was shorter than one week but extensive work with oil processing had to be done (e.g. change of bushing).

The Excel spreadsheet tool used by CIGRE WG A2.37 was updated to collect data in a standardised way and in accordance with the definition of a major failure. Data on failures and retirements, causes, outcomes, detection and consequence were collected. Also, information about the population of operating transformers was gathered to determine the hazard rate. This data was then analysed and evaluated for presentation in this brochure.

Results of Performed Reliability Survey

Presents the results and analysis of the reliability survey, including the transformer population and failure data by voltage class, continent and application, the failure rate and failure distribution by location, cause and mode, and the comparison with previous surveys.

In conclusion, the power transformers have overall become more reliable over the years, which is unsurprising given the efforts made by the industry to improve technology and management. The overall hazard rate now was found to be less than half what it was for the last A2.37 survey, in the order of several tenths of one percent.

Of the 425,000+ transformer-years of operation collected there were 1,204 major failures and 1,916 retirements from 66 utilities in 27 different countries. Overall, the worldwide failure rate has fallen since the 2015 survey, with the hazard rate now less than half (0.27 %). Given the extensive effort made by the industry to improve reliability, this is not surprising. The failure rate increases as the voltage class rises. It is highest in transformers with voltage class ≥ 700 kV (1.46 %) while lowest (0.23 %) in class 100 ≤ U < 200 kV. This too is expected because of the higher voltage stresses. The surveyed population primarily comprises substation transformers, accounting for 96 % of the total. Shunt reactors and generator step-up transformers contribute 2.3 % and 1.7 %, respectively. Compared to substation transformers the failure rate of GSU's is higher in almost all voltage classes. This may be because GSU units are usually operated continuously at high load.

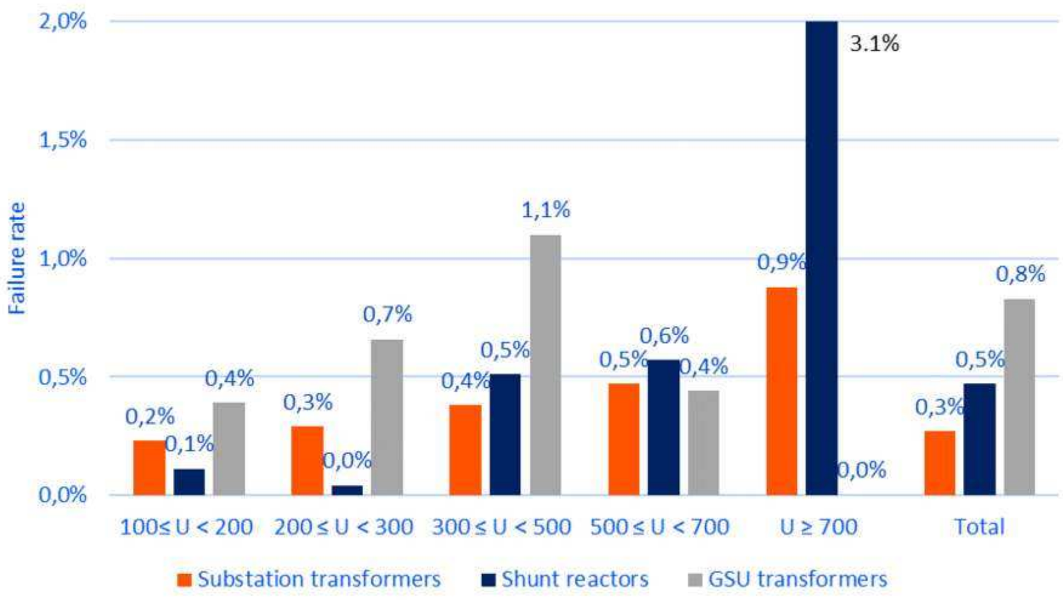

Figure 1 - Failure rate dependent upon voltage class and application

Windings related failure (37 %) proved to be the largest contributor to major failures, irrespective of the transformer voltage class. Previous studies have indicated bushings and OLTCs being leading causes of failure, however new technologies have reduced this. Substation transformers had higher contributions of winding failures than GSU transformers and shunt reactors. This may be because substation transformers are electrically closer to downstream faults which cause winding deformation. Shunt reactors on the other hand had higher contributions of bushing related failures than GSU and substation transformers. Electrical and dielectric mode failures were the most prominent irrespective of the voltage class of transformers. Substation and GSU transformers had higher contributions of electrical type failures, while shunt reactors had higher contributions of dielectric type failures. In root cause analysis study, external short circuits appeared to be the major contributor. However, the root cause of a large portion of the population was unknown and, in some cases, different failure causes were present. Thus, results of root cause analysis should be evaluated with caution.

