B3 - 00

SPECIAL REPORT FOR Study Committee B3 (Substations and Electrical Installations)

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Special Reporters

The special report, prepared by Study Committee B3, has been updated with the new requirements for the CIGRE 2021 Virtual Centennial Session.
Revised parts are indicated in red and crossed through to easily identify the changes.
Additional updates are indicated in green.

CIGRE Substation Study Committee B3 is responsible for activities, which cover the design, construction, maintenance and management of substations and the electrical installation in power stations excluding generators. The aim is to bring value to the engineering community through highlighting state-of-the-art practices, establishing recommendations and reporting best practices.

The major objectives of B3 are to facilitate technical guidance which enables the electrical supply community to increase reliability and availability, encourage cost effective engineering solutions, manage environmental impact, support effective asset management and encourage the adoption of appropriate technological advances in equipment and systems to achieve these objectives.

Substations are integral parts of the power system and central to the safe reliable transmission and distribution of power, through providing access to the network, fault isolation and facilitating expansion. This is evident all round the world as energy networks adapt to meet the challenges placed on them.

The 2021 Discussion session will be a little different to previous meetings. Following on from the successful 2020 e-session conference online, this session will aim to build on the presentations from last summer. We would like to receive material to share with the B3 community, related to experiences from designing, operating or adapting substations during this unprecedented period, as the world has learned to adapt to the changes that COVID-19 and the associated lockdown has required.

The Preferential Subjects (PS) for the special 2021 Session remain the same as the 2020 session and aim to elicit thinking and discussion around the following topical developments and challenges:

PS 1. Design and Technologies

- Impact on design and installation of disruptive and emerging technologies
- Mitigating environmental, Health, Safety and security impacts
- Rapid deployment and cost-effective contemporary solutions for electrification of developing communities

PS 2 Optimised Management

- Best practice in design of assets by optimising their life in a cost-effective way
- Service continuity for maintenance, refurbishment and replacement
- Evolution of skills and managing competency

PS 3 Integration of Intelligence

- Applications of new technologies, e.g. internet of things, virtual reality, augmented reality
- Challenges and expectations for digital substations

Executive Summary

A total of 46 papers from 24 countries addressing the 3 preferential subjects were submitted to the 2020 CIGRE e-session. This material is a core contribution to the active work of Study Committee B3 and a snap shot of the key issues for the industry during this period. The effort and time afforded by the authors and their supporting organisations in producing these papers is greatly appreciated. CIGRE's aim is to encourage participation in the Paris session through stimulating discussion around the material reported in the submitted papers.

2020 e-session

The 2020 COVID-19 Pandemic resulted in the Paris General Discussion Session being cancelled and a virtual conference called the CIGRE e-session being held in its place. This event was more traditional in that each paper was presented in its entirely, with 46 of these papers presented in full.

In addition to the papers and recorded presentations, there were 200 comments and questions asked across the B3 e-session. These can be seen on the B3 public web site (https://b3.cigre.org), on the link to the B3 2020 e-session Q&A. Everyone can access this link, this also includes the recording of the verbal responses.

The most popular topic discussion was certainly around the alternatives to SF_6.
- B3-107 First 145kV GIS using Clean air - life-cycle evaluation, impact on the seals to prevent future leaks, monitoring the integrity of vacuum bottles inside the GIS
- B3-115 g3 based solution raised many questions regarding managing and testing of gas mixtures. The interpretation of LCA is also raised regarding the manufacturing footprint versus the emission contribution to global warming
- B3-118 - considerations regarding the use of C5-FK gas mixture and composition for active and passive compartments, impact of the operational environment, and gas handling management.

Other noticeable discussions centred around:
- B3-104 - TenneT discussed their 140 substation replacement programme, this raised a number of questions demonstrating use of digital tools in the design and development, use of new tools and prefabricated buildings
- B3-109 - applications using BESS proved to be a popular topic, particularly issues around the protection design and catering for bidirectional power flows
- B3-117 - optimised replacement of AIS substations - challenges around transporting prefabricated components to the site, realising the benefits of pre testing and interfacing challenges
- B3-120 HVDC GIS - comprehensive response to the charging and electric field management around the risk of particulate matter contamination.
- B3-305 connecting IoT technology into substations - good discussion around the role of standards in and data management and ownership.

