# PROTECTION & AUTOMATION
# B5 - 00

## SPECIAL REPORT FOR SC B5

**Special Reporters**
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**Summary**
The CIGRE Study Committee B5 – Protection and Automation - or SC B5 for short, focuses on Protection, Control, Monitoring and Metering, and aims to cover the whole Power system, end to end related to this topic, from transmission, to distribution systems, including generation and HVDC systems.

Two Preferential Subjects are presented in this Special Report:
• PS1 - Human aspects in Protection, Automation and Control (PACS)
• PS2 - Communication Networks in Protection, Automation and Control (PACS): Experience and Challenges

Contributions of 2-3 minutes are requested, to be presented during the Paris session, to answer the questions below from the authors of the papers, and from the Protection and Control community around the world.

**The SC B5 Group Discussion Meeting (GMD) is scheduled for Tuesday, August 24th for PS1 and Wednesday August 25th for PS2, Virtual Centennial session, studio 1**
***- New procedure for contributions.***

1. Contributors should **upload your contribution** on the Registrations platform – "Contributions to Group Discussion Meetings" section - using your existing account and own credentials **before 20th of July 2021, 15.00 CET** for a prior screening and a good organization of the Group Discussion Meeting. **Important points;**
   - Access to contribution uploading is given only to duly registered delegates.
   - As a consequence, **registration to CIGRE Session** should be finalized before uploading contribution(s) online.
   - Register now for the Session Click here
   - Contributions uploading will be open at the beginning of May.
2. Special Reporters will review the prepared contributions (Power point presentation with max 3 slides + written word file with max 1000 words pr contribution). 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
3. Any recommendations or changes to the contributions will be provided to the contributors by the Special reporters directly on the Registration platform between **20th of July and 2nd of August 2021**. Contributors are encouraged to visit their account on the Registration Platform to see the result of this review.
4. All contributors with accepted/finalised contributions will be contacted by the Special reporters of SC B5 by email between **20th of July and 2nd of August 2021**, to finalize the presentation and receive the instructions regarding the session. There will be a limit of about 30 contributions for each Preferential Subject (PS1 and PS2).

## 1. PS1 – Human aspects in Protection, Automation and Control (PACS)

### 1.1 Introduction

This special report reviews a total of 17 papers from 13 different countries. These papers can be broadly classified into four groups but with many papers covering more than one topic:

- Work processes and organisational change (US, BE, BR, IT, TH)
- Investigation and classification of errors (BR, AU, CN)
- Application of new PACS technologies (ES, GB, CH)
- General tools for mitigating errors (BR, AT, ES)

### 1.2 Work Processes and Organisational Change

Electrical power utilities are facing demands for improved power system reliability and security of supply such that there is now less tolerance than ever for the serious impacts of human errors in PACS. At the same time, utilities are adopting new PACS technologies and out-sourcing more PACS work, requiring increased levels of expertise across a greater range of competencies for the in-house PACS engineering and asset management teams. These circumstances have led many utilities to challenge existing PACS design paradigms, engineering processes and organisational structure.

**Paper B5-101** (US) expands on the object-oriented approach to PACS standardisation discussed in CIGRE technical brochure 584. It is proposed that the development of standard schemes should be based on the use of the IEC 61850 system configuration language and should be carried out by a dedicated standardisation team with domain experts from within the organisation. The importance of standardised test procedures as part of this process is also discussed. It is proposed that Role Based Access Control (RBAC) for PACS engineering, testing and maintenance activities should be a feature of such standard schemes.

**Paper B5-103** (BR): 14% of the forced shutdowns on Brazilian electrical utilities in the period 2014-2018 can be attributed to human errors in the secondary systems. However, reduced PACS teams with limited expertise across the complete domain of new technologies is presenting a challenge. This paper proposes a strategy to address human errors and the current resourcing and technological challenges. It focuses on the qualification and integration of teams across the PACS domains, comprehensive documentation, software tools and procedures.