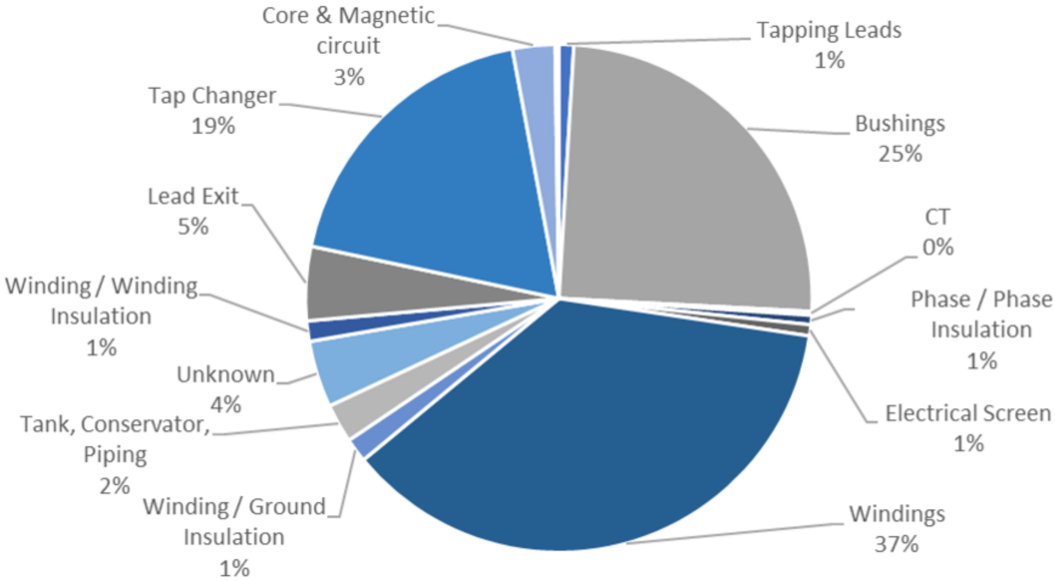

Figure 2 - Failure location analysis for 848 failures

Differential protection and Buchholz relay are the most common devices in all voltage classes to detect major failures. Approximately one quarter of all major failures resulted in an explosion, and of these there was a fifty-fifty chance of a fire. While this study found that 41 % of transformers were scrapped as the result of a fault, this may have changed caused by the current global supply chain problems.

Hazard Curves and Population Statistics for Failure and Retirement

In terms of hazard rates, in many cases two Weibull distributions were used to model failure, one for random events and the other for age-related failures. For all major failures (both repaired or scrapped), the hazard curve was fairly random with a slow increase with age. However, when focussing on only scrapped units the hazard rate started to accelerate after a few decades. One reason could be that some subcomponents are not designed to last the full operating life of the transformer, so when they fail they are unlikely to result in the transformer having to be scrapped. There may be economic considerations whether to repair a transformer after a fault versus scrap, but as these considerations may be different between countries they were not explored. Across continents the hazard rates were broadly consistent. However, in Oceania many transformers are retired rather than run to failure, and so a lower proportion are surviving at an old nameplate age compared to other regions.

