SPECIAL REPORT

Special Report for CIGRE Study Committee B5 colloquium 2025 in Osaka June, 30 to July, 6 2025

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SUMMARY

This document is the special report for the three Preferential Subjects (PS) selected for the General Discussion Meeting (GDM) of the CIGRE Study Committee B5 colloquium in Osaka (JP).

PS1: IEC 61850 based Interoperability of IEDs of different manufacturers and technologies integrated in one PACS

Special Reporter: Maud MERLEY, FR

PS2: PACS Life Cycle Performance and Longevity

Special Reporter: Kazuhiro ENOMOTO, JP

PS3: Sharing of best practices on revised principles enabled by modern protection IEDs
Special Reporter: Mikko HOLMGREN, FI

This document also gives instructions about the submission of prepared contributions for the GDM and a general overview about SC B5 and the colloquium in Osaka.

0. General Information

0.1 Introduction to SC B5

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.
It participates in the CIGRE General Session with all other Study Committees in Paris every even year and organises in general a colloquium limited to B5 in the odd years. For 2025, this colloquium is organised in Osaka (JP) from 30th June to 6th July 2025.
More information on the colloquium, including the technical program and instructions for registration, can be found on the colloquium website (https://cigre2025osaka.jp/).

0.2 Session Papers

Session Papers focus on a number of Subjects – referred to as 'Preferential Subjects' – selected in advance by SC B5 of CIGRE and available in the Call for Papers.
Session Papers are selected through a two-phase review process – synopsis and full Papers.
The list of accepted full papers for the CIGRE B5 colloquium in Osaka is given in the Technical Programme, available on the website.
The papers will be presented in a dedicated poster session on July, 2nd.

0.3 Format of colloquium Group Discussion Meetings

As mentioned above, authors are given the opportunity to present their Paper during a half-day Poster Sessions. Three half-day "Group Discussion Meetings" GDM are organised on July 3rd and 4th. The purpose of these meetings is the discussion of the Session Papers on the basis of the "Special Report" (this document), which incorporate the essence of the Session Papers for each Preferential Subject and raise a number of questions for discussion.
For fruitful discussions, delegates are strongly encouraged to read the Papers before the Session.
The set of Session Papers is made available for downloading to all duly registered delegates before the Session through their private account on the registration's portal.

Three Preferential Subjects are presented in this Special Report:

PS1: IEC 61850 based Interoperability of IEDs of different manufacturers and technologies integrated in one Protection, Automation and Control System (PACS)

- Interoperability experience feedback including interfacing of virtualised functions
- Interoperability of engineering tools, test tools and settings
- Standardisation and unification of PACS including User Profiles, Product Standards and Basic Applications Profiles

Special Reporter PS1: Maud MERLEY (FR)

PS2: PACS Life Cycle Performance and Longevity

- Reliability of PACS and its components - Design and experience feedback
- Redundancy and lifetime expectations in digital Protection Automation and Control Systems

- Flexibility and updating of components during PACS lifetime

Special Reporter PS2: Kazuhiro ENOMOTO (JP)

PS3: Sharing of best practices on revised principles enabled by modern protection IEDs

- Settings and functional principles that could be updated or upgraded thanks to the increased performance and flexibility of moderns IEDs
- Improvement in maintenance policies and maintenance procedures
- Benefits resulting from increased functional integration capabilities

Special Reporter PS3: Mikko HOLMGREN (FI)

0.4 Participating in the 2025 B5 colloquium GDM

All registered delegates are invited to participate in the discussion of the topics in this Special Report at the B5 Group Discussion Meetings on Thursday, July 3rd and Friday, July 4th in the colloquium venue in Osaka.

The reporters have compiled 26 questions, spanning over the three Preferential Subjects. These questions are not specifically aimed at the papers' authors, but are synthesised from common issues and trends identified across the papers. This provides the opportunity for a broader response and participation in the discussion session.

We encourage all registered delegates to share their views or experiences in the form of Prepared Contributions in response to the specific questions in this report.

Procedure for contributions:

1. Contributors should upload their contribution on the registration portal – "Contributions to Group Discussion Meetings" section - using your existing account and own credentials by **June, 15, 2025** 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 SC B5 colloquium should be finalized before uploading contribution(s) online.
   - Contributions uploading will be open between May, 5th and June, 15, 2025.
     No prepared contributions will be accepted after June, 15, 2025.
   - A detailed guideline and templates for the prepared contributions are available on the conference website.

2. Special Reporters will review the prepared contributions. Two files have to be submitted for each prepared contribution:
   1. a power point presentation with maximal 3 slides
   2. a written word file with maximal 1000 words

   Templates and sample pages are available on the colloquium webpage. Any recommendations or changes to the contributions will be provided to the contributors by the Special Reporters directly by mail to the contributors before June, 25, 2025. Final acceptations will be notified before June, 27.

There might be the opportunity for spontaneous contributions during the session, which will only be verbal with no slides. Attendees who have made a spontaneous contribution are encouraged to summarise their contribution as a short, written response for the Proceedings. This text is required to be forwarded within two weeks after the SC colloquium session to the colloquium secretariat (secretariat@cigre2025osaka.jp) to be considered in the proceedings.

0.5 Poster Session

Authors of SC B5 colloquium papers are required to present their papers during the SC B5 Poster Session scheduled for Wednesday July, 2nd afternoon. Posters will be printed out on A0 paper by the colloquium secretariat and displayed in the poster session area. The number of poster pages is limited to one A0 page for each paper.
A PowerPoint template and a document with instructions for preparing the poster is available in the conference website (https://cigre2025osaka.jp/). The authors must upload the posters to ConfTool **at latest May, 30**. The compliance with poster instructions will be verified by the Poster Session chair.
The poster session is an opportunity for you to meet authors and discuss papers.

0.6 Key dates for SC B5 Osaka colloquium

- **Preparation**
  - June, 15, 2025 – Deadline to upload prepared contributions for GDM
  - June, 30, 2025 – Authors of prepared contributions are informed if their contributions will be included in the Discussion session. In this case, an estimated time slot is given.

Colloquium

- Wednesday July, 2nd afternoon: SC B5 Poster Session. All paper authors are invited to present a poster.
- Thursday, July 3rd morning – Opening ceremony and tutorial
- Thursday, July 3rd afternoon and Friday, July 4th - SC B5 Group Discussion Meeting - Prepared contributions and this Special Report will be presented and discussed.

1. PS1: IEC 61850 based Interoperability of IEDs of different manufacturers and technologies integrated in one PACS

Special Reporter: Maud MERLEY (FR)

1.1 Introduction

The preferential subject PS1 of CIGRE B5 Osaka session 2025 is "**IEC 61850 based interoperability of IEDs of different manufacturers and technologies integrated in one PACS**". The call for papers gives more details and refers to interoperability experience feedback (including interfacing of virtualized functions), interoperability of tools (engineering, testing), and standardization and unification of PACS using profiles and product standards.