Therefore, this time, for the Special report and subsequent Paris 2021 session we are seeking information and knowledge beyond that provided in each paper. For the e-session, 7 of the 46 papers were revised, with more up to date content. These are denoted with an 'R' in the reference.
As always within the Substations sector, the papers cover a broad scope of issues and all the preferential subject criteria has been addressed to some degree, the key themes which authors highlighted in PS1 were;
- Health & Safety factors affecting substation design
- Reducing the impact of Substations on the environment, in particular the proving of SF_6 alternatives
- Facilitating the connection of renewables both on and offshore.

- Substation operational configuration considerations for new and legacy applications
- Evolution in HVDC substation design.

PS2 focus around the innovation and progress of substation optimised design and maintenance; particularly the;

- wider application of condition-based monitoring with analytics
- Understanding the role and value for digitization of substations and equipment
- Substation legacy spare parts fabrication

PS 3 contributions illustrate that substations are embracing digital and intelligent new technologies:

- Growing role for Digital solutions in planning, design, construction, operation and maintenance
- More effective operation
- Benefit for Asset Management
- Pilot projects are underway to prove the benefits.

Participating in the 2021 Paris session

You are invited to participate in discussing this Special Report at the Study Committee B3 Group Discussion Meeting (GDM) for two days on Thursday 26th and Friday 27th August 2021, which will be broadcast live from Palais de Congress, Paris~~. on **Wednesday 25th August 2021** in the Grand Amphitheatre (Level 1) at the Palais de Congress, Paris.~~

GDM session style in the Centennial Virtual Session (2021) is on-live, emulating the regular GDM as much as possible. Contributors are asked to make a live presentation from remote.

The reporters have compiled 12 questions, these are not specifically aimed at the papers' authors, but are synthesised from some common issues and trends identified in the papers. This provides the opportunity for a broader response and participation in the discussion session.

You should prepare and submit your contribution in response to the specific questions in this report. Contributors should upload their contribution on the Registration platform – "Contribution to Group Discussion Meetings" section - using their existing account and own credentials before **Wednesday 4th August 2021.** Each contribution will be reviewed to help with the organization of the Group Discussion Meeting.

Important note for Contributors;

- Contributions can only be uploaded by registered delegates.
- Registration for the CIGRE Session should be finalized before attempting to upload any contribution(s) online.
- To register for the Session Click here
- The portal for uploading contributions will be open at the beginning of May.

Contributions will be made available to Study Committee Chair and/or Special Reporters for reviewing and comments.

A guide for contributors as well as templates and sample pages will be available on the CIGRE Centennial website, see Group Discussion Meetings in the top menu bar.

~~It is unlikely everyone will be able to attend the 2021 Paris Discussion session due to national and corporate travel restrictions. Consequently, the session will need to accommodate remote web interaction.~~ The session will be managed via remote web interaction. Therefore, to maintain a smooth and interactive meeting, all prepared contributions shall be;

- ~~pre-recorded~~ Power point presentations ~~with voice-over and suitable for webcast - in a similar manner to the 2020 e-session.~~
- of a duration no longer than four~~five~~ minutes (shorter durations are welcome),

- the number of slides should be no more than four including the title slide.

The Special Reporters will review the suitability of the power point presentation and Word document, and confirm the final time slot with each author. Where necessary, the Special Reporters will make recommendations to the contribution authors and inform them whether the prepared contribution will be accepted and is suitable by **Wednesday 11th August 2021**. Contributors are encouraged to visit their account on the Registration Platform to check the status of their contribution.

After acceptance, CIGRE Central Office (CO) will ask all accepted contributors to access the LENI system to record voice-over files as a backup in case the lively participation shows any issue. CO provides the guidelines and suitable information related to this LENI system shortly on the CIGRE website.

~~Successful contributors attending the conference in Paris will be invited to meet the Special Reporters on **Tuesday 24th August 2021** to finalise their intended contribution to the session.~~ More details will be available before the event. No contributions will be accepted after the **Wednesday 4th August 2021**.

There will be the opportunity for spontaneous contributions during the session, this will only be verbal with no slides. Attendees who provide a spontaneous contribution, are encouraged to summarise their contribution in a short written response for the Session Proceedings. This text is required to be forwarded within two weeks after the SC B3 Session by **Tuesday 7th September 2021** to mark.osborne@nationalgrid.com to be considered in the proceedings.