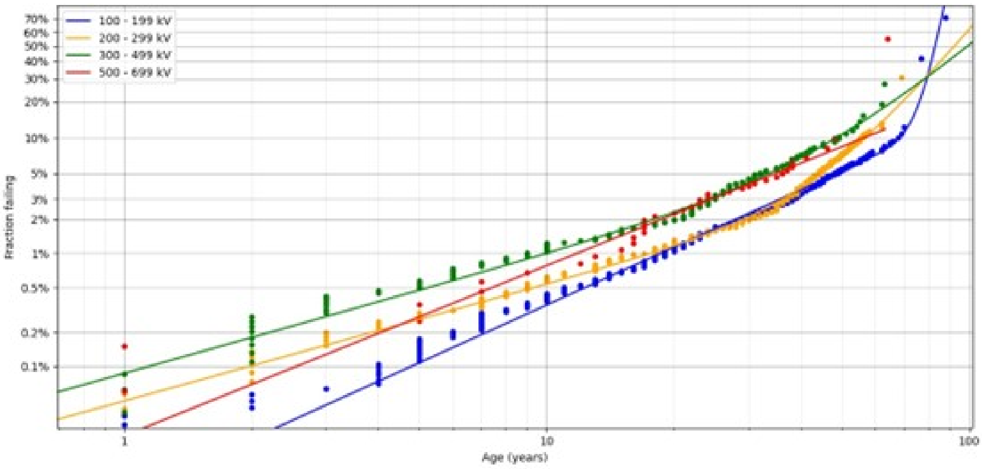

Figure 3 - Fraction failing, all major failures by voltage class

As transformers can be retired, as well as run to failure, a hazard rate for retirements was also given. It is realised that the retirement rate can be self-fulfilling, as owners make decisions when to remove a transformer. The criteria for when to retire was not explored. For instance, risk can be used based on the consequence of a failure, the disruption to the customer, and ease of restoration. Regulatory pressures such as outage fines can also impact decisions.

— Failure of Transformers Connected to Wind Farms, Using New Liquids, and Connected to Shunt Reactors

The working group goals called for the individual analysis of failures of transformers connected to GIS, wind farm transformers, transformers filled with new liquids and shunt reactors. The focus was still on transformers with a voltage of at least 100 kV, and so excluded many smaller units such as those directly connected to the generator.

The potential impact of new generation technology such as wind and solar farms was investigated. However, there is still an insufficient number of service years of transformer operation. A known problem is extra heating caused by current harmonics. However, a utility can control this through connection agreements with the generator and measure the harmonic spectrum. Another option is to derate the transformer in accordance with a k-factor.

— Conclusions and Recommendations

Summarises the main findings and conclusions of the reliability survey, such as the decrease of the failure rate over time, the impact of retirement decisions on the failure statistics, the importance of bushing and tap changer maintenance, and the need for further data collection and analysis for new applications and technologies.

The reliability survey found that the global power transformer failure rate has decreased by more than half since the last survey, due to improved design, testing, monitoring and maintenance practices. The survey also collected retirement data, which showed that the retirement rate increased with age, and that retirement decisions varied depending on the region, application and risk tolerance.

The survey suggested some areas for future work, such as developing a framework for retirement decisions, updating the technical specifications and standards, improving the design and testing methods, and enhancing the monitoring and maintenance practices. The survey also recommended to continue the data collection and analysis for new applications and technologies, such as solar and wind farms, ester liquids and variable shunt reactors.

TB 940 | WG A2.54

Power Transformer Audible Sound Requirements

The brochure covers all aspects of audible sound relevant for new power transformer purchases > 3 MVA to be considered in the process from specification until installation. Strict distinction is made between the individual sound level components 'no-load sound level', 'load sound level' and 'cooling system sound level' but the combination of the components is also explained. Key results are provided in easy-to-use graphs. The brochure is also intended to serve as educational document for transformer acoustics.

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Introduction

Environmental requirements have steadily increased across society in recent years. In terms of power transformers and reactors, one environmental concern that stands out from others is the audible sound generated and emitted into the surroundings, affecting residents living nearby as well as substation staff. Permissible sound pressure levels for substation and residence boundaries are given by lawful authorities and are set so as to avoid negative effects for people. Today's sound level specifications reveal on average more stringent requirements than in the past.

As power transformers (and reactors) are usually the most significant sound sources in a substation, it is necessary to consider their acoustic characteristics with care, particularly for new purchases. This however is often challenging because validated information for transformer sound level specification is almost not available. As a result, transformer sound level specifications are found to be repeatedly technically unreasonable.

Looking to the ways utilities handle sound level aspects when purchasing transformers, it can be observed that their practice for sound level specification is not at all harmonized but often influenced by vague factors instead of physical facts. It was therefore an urgent need to develop figures and guidelines for a technically realistic transformer sound power level specification that can be used easily by utilities for the technical transformer procurement process but also serve for vendors as rough information while quoting.

CIGRE WG A2.54 has started its work in March 2016. It is the first CIGRE body dealing with a subject related to transformer sound after more than two decades. The last two CIGRE publications date from 1992 and 1996. Ever since, a lot of work has been done in the field of transformer acoustics related to sound control by design (manufacturers), sound level measurement (IEC, IEEE) and external sound mitigation (utilities, manufacturers); however, no activities on sound level specification have taken place.