**Paper B5-105** (BR) describes a review of the PACS processes within the CEMIG in order to reduce human errors. It established that a restructuring of PACS activities and requirements was required. These activities were divided into “Domains” of specific assets and their interfaces with their defined perimeters, which were used to develop new mapping of PACS activities, specifications, updated procedures and process-flow diagrams. This resulted in the use of specialist teams at the various stages in the process; improved training, testing at all levels, asset management and IEC 61850 monitoring tools, staff motivation, and resource usage.

**Paper B5-107** (BE). The human errors arising during the development, installation, operation and maintenance stages of the PACS lifecycle and a comprehensive list of the specific mitigations introduced by Elia are described in detail. Some of the key error mitigation strategies applied include: simplification and generalisation; rationalisation of primary plant topologies; IED qualification; minimising preventative maintenance; the use of engineering tools; the use of standard rules for selectivity studies and settings calculations; FATs and SATs; design ergonomics; role based certification; training; cross-checking; test standardisation and automation.

**Paper B5-108** (IT) presents the initial findings of WG B5.63. It discusses the key challenges facing utilities in the area of knowledge management in their PACS asset management functions in the digitalization era; and identifies the key factors necessary for a successful implementation of PACS asset management. The results of analysis and of a survey conducted by WG B5.63 into the human aspects of PACS asset management are presented. Utility experience regarding PACS knowledge management is presented both from Terna (IT) and from Electrosul (BR).

**Paper B5-116** (TH) describes EGAT's experience of the impact and mitigation of human errors in PACS on their networks. Human errors in PACS is addressed through design, training and work procedures. Standardised use of secondary test facilities and specialised disconnection terminals is a feature of hardwired PACS circuits. Three case studies are presented covering a 115 kV busbar trip issuing during maintenance testing due to unfamiliarity with the scheme being tested; a 500 kV line trip during maintenance of line reactor protection due to a test switch not being operated; and a staff member receiving a non-fatal electrical shock who had cut a CT secondary circuit having verified that there was no current using a digital multimeter with the selector switch set to measure dc Amps. EGAT have determined that many of the human errors in the PACS can be attributed to forgetting, misunderstanding, lacking knowledge or not studying existing drawings.

**Question 1.01: What is the experience of standardised PACS designs reducing the numbers of human errors?**

**Question 1.02: What other experiences are there of fundamental reviews of the PACS engineering and processes carried out to address the current challenges facing the industry?**

**Question 1.03: In the context of the increased flexibility, functionality and scope of application of new PACS technologies, what measures are being taken to capture the PACS knowledge and expertise within utilities, so that previous human errors that have been learned from do not re-occur in the environment of the new technologies?**

**Question 1.04: What is the experience of incorporating features into PACS designs expressly to prevent human errors, where these might otherwise have been addressed by strictly following written procedures?**

### 1.3 Investigation and Classification Human Errors

Fundamental to the prevention of human errors is a considered approach of investigation and classification of these errors and their contexts, in order to determine the root causes and to determine how to prevent their recurrence.

**Paper B5-106** (BR) presents a structured experience-based approach to dealing with the technical aspects of human errors in PACS commissioning and maintenance activities in the CHESF utility. The need for human errors to be characterised and reported, and for the root causes of the errors and any preventative or mitigative measures is highlighted. A comprehensive list of the key issues to be considered to prevent recurrence of human errors is presented and some practical examples are given.

**Paper B5-111** (AU) presents some of the common human errors in PACS, and their associated resolutions, that have been encountered by the authors from TasNetworks and ElectraNet. The paper provides some practical measures and controls that can be taken during the design, ordering, acceptance testing and on-load checking stages of the PACS life-cycle to reduce human errors. A process of systematic tracking of the underlying patterns of errors is proposed, including a PACS incidents fishbone diagram, which may be used as an effective tool to assess every incident properly and to determine and resolve the root causes in order to eliminate or reduce their occurrence.

**Paper B5-115** (CN) analyses the characteristics of the field protection relay defect data gathered by the North China Electric Power Grid company in the period 2009-2018 using a decision tree methodology. This is used to determine the defect rating characteristics of the various protection relays of the different vendors. It is proposed that this methodology may be useful to identify common defects and the weaknesses of different protection devices; and may improve the efficiency of operations and maintenance work.

