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SPECIAL REPORT FOR SC B3
(Substations)

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Special Reporters

CIGRE Study Committee B3 'Substations' is responsible for activities that cover the design, construction, maintenance and on-going management of substations and the electrical installation in power stations excluding generators. The Study Committee aims to bring value to the engineering community through synthesizing state-of-the-art practices, developing recommendations and providing best practice. The major objectives of B3 are 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 an integral part of the power system and central to the safe reliable transmission and distribution of power providing access to the network, fault isolation and facilitating network expansion. This is evident all round the world as energy networks expand providing electricity to more people than ever such as India and China or move into new regions such as offshore to generate clean renewable energy.

There are many substation related design, operation or management issues across the world, however it is noticeable there are some consistent underlying themes challenging the engineer in particular improving efficiency and reducing life cycle costs. It is very important to remember that sustainability needs to be a key design principle, since the longevity associated with a substation, would suggest that it is likely to exist for more than one regulatory regime, multiple customer connections and change in government, however from the outset the designer must be able to consider all these challenges and balance the technical requirements with economic, environmental, social and amenity issues.

The Preferential Subjects for the 2014 Session aimed to promote thinking and discussion around the following topical developments and challenges:

PS1: Substation developments to address future needs
- Integration of new approaches to grid automation in transmission and distribution substations.
- Impact of new grid developments on substation design.
- Off-shore substations.
- Low cost and fast deployment distribution substations.

PS2: Life-cycle management of substations
- Renovation, refurbishment, extension and up-rating of substations.
- Asset management, maintenance, monitoring, reliability and sustainability issues.
- Managing risk in design, installation and operation of substations.

This year a total of 34 papers addressing the 2 preferential subjects have been submitted to the 2014 CIGRE Substation Session. The material provides a valuable contribution to the active work of Study Committee B3. The effort and time afforded by the authors and their supporting organisations in producing these papers is greatly appreciated. CIGRE aims to encourage discussion and involvement in the Paris session through stimulating discussion and participation around the material reported in the submitted papers. The following summary from the Special Reporters and accompanying questions aim to address topical but generic aspects highlighted in the preferential subjects and authored papers.

The papers cover a broad range of subject matter and all the preferential criteria has been addressed to some degree. While many of the usual topics have been well covered, it was good to see papers reporting the challenges with distribution substation design development and automation. There is an increasing interest in the use of monitoring and risk management for decision making in both new build and asset replacement. While offshore substations and UHV was addressed, although surprisingly only one paper was authored on each subject.

1. Substation developments to address future needs

The last few years has seen a focus on new concepts in substation design, configuration and operation, principally driven by the need to economically connect and manage renewable generation. This is particularly evident at lower voltages where the role of the distribution substation is changing significantly to manage the emergence of embedded and distributed energy resources. This change is compounded in mature networks where ageing infrastructure may have to be replaced at the same time as the substation is being extended, requiring security of supply and safety to be managed. As the electricity networks adapt to facilitate expansion or manage the challenge, this provides the opportunity to do things differently with new technology and solutions. The 2014 session will provide a very good opportunity to gather the experience gained so far and identify where new learning is still needed.

The choice of preferential subject aimed to tease out how both old and new substations are responding to the challenges emerging around the world. Most of the activity reported within the substation arena is of an enabling nature to increase or free up capability in the network, thus enabling utilities to manage more complex and dynamic power systems. A variety of new technologies and methodologies are being installed to addressing the challenges.

Enhancing substation utilisation is a big topic of interest, offering the potential to harness the latent capability in the existing network without the need for major new construction, particularly where planning may be restrictive. Noticeably, developments in information systems, communications and automation technology, frequently referred to as 'Smartgrids', is enabling substations to provide new or improved capability such as flexible operation, active control, better system security, increased power flow and voltage control. Paper B3-102 describes the successful experience in New Zealand with a wide area control scheme to manage voltage at a regional level and the role that the substation hierarchy controller plays in coordinating different voltage control mechanisms, improving network performance. Voltage control is just one element of a 'self aware' control scheme reported in paper B3-103 which considers a future where substation automation coupled with modern technology across a network coordinated by a wide area control scheme could manage network security through a self healing control methodology and the plans for a pilot in the coming years. Paper B3-113 outlines the design hierarchy and experience in the US around implementing different automation schemes into a distribution substation environment and the challenges around integrating multivendor systems.