Content of Brochure

WG A2.54 split up the given task into the following areas:

- Basic acoustics and sound development in transformers
- Derivation of typical sound power levels of transformers
- Sound level specification and legislation
- Sound mitigation

Results presented in the technical brochure reflect this structure with following chapters:

Chapter 1 – Introduction – Scope, Range of application, Clarification of basic acoustic terms, Remarks.

Chapter 2 – Background – Physics of sound, Sound development in power transformers, Transformer sound level control.

Chapter 3 – Sound levels of liquid-immersed transformers – Concepts and boundaries for the derivation of typical sound level ranges, Typical ranges of no-load sound power level, Typical ranges of load sound power level, Typical ranges of cooling system sound power level, Combination of sound levels, Sound power levels of transformers for 50 Hz vs 60 Hz power frequency, Sound power levels of single-phase units forming transformer banks.

Chapter 4 – Sound levels of other transformer types – Dry-type transformers, Gas-insulated transformers, Transformers with cores made from amorphous steel.

Chapter 5 – Sound level specification and legislation – Survey / questionnaire, Noise and substation design, Impact of sound level specification on costs, losses, transportation, Parameters for specification purposes, Achievable sound power levels for specification purposes (case studies), Sound Levels and Transformer purchasing, Tender process, On-site noise measurements after transformer installation.

Chapter 6 – Sound mitigation techniques – Overview, In-tank solutions, Cooling system solutions, Design of sound barriers, Factory-installed sound barrier solutions, Site-installed sound barrier solutions, Sound mitigation technologies not in regular use.

Chapter 7 – Summary and further work

In six appendixes additional information is provided:

- **APPENDIX A – Typical sound power level ranges of liquid-immersed power transformers – Essential information at a glance for everyday use**
- **APPENDIX B – References**
- **APPENDIX C – Sound level specification using frequency bands**
- **APPENDIX D – Extension of the formulation for load sound power levels**
- **APPENDIX E – Cavitation**
- **APPENDIX F – Survey on transformer sound level specification**

Out of the comprehensive brochure content provided on more than 130 pages, the most essential content only is presented within this short report and will refer to chapter 1, chapter 3 and chapter 4.

Basic acoustic terms

Because the usage of some generic acoustic terms (Sound, Noise, Sound level) in the industry is widely habitually, with a clear and consequent distinction of their actual meaning rarely in users' mind, a clarification is made at the brochure beginning. Although main reason is to understand the brochure's content correctly, it applies generally in the field of transformer acoustics and beyond:

- ### SOUND versus NOISE

Throughout this document, the term **SOUND** is used to describe the **radiation of acoustic energy by a source**, in this case from transformers including accessories such as cooling systems. **NOISE** is used to describe **an immission of acoustic energy that is undesired by a recipient**. Transformer humming is therefore classified as SOUND rather than NOISE. The term NOISE is used in the brochure mainly in chapter 5 when the acoustic performance at installation sites such as in and around substations is discussed. NOISE however may also be used habitually when the term SOUND would actually be preferred and vice versa.

- ### SOUND LEVEL

Although the term **SOUND LEVEL** is frequently used in the brochure it must be recognized that it is a generic term that **can stand for three different precise terms: sound pressure level, sound intensity level, sound power level**. If the term is used, the context does either not require to distinguish because the relevant clause is generic, or it is fully clear which of the precise terms is meant.

Remarks

A few important remarks are necessary to be considered when reading the brochure:

- It is important to understand that WG A2.54 did not deal with sound level control by design – this is the task and proprietary matter of manufacturers and not up for public exchange – but based the entire work on the sound level performance of existing/installed units in a fully anonymous manner. The brochure therefore does not give any insights on how to improve the sound level performance of transformers beyond commonly known techniques. Instead, it provides guidance based on average observations of existing installations.
- Throughout the brochure, sound levels will be given as A-weighted levels because this notation is globally standardized and most used in practice.
- Throughout the brochure, sound levels comprise the entire frequency range of interest. Tonal/tonality considerations are not made, although transformer no-load sound and load sound consist naturally of individual tones.