**Question 1.05: What other structured approaches to the investigation and classification of human errors in PACS are being used?**

**Question 1.06: What is the experience of applying the learnings from investigations into human errors in PACS to ensure that they do not re-occur?**

### 1.4 Application of New PACS Technologies

IEC 61850 has removed many of the design, functional and physical constraints of legacy PACS technologies and offers a fundamentally different way of implementing familiar or improved PACS. However, this new implementation platform does not alter the need for full documentation of the PACS designs, nor for comprehensive test facilities that permit functional isolation of the object being tested, without impacting on objects that are not being tested.

Phasor measurement units sharing sampled values over wide areas are another new PACS technology that can provide real-time decisions for the automation and optimisation of power system control processes that had previously required human judgement and intervention.

**Paper B5-112** (ES) discusses the concerns associated with adapting test procedures to applications with full implementations of IEC 61850, and the organisational and test methodology changes needed to achieve this. Three examples of test processes of IEC 61850 systems are presented, namely a 400 kV reactor feeder in Spain; a 300 kV line bay in Norway; and a set of four 110 kV substations in Azerbaijan. The need for the test process to be developed by multi-disciplinary teams from the affected technological areas within utilities; together with the need for solutions to be validated and refined both in laboratories and in pilot projects is identified.

**Paper B5-109** (GB) identifies the benefits of using IEC 61850 process-bus based distributed busbar protection compared with conventional distributed busbar protection schemes. Process-bus based busbar protection schemes can be directly retrofitted to replace conventional schemes in both digital and conventionally hardwired substations and can retain existing bay-level wiring, secondary injection test facilities and test procedures, if desired. The replacement of the proprietary bay units and communications protocols of the conventional schemes with generic standalone merging units and communications using IEC 61850 sampled values and GOOSE in the process-bus based schemes permits the use of redundant communications (PRP or HSR), redundant busbar protection devices, testing using the IEC 61850 test mode and sample value simulation, easier trouble-shooting and less mistakes. The removal of the proprietary nature of the bay-level equipment results in easier installation, better life-cycle management and easier future extensions to the schemes.

**Paper B5-114** (ES): A fully automated scheme to control the HVDC link between mainland Spain and the Balearic Islands is described. Operators had previously controlled the operating mode of LCC technology bi-polar HVDC link using experience-based estimates of the short-circuit power and were responsible for the consequent emergency actions to correct and stabilise operation following a change of operating mode. The new Automated Stability Phasor-based Algorithm System (ASPAS) now estimates the short-circuit power on-line using data from PMUs at various points across the AC system of the islands; to determine the optimal operating mode of the HVDC link and notifies operators of any preventative or corrective action that may be required.

**Paper B5-117** (CH): The mitigations of human errors afforded by fully digital substation solutions are described. The minimisation of the number of discrete conventional components and of the number of IEDs is seen as key for the simplification of the design, construction, testing and maintenance stages of digital substations. The need for efficient documentation of the data flows and exchanges in digital substation automation systems and for tools to interpret and represent these are highlighted. Extensive testing of such schemes can take place in the factory, due to them being largely not dependant on wires, reducing the extent of site acceptance testing.

**Question 1.07: What is the experience of IEC 61850 based implementations of PACS designs reducing the occurrence of human errors?**

**Question 1.08: What is the experience of testing procedures being developed primarily for IEC 61850 based implementations of PACS, rather than adapting existing conventional testing procedures?**

**Question 1.09: What other experiences are there of new PACS technologies being used to replace legacy processes or designs that had required human intervention?**

## 1.5 General Tools for Mitigating Human Errors

The following papers discuss the general issues of simplicity and specificity which are key to reducing human errors. A virtual relay replica tool is also described which can facilitate the application engineering process and technical support of PACS.

**Paper B5-102** (BR): The elimination of settings from fault location and certain protection solutions is presented in this paper as an efficient way to prevent human errors. Up to 52% of protection maloperations in Brazil have been attributed to human errors during setting calculations or during their upload to the relays. The impact on performance of different settings errors is considered for different protection and fault location functions. It is proposed that relay setup platforms should be optimised, especially where reduction of the number of parameters is not possible; and that adaptive or settings-free approaches should be adopted where possible.