Poster session – No poster session will be scheduled at the Virtual Centennial Session. ~~All paper authors who are attending the conference in person are invited to the poster session. Further information will be announced shortly.~~

Key dates

- **Wednesday 4th August 2021** – Latest date for prepared contributions to be submitted for review (**no contributions for presentation will be accepted after this date**). Any contribution after this date will have to use the spontaneous contribution option.
- **Wednesday 11th August 2021** - Authors informed that their contributions will be included in the Discussion session.
- **Thursday 26th August 2021 –** B3 Discussion meeting, Day 1
  Prepared contributions for PS1 in this Special Report will be presented and discussed.
- **Friday 27th August 2021 –** B3 Discussion meeting, Day 2
  Prepared contributions for PS2/PS3 in this Special Report will be presented and discussed.
- ~~**Tuesday 24th August 2021 –** All contributors are requested to meet with Special Reporters to check their prepared contributions meet the required standard for uploading into the session presentation – The room number of the Palais des Congrès will be informed later.~~
- ~~**Monday 23rd August 2021 –** 9:00-12:30. B3 Poster Session Halle Ternes (Level 1). All paper authors who are attending the conference in person are invited to the poster session. This is an opportunity for you to meet authors and discuss papers.~~
- ~~**Wednesday 25th August 2021 –** B3 Discussion meeting - Grand Amphitheatre (Level 1). Prepared contributions and this Special Report will be presented and discussed.~~

Special Topic: The Impact of the COVID-19 Pandemic on Substations

The restrictions have required everybody associated with substation design, construction and operation to think and operate differently. During this time the reliability of power systems and communication services have been even more critical, so essential maintenance and ongoing construction projects had to be addressed.

Utilities, have had to adapt their daily operations to cater for the restrictions brought about to manage the safety of personnel associated with site activities, including hygiene, testing, face coverings and physical separation.

The restrictions around travel, have significantly impacted on the traditional methods around face to face design evaluations, site visits, witnessing product testing. Manufacturers and contractors have had to develop new ways to facilitate remote and virtual acceptance testing. Making use of the internet like everyone else to enable assessments and work to go ahead.

Question PS1.1: We would like to receive and prioritise contributions which address how working through COVID-19 has impacted on substation operations. In particular, how these experiences have this changed your thinking for the long term.

Summary of the B3 Session papers

The following summary and accompanying questions prepared by the Special Reporters, aim to address aspects highlighted in the preferential subjects and authored papers.

PS1 Summary: Design and Technologies

This preferential subject was very popular with 20 papers accepted for the session. The subject matter is broad covering all the topics identified in the PS, in particular substation safety, asset replacement strategies and alternatives to SF_6.

New concepts in substation design

The Bus-node substation is a new concept in busbar layout which revolutionizes the way we think about the 3-phase substation. Paper B3-119 outlines the lightning performance of a 245kV facility. This new design occupies only one third the size compared to a traditional AIS substation of a similar scope. The designers claim this fundamentally avoids 2 or 3 phase fault currents, allowing low mechanical loads. The studies suggest much lower electrical stresses, so theoretically smaller electrical clearances could be achieved, however sticking with the traditional margins provides a higher reliability. Surge arresters feature in the Busnode design to is this the case for other AIS designs. Given the widespread application of surge arresters and cable connections, what changes, if any, can be considered around lightning and switching impulse design levels and associated clearance in substations

As networks expand and adapt to connect new customers, FACTS technologies are increasingly being installed to optimise and manage power flow for the existing site and infrastructure, paper B3-108 describes the impact that Phase Shifting Transformers (PST) and other FACTS devices are having on the 50Hertz network in Germany, where power flows are changing due to increased penetration of distributed and renewable generation sources. Innovative busbar configurations are required to make the network flexible, helping them 'swing' between circuits to add PSTs in series or on separate circuits. The rapid change in networks requires these large expensive assets to be utilised to the maximum such that they can be selected to different circuits.

Asset replacement strategies

Return of experience from a number of papers shows the challenges and chosen solutions of such upgrading projects.