Sound levels of liquid-immersed transformers with rated power S > 3 MVA

Typical ranges of sound power levels for specification purposes have been developed for the transformer sound components “no-load sound”, “load sound” and “cooling system sound”. While for the no-load and load sound power level a statistical approach based on a large number of FAT measured sound power levels of transformers, produced and tested between years 2010 and 2018 were used (more than 1000 measurements for each component), a number of cooling system case studies covering the different cooling modes over the transformer power range of interest were performed and the typical sound power level ranges derived by interpolation. A large database was established for the statistical approach, containing the measured sound power levels together with a minimum of transformer basic parameter, all known at the time of transformer specification. By using these parameters only, generic models describing the predominant physical modes of the sound generation processes of the no-load sound level and the load sound level were developed and scaled using the measured sound level data. By recalculating the sound levels of all transformers in the database with the now scaled models, the typical ranges of sound power levels for specification purposes have been developed. Important to mention is that besides the generic sound generation principles, the sound level components of a transformer are of course also impacted by the design concept and certain design details. To assure acceptance of the derived typical sound power level ranges while utilizing statistical methods, it was mandatory to involve a representative number of transformer manufacturers utilizing different transformer design concepts that contribute to the established database. Representatives from 13 countries and 19 different companies were active (standing in for 14 transformer and 2 cooler manufacturers as well as 4 utilities). Due to the number of contributors representing many different design concepts, and also with respect to the large number of collected datasets, the derived figures, exemplarily shown hereafter for 3-phase 50 Hz units, are considered universally representative.

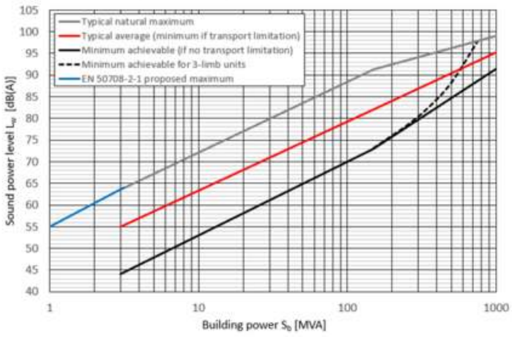

Figure 1 - Typical ranges of no-load sound power levels for specification purposes of 3-phase 50 Hz transformers

Note: Input quantity for Figure 1 is transformer building power Sb, that is equal to transformer rated power for separate winding transformers but is reduced for auto connected transformers and for the latter to be calculated from rated voltages of the two main voltage systems, see brochure chapter 3.2.

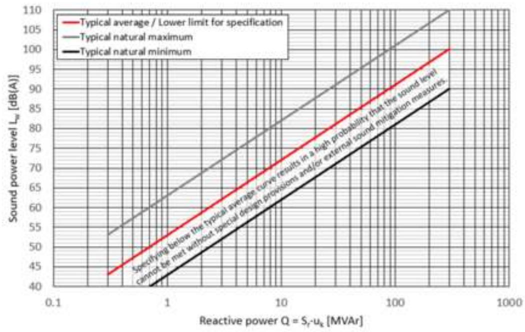

Figure 2 - Typical ranges of load sound power levels for specification purposes of 3-phase 50 Hz transformers

Note 1: Input quantity for Figure 2 is transformer reactive power Q, calculated by multiplying the transformer rated power Sr with the impedance voltage uk in pu.

Note 2: As load sound level control by design involves much higher uncertainties than no-load sound level control, specifying levels below the red average curve is normally not recommended and this is clearly indicated in Figure 2.

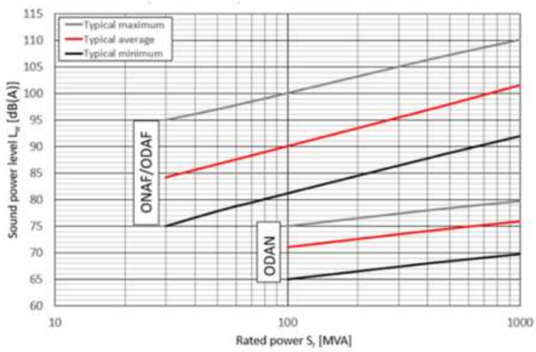

Figure 3 - Typical ranges of cooling system sound power levels for specification purposes of 3-phase 50 Hz transformers

Note 1: Input quantity for Figure 3 is transformer rated power S_r.