**Paper B5-104** (BR) proposes a Domain-Specific Language (DSL) using a formal syntax and precise semantics for non-technical human communication or specification of functional requirements of PAC solutions for the electricity supply systems of the future. It is claimed that a DSAS can be conceived to comply with higher reliability, robustness, efficiency and efficacy, in order to prevent human failures.

**Paper B5-110** (AT). The concept of an automated model-based engineering and validation support framework for power system automation and control applications is proposed. This is intended to automatically generate and deploy target code and configurations for smart grid applications from a user specification prepared using a formal domain-specific language (DSL). This will include automatic testing and validation to improve quality and to reduce the potential of human error in the process. Proof-of-principle prototypes of the framework have already been developed

**Paper B5-113** (ES) demonstrates how use of digital twins can be used in all phases of an PACS lifecycle, including design and engineering, settings validation, qualification, training, fault analysis and technical support. A manufacturer’s proprietary PACS digital twin tool is presented in which a virtual replica of an IED or set of IEDs can be created. In-built static and dynamic test facilities permit the digital twin to be used to configure, set and test IEDs for specific user-defined applications, without the application engineer needing access to physical IEDs or test equipment; or indeed access to a substation or test lab. An application of a bay protection scheme for Red Eléctrica de España is described in the paper. It is envisaged that the use of such virtual twins will facilitate faster and more effective development and validation of standard PACS solutions, reduce OPEX, result in faster turnaround of fault investigations, faster and more efficient technical support, and reduce dependencies between different departments.

**Question 1.10: What other tools are being used to clarify, simplify and assist human interactions with PACS engineering?**

## 1.6 Final Remarks

There is less tolerance now than ever before for the serious impacts of human errors in PACS. However, this is coincident with significant upheaval in PACS technologies; difficulties in developing and retaining suitable levels of PACS competence and expertise within utilities; and increased participation of third-parties in the PACS activities of utilities. In response to this, many utilities are revising their PACS work processes, resourcing, engineering delivery and asset management models.

The 17 papers received have been grouped into 4 topics. These papers indicate that continuous learning from previous human errors remains a fundamental feature of many PACS engineering processes and that this must continue as the nature and scope of PACS engineering evolves.

## 2. PS2 - Communication Networks in Protection, Automation and Control (PACS): Experience and Challenges

### 2.1 Introduction

This special report reviews a total of 23 papers from 15 different countries. These papers can be broadly classified into five groups, many papers covering more than one topic:

- Emerging Technologies (3 papers)
- Network Design and Optimisation (5 papers)
- Site Trials and Return on Experience (8 papers)
- Testing & Monitoring (3 papers)
- Communications for Protection Systems (4 Papers)

### 2.2 Emerging Technologies

The implementation of new technologies is vital if PACS are to evolve to meet the changing needs of the industry. As such, continued research and investigation into new and emerging technologies is essential. Considerable advancements have been made in communications technology over recent years and as an industry we are still pushing the envelope to strive for improvements. Three papers provided an insight into this area; two were focused on the application of software defined networking (SDN) and one on the use of 5G networks. All had a similar goal; use evolving technology to enhance the communications infrastructure and ultimately the efficiency of the PACS.

**Paper B5-201** (US) is based on work carried out by Cigre Working Group B5.66. It proposes the significant benefits to be gained from Software Defined Networking (SDN) in the areas of network switch management in the process bus along with enhanced cybersecurity protection. Using commercial model-based systems engineering (MBSE) tools and examples it describes a MBSE description of the process bus operating configuration and associated benefits to the analyst in the development of the model. It concludes that the use of white box solutions offers the promise of eliminating vendor lock-in.

**Paper B5-215** (CN) summarises the work of China Southern Power Grid to utilise 5G communications in (PACS). Using partitioned slices of the 5G network, a multi-terminal numerical current differential scheme is realised. The application is chosen because of the stringent tele protection requirements (speed, reliability, and latency). A multi-functional, multi-interface 5G gateway is designed to deliver the solution. Verification of its effectiveness was achieved by establishing a 5G smart grid slice field trial for joint differential protection and automation control. The paper concludes that a 'sliced' 5G communications network can meet the demands of such PACS applications and is an ideal arena for the development of future distributed smart grid applications.