Question PS1.1 **Is there any experience to share on the impact that installing and operating automation schemes and smartgrid solutions has on the design and requirements for the substation? How much consideration has been given at this stage to the lifetime management of such schemes particularly extension or replacement?**

Question PS1.2 **Given the similarity of the automation technology, does the industry think there is likely to be a difference in the design and cost of substation automation schemes depending on whether they are applied at transmission or distribution level?**

A few papers highlight the 'digital substation' concept that is emerging at all levels within the power system. Paper B3-106 demonstrates how constructing a substation using electronic transducers and IEC 61850 can optimise programmes using less copper and more optical fibre and modern communication protocols resulting in quicker build. Similarly, paper B3-211 describes the greater flexibility offered through integrating non conventional instrument transformers (NCITs), merging units and IEC 61850 protocols can expand the role of the secondary system to provide additional capability such as billing metering which will enable networks to become more diverse and commercially flexible.

Paper B3-104 expands the concept to consider a fully capable future substation that integrates all the new developments in switchgear and electronic transducers on the primary side and intelligent devices and process bus at the secondary level. The extent and impact of substation automation still varies significantly between countries and utilities and is still in the R&D phase, with pilot applications becoming more common. This is reinforced in paper B3-110 that highlights the major shift in thinking when moving from the traditional secondary architecture to the IEC 61850 'bus' concept and is further qualified with the need to establish a development programme lasting a number of years to safely introduce this new concept into the grid.

The introduction of digital technology in a substation environment changes the testing and commissioning regime, requiring a completely different process management concept to the traditional substation equipment. B3-109 reports on the field experience with integrating and testing merging units with substation supervisory and control systems. It emphasises the need to establish confidence in the end to end 'substation bus' solution performance, particularly interoperability, before looking at the 'process bus' which is much more critical.

Question PS1.3 **Is the adoption of IEC 61850 being driven by the manufacturers or Utilities? What challenges should utilities and developers focus on who have not piloted or implemented digital solutions involving NCITs, IEC 61850 or smartgrid applications? What are the different skill sets, testing and tools required to successfully roll out digital substations?**

As networks begin to expand further away from the demand centre into rural regions or offshore and generation starts to penetrate lower voltage levels, that traditionally only saw load, the need to manage power flow control and voltage control becomes more complex and difficult. This is driving changes at two levels; firstly the development of smarter substations using monitoring, intelligence and automation (as discussed) and secondly the requirement for new capacity that can range from up-rating the network to higher voltages to the construction of new circuits which could be either AC or HVDC.

As T&D networks grow and evolve, due to changing generation and demand profiles, it is likely that parameters may change that impose different performance requirements on the existing substation necessitating equipment specifications to be reviewed. Paper B3-108 highlights the importance that analytical studies play in determining the change in performance criteria for substation equipment especially at higher voltages such as 765kV and above, where switching becomes more onerous. There is a lot of interest and discussion around HVDC networks and in particular the need for multi-terminal and bussing substations to safely marshal power during system faults. Paper B3-115 examines the selection criteria around the selection between indoor and outdoor DC AIS switchgear.

Question PS1.4 Is there any experience to report on the design or operational experience of offshore, UHV or HVDC substation installations, especially where the actuality of operation has proved to be different to that expected or predicted in the design phase?

Substation design is a constantly evolving process, where designers have to optimise the solution to be a compromise between lower cost, efficiency or fast construction. At a generic level, paper B3-117 describes how a reliability based assessment has resulted in the development of standard substation configurations for MV substations. The concept of modular installation is becoming more popular, paper B3-116 reports on the development of a prefabricated rapidly deployable 38kV distribution substation that can be installed and commissioned in a matter of days. A similar strategy can also be applied as part of an emergency plan to ensure supplies can be quickly restored following an incident as reported in B3-209, that uses mobile solutions to facilitate fast deployment and a polytransformer to manage different operational voltage levels, quick hook up and commissioning.

Question PS1.5 What strategies are being considered with regard to standardized substation design? Are these new strategies and practices dictated by manufacturer equipment or utility planning & operational practice? What is the future trend in this matter likely to be?