Note 2: The cooling system sound level is strongly related to the footprint of the cooling plant: The larger the footprint, the lower the sound level. By a suitable selection of the cooling mode and plant, the cooling system sound level is well controllable over a wide range (up to or even more than 30 dB(A)) and is therefore rarely the limiting sound level component for new purchases.

Details for the application of the graphs with practical examples are given in chapter 5.6 of the brochure.

So far, 3-phase transformers have been discussed. As for very high voltage classes and/or large 3-phase power transmission duties the use of 1-phase transformers forming transformer banks is a common solution, such units/applications were also studied by WG A2.54. As the collected database for 1-phase units was much smaller than for 3-phase transformers, a separate analysis was considered not fair/useful and not made. Instead, collected 1-phase datapoints are presented in the developed figures for 3-phase units and this reveals two important facts:

- 1-phase units with a given 1-phase power exhibit in average a comparable sound power level as 3-phase units with a 3-phase power being the same as the 1-phase power of the 1-phase unit.
- The spread of sound levels of 1-phase transformers is larger than that for 3-phase units. Main reason are the different design concepts applicable for 1-phase transformer designs.

Sound levels of transformer banks formed by three 1-phase units in side-by-side arrangement can normally not be tested in a test bay due to limited space. It is therefore necessary to apply a theoretical approach for the estimation of the bank sound level from the measured sound levels on the 1-phase units. Main question is if a simple logarithmic addition of the three individual sound levels reflects the total sound level radiated by the bank properly, or if other effects impact the bank sound field and lead to a different bank sound level. The results found by WG A2.54 based on sound level tests done with high effort on a 1200 MVA transformer bank confirm the superposition (addition) of the three individual sound levels of the 1-phase units being sufficiently accurate and means, interferences between the three individual sources are negligible. This applies to the no-load sound as well as to the load sound level. If assuming about identical sound levels of the three pole units, then the bank sound level can simply be derived by adding 5 dB to the sound level of a 1-phase unit. In most cases, this is approach is sufficiently accurate and should therefore normally be accepted. Alternatively, all three poles can be sound level tested and the results logarithmically be added to derive the bank sound level. More details are given in brochure chapter 3.7.

Sound power levels of transformers for 50 Hz versus 60 Hz power frequency

Differences in the emitted transformer sound power level as a function of power frequency are well known and handled by manufactures in the design process. Common practice is to consider a fixed dB value in the sound level design if deviating from the principal power frequency a manufacturer is working with. A more detailed distinction is normally not made.

While analysing the 50 Hz and 60 Hz sound level data collected, the somewhat surprising observation was made that the sound level difference is not a constant (fixed) value but shows clearly a decreasing dependency with increasing power rating. Figure 4 and Figure 5 were derived from the average sound level difference of the database entries for no-load and load sound. The dependency is obviously related to a dimensional impact: the larger the unit is, the smaller is the sound power level difference between 50 Hz and 60 Hz transformers and is valid for no-load and load sound levels.

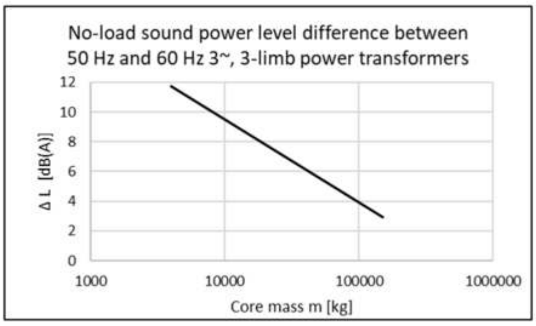

Figure 4 - No-load sound level difference between 50 Hz and 60 Hz power transformers

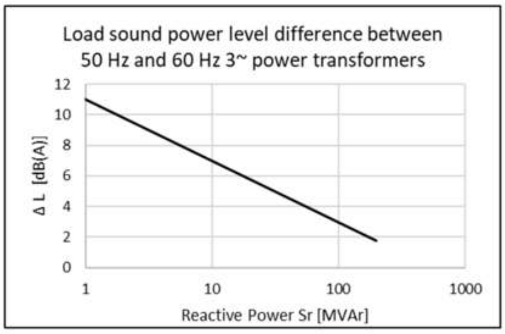

Figure 5 - Load sound level difference between 50 Hz and 60 Hz power transformers

A difference of up to 10 dB(A) or even more for small units is a lot and means that small 60 Hz power transformers radiate significantly more sound than comparable 50 Hz units. At the other end of the scale, very large 60 Hz power transformers are acoustically (on average) only to a minor extent affected by the larger power frequency. It is noted that derived curves are of average nature and sound control of individual transformer designs to overcome this principal characteristic is at least within limits possible.