Paper B3-104 addresses TenneT's substation replacement work on the Netherlands 110kV and 150kV grid. A standard modular design brings together many of the new technology features discussed in previous sessions to facilitate over 1100 replacements over the next 10 years. This is achieved by skidding in pre-assembled bays for fast replacement. The concept is being evaluated through proof of concept projects. The like for like replacement includes all aspects of the bays; primary, secondary and busbar infrastructure on both AIS and GIS new bays. The design incorporates full IEC 61850 secondary systems, this also features in the supervision and condition assessment to monitor primary switch operation. The GIS design utilises a novel ring arrangement to enable a spare module to be quickly inserted to replace the faulted unit.

Statnett is using compact GIS to help upgrade their 300kV corridors to 420kV. Having to transition from an AIS to GIS technology mind-set including using more cabled circuits. Paper B3-102 introduces the use of a new dry-type GIS/cable interface which removes the need for the cable basement. The adoption of this approach is reliant on high quality control in the manufacturing and installation phase is essential, the role for testing and post commissioning fault inspections, in particular, testing at differential pressures across the barrier.

Question PS1.2 What are the main impacts we are we likely to see on existing substation, design, infrastructure and equipment as the move towards a Net Zero Carbon future?

HVDC substations

Paper B3-120R, is a very informative describing how the compaction offered by GIS allows many of the traditional issues for HVDC to be mitigated, such as environmental pollution and reliability. In particular HVDC compact GIS design can significantly reduce the footprint for both offshore and on-shore substations, (including underground). The paper summarises the development history of GIS for HVDC application, the key features and the testing evolution. The paper explains how the dielectric performance of DC relates to the IEC 62271 standards for AC dielectric testing and the pertinent elements for HVDC GIS.

Paper B3-121R introduces the EU funded project PROMOTioN looking at meshed offshore HVDC grids. This the work concentrates on the research aspects of a HVDC Hub 320kV GIS substation trial, with a focus on the testing to investigate the longer-term dielectric performance of this technology. The challenge is around observing any abnormalities in the GIS due to DC phenomena and the role for PD detection. A new methodology is described using magnetic antenna placed in the coupler windows to detect and process the DC effects is introduced to help move the possibility of HVDC GIS forward.

Question PS1.3 Are there any practicable recommendations around the testing and routine maintenance activities and methods to ensure exposure is managed in predominantly power electronic facilities e.g. HVDC substations and BESS facilities.

Making the substation a safer place

Continuing with the focus on HVDC, Paper B3-103 compares the EMF issues in EHV HVDC converter installations and the impact on human occupational safety with AC compounds. Generally, AC fields are more impactful on the human body and as such exposure limits have been in place for a long time. The paper highlights there are no specific exposure levels defined for workers in DC, only that which is already in place for AC.

Electric & Magnetic Field (EMF) exposure is the subject of paper B3-112. EDP report on work carried to evaluate the impact that additional non-ionizing harmonics from converter connected generation

and HVDC has added to the substation environment. Different measurement and analysis techniques are considered for their suitability to examine the full exposure of personnel (exposure index) from not just the 50Hz component but also the harmonic contribution. Further work is ongoing, but initial indications suggest there may be more of a contribution by harmonics to the magnetic field effect, however the detection is sensitive to the measurement technique.

Paper B3-101 considers a key substation safety and environment concern, introducing a new retrofit solution for transformer oil containment in constrained spaces. The new solution combines on-line active detection of oil using sensors leaks with a novel miniature chamber, which reduces the need for large concrete structures, testing reported to cope with the hot oil containment needs to be considered during a transformer fault.

Paper B3-114 describes the initiative employed in France since 2014, to manage site safety through a nationwide policy in which working parties agree to a safety charter. The 'HV PASS' is an industry wide passport to enable subcontractors to work on utility projects with the aim of encouraging ‘zero harm’. The Safety Manager Network provides common documentation and best practice from design through to commissioning and site maintenance activity.

Paper B3-113 introduces a SF_6 circuit breaker condition monitoring application used on the Ukrainian power system. The solution which collects performance data on the CB operation, is widely deployed and avoids the need for proprietary software to read the monitors. The algorithm has been modified to get around the buffering problems when measuring component travel time and short circuit switching currents.

Arc flash energy is the subject of paper B3-105. This is major safety issue, and increasingly poignant as the number of MV substations is significantly increasing due to embedded and renewable generation and grid technologies connecting in the lower voltage grids. Electro-magnetic Transient (EMT) analysis is used to calculate the arc flash energy to establish the risk to personnel in the Italian utility industry. The studies focus on studies at 150kV and 400kV sites. The work suggests existing guidance is conservative and safety distances could be reduced, providing a good understanding of the fault current and fault clearance times are fully understood. IEC standard drives the need to more investigation on this topic.