To understand the reasons why we are dealing with IEC 61850 based interoperability inside PACS, we should first state that **IEC 61850 has become a widely spread standard** for Protection, Automation and Control Systems. This is commonly adopted as starting point for most of the received papers.

> **Paper B5-1121** (BR): "*The entire technological evolution in Protection, Automation, and Control Systems (PACS), driven by the advent of the IEC 61850 standard, has culminated in the current stage where various digital substations are being implemented worldwide.*"
>
> **Paper B5-1129** (JP): "*The application of the international standard IEC 61850 to substation equipment in Japan has moved from the study and demonstration stage to the application stage to actual substations.*"
>
> **Paper B5-1130** (CN): "*The IEC 61850 standard has been applied and developed in China for about 20 years, and the industry generally believes that there are two development stages: digital substation and intelligent substation. [...] there are some differences in the application ideas of IEC 61850, which the author classifies into two types: centralized large system and distributed small system.*"
>
> **Paper B5-1146** (BR): "*Protection, Automation and Control Systems (PACS) conceived with IEC 61850 and Process Bus (PB) communication is a reality.*"

The use of IEC 61850 alone does not guarantee the interoperability between manufacturers or technologies. Nevertheless, the electricity sector, as a key actor of the energy industry transformation, is undergoing major changes since its creation, and facing new challenges. **An IEC 61850 based interoperable solution supports the energy transition** in a reliable, efficient and flexible way. Indeed, interoperable or interchangeable components in the PAC system, as well as shared process and tools are a way to gain more efficiency during development, deployment, commissioning and maintenance of substations. In addition, the capability to interface legacy technologies with advanced ones is a necessity to launch a low impact transition to new PAC systems.

> **Paper B5-1114** (US) : "*[...] there is increasing pressure to improve the efficiency of engineering, commissioning and maintenance, while improving the interoperability between IEDs to avoid increased costs, undesired protection operation and extended outages.*"
>
> **Paper B5-1117** (JP): "*With the introduction of the revenue cap system in Japan, there is a growing demand to reduce the cost of equipment installed in substations. As a result, IEC*

> *61850-compliant Intelligent Electronic Devices (IEDs), which are cost-effective and highly functional with unified communication services, are gaining attention domestically*."
>
> **Paper B5-1121** (BR): "*The exchange of information between Intelligent Electronic Devices (IEDs) from different manufacturers, using standardized communication protocols […] ensuring system interoperability, is one of the greatest contributions - if not the greatest - of the IEC 61850 standard to the power system."*
>
> **Paper B5-1142** (BR): "*Standardized, vendor-agnostic solutions are critical in the utility sector to ensure interoperability and streamlined network operations*. […] *The vendor-agnostic nature of the solution ensures that utilities are not locked into a single vendor, which increases flexibility and reduces long-term costs.*"

However, this quest for greater efficiency has to be done preserving the reliability, predictability, security and performance of protections and automations of the electric power system. To achieve this, **some challenges regarding IEC 61850 interoperable PACS should be addressed**. This will constitute the core part of this PS1 special report, where the 17 papers from Brazil (7), Japan (3), China (2), France (1), Germany (1), Spain (1), USA (1) and CIGRE WG (1) are grouped by interoperability issues:

- Functional interoperability (4 papers)
- Process bus interoperability (3 papers)
- Engineering and testing tools (5 papers)
- Information Technology & communication network (2 papers)
- Operation and maintenance (3 paper)

At the end, based on feedback and recommendations of the received papers, the PS1 special report will highlight various approaches to go further with IEC 61850 based interoperable PACS.

1.2 Functional interoperability challenges

The use of IEC 61850 standard gives a first level of interoperability, with a set of common rules to model the information, define the communication, and perform the configuration of the system. Nevertheless, **the application of the standard is not always sufficient** to ensure the required behavior of PAC applications.

> **Paper B5-1110** (BR): "*One of the main topics […] is related to the devices' interoperability once there is no assurance that all devices will perform their functions perfectly since different vendors can have different interpretations of IEC 61850. From the facilities' point of view, the risk of assembling a set of devices from different vendors, resulting in a lack of functionalities or problems in PACS operation, is too high to be acceptable.*"
>
> **Paper B5-1130** (CN): "[…] *due to factors such as physical distance, information gaps, and interoperability testing grouping, it is impossible to cover all equipment manufacturers in the industry, which results in some interoperability problems not being able to be fully exposed.*"

To foster maturity and confidence of the market for the performance of applications in an IEC 61850 interoperable system, **Proof of Concept** systems are developed to demonstrate and validate these implementations. **Paper B5-1110** (BR) presents a major technological update on the Itaipu powerplant, considering the implementation of IEC 61850 devices. Based on numerous guidelines from literature on fully digital PACS, a testbed has been set up in 2022 to verify the performance and interoperability of the system. Testing has been performed with the Hardware In the Loop (HIL) simulator and real IEDs, under network disturbances, to analyze the impact of IED behavior. Some specific issues have been identified on missing network information management, vendor's mandatory information, SCL files reading, SCL versions management and transformer protection specific requirements.

On the other hand, some real applications of **in-operation IEC 61850 interoperable PACS** are mentioned in the PS1 papers, which confirm that these multi-suppliers or multi-technologies implementations are achievable with adequate specifications.

- **Paper B5-1113** (FR) gives some feedback on Rte full-digital and multi-suppliers PACS, with 2 substations alive since 2023. It gives an overview of the specification process which goes beyond data model and communication interoperability (covered by IEC 61850), with profiles, application-level interoperability and "non-operational" requirements about configuration and settings, administration, cybersecurity and supervision. It illustrates with selected examples the specification requested to fulfill some interoperability issues, such as the management of temporally disabled applications, phasor calculation with signals of low amplitude, expected behavior in case of time jump, or functional interoperability between applications.
- **Paper B5-1117** (JP) explains how a gateway device developed with IEC 61850 features could be used to interface a legacy SCADA system with IEC 61850 IEDs in substations. It underlines, with a real project, that moving all the eco-system including SCADA to the IEC 61850 is not necessary, without restraining the deployment of other IEC 61850 applications.
- **Paper B5-1129** (JP) discusses the usage of an IEC 61850 fault recorder in a multi-vendor solution commissioned in 2024, that can be compliant both with analog and digital substations. The specifications of the application (including monitoring and cybersecurity) are described, as such as testing performed on functional interoperability and communication (GOOSE timestamping for instance),

The use of **standardized or user profiles** is also noted as a means of achieving functional interoperability.

Question 1.01: A specific set of requirements (functional, communication, configuration, cybersecurity…) or standardized / user profiles seems to be necessary in addition to the IEC 61850 standard to reach functional interoperability. Which tools, methods and best practices could be used to manage these requirements and profiles and their evolution in an industrial way?

1.3 Process Bus interoperability challenges

Several factors, such as cost optimization and safety operations, are **pushing towards the digitalization of the process** interfaces, with the deployment of Process Bus in substations. This transition from the wired and analog domain to digital LAN raises several questions regarding interoperability of the PACS, in addition to the points identified in the previous chapter.