**Paper B5-219** (GB) presents a lab assessment of SDN to achieve a secure and agile IEC 61850 communication network for a digital PACS. It focuses on the functional and performance testing of the PAC functions using Sampled Values and GOOSE communication services to investigate OpenFlow protocol implementation and process bus secure connectivity issues via the SDN. The study has also examined network redundancy with a dynamic and programmable rerouting strategy of the SDN simulated using a real-time data network emulator. The results have shown that SDN-based process buses can achieve a similar performance compared with traditional star process buses with additional network security to discard/block the packets not defined in flow tables

**Question 2.01 - How well defined are the processes and standards for emerging communications technologies such as SDN, 5G etc? What improvements are required to capitalise on such developments?**

**Question 2.02 - Using practical examples where possible, explain how the latest research and advancements in communications technologies can help improve the performance of PACS? What are the challenges preventing such technologies being implemented?**

### 2.3 Network Design and Optimisation

It is widely recognised that the implementation of an optimised and efficient communication network along with the adoption of a standardised approach to design results in significant improvements in PACS efficiency and performance. As the digital substation and in particular the process bus gains popularity and acceptance there is considerable interest in the industry around optimising not only this aspect, but the overall communications network architecture, configuration tools and testing associated with this. Five papers addressed these topics focusing on key components, such as redundancy, bandwidth, network performance attributes, quality of service, testing and monitoring.

**Paper B5-202** (BR) investigates the limits of data transmission in the process bus, particularly the bandwidth occupied by the merging units (MU). The authors present an equation to determine the maximum number of MU`s tolerated by the network and the bandwidth consumed. Three test scenarios along with the impact of VLANS, network speed and latency were considered. It concludes that calculations based on bandwidth alone to determine the number of MU`s can lead to mistaken results.

**Paper B5-204** (BR) provides a high-level description of the key stages of digital substation communication network design, such as device and topology definition, bandwidth, traffic segregation, latency requirements using suitable message prioritisation, redundancy protocols, time synchronisation and cyber security, VLANs and multicast filtering - resulting in the definition of key parameters of the network. Based on a case study the paper notes the importance of finalising all configurations ahead of FAT and replicating site conditions as far as possible during FAT. It also highlights the benefits of fully redundant architectures which enable testing without service interruption.

**Paper B5-214** (AU) explores how to achieve the traditional PACS requirements of reliability and stability when the protection schemes are dependent on LAN for acquiring data and issuing control commands. The author explains in the case of digital PACS with typically more functionality and complexity than conventional, resilience is as important as redundancy. The author then goes on to explain the LAN architecture options and traffic control mechanisms, particularly the impact on time-critical GOOSE messages. The paper proposes a ‘High Resilience’ architecture combining RSTP and PRP as the optimum solution for PAC systems to meet the Australian requirement of ‘sufficient redundancy’.

**Paper B5-220** (IN) details various methods of calculating potential network loading and data transmission rates on station and process bus implementations. Design practices for both station and process bus implementations are discussed including segmentation of networks where multiple voltage levels are involved. The use of VLANs is extensively explored and associated challenges are discussed including switch configuration overhead and complexity of design and expansion. Traffic control through network splitting and MAC filtering are discussed in detail and the benefits of each, where possible, are highlighted. Test results are shown for a system with 3 voltage levels with 22 bays comprising 74 IEDs, 56 SAMUs and 54 SCUs. The results show that the designed system allows all messages to report as required over the designed system infrastructure.

**Paper B5-221** (CL) describes the development and implementation of a digital substation test laboratory developed by Transelec with equipment from several different suppliers including process bus and station bus networks. VLAN segregation, redundancy, bandwidth and the Q-tag, as defined in IEEE801.2D (Quality of Service) enabling network switches to prioritise messages with 8 traffic classes and associated priorities are all addressed. The tests described in the paper illustrate how QoS ensures that any abnormality within the process bus safeguards critical information.