There is wide interest in the application of compact and modular equipment such as Mixed Technology Switchgear (MTS) and integrated switchgear with simpler configurations to achieve similar or better reliability. B3-201 provides some examples on the application of MTS based solutions for replacement and up-rating where improving reliability is a key driver. Performance and reliability is the focus of paper B3-216 that examines the suitability of different single line configurations for AIS and GIS equipment and provides a useful summary of the key issues to consider. It highlights the impact that data accuracy and sensitivity has on performance studies, and the role that disconnectors play in substation reliability.

Question PS1.6 Is there any experience to report concerning the performance of MTS as a result of operating GIS equipment outdoors with AIS busbars? Are there any examples of different maintenance policies arising as a result of using MTS?

B3-107 discusses some of the thinking around offshore GIS substations, were developers are investigating the use of 66kV GIS as opposed to the more typical 36kV to optimise the platform capacity from the collector arrays to improve the power density offshore.
The ambition to develop more environmentally sustainable equipment is reported by a couple of manufacturers. Improvements in GIS technology are reported in B3-112 indicating that design optimisation can reduce the footprint, and the volume of SF_6 required in modern switchgear. These improvements coupled with a more modular design concepts is helping lower project costs and achieve higher energy density solutions, however B3-105 highlights some of the design challenges introduced when developing GIS disconnector capability from 420kV to 800kV.

Question PS1.7 Considering further AC GIS requirements and developments, are there any others besides bus transfer performance and SF_6-reduction? What kind of experience is available nowadays?

Question PS1.8 Given the future challenges around the management of SF_6, what is the likely uptake in HVDC GIS based applications? What issues are anticipated as the major challenges in asset management of HVDC GIS?

2. **Life-cycle management of substations**

This a very broad topic and the preferential subject areas focus on some important issues facing most utilities. Asset Management is increasingly concerned with evaluating risk and predicting end of life to inform construction programmes and replacement strategies, however it is noticeable that governance and business processes are demanding more analysis and demonstration of design options and risk management decision making.

Preferential subject 1 reported on the growing application of integrated and mixed technology switchgear (MTS) providing examples of how availability can be increased through eliminating disconnectors (B3-201). This equipment is being used to support substation refurbishment and replacement activities where utilities seek better equipment reliability and a lower maintenance burden. B3-114 discusses the merits of gas density monitoring in GIS coupled with diagnostic analysis to identify reliability and performance issues at an early stage to highlight possible developing fault conditions.

Question PS2.1 **When considering the reliability and performance of a new substation, is it better for a study to be based on the utility's numbers based around interpretation and experience of its own obsolete equipment or should the study use estimates provided by the manufacturers? How does this data compare with the results of the CIGRE reliability studies?**

Two papers discuss the drivers and experiences around substation replacement, B3-118 describes how GIS has been selected to improve service reliability and personnel safety, with the addition of gas barriers in the GIS specified to meet utility maintenance requirements. B3-219 reports on how the utility met network expansion and supply security requirements, using GIS to replace the existing AIS. Furthermore to maintain a high level of service, performance diagnostics using various types of monitoring including on-line pd have been introduced to provide advance warning of problems in critical assets such as the GIS, transformers and bushings.

Question PS2.2 **Is there any evidence to suggest an increase in the use of GIS or MTS technology when either extending or asset replacing a substation?**

The regulatory environment requires utilities, as good commercial practice, to demonstrate a robust and economic business case to justify any asset replacement or refurbishment programme. Traditionally, substation renewal involved wholesale replacement of the substation based on a finite asset lifetime determined at the design stage, B3-215 describes a mechanism and decision process to establish the optimal timing and degree of replacement or refurbishment for various elements of substation plant. It also provides a couple of examples describing the scheme specifics and outcomes.

Question PS2.3 **What is the current thinking being given to the end of life and asset replacement of GIS substations, especially where space is limited and supply security critical?**

The greater availability and utilisation of analytical tools for decision making and asset life-time prediction, is helping asset managers to determine the remaining reliable asset life and replacement priority using asset health indices and condition monitoring data. B3-217 focuses on using a decision hierarchy, based on assigning asset condition criteria and importantly considering equipment performance, to rank ageing equipment for replacement. Establishing and evaluating asset health metrics are key elements in the decision making process for substation renewal. B3-214 reports on how utilities are now looking to enhance comprehensive life-cycle management processes with visualisation tools to more easily highlight replacement priorities in their asset management strategy, so to better understand emerging risks and their impact on asset performance. Paper B3-213 highlights a risk management strategy using dissolved gas analysis (DGA) and equipment failure rates to address asset performance, but also considers the criticality of the equipment based on its role in the network.