> **Paper B5-1110** (BR): "*Nowadays, a significant share of the existing worldwide electric facilities is facing challenges regarding the transition of the technology from analog-based systems to a digitalized architecture firmly based on Ethernet networks.*"

First, the digitalization of process bus comes with an **increased criticality regarding time synchronisation**, requiring the use of PTP protocol.

> **Paper B5-1121** (BR): "[…] *all information exchanges between IEDs from different manufacturers, using the communication protocols defined by IEC 61850, demonstrate the importance of interoperability. Moreover, the Process Bus stands out due to the relevance and criticality of the data transmitted through its network, with particular emphasis on time synchronization, achieved through Precision Time Protocol (PTP)*"

Once different manufacturers are involved in the PAC system, the reference to PTP is not sufficient to determine the behaviour of the applications, especially during time synchronisation disturbances. **Specific requirements on time synchronization are crucial** to coordinate the protections actions.

> **Paper B5-1113** (FR): "*For the protection functions, the most important is to avoid an unwanted trip in case of a jump of the synchronizing clock*."

This assumption is illustrated by **Paper B5-1121** (BR), that describes interoperability tests performed on time synchronization behavior impacting the process bus. The test set used specialized tools to monitor and interpret the merging unit and protection IED behavior during a time synchronization disturbance (time jump in PTP signals). Some issues that can affect the safety and reliability of the PACS have been identified for further analysis.

Besides, while there is no interoperability issue between protection IEDs and their wired process interface in conventional PACS, **the use of Process Bus increases the number of interfaces to manage** in a multi-vendor system. Interoperability between protection and digital process signals should rely on international standards, as IEC 61850, and IEC 61869. However, the widespread **use of profiles** based on the standard (for instance 92-LE for Sampled Values) **is sometimes associated to restrictions** that limit the compatibility between manufacturers.

> **Paper B5-1128** (JP): "*To maximize the effectiveness of the process bus in substations while ensuring interoperability, adherence to IEC 61850 and IEC 61869 is paramount. However, variations in the interpretation and application of these standards by different vendors can result in interoperability issues*."
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> **Paper B5-1128** (JP): "*In the PAC function tests, specifically during circuit-breaker control assessments, several combinations of IED/MU pairs initially failed to operate as anticipated. This outcome highlights the significant shortcomings of existing standards, especially regarding the definition and execution of control sequences when extending control to the process level via GOOSE Messages*."

Some of the papers grouped in chapter 0 address specific issues related to process bus interoperability (papers **B5-1110**, **B5-1113**) among more comprehensive project overview, while others (papers **B5-1128, B5-1138)** are dedicated to interoperability.

Paper B5-1128 (JP) evaluates the interoperability of protection IEDs and merging units in a multi-vendor environment in Japanese substations. It starts from the functional specifications based on IEC 61850 and IEC 61869 standards, with the identification of gaps regarding Japan-specific requirements. After that, the results of interoperability testing with several IEDs and merging unit are displayed, with selected encountered issues and their resolutions.

Paper B5-1138 (CIGRE) is related to an active CIGRE B5 Working Group dealing since 2020 with busbar protection using IEC 61850 process bus merging units. It covers an interoperability test performed as Proof of Concept with several busbar protection IED, and merging unit vendors, covering the configuration, the performance and time synchronization of the application. The feasibility of busbar protection based on Process Bus has been demonstrated, even if some limitations have been identified, related to the use of different Sampled Values profiles, or IEC 61850 editions for instance.

It could eventually be considered that substation level applications may have to **interface both legacy technologies and IEC 61850 process bus**. In this case, it requires for the subscribing application to be designed to manage the different inputs.

> **Paper B5-1129** (JP): "[…] *for existing analog substations, there may be a situation that metal cable connections and IEC 61850 connections are mixed because some protection and control devices are not compliant with IEC 61850. For this reason, the IEC 61850 compliant multi-functional fault recorder designed this time is designed to allow both physical and transmission binary inputs to be used together*."

To conclude, as for the functional interoperability, there is **no blocking technical issue** identified to apply interoperable Process Bus in PACS. The identified issues can be solved by appropriate specification. Beyond the strict replacement of wiring by merging units, the use of Process Bus in an interoperable way may **open new opportunities in design and conception of applications**.

> **Paper B5-1138** (CIGRE): "*busbar protection in digital substations is more than just bus protection with merging unit, differential bus bar relay and sampled values. It is a new and complete solution that eliminates restrictions compared to the conventional bus protection solution distributed from the connections of the bays in the field to the central unit, and can simplify testing, increase the reliability and stability of the protection*."

Question 1.02: The deployment of interoperable IEC 61850 Process Bus offers opportunities beyond the strict replacement of wiring by merging units.
What are the advantages and drawbacks regarding the functionalities of Process Bus IEDs, for a basic implementation (digital interface only without IEC 61850 services) up to a complete IEC 61850 IED hosting the process interface and protection applications?

Question 1.03: Which measures could be taken to ensure the reliability, security and performance of the PACS with digital process bus, including non-nominal network and synchronization states? What is the impact of these measures on the design and cost of the PACS ?

1.4 Interoperability challenges of engineering and testing tools

One of the advantages of IEC 61850 is related to the common understanding of the SCL language in every stage of the PACS lifecycle. This offers the opportunity to develop nonproprietary tools to **specify, configure, test and monitor the digital PACS in an interoperable way**.

The engineering process is well documented in literature with the promotion of **top-down engineering** to configure the interoperable system in accordance with IEC 61850-6.

> **Paper B5-1146** (BR): *"the utility has developed a PACS specification based on the data model described by the IEC 61850 standard to take advantage of the top-down engineering process. […] The PACS development starting from the utility specification written on machine language allows an automatized device configuration process, reducing the time spent and human errors in the configuration stage*."

Paper B5-1114 (USA) presents a **theoretical analysis** on recommended methods to achieve the full gain of optimized engineering processes. It clearly explains the interoperability issues related to the presence of optional elements in the IEC 61850 standard, and how a top-down engineering combined with a hierarchical object-oriented approach could resolve this. It gives the theoretical description of a standardization process based on standard bay types, and standard substation schemes from template to instantiation.

In other papers, the engineering methods are **analyzed against the real-word market** and applied as Proof of Concept, real projects or industrial deployment with real IEDs and tools. This allows an evaluation of the maturity of the market and stakeholders regarding the target engineering process and helps to identify the gaps to fill to take full advantage of this approach.