**Question 2.03 In the interest of designing an optimised communications network, is there a preferred communications architecture / network for PACS? What are the key considerations to ensure efficiency and optimisation; please also consider the associated tools and techniques used to determine this and any associated challenges?**

**Question 2.04 When designing a PACS architecture how important is standardization, templates and a clearly defined Network Engineering Process from specification to documentation, implementation and testing?**

### 2.4 Site Trials and Return on Experience

For many, the station bus is now common practice and in some cases for over 10 years. As of today, there are also a number of PACS employing the process bus either on trial, at the "piggyback" stage or in full implementation, particularly at the transmission level. This is evident from the eight papers addressing this area. A number of common themes seem to emerge from the papers, namely, the requirement to standardise in order to improve efficiency and costings, the need for a robust engineering design process, optimized architecture, cyber security, monitoring, testing and asset management. As can be witnessed from the papers, process bus is a mature technology and ready for mass deployment.

**Paper B5-203** (BR) investigates the specifications and future requirements for a fully digital PACS. For the past 13 years Electrobras CGT Eletrosul has adopted IEC 61850 for PACS at the station bus level, mainly utilising MMS and GOOSE and as such, it is now the standard mode of operation for transmission utilities in Brazil. This paper investigates the next step, namely the process bus with a view to defining the technical specification requirements. Based on their own experience the authors feedback both the current station bus specifications and the future requirements for a fully digital PACS solution.

**Paper B5-206** (NO) provides an overview of the communication network architecture in Statnett digital substation pilot project. The paper points out that one of the main challenges for a digital substation is to ensure that the reliability and availability of the system is not worse than a conventional system. To this end it evaluates the options of using redundancy protocols namely; Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR) and other alternatives network architectures for the process bus. Two suggested architectures; one based on PRP and the other with two independent systems related to management of redundancy in the communication network for application of IED`s are discussed.

**Paper B5-207** (NO) This paper is one of the outputs from WG B5.69. It summarises the preliminary review of 5 process-bus IEC 61850 based PACS projects; two full scale deployment (Trans Grid project Avon (AU), RTE "Postes Intelligents" project (FR) and three open loop demonstration (FITNESS SP Energy Networks (UK), Statnett R&D project Digital Substation (NO) and National Grid VSATT project (UK). Its purpose is to compare and classify the different projects and associated publications related to PACS with regards to advantages and challenges. The paper concludes that process bus technology is mature and ready and that vendors have an important role to play to ensure interoperability. Finally, it looks at emerging trends, such as centralised protection.

**Paper B5-208** (GB) Project FITNESS – Future Intelligent Transmission Network Substation) is the first live demonstration of a multivendor digital substation and automation system in GB based on IEC 61850. The project led by Scottish Power Energy Network's in Scotland was trialled and tested alongside conventional technology on the Scottish Power transmission. The paper focusses on the design, testing, operation and maintenance of various communication and redundancy architectures, through experiences and test results from both offsite and onsite live testing of the engineering design requirements. The paper clearly highlights the need for the robust communications network for safe and reliable operation of digital substations.

**Paper B5-212** (RU) presents the practical experience and research activities in Russian power system operator in terms of building communication networks for PMU data transmission for PAC applications.

PMU`s and PDC`s measure and transmit a very high volume of information, without optimal architecture design the communications network can significantly constraint the use of PMU data in PACS. The paper reviews different approaches to create communication networks and discusses requirements for data transmission and the importance of real time data quality monitoring to identify "weak link" in communication infrastructures is also discussed in the paper.

**Paper B5-216** (FR) outlines RTE`s R#SPACE project which aims to develop an IEC 61850 based PACS to address technical constraints posed by asset management, optimize network operation and maintenance. This in turn implies an extended use of information technology and communication network. It discusses the choices made in selecting the architecture and the rationale behind the choices made in order to adapt to the evolving constraints of France's electrical transmission system, such as: digital interface of HV equipment, monitoring devices and sensors, capacity to perform maintenance remotely and optimization in functional integration. Based on IEC 61850, a network architecture providing speed, synchronisation, selectivity, redundancy, PTP distribution and virtualisation was selected for validation.