The large number of datasets involved in the derivation of such findings clearly suggest a ruling physical phenomenon behind and is related to the sound wavelengths for 50 Hz and 60 Hz transformers in oil and air relative to the transformer dimension. The impacting key parameter is “radiation efficiency” that varies significantly with transformer dimension for the frequencies under consideration. It is large for small transformers and reduces with increasing transformer dimension. For (very) large transformers it is getting such small that it has practically no impact on the emitted sound level and the differences of the sound wavelengths for 50 Hz and 60 Hz transformers are therefore of no importance. The opposite is true for small transformers. Here the radiation efficiency is large and impacts substantially the emitted sound level. The same variations in the wavelengths have now a significant impact on the emitted sound. Details of the phenomenon are described in chapter 3.7 of the brochure.

More studies are necessary to explore the dimensional effect and further impact parameters. With the explanations given in the brochure, CIGRE WG A2.54 just wants to raise awareness of the topic and trigger further research activities as this is aspect was observed/formulated first time in the brochure.

— Sound levels of other transformer types

Sections 5 and 6 of this report present key findings/developments related liquid-immersed power transformers. Three other common types of power transformers were also studied with target to identify typical ranges of sound power level: Dry-type transformers, Gas-insulated transformers and Transformers with cores made from amorphous steel. As the collection of sound level data as done for liquid-immersed transformers turned out to be not feasible/not possible, only for dry-type transformers with 50 Hz power frequency it was finally possible to provide a graphical representation of the typical range of no-load sound power level. For the other two transformer types, but also for dry-type transformers for easy use, a general average relative sound level difference to liquid-immersed transformers with cores made from electrical steel has been derived as a “rule of thumb”. In addition to the sound level clarifications made in brochure chapter 4, for all three transformer types more information is provided to underlay the technologies somewhat because it must be assumed such being not commonly available to brochure readers.

- **Dry-type transformers**

Dry-type transformers reveal an increased **sound power level of about 10 dB(A)** if compared with comparable liquid-immersed transformers of about same rated power.

For 50 Hz, 3-phase dry-type transformers a database of reasonable dimension and quality could be collected for no-load sound power levels and following typical range be derived. It is noted that the no-load sound level is usually the determining sound level of dry-type transformers.

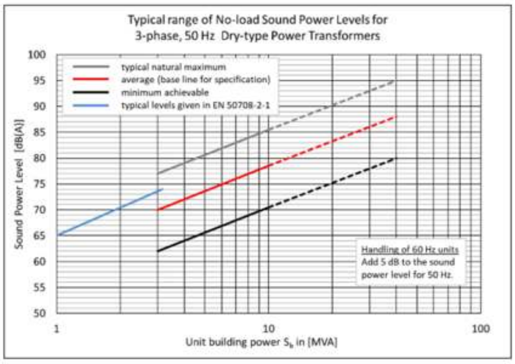

Figure 6 - Typical ranges of no-load sound power levels for 3-phase dry-type transformers

Note 1: Curves are based on CGO / RGO steel grades. The use of HiB based steel grades provide potential for a sound level reduction of a few dB.
Note 2: The typical range of sound power levels between the “minimum achievable” and the “typical natural maximum” boundary curves is mainly controlled by varying the core induction and steel grade.
Note 3: Due to insufficient sound level data for 60 Hz transformers, typical ranges of sound power levels could not be derived. Instead, a best possible rule is provided by A2.54, taking all available information and knowledge into consideration.
Note 4: As the available sound level data for transformers above 10 MVA was limited, curves are shown in dotted format. Although this is intended as a warning, there is no physical reason why this range should not be valid.

- **Gas-insulated transformers**

Based on an analysis done on six gas-insulated transformers and exchanges held with experts, overall, it was concluded that the differences in sound levels between liquid-immersed and gas-insulated transformers are not very significant. As the technology is so far using SF6 as insulating medium, new installations are not in focus any longer due to the high GWP (Global Warming Potential) of more than 23500 times that of CO2.