- **Paper B5-1100** (SP) relies on top-down engineering process to introduces a novel engineering and validation methodology, based on the IEC 61850 data model, SCL files and IEC 61850 tool roles (ICT, SCT). The method is then applied to some commercial tools to illustrate the concept, whereas the methodology is not limited to specific software and hardware solutions.
- **Paper B5-1146** (BR) shares the experience feedback of the top-down engineering process applied to the 230/138 kV Itajai substation. It gives significant inputs on real-life application of the implemented IEC 61850 configuration process and highlights the experienced difficulties. For instance, the current state of the art for devices and tools limits the expected gains on reduction of human errors and deployment times. Finally, the paper underlines that an active engagement is requested from end-users to support top-down engineering.
- **Paper B5-1149** (DE) first details the IEC 61850 features involved in the interoperation capability of engineering and testing tools (SCL, later binding, multiple edition handling), and the opportunities to maintain and improve them, such as virtualization for virtual testing. The paper provides insights not only on the theoretical approach, but also on the market position and challenges regarding IEC 61850 engineering and testing tools. It illustrates the advancements that can be reached with a collaboration of tools suppliers, manufacturers and end-users.

These papers highlight significant improvements in the engineering and testing process strongly related with the **development of tools,** that need to rely on the standard and not on proprietary solutions.

> **Paper B5-1149** (DE): *"Engineering tools on the market have significantly progressed, supporting not only bottom-up, but also top-down engineering workflows. Research and pilot projects have further driven the advancement of interoperability, leading to recent standard extensions such as IEC 61850-90-30.*

> *Test tools to simulate SCL files allow early detection and troubleshooting of communication issues, reducing project execution time."*

While there is a wide consensus on the benefits of top-down engineering, **work remains to be done in this area** before being able to apply it to real-life applications in a seamless and standard way.

> **Paper B5-1146** (BR): "*The PACS top-down engineering process demands from the final user an active engagement from the specification until the test stages*. […] *The tools currently available to perform the top-down engineering process, despite that they make it (hardly) possible to use top-down, need to improve some aspects to allow a fully automated process. […] Professionals involved in specification and devices configuration must be trained not only in the IEC 61850 standard but also in how to perform the top-down process, as this process is not yet a common place on PACS deployment.*"

At the end, as a major part of the papers dealing with configuration focus on top-down engineering, **paper B5-1157** (BR) comes with a new approach based on generative **Artificial Intelligence (AI) to simplify the IEC 61850 configuration process**. The main purpose here is more related to the reduction of the complexity for users rather than the interoperability itself. Several use cases have been evaluated, such as the capability to generate a configuration and validate it with AI mechanism, or the verification of IED capability compliance with a specification. While results of this study are encouraging, further work is still needed on this topic.

> **Paper B5-1157** (BR): "*the AI engine was able to provide accurate, context-aware answers, effectively summarizing key concepts and offering real-world application examples. […] However […] its ability to generate valid configuration files for IEC61850-compliant Intelligent Electronic Devices (IEDs) remains limited*. […] *With further refinement and domain-specific adaptations, Generative AI could become a crucial component in bridging the knowledge gap and streamlining configuration processes, paving the way for more reliable and intelligent automation solutions in power systems*."

Question 1.04: What are the enablers and obstacles for the market deployment of interoperable engineering, testing, and monitoring tools?

1.5 Information Technology and network interoperability challenges

PAC systems based on IEC 61850 rely on **standard protocols for communication networks** that inherently ensure the interoperability of the transmissions and communications. Thus, the challenges regarding interoperability in this domain are more related to the **capability to use interoperable tools to configure and monitor the IT and network components** of the system.

> **Paper B5-1142** (BR): "*Modern utility networks are undergoing a rapid transformation, driven by digitalization and the increasing need for scalable, efficient, and resilient infrastructure. These advancements, while beneficial, have introduced new layers of complexity that challenge traditional networking approaches. Protection, Automation, and Control Systems (PACS) play a critical role in ensuring the stability and reliability of these networks, yet their engineers are often constrained by outdated practices"*

Paper B5-1142 (BR) explores a solution combining IEC 61850 and IBN (Intent-Based Networking), a software that use AI, analytics and orchestration to improve network administration by the definition of high-level operational goals. As IEC 61850 and IBN are both already used separately, the potential of the approach lays on their combination, by translating information from the SCD file to IBN policies. This theoretical approach can offer advanced network capabilities for network management, in an interoperable and vendor agnostic way.

Another way to reach tool interoperability for network switches and other IT components (servers, clocks…) could be to **consider them as IEC 61850 IEDs** of the system. This makes sense considering the increasing role of network and IT components in PACS.

> **Paper B5-1143** (BR): "*As Ethernet-based communication continues to dominate substation networks, network switches play an increasingly critical role in ensuring seamless data flow between IEDs and supervisory systems*."

Paper B5-1143 (BR) proposes a practical application of integration of network switches as IEC 61850 components of the system. It first defines an IEC 61850 data model, based on part 90-4, to represent the network switches, and then checks its compliance with devices from different manufacturers. At the end, improvements to the switch data model are proposed to increase the potential of IEC 61850 implementation in networks switches. Once achieved, these applications could be a real alternative to a typical network monitoring protocol, such as SNMP.

> **Paper B5-1143** (BR): "*[…] the true value of IEC 61850 and its data model is to offer a standardized data model across different vendors, instead of relying on private MIBs and SNMP currently does in such cases, in addition to becoming fully integrated with the same structure that all PACS devices present in the network are already based on*."

Although it is not a dedicated thematic of PS1 papers, some contributions raise the question of **cybersecurity criticity** in IEC 61850 interoperable PACS, especially with the shift to full integrated IEC 61850 including IT components.

> **Paper B5-1129** (JP): "*Because substation equipment that complies with IEC 61850 is connected to control IP networks, such as station buses and process buses, cyber security is becoming more important than ever before.*"

Question 1.05: Is the integration of IT components (switches, servers, clocks…) as IEC 61850 IEDs an opportunity, a necessity or an obstacle for the deployment of interoperable PACS? Does it bring specific considerations regarding the IT / OT convergence or cybersecurity management?

Question 1.06: What is the impact of virtualization of PAC applications on the interoperability of IEC 61850 systems, for instance by considering the compatibility constraints between virtual IEDs and hardware platform hosting them?

1.6 Operation and maintenance interoperability challenges

Beyond technical aspects related to interoperability described above, some papers identify a link between interoperability and operation and maintenance of IEC 61850 PACS. These can be related to the use of different manufacturers for IEDs and tools, or to the shift from legacy technologies to IEC 61850. The key idea here is that it is not only

required to set up and commission an IEC 61850 interoperable PACS, but also to be **able to operate and maintain the system during the whole life cycle, with non-specialist IEC 61850 end-users**.
First, the physical connections made by wiring are replaced with the Process Bus by digital signals (GOOSE and Sampled Values), which is a **major change in practices** for operation and maintenance of PACS.

> **Paper B5-1159** (BR): "*In conventional PACS there is significant concern regarding the development of a consistent electrical schematic and ensuring that the internal wiring of panels, as well as the cables connecting various panels and equipment, have consistent identification and robust designs. This approach aims to assist commissioning, operation, and maintenance teams in quickly identifying connections during troubleshooting scenarios*."

Methodologies need to be derived to **maintain the same level of information for end users** regarding the data flows in the substation, and the interface connection between digital applications and wired ones.