The resilience of substation design to accommodate the latest understanding in the seismic impact of earthquakes and other natural disasters is examined in paper B3-106R. It considers new types of seismic response spectra established through better analytical techniques. A new category - type 2 is designated for the most onerous environments. The analysis identified that most of the equipment is good for the new range of considerations, with some additional measures for GIS disconnectors and instrument transformers. Additional damping can provide better resilience to the most onerous earthquake (type 2), reducing the use of porcelain where a polymeric alternative exists.

Question PS1.4 How do the developments in substation safety, environment and security translate to MV equipment and installations?

Modularisation

Utilities need to adapt their substations to cater for renewables and more stringent environmental practices, paper B3-117 introduces the work on design optimisation for AIS substation in Colombia. This discusses the growing South American practice to consider pre-assembled packages to reduce the delivery time and delays due to external licensing and permit approval, such skidding pre-assembled components, containerized P&C and precast foundations. The example demonstrates a reduction of in approximately 20% in the delivery programme on a 220kV project. This also avoids the use of GIS, only considering AIS sites.

The concept of a standard design called the Modular Green Substation (MGS) has been designed to help integrate renewable and BESS technology onto the Korean power grid. Paper B3-110, describes the technology used including ester based transformer insulation to reduce environmental pollution risk and SF_6 alternatives to populate GIS. This modular approach facilitates a fast deployment approach utilising plug in modules and IEC61850 SCADA interfaced via optical fibre.

In paper B3-116, RTE describe how they will soon also become responsible for the ownership of offshore substation platforms. The article introduces the French approach to managing the offshore platform design challenge. High-level design standardisation and considerations for fixed and floating platforms consider access and maintenance. This builds on the work from two B3 publications TB585 on substation configurations and TB 483 which records other users' experiences and the significance of work carried out by CIGRE in this area. Comment on new working group starting in this area

Question PS1.5 With the drive to achieve 'Net zero by 2050' or earlier… what will be the key issues to manage? What role does economics or legislation play in the future of substation design and operation?

Application of alternative gases to SF_6

Paper 107R describes experience of a new GIS solution using climate neutral insulating gas installed in Bergen, Norway with BKK Nett as part of a substation upgrade from 45kV to 132kV. Blue GIS is SF_6 free using 'clean air'. The GIS CB relies on vacuum interrupter technology and LPIT Rogowski coil technology to replace the traditional CT design and further reduce the size and weight. this coupled with IEC 61850 merging units also heralds the move to a more digital platform on protection.

The experience from a trial of the SF_6 alternative 'g3' in a 145kV GIS substation at Grimaud, France, based on a Fluoronitrile alternative is the subject of paper 115. The focus is on the maintenance aspects of the GIS, specifically gas handling and processing to ensure gas homogeneity. This highlights the factors which need to be considered as we transition to a world, where alternatives to SF_6 are used in the GIS compartments.

Following on from the continuing successful experience of a 170kV GIS facility in Switzerland. Paper 117 reports that Transnet BW are now looking at a 420kV design using SF_6 alternative in the passive compartments of a single bus GIS substation in Germany. A number of small modifications are considered for the C5-FK gas mixture, which is less than 1 in terms of GWP equivalent. This variant shows good potential for the other switchgear related factors. The paper focuses on the utility specification regarding whole life and the service continuity requirements, in particular gas handling. There is a strategy to upgrade the whole single busbar GIS substation to the alternative as confidence in the capability in switching compartments is demonstrated.

Paper 109 discusses the learning and experience from Iberdrola in Spain with respect to the upgrading and replacement of older GIS facilities. Issues with maintenance, drives a need for double busbar designs. However, the interfacing and compatibility issues between GIS and older cable technology is more of an issue. A move towards gas ducting to line circuits to reduce interfacing risks and fire hazards of the cables. A focus on project management introduces some contradictory behaviour from an asset management perspective on the sustainability aspect of their decisions in respect of SF_6. Alternative gases are being considered, but it is the utility's responsibility to specify what is used.

Question PS1.6 What impacts will the pressure to reduce the industry's reliance on SF_6 have on the current work? How will the challenges to the longer-term use of SF_6 affect the future of HVDC and UHV GIS? How are the alternatives being considered at this time?