**Paper B5-217** (KR) describes KEPCO`s experience in the implementation of 154kV substations. It focuses on some key features to enhance the reliability and monitoring of the system. The paper focuses on three main areas: communication compatibility with existing equipment, interfacing to legacy primary equipment and monitoring / diagnostics of the station bus network. The goals of system reliability improvement and accurate network analysis were achieved through the application of information connecting devices, local information processing devices and information monitoring and diagnostic devices with both device and network redundancy.

**Paper B5-218** (IN) details Power Grid Corporation of India's emphasis on the importance of communication network architecture and its engineering in the implementation of IEC 61850 PACS in digital substations. The paper details two case studies; one greenfield and one retrofit site and considers aspects such as redundancy, network size, bandwidth, configuration, time sync and relay capabilities. The benefits of using the LGOS node in Edition 2 are detailed to assist with auditing and testing. The inclusion of SLD information in SCD files to allow 3rd party tools to provide a meaningful view of the system are also discussed. The necessity of bandwidth testing under significant load is reinforced.

**Question 2.05 – What are the challenges with regards to implementation and compliance with the standards when designing and testing a digital substation architecture? To what extent and how does multi-vendor digital solutions impact this?**

**Question 2.06 – What are the challenges and return on experience when designing and testing a green field digital substation as opposed to a retrofit? – Where technology is mixed between hardwired and digital – how are the interfaces managed.**

### 2.5 Testing & Monitoring

Testing, commissioning, and monitoring of a PACS is an area which continues to promote innovation and is considered a key area when it comes to the realisation of a reliable, efficient and cost-effective end to end digital substation. It is clear from the three papers in this section that the standards and associated testing facilities are continuing to evolve and proving to have a positive impact when it comes to testing the system. The mix of substation communication traffic and test traffic introduces new challenges, particularly as the networks expand in size, many of which can be addressed by considering the test system components and connections during the design phase. It is also evident from the papers that monitoring and diagnostics has a key role to play in improving the performance, security, and reliability of the PACS.

**Paper B5-205** (US) sets out to highlight the challenges that testing brings to digital substation communications. Its starts by discussing the requirements for the design of an IEC 61850 based communications network for a digital substation. It then goes on to explain the requirements for the communications interface for testing and the simulation of streams of sampled values by the test equipment acting as a specific merging unit simulator for testing. Finally, the impact of simultaneous operation of test equipment used for maintenance testing of energised digital substations. It concludes by demonstrating that the testing system should be included in the engineering process.

**Paper B5-211** (IT) this paper emphasises that communication services and facilities are a key pillar for PACS. It first describes data segregation solutions adopted in order to balance the need for integration to profit from large bandwidth communication networks. It then goes on to discuss a traffic anomaly detection system based on machine learning methods aimed at improving the protection of the system against unknown threats.

**Paper B5-213** (RU) presents the experience to improve the security and reliability of IEC 61850 system communication, using monitoring and diagnostics systems to support design, commissioning, and maintenance of a PAC system. The designated network monitoring devices (Live View Boxes - LVBs) are discussed and to illustrate the application of this monitoring and diagnostics system, engineering process and development procedures for an IEC 61850 PAC system are also described in the paper. An increase in the quality of operation with the IEC 61850 PAC systems in one of the pumped-storage hydro power plants in Russia is demonstrated.

**Question 2.07 How can the testing related features in the IEC 61850 standard be used to optimise the overall testing process? Consider the impact if the components of the test system were taken into account at the design phase and included as part of the engineering process.**

**Question 2.08 How can monitoring and diagnostics have a positive impact on efficiency, quality, reliability and security of the substation communication network? Please consider if the current standards adequately address this area.**

### 2.6 Communications for Protection Systems

Traditionally, communications associated with protection systems were adopted to enhance performance and often exchanged a limited amount of data. The landscape of the electrical network is evolving, we are introducing more Renewable Energy Sources, pushing the system harder by operating closer to stability boundaries and strive to obtain a more resilient system. As a result, complex protection, and system integrity protection schemes (SIPS) are being introduced that require more data to be exchanged. It is therefore important to ensure that we employ the most efficient and cost-effective communications infrastructure so as not to hinder performance. Recently, with the aim of improving flexibility, optimising communication traffic and operating costs there has been a shift from traditional networks to packet based systems and the adoption of alternative network architectures. The four papers in this section look to highlight some of the challenges and advantages to be gained in protection performance from adopting new methods and techniques.