> **Paper B5-1120** (CN): *"[...] the absence of digital modeling for the design of secondary circuits connected by cables has posed obstacles to the efficient construction and maintenance throughout the entire life cycle of substations. [...] with the advancement of the operation and maintenance technology for substation protection based on secondary equipment information, there is an urgent need to realize the automatic correlation between primary and secondary equipment models."*

Paper B5-1159 (BR) proposes a standard configuration of GOOSE and Sampled Values message to reproduce the consistency of electrical panel as much as possible and lower the impact on end-users' practices regarding conventional PACS. The method is based on IEC 61850 objects (VLAN ID, destination MAC Address, application ID, GOOSE and SV ID) with pre-determined values. Even if it seems difficult to standardize the implementation presented in the paper, the method itself can be adapted by users and applied in their environment.
Paper B5-1120 (CN) proposes a method based on non-standard XML files to model the digital secondary circuits (substation, cubicles, device, component, pin for instance), and the association between primary and secondary equipment. With this digital circuit model, and specific tools, it becomes possible to run automatic generation and online monitoring of wired information, and to perform some automatic circuit testing.

Another aspect lays on the **system management of the PACS**, with local and remote operation to deploy new configurations or firmware, or cybersecurity patches for instance. The variability of manufacturers and technologies inside the interoperable system should not be a restriction to **perform efficient upgrades**, and users may require using **vendor agnostic tools and process**.

> **Paper B5-1130** (CN): "*A review of the relevant literature shows that there is limited research on the remote operation and maintenance of secondary equipment itself. The author proposes a remote operation and maintenance upgrade method with the goal of reducing power outage losses and easing the workload of operation and maintenance."*

Paper B5-1130 (CN) introduces a method to perform remote operation and maintenance upgrade with minimum impact on the power system. The approach defines an "external part" with full interoperability with IEC 61850 services and private standard extensions, and the "internal part" acting as a black-box process handled by IEDs. A real application in a 110kV substation has been realized, demonstrating the efficiency of the update following this process.

At last, IEC 61850 eco-system requires **specific skills** that may not be usually trained in operational teams. The research for interoperability in substations will not by default decrease the complexity of PAC system.

> **Paper B5-1159** (BR): "*Solutions based on IEC-61850 with process bus, GOOSE, and SVs represent a paradigm shift that involves various aspects, such as adapting conventional project standards to digital projects and ensuring professionals working with PACS have a better understanding of communication networks*."
>
> **Paper B5-1157** (BR): "*The breadth and ambition of IEC61850 bring significant advantages but also introduce a set of challenges that span technical, operational, and knowledge-related domains. The wide scope of IEC61850, covering both communication and system modelling, inherently adds layers of complexity*."

Thus, the development of interoperable IEC 61850 PACS should be used as an **opportunity to support end-users**, and to ease later operation and maintenance of the system.

Question 1.07: What are the key aspects to successfully perform the industrial deployment of interoperable IEC 61850 PACS, including operation, maintenance, and asset management of PACS combining both legacy and IEC 61850 technologies ?

1.7 Addressing the challenges

The contributions of PS1 not only detail the challenges faced to achieve interoperable PACS, but also come with recommendations and best practices.
On the one hand, it has been recognized that the **IEC 61850 standard** should remain the basis for PACS interoperability. It could happen that some issues may be solved with already existing features of the standard, once adopted by the market.

> **Paper B5-1100** (SP): "*Although widely recognized for its communication protocols, many of the standard's concepts and features remain underutilized.*"

Otherwise, the feedback and requirements from users and industry could be submitted to standardization bodies, to **provide guidelines, profiles or even improve the standards** to fulfil the gaps. The power of the PAC community conducting research worldwide supports the process of evolutions of the IEC 61850 standard.

> **Paper B5-1128** (JP): "*Where applicable, specific outcomes will be evaluated for potential integration into international standards*."
> **Paper B5-1149** (DE): "*This iterative process of standard evolution, field experience, and market collaboration has been instrumental in enhancing the overall interoperability and practical deployment of IEC 61850-based protection, automation, and control systems. As the power industry continues to embrace this global standard, the PACS community remains committed to addressing emerging challenges and expanding the capabilities of this transformative technology for an efficient engineering and reliable operation even in the face of increasing device heterogeneity*."
>
> **Paper B5-1149** (DE): "*Over the past two decades and countless system deployments worldwide, the IEC 61850 community has gained valuable insights into the practical challenges of IEC 61850-based interoperability. Via a continuous improvement process,*

> *identified technical issues have been systematically integrated into clarifications and extensions of the IEC 61850 standard.*"
>
> **Paper B5-1113** (FR): "*IEC TC 38 plans to publish an amendment to [IEC 61869-9:2016 "Instrument transformers – Part 9: Digital interface for instrument transformers"] with some evolutions of the requirements regarding time jumps*"

As an alternative, the use of **specific requirements** remains an option. It is generally useful for temporary situation when the standard is not still aligned with the needs, or for specific local market.

> **Paper B5-1113** (FR): "*specific requirements, in addition to the implementation of the IEC 61850 interface, are necessary to obtain a full operational interoperability. These requirements need to be covered by specific tests in the integration and qualification phase of the PACS. […] Efforts to elaborate function specific standards covering this type of interoperability requirements should be undertaken*."
> **Paper B5-1128** (JP): *"these guidelines [IEC 61850-7-500] may be insufficient to address the requirements of transmission system operators (TSOs) in Japan. […]Consequently, the development of tailored functional specifications and interoperability tests is essential for domestic applications in Japan."*

Finally, one of the main challenges is not the design of the interoperable system, but rather the **user's ability to understand how the PACS works, and to be able to operate and maintain it effectively**. For this reason, the development of tools and procedures to automate and support the actions to be carried out throughout the life of the system is essential. Logically, we find a large number of recommendations on this subject in the PS1 papers.

> **Paper B5-1120** (CN): "*The proposed automatic testing method, which is founded on digital circuit modeling, can achieve the automatic configuration of test cases at the device level, cubicle level, and substation level. […] The automatic association of primary and secondary equipment models in the substation is accomplished based on the digital circuit design.*"
>
> **Paper B5-1146** (BR): "*The tools currently available to perform the top-down engineering process, despite that they make it (hardly) possible to use top-down, need to improve some aspects to allow a fully automated process."*
>
> **Paper B5-1149** (DE): "*IEC 61850 tools have integrated the latest functionalities and lessons learned*."
>
> **Paper B5-1157** (BR): "[…] *generative AI is a valuable tool for assisting engineers and technicians, with and without being specialists in IEC 61850, by acting as an intelligent assistant for P&C with focus on IEC 61850 matters, being able to understand the standard and its practical applications. […] Generative AI could become a crucial component in bridging the knowledge gap and streamlining configuration processes, paving the way for more reliable and intelligent automation solutions in power systems*."

The IEC 61850 has for sure not reached its limits, and the interoperable PACS is probably only a step towards the substations of the electrical power system of the future.