PS 2 Optimised Management

PS2 had 13 papers accepted for publishing. The subject matter attracted many utility contributions showing that good asset management is a growing issue across the sector.

The second set of preferential subjects focus around the innovation and progress of substation optimised design and maintenance; particularly the;

- Wider application of condition-based monitoring with analytics
- Understanding the role and value for digitization of substations and equipment
- Substation legacy spare parts fabrication.

The advancement of digital technology in the utility industry has led to greater efficiencies and methods to improve service reliability. The better management of assets through digitization, monitoring and analytics were the subject 6 papers. The challenges focus around legacy upgrades, provision of spare parts and the transfer of knowledge to the next generation. These topics are the subject of much interest and concern in the utility industry as evolution of the grid transitions to an environmentally sustainable product.

Advances in monitoring and impact on operations are highlighted in paper B3-201, B3-205 and B3-206. The accumulation of data in real time allows for proactive decisions that affect grid ratings and prevent outages from equipment failures.

In the UK, significant work on analytics to address all aspects of substation equipment life and health are more than just concepts. Examples of services and benefits are displayed as ideas for asset managers and engineers to foster and possibly improve on. Substation digitization is growing as a mature deployment and these papers provide a method for economic value and possible justification.

Question PS2.1 How can digitisation of substations enhance or improve new methods of asset management and operations?

Assessing equipment capability and conditions are part of condition-based maintenance strategies. The difficulty in developing and analysing information requires the data to be gathered while it is in service. Paper B3-210 emphasizes non-invasive techniques for asset evaluation to allow for in service monitoring that can prevent a forced outage or removal of necessary equipment from service during an in opportune time. The evaluation of key equipment health during times of peak load and high system stress are achievable.

Question PS2.2 What new methods are being developed to detect in service rating and prevent forced outages of equipment from premature failures?

Advanced computer software provides more than just faster calculations and analytics. New 3-D design platforms facilitate a range of features from the visualisation of field deployment through to virtual design of substations. New virtual platforms discussed in paper B3-204 reflect progressive team learning and communication abilities to improve processes. The ability to better document key learning skills and to perpetuate the transfer of knowledge throughout the utility industry is a growing need and is discussed in B3-207.

Electrical equipment designs, materials and techniques are constantly evolving as market forces predicate mergers and retirement of different models of equipment and the vendors that manufacture the assets. Management of spare parts and inventory volumes have always been difficult to judge. Paper B3-202 promotes the evolution of 3-D computing, capable of producing legacy spare parts for equipment in service that otherwise would require costly capital replacements.

The enhanced management of utility substation equipment through the use of digital technology allow for reliable service with minimization of cost. Reduction in maintenance needs and capital replacement though better asset utilization produce benefits for environment to prevent spills, leeks and possible catastrophic failures.

Question PS2.3 What new technology and tools are being implemented in the design of substations and how do they impact learning as well as aid in legacy spares management?

The PS2 collection of papers not only presents new concepts and ideas but provide practical examples of what is possible. The sharing of examples is the catalyst of new ideas. Engineers benefit from building on the experience of others but also on the necessity of invention. These papers are good examples of the advancement of substation operation based on learning, technology and imagination.

Preferential Subject 3: Integration of Intelligence

This preferential subject had 12 papers accepted for the session. The subject matter is broad covering all the topics identified in the PS, in particular, intelligent IoT-connected power equipment, digital twins, application of new digital solutions and prototype installations of digital substations.

Paper B3-303 highlights the intense learning curve on a fleet of digital substations. Fault location was combined with an advanced centralized protection and control system for roll-out in > 300 substations. The new architecture separated the concern of asset management on the longevity and flexibility of the digital solution in a simple and cost-effective manner. A design criterion was the flexibility to change functionality without an overhaul of the hardware in the substation. The proof-of-concept started with 10 pilot installations.

In Paper B3-305R a new generation of intelligent transmission products like transformers and switchgears is introduced and an outlook on the future interaction in systems and substations is described. The integration of intelligence in T&D equipment and substations offers the potential to operate the power grids of the future more effective. Smart and robust IoT devices should transfer relevant information to a cloud-based storage platform. Digital twins of the equipment lead to an increased operational performance and were proven by pilot installations.