- **Transformers with cores made from amorphous steel**

Amorphous cores are commercially used mainly for liquid-immersed distribution transformers. Approximately 5 million transformers with amorphous cores are in operation worldwide – in India 2 million, in China 1,5 million and in Japan, the USA, Canada, Brazil and South Korea together about 1,5 million units. In other regions, such as in Europe, the technology is practically not utilized. One reason for this is the availability of the amorphous material.

Liquid-immersed transformers with cores made from amorphous steel reveal **an increased no-load sound power level of about 14 dB(A)** if compared with liquid-immersed transformers of about same rated power made with cores from grainoriented steel. At the same time, the **no-load losses reduce to about 25%** to such made with 0.23 mm HiB domain refined steel.

TB 941 | **JWG C2/C5.06**

The impact of Electricity Market Interventions by System Operators during Emergency Situations

During emergency situations System Operators are typically able to intervene in power system operation and also when relevant in market activities.
This work explores the impact of such interventions on electricity markets during or close to real time dispatch. Interventions support System Operators actions to restore power systems to normal operation by instructing market participants, to act in ways they would not voluntarily do and may have financial consequences on affected participants This impact on market actors often receives little attention, and in many cases, there are no clear rules or procedures in place to compensate affected market participants, complicating the resolution of the aftermath of such interventions. This work is expected to help rule makers better understand the topic and its consequences when designing regulations.

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— Scope/Methodology

A survey was performed to collect insights from System Operators around the world on what options they have for intervening in ways that impact markets, get information about actual events where intervention was used plus several related topics. When designing the survey it became clear that we should have a frame work of which markets to consider, what system situations to consider and how to define a market intervention by a System Operator. This became even more clear when the survey responses were analyzed, which made clear that there are different interpretations of this topics around the world. Therefore it was agreed that for this work the focus would be on physical markets close to real time and not on any financial markets, future markets etc.

It was also explored how system states are defined around the world, but finally it was decided to focus in the Technical Brochure on the interventions and leave out the system state(s) during which this was executed. The rationale for this was that it was deemed more important to look into interventions that affect markets, independent of the reason/system state why it was executed.

This then led to the definition of "intervention" to be used in this work, which reads as follows:

An intervention is an action by the System Operator to maintain or improve the integrity of the power system, that obligates a party to act in a way other than they would otherwise do, according to their preferences, under the prevailing system and market conditions, as established by the system and market operator under the market rules.

Throughout the document, the described measures and actions are compared to this definition to determine whether they qualify as interventions. To illustrate this, several examples from the survey are described, including those that do not qualify as interventions, with explanations provided. These examples, collected in tables, illustrate what kind of actions are considered interventions and why others are not. The consequences of such actions for market participants are also described.

— Description of the Technical Brochure

The Technical Brochure begins by establishing the general background of the subject and the rationale behind undertaking this work. Additionally, it provides insights into several relevant related topics that, while not directly within the scope, are considered valuable for documentation and may serve as input for future endeavors. These aspects are elaborated upon in 4 main chapters of the Brochure, the focus of which can be summarized as follows:

First chapter of the TB deals with markets, emergency situations and interventions, it describes the scope of the work in terms of the mentioned topics. And it delivers a definition of intervention that is further used (see above). Some illustrative cases are given.
Second chapter of the TB, current practices and experiences, describes the results coming from the survey. It also includes observations and discussions of a number of topics where different approaches were chosen sometimes at a regional and other times more at a market organization level. It shows the differences in this respect between more mature markets and markets that are still developing. The main topics discussed include governance structure, triggers, communication and information sharing and dispute resolution. The TB also describes a variety of possible measures and discusses around classification as an intervention or not. Furthermore, lists a number of measures describing their effect in system supports and the consequences of such measures for market participants involved.
Third chapter, current trends and future outlook, addresses a number of topics that are closely related to intervention but do not (fully) fit in the adopted definition. For example the development of demand response in different parts of the world, and

also a number of developments in the power system that could help respond to addressing emergency situations.

The final chapter, conclusions and recommendations, gives the overall conclusions and some recommendations.

Conclusion

Diverse viewpoints exist regarding interventions, even in regions governed by the same overarching rules, leading to variations in implementation and interpretation. Therefore, this Technical Brochure (TB) develops a specific definition of market intervention for its purpose. Experience with actual market interventions in real-life events is limited, resulting in primarily theoretical observations. However, it is widely agreed that intervening in markets should be considered a measure of last resort.


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