> **Paper B5-1117** (JP): "*In the future, we aim to further reduce device costs and improve adaptability to environmental changes through the use of general-purpose devices. We will explore strategies for the full-scale implementation of these devices. […]* »

> **Paper B5-1143** (BR): *"[…] future developments such as Time Sensitive Networking (TSN), cybersecurity enhancements, and Intent-Based Networking (IBN) integration will shape the next evolution of IEC 61850-based PACS. Traditional network management methods […], and upcoming new standards […], remain relevant for general network operations, but IEC 61850 is indispensable for ensuring PACS-specific communication integrity and performance. The adoption of these enhancements will drive the next generation of smart, automated, and resilient PACS networks, reinforcing the critical role of IEC 61850 in modern power systems*."

Question 1.08: What are the priority actions and work items to encourage and facilitate the deployment of interoperable PACS? What are the obstacles?

Question 1.09: What could be the next PACS technologies for future substations, beyond IEC 61850 based interoperable systems?

2. PS2: PACS Life Cycle Performance and Longevity

Special Reporter: Kazuhiro ENOMOTO (JP)

2.1 Introduction

The preferential subject PS2 of CIGRE SC B5 2025 Osaka Colloquium is entitled “PACS Life Cycle Performance and Longevity”, which is the same preferential subject as the 2008 Paris session. There has been continuous progress in digital processing capacities and the use of off-the-shelf components has increased. On the other hand, rapid technological advancements are causing issues such as the shortened lifespan of products and standards. SC B5 decided to focus on the same topic again in the Osaka Colloquium. Instead of the 17 papers written for the 2008 session, this special report covers 9 papers from four different countries. These papers can be broadly classified into five groups:

1. Lifespan of digital components in PACS (3 papers)
2. Adapting to upgrades in communication standards (2 papers)
3. Updates of existing substations to digital substation (1 paper)
4. Improving the efficiency and reliability of replacement work (2 papers)
5. Flexibility of PACS to the changes in power system characteristic (2 papers)

2.2 Lifespan of digital components in PAC

It took 60 years from the invention of the mechanical relay to the arrival of the digital relay. The performance of semiconductors continued to improve dramatically from the second half of the 1970s, and combined with the intensification of competition between companies, semiconductor devices such as CPUs were updated in a short period of time. As a result, operation duration of the devices is shorter, and relay devices are also becoming shorter-lived due to digitalization.

Paper B5-1127 (JP) examines the evolution of protection relays and the associated challenges. From the 1980s, relays transitioned from analog to digital with improved performance and reliability, leading to the introduction of second-generation relays in 1995. Many models were discontinued due to component production issues. The Institute of Electrical Engineers of Japan investigated technological trends and maintenance parts procurement, emphasizing retrofit updates. It also addresses the impacts of an aging population on technology succession, proposing effective maintenance measures to ensure sustainable operations.

Paper B5-1131 (JP) examines Japan's power transmission system, focusing on protection relays. It highlights challenges from aging relays and shortened component lifespans, proposing a unit-replacement method to reuse durable parts like cubicles and wiring. This approach enhances safety, reduces outages, shortens replacement time, cuts costs, and supports sustainable maintenance, widely applied in EHV systems for busbar and transmission line relays.

Paper B5-1155 (BR) provides an overview of Protection Automation and Control Systems (PACS) for drilling vessels (DV) with dynamic positioning systems, crucial for oil exploration. It emphasizes busbar strategies for maximizing operational availability, minimizing faults, and avoiding essential load disconnections. The study discusses typical DV protection setups, intelligent automatism logic, and IEC 61850 protocols while proposing lifecycle guidelines for managing Intelligent Electronic Devices (IEDs). It highlights challenges, concerns, and best practices for designing reliable systems with optimal safety and performance.

Considering all of these approaches, we can formulate the following questions:

Question 2.01 - How is the shortening of the lifespan of components such as microprocessors affecting the maintenance and renewal plan of PACS? How are stakeholders responding to this?

Question 2.02 - It is believed that the product life cycle for both hardware and software used in PACS will become shorter. How should the industry respond to this in the future?

2.3 Adapting to upgrades in communication standards

In the 1980s, high communication costs limited usage for utilities to leased lines, which supported reliable protective relay functions. The invention of optical fiber cables enabled high-speed, long-distance communication, dramatically lowering costs and fostering the rapid expansion of the Business to Consumer market. Packet communication, due to its scalability and low cost, became mainstream. Protective relay communication must adapt to packet communication for cost and supply continuity; however, widespread replacement is impractical, making adaptation to existing communication standards a key challenge.

Paper B5-1144 (BE) focuses on the challenges utilities face as they transition from time-division multiplexing (TDM)-based networks to Multiprotocol Label Switching–Transport Profile (MPLS-TP) in response to the ongoing digital transformation in the power industry. As PDH and SDH networks become outdated, ensuring the durability of telecommunications and enhancing the reliability of communication among protection relays is critical. The adoption of IEC 61850 standards further emphasizes optimizing differential protection systems and designing a future-ready wide-area network.

Paper B5-1165 (CA) explores the challenges of 87L line differential protection systems to ensure power grid safety and reliability while demonstrating how IP/MPLS networks enable highly reliable communications. It addresses communication requirements such as latency, jitter, symmetry, and instant recovery, alongside discussions on specific mechanisms for high reliability. Furthermore, it highlights achieving interoperability with existing protection systems, providing industry validation results to confirm the capability of modern IP/MPLS networks for grid resiliency and availability.

Considering all of these approaches, we can formulate the following questions:

Question 2.03 - In the field of PACS, how do we ensure compatibility between existing systems and devices in order to keep up with the changing communication standards?

Question 2.04 - Are there any concerns or issues about use of standard communication protocols for PACS or for inter-substation communication, or any problems that have already occurred?

2.4 Updates of existing substations to digital substation

Primary equipment, such as circuit breakers and power transformers, have a much longer lifespan than monitoring and control systems, and it is difficult to promote the digitization of substations if utilities have to wait for the replacement of primary equipment. On the other hand, the acceleration of the aging of society and the declining birthrate is making the efficiency of operation and maintenance major management issue.

Paper B5-1139 (JP) discusses the digitalization progress of distribution substations in Japan's Kansai region since the 1990s, focusing on implementing IEC 61850-compatible IEDs for seamless and cost-effective substation modernization. It highlights IED enhancements supporting multi-vendor interoperability and transitioning from analog signals to digital communications. With compact, efficient designs and robust standards, IEDs replace traditional Interface-Units to enable full digitalization without replacing main equipment. These advancements aim to optimize substation operations while extending the lifecycle of existing analog and digital systems for resilient power distribution.

Considering all of these approaches, we can formulate the following question:

Question 2.05 - What kind of measures are being taken to migrate to digital substations while the lifespan of the primary equipment such as switchgear in existing substations is substantially higher?