These are combined to optimise the replacement around key substation assets such as transformers and circuit breakers.

The ability to predict failure modes and locate faults in complex or large constructs quickly, aiding the return to service and minimising downtime, paper B3-212 describes developments in fault location techniques using a protection algorithm to determine unbalance in capacitor banks and locate the damaged unit avoiding the need for lengthy testing. Paper B3-206 reports on the role that UHF partial discharge (PD) monitoring plays in assessing the performance of 420kV GIS and outlines an optimised design that has evolved from experience gained on the legacy system, and implemented when the GIS was recently extended. Determining the location of PD in a GIS substation with cables and transformers is the subject of paper B3-210, which describes how an integrated high frequency PD measuring system is used to provide comprehensive monitoring of the complete substation, leading to early defect detection and location avoiding un-necessary long outages fault finding, thus improving performance and availability by reducing costly unplanned faults.

Question PS2.4 What degree of reliability and availability should be considered for substation asset monitoring where critical systems, personnel safety or environmental performance is at risk? What is the future trend in this matter likely to be? What has been the experience of users to date regarding all mentioned asset management issues?

A number of design tools and methodologies have been reported in this session, particularly the application of these techniques on real projects. It is noticeable that economics and risk are increasingly entering the scope of the substation design engineer and are being used to optimise design and cost or mitigate external risks through reliability studies and optimisation. Paper B3-205 describes how a design review and change in disconnector selection policy has resulted in a lower impact on maintenance and substation operation. A very topical subject is raised in B3-207, which describes the role that risk assessment plays at the design stage in the selection of safe substation assemblies employed for distributed energy resources. The evaluation considers where internal arc faults could occur in the confined space of the MV cubicle putting personnel and the public at risk. This is all put into context and practice by paper B3-203 which articulates the role that risk management plays in the project decision making process and is further demonstrated in the execution phase on an actual substation refurbishment project.

Question PS2.5 How widely is risk management employed in the substation design process as opposed to the project delivery phase? Do designers have sufficient access to the appropriate technical material or reliability data for the utility or is CIGRE data used?

The growing range of software tools and applications is enabling substation designers to consider more scenarios or options before having to commit or finalise the design. Being able to model and assess complex issues such as voltage stresses, electromagnetic fields or augment reality is evolving as computing power and software developers consider the energy sector. Paper B3-101 describes how an application from the building industry is being used to manage the substation build programme and help engineers visualise the completed project and the possible pit falls during project delivery. The adoption of design tools complimented with specialist technical software applications will help the asset manager to understand a variety of complex or hidden substation issues such as electric fields, ground potential or corona modelling. This is the subject of paper B3-202, which reports on a new simulation methodology and its application on a 500kV substation. There are numerous hidden safety and risks associated with substation operation. Grounding is the subject of B3-218, which highlights the impact of better understanding that the ‘grounding’ system has on substation operation and how through modelling using industry standard packages it is possible to optimise the design and the amount of copper needed in the earth mat, reducing installation costs.

Question PS2.6: **How important is the role that software design tools, such as Building Information Management and other packages, play in the development, construction and asset management of substations? Are there any real examples to indicate the scale of benefits that has been achieved using these new tools? What software tools are in use to supplement traditional substation design approaches?**

Concluding remarks

This Special Report for the 2014 CIGRE Paris Substation Session has reviewed the contributions of 34 papers from 20 countries. The subject matter has covered an extensive range of topics that highlight the role and importance of the substation in delivering power securely and safely. The content has demonstrated the wide and varied approaches to substation design, construction and operation around the world, whether as part of a developing power grid or a mature power system.

The special reporters have reviewed the papers and posed some questions to further probe and understand the challenges facing substations around the world. It certainly is the intention of the special reporters that the questions raised will hopefully provide a stimulating session in Paris.

The papers have demonstrated that there is an appetite to share understanding and learning about the issues that face substation designers and asset managers around the world. This hopefully reinforces the belief that CIGRE is an effective force in moving forward the boundaries in knowledge and understanding of electrical power systems that underpins CIGRE's mission.