Paper B3-310 describes the experience with reconstruction of a SVC analogue controller by a modern digital controller. It is shown that the refurbishment of the control system enhance the lifetime and performance of the SVC equipment. Another benefit is the ability to use different settings for flicker reduction.

In Paper B3-312 a green and digital 50 kV GIS substation including the first return of experience is described in detail. An innovative alternative insulating gas with low GWP (g^3) was applied for the new GIS. Low power instrument transformers (LPIT) were connected to the digital substation automation system based on the IEC 61850 and IEC 61869-9-2 standard. This pilot project is used to demonstrate and test new technologies and get operational experience.

Question PS3.1 What examples and return of experience can be provided on digital substations and digital twins? Which measures are necessary to increase the acceptance of intelligent IoT-connected power equipment in substations?

The development of a working prototype for a substation gateway based on IEC 61850-9-2 is described in Paper B3-302. The study showed that a service oriented architecture together with the application of IEC 61850 and IEC Common Information Model (CIM) standards allows for reuse of information

integration flows. This improves robustness in the solution. The paper discusses the challenges and the lessons learned in this project.

Paper B3-304 outlines the variety of measurement chains demonstrated in the FITNESS project (Future Intelligent Transmission Network Substation) which deploys a multi-vendor IEC 61850 full end-to-end digital substation platform running in parallel with conventional equipment. It also identifies and discuss remaining functional challenges associated with the capability of a digital substation architecture to support all measurement use cases, such as Travelling Wave Fault Location and transformer neutral DC current monitoring.

In Paper B3-307 a pre-qualification test procedure for digital substations is described. It proposes to use high-power laboratories for a complete system verification of the protection chain before commissioning. The possibility to generate multiple fault events is useful to compare analogue and digital solutions. Test results are shown for multi-vendor solution with conventional instrument transformers, low-power instrument transformers (LPIT) and stand-alone merging-units (SAMUs).

Question PS3.2 Are the available test protocols and test standards sufficient for digital substations and IoT-connected power equipment? What are the differences in digitalizing MV and HV substations including aspects of cyber-security?

Paper B3-301 deals with the expectations, current realities and future opportunities regarding 3D design, building information modelling (BIM) and digital twins for electrical substations. The authors briefly explain some of today's emerging technologies (VR, AR, AI) and re-align users' expectations on these technologies in respect to a definition of needed information and who will be using the information.

Paper B3-306 describes the application of an artificial neural network (ANN) for minimizing the effort spent on the engineering design of steel cap plates of substation support structures. The proposed ANN structure was proved to have both interpolation and extrapolation capabilities with a high level of accuracy and rapidity.

In Paper B3-308R different digitalization solutions are demonstrated for substation planning, design, construction, operation and maintenance. Examples are drone patrol, artificial intelligence (AI) diagnostic system based on application of network cameras and image analysis, and thermal rating system for transformers. 3D substation models are useful for construction work and virtual reality (VR) and mixed reality (MR) techniques are supporting the operation and maintenance work on substation level.

Paper B3-309 describes the benefits of virtual reality (VR) technology for substation maintenance. A novel maintenance operation scheme based on VR technology is introduced as part of remote supervision.

Paper B3-311 reports about a specification for an intelligent monitoring system on power transformers which is based on IEC 61850 technology and edge computing. Different IoT sensors provide data for monitoring, control, and preventive diagnosis of the power transformers. The advantages of edge computing compared to cloud computing are discussed in detail.

Question PS3.3 What are the benefits of digital solutions like artificial intelligence (AI), virtual reality (VR), drones, robotics etc. for substation life cycle from planning to maintenance? Which emerging digital technologies will improve substation operation?

Concluding Remarks

This session's collection of papers covers a wide range of issues. As always, the challenges facing the substation engineers and operators are extensive, reinforcing the fact that bodies like CIGRE are an essential element to minimising the number of times a problem proliferates and adds value through having networks to quickly develop solutions and share best industry practice.

There is no one single solution, each utility must balance the issues specific to its own operation and business environment, but which ever approach is taken, the utility needs to be able to determine the appropriate level of resilience that is required.

The value for utilities of participation in CIGRE, is the ability to be exposed to new ideas and technologies that have shown promise in the management of substations performance, health and condition.

We hope you find this summary useful and the questions representative. We look forward to reading your responses and contributions this summer.

End.