2.5 Improving the efficiency and reliability of replacement work

With the declining birthrate and aging population, and the resulting reduction in the number of workers, reducing the amount of work and construction is a major issue that power companies in many countries must resolve. In this context, upgrading PACS usually requires a power outage because it involves changing the secondary connections of the instrument transformer circuits. Because de-energising primary feeders and busbars often leads to operational constraints and reduces the overall reliability of the power system, there are restrictions on when the work can be carried out. There is also the hassle of coordinating with customers about when the power should be turned off, so methods for carrying out the work on the PACS without de-energising priary equipment are being investigated.

Paper B5-1125 (JP) outlines a method to renew aging data recording equipment, originally introduced in the 1990s, without shutting off primary circuits. By converting existing panels into relay panels, the proposed approach simplifies the renewal process, reduces work periods, and ensures operational continuity. The equipment’s critical functionality, including fault waveform recording and voltage drop detection, is preserved while addressing aging issues effectively for power system reliability.

Paper B5-1131 (JP) examines Japan's power transmission system, focusing on protection relays. It highlights challenges from aging relays and shortened component lifespans, proposing a unit-replacement method to reuse durable parts like cubicles and wiring. This approach enhances safety, reduces outages, shortens replacement time, cuts costs, and supports sustainable maintenance, widely applied in EHV systems for busbar and transmission line relays.

Considering all of these approaches, we can formulate the following questions:

Question 2.06 - In order to improve the reliability of the power system and reduce the burden on workers, it is necessary to shorten the on-site work time. What kind of measures are being taken to shorten the PACS related on-site work time?

Question 2.07 - What is done to reduce the risks or improve the safety of on-site work related to PACS?

2.6 Flexibility of PACS to the changes in power system characteristic

The characteristics of the grid are changing due to the interconnection of distributed power sources, including renewable energy, and inverter power sources. For this reason, there is a growing need to upgrade the functions of PACS even during the period before a complete replacement.

Paper B5-1126 (JP) outlines the 50-year evolution of the Block System Stabilizer (BSS) in the Kansai Grid, emphasizing its role in maintaining grid stability during large power plant outages. Initially developed in 1971 after a major blackout, BSS has advanced through four generations, adapting to grid structural changes and introducing innovative features. The latest system, operational since 2011, consolidates previous systems, enhances control speed, integrates lifecycle-aware devices, and ensures resilient, efficient grid operations using high-speed communication.

Paper B5-1111 (JP) describes the development of the Integrated System Emergency Preventive Controller (ISPC) for Japan's 500 kV networks, addressing challenges from renewable energy expansion and system faults like route interruptions. Set to operate in 2027, ISPC stabilizes the grid through high-speed controls such as generator shedding, capacitor switching, and load tripping. Designed for future network growth, ISPC ensures long-term reliability, mitigating instability phenomena, and supporting the increased power flow between the Tohoku and Tokyo regions

Considering all of these approaches, we can formulate the following questions:

Question 2.08 - Are there any examples of existing protection systems being modified to address the various issues that have arisen as a result of the increased introduction of distributed power sources into the power grid?

Question 2.09 - What are the technical issues involved in adding new functions and technologies to existing PACS?

3. PS3: Sharing of best practices on revised principles enabled by modern protection IEDs

Special Reporter: Mikko HOLMGREN (FI)

3.1 Introduction

The preferential subject PS3 of CIGRE B5 Osaka colloquium is entitled "Sharing of best practices on revised principles enabled by modern protection IEDs". Submitted papers came from five different continents and the most papers from a single country came from the hosting country Japan (9 papers). This section of the special report compiles 22 papers divided into four subtopics:

- New protection concepts and functions (8 papers)
- Protection functionalities in process bus and Low Power Instrument Transformer (LPIT) environments (4 papers)
- Actions and schemes to secure the operation of the network (4 papers)
- Revising protection and maintenance related principles (6 papers)

This report aims to provide a comprehensive overview of the latest developments and best practices in protection and maintenance principles enabled by modern protection IEDs reported in the submitted papers.

3.2 New protection concepts and functions

The following summaries of the eight papers provide an overview of recent advancements in electrical protection schemes and fault detection methods across various applications and systems. These papers explore innovative techniques and propose solutions to enhance the reliability, accuracy, and efficiency of fault detection and protection mechanisms in power systems. From addressing challenges in medium voltage microgrids and low resistance grounding systems to improving fault location accuracy in high voltage transmission lines and substations, these studies offer valuable contributions to the field of electrical engineering. The summaries highlight the key findings, methodologies, and implications of each paper, showcasing the diverse approaches and technologies being developed to ensure robust and dependable power system protection. Differential protection is a recurring theme in several papers, showcasing its important role in enhancing the reliability and security of power systems.

Paper B5-1107 (JP) presents a short-circuit detection scheme for inverter-based resources (IBR) in medium voltage microgrids. The scheme addresses the challenge of detecting short circuits in microgrids with lower power capacity, where traditional methods are costly. It utilizes an inter-harmonic current injection method to detect short circuits by monitoring impedance changes. The proposed method is advantageous as it does not require increasing the inverter power supply capacity. Simulation results demonstrate the scheme's effectiveness in detecting short circuits under various conditions, ensuring reliable protection and maintenance of regional microgrids.

Paper B5-1112 (CN) proposes a method for single phase-to-ground fault protection in low resistance grounded systems. It identifies faults by analysing the active component of the zero-sequence current. The study finds that the active component of the zero-sequence current in faulty lines is significantly higher than in sound lines. By setting a threshold for the active component coefficient, the method can reliably detect faults with resistance up to 1500Ω. Simulation results validate the method's accuracy and reliability, ensuring effective discrimination between faulty and sound lines.

Paper B5-1115 (US) discusses the implementation of cross-differential protection in IEC 61850 based digital substations for high voltage double circuit transmission lines. The paper explains the principle of cross-differential protection, which compares currents from both circuits to detect internal faults and clear them without delay, enhancing system reliability. It also covers the integration of this protection in digital substations using sampled values and GOOSE messages and highlights the benefits of faster fault clearing without relying on communication channels. The paper concludes with the advantages of this method in improving grid stability and supporting distributed energy resources.

Paper B5-1145 (DE) presents a new method for double-ended travelling wave fault location using unsynchronized data. The method addresses the challenges of time synchronization errors in traditional fault location techniques. It evaluates the accuracy and reliability of the new method compared to single-ended and synchronized double-ended methods. The paper highlights the advantages of the new approach, including its independence from propagation speed settings and its ability to verify results even with synchronization issues. Real-world recordings are used to demonstrate the method's effectiveness in accurately locating faults on transmission lines.

Paper B5-1147 (DE) presents a novel protection scheme for power transformers against turn-to-turn faults (TTF) using incremental negative-sequence differential current between the pre-fault and fault state. The scheme aims to detect TTFs of transformer failures, by enhancing existing negative-sequence differential current protection by introducing advanced stabilization criteria and vectorial similarity criteria to discriminate TTFs from other conditions like inrush or overexcitation. The paper demonstrates the scheme's performance in terms of dependability and security through real-time domain simulation models.