**Paper B5-209** (JP) explains how the increasing amounts of RES on the network can have a significant impact on stability and control of SPS. To keep pace with this change and ensure the SPS is fit for purpose, an increasing amount of data is required to be exchanged on the network compared to conventional SPS. This in turn would require a more complex communication infrastructure and poses a serious obstacle for the development of SPS. As such, the paper proposes a new advanced communication unit (PDH-R) for a ring topology network. The paper describes the features of the ring topology network using PDH-R and shows the experience of applying it to the latest wide area SPS, namely the integrated Stability Control System (ISC).

**Paper B5-210** (JP). In Japan the growth in RES sources has resulted in an increased overloading of transmission lines and transformers. As reinforcement of the infrastructure is not always feasible an Overload Protection Relay (OLR) system is often adopted. Conventional OLR systems are failing to meet the complexity needs of a power system with increasing levels of distributed generators. This paper describes a new OLR system based on GOOSE and IEC 61850 communications adopting a point to multipoint architecture, it discusses the relative merits of the new system against the conventional.

**Paper B5-222** (PT) describes the learnings of the Portuguese TSO (REN) and its associated research centre in the area of line protection systems adopting an IP/MPLS network for communication services as oppose to standard SDH network. Utilising a purpose-built test platform, multivendor equipment performance was assessed, specifically looking at areas such as latency, jitter, asymmetry and error rate. It concludes that it is feasible to operate line protection on communications circuits emulated in packet networks.

**Paper B5-223** (CH) presents a pilot field installation within the electrical high voltage grid of Transco and shows how IEC 61850 GOOSE and Sampled Values signals can be used to exchange line protection signals between substations. Non-conventional instrument transformer and standalone merging units were also used in the project. Several test cases have been presented to evaluate protection performance under fault conditions compared with C37.94. The pilot has successfully passed factory acceptance test and will be commissioned in the next few months.

**Question 2.09 – How has advances in communications technology improved the performance of protection and system integrity protection schemes? Please consider management of traffic, complexity of the network and mitigation strategies.**

**Question 2.10 – What are the advantages and challenges in adopting a packet-based communications network such as IP / MPLS for protection system?**

### 2.7 Final Remarks

The influence, reliance and importance of the communications network in PACS has grown exponentially over the last few decades: Historically, used for basic control, monitoring and to enhance the performance of protection schemes, today; it forms the backbone of many PACS, realising many applications that would not have been technologically feasible only a few years ago.

This progress has been accelerated by the enhancements in communications technologies and the introduction of the IEC 61850 standard which has allowed a common platform to work from thus removing many of the previous interoperability challenges. It is important that we fully understand the advantages and challenges associated with this new way of working and its impact on both the new and existing PACS infrastructure and the associated wider power system.

A considerable amount of research, experimentation and return on experience has been gained over recent years and continues to grow as we overcome more challenges and strive to improve the PACS for the future. It is apparent from the contributions that form this special report, to meet the challenges of the evolving power system, PACS also need to evolve. This will invariably lead for the need to exchange more data, securely at ever increasing speeds. To achieve this an efficient and optimised communication system will be required and it will be necessary to take advantage of the developments in communications and emerging technologies along with of associated tools, standards and processes to allow us to push the envelope. As we move forward, return on experience and knowledge sharing will be vital to identify opportunities and challenges and continue to develop, progress and build confidence. Due to the nature of the new complex PACS design; testing and monitoring will play a vital role since traditional techniques may no longer apply as the test environment changes and we deal with more digital data. As we progress towards the digital substation, we will have to ensure that we have a migration strategy as mixed technologies are likely to coexist for many years. In summary, communication networks can no longer be considered as a standalone entity, but an integrated part of the PACS.