Paper B5-1151 (GB) discusses a novel approach to line differential protection for long-distance remote assets using passive optical sensing. The paper addresses the challenges of protecting mixed conductor circuits, particularly distinguishing between faults on cable and overhead line sections. It introduces a solution using passive sensors to acquire remote measurements from current transformers (CTs) without requiring active electronics or telecommunications. The approach is experimentally validated over a distance of 60 km, demonstrating sub-cycle differential protection operation and providing a cost-effective method for selective auto-reclose control.

Paper B5-1152 (DE) discusses the application of directional ground-fault protection to detect turn-to-turn faults (TTF) in high-voltage shunt reactors. The paper highlights the challenges of detecting TTFs due to low fault currents and minimal voltage changes in high-resistance grounded systems. It proposes an optimal protection scheme using directional ground-fault protection that reliably discriminates fault direction without relying on voltage measurements. The scheme's performance is validated through real-time domain simulation models, demonstrating its effectiveness in ensuring both dependability and security for shunt reactors in high-voltage transmission systems.

Paper B5-1161 (BR) evaluates a line protection system with a series-compensation capacitor (SCC). The study focuses on the challenges and performance of various protection functions, such as differential, distance, and directional protections, in the presence of SCC. Using real-time simulations, the paper highlights the impact of SCC on protection reliability and response times. It finds that, while line differential protection operates consistently, distance and directional protections face instabilities due to SCC. The paper suggests adjustments to improve protection performance and reliability in such scenarios.

Power system protection is facing new kinds of challenges and uncertainty as the power system is evolving. Power generation sources are more often connected with power electronics and new types of loads are introduced to the network. This means power system protection must adjust to the change and come up with new solutions. The protection needs to be redundant in many ways. It is common to have Main 1 and Main 2 protection but, also, to have a remote backup protection from remote substation. This leads to the following questions:

Question 3.01: What kind of development is expected in protection systems to meet the various challenges posed by the changing power system?

Question 3.02: What are the intermediate targets to secure the operation of the protection assets in the future in power electronics dominated networks?

3.3 Protection functionalities in process bus and LPIT environments

The following four papers discuss the impact of process bus and LPITs on protection applications. The papers showcase the development of a new type of merging unit, accuracy of measurements of LPITs, implementation of trip circuit supervision and network monitoring on process bus applications.

Paper B5-1109 (JP) introduces a new Sampling Rate Interchange-Merging Unit (SRI-MU) compliant with IEC 61850/61869 standards and discusses the topic together with current differential protection. The SRI-MU supports multiple PTP masters and sampling frequencies, addressing issues of sampling synchronization in process bus systems. The paper details the development and evaluation of a prototype SRI-MU, which uses oversampling technology to generate ultra-fine data and allows for multiple synchronization networks. The results show that the SRI-MU can maintain protection functions even during synchronization failures, enhancing system reliability and reducing construction costs.

Paper B5-1134 (DE) examines the impact of Low-Power Instrument Transformers (LPITs) on protection algorithms. It compares conventional instrument transformers with LPIT sensors, including Rogowski coils, in gas-insulated switchgear. The study involves primary current and voltage injections, transient tests with fault currents up to 65 kA, and evaluates the accuracy and reliability of measurements. The findings indicate that LPITs, especially Rogowski coils, provide more accurate and reliable measurements under fault conditions, enhancing the effectiveness of modern protection schemes. The paper also discusses the future integration of LPITs into electrical protection systems.

Paper B5-1137 (JP) discusses the implementation of automatic supervision for trip circuits in process bus systems. The paper introduces two key functions: the Inspection Function for Trip

Circuit (IFTC) and the Trip Circuit Supervision function (TCS) and how they can be used in process bus systems. IFTC periodically forces the operation of trip circuits to ensure they function correctly, while TCS continuously monitors the trip coil current to detect disconnections or contact welding. These functions enhance the reliability and flexibility of protection relay systems and necessity also in process bus systems.

Paper B5-1163 (BR) discusses the need for a monitoring system for communication networks in digital substations, highlighting the increased flexibility and new failure modes introduced by these networks. It emphasizes the importance of continuous monitoring to ensure the safe operation, maintenance, and transition to digital substations. The paper outlines specific requirements for the monitoring system, including the detection of message integrity loss, absence of predicted messages, and abnormal intervals between messages. The Brazilian Power System Operator (ONS) has proposed a monitoring system for the local area network to enhance the reliability and security of protection systems in digital substations.

High reliability and dependability are mandatory requirements for the protection systems. Conventional measuring transformers and copper cables have been a reliable way in providing measurements from the primary system to the protection devices. In many countries, the protection community might have reservations towards fully digital substations and the progress has been moderate. This leads to the following questions:

Question 3.03: What could be the next steps to lower the barriers of wide scale utilization of process bus in utilities when considering the importance of the protection systems?

Question 3.04: What could be the large-scale advantages or external motives that would push the protection and automation field to move to fully digital substations?

3.4 Actions and schemes to secure the operation of the network

The following four papers from Japan present examples of different kinds of actions and schemes needed to secure the operation of the electricity network in challenging operational situations. The papers also highlight the cost-effective solutions, the need for more utilized network capacity and the safety of the maintenance personnel.

Paper B5-1119 (JP) discusses the implementation of the Integrated Remedial Action Scheme (IRAS) in Hokkaido's power grid to prevent blackouts following the 2018 Hokkaido Eastern Iburi earthquake. The earthquake caused a rapid frequency drop and cascading failures, leading to a total blackout. IRAS, operational since March 2024, enhances grid reliability through frequency stability control and synchronous stability control. It automatically sheds load and trips generators to prevent significant frequency drops and generator instability. The centralized system collects real-time data from multiple locations and executes control actions to maintain grid stability. Additionally, IRAS employs a dual-redundant system configuration to ensure functionality during disasters, with central IEDs installed at geographically distant locations.

Paper B5-1123 (JP) discusses the development of a portable transfer trip device to address the challenges posed by reverse power flow in substations due to increased renewable energy sources. Reverse power flow occurs when excess electricity flows back into the grid, complicating maintenance work when voltage transformers (VT) are inactive and, thus, the normal reverse power flow relay cannot operate. The device, consisting of a transmitter and receiver, allows for safe maintenance work when VT is inactive by cutting off the power source from renewable energy during faults. The device is lightweight, easy to install, and reduces costs compared to permanent installations.

Paper B5-1135 (JP) presents the development of an N-1 inter-trip scheme using IP transmission to address the lack of free capacity in Japan's power grid due to the increase in renewable energy sources. The scheme aims to expand operational capacity without constructing new transmission facilities by eliminating overloads during N-1 failures. It consists of an overload calculating central device, power flow measuring terminals, and generator shedding terminals, all communicating via existing IP infrastructure. The system ensures redundancy and security through dual communication routes and protocol conversion devices. This flexible, cost-effective solution is set to enhance grid reliability and accommodate renewable energy expansion.

Paper B5-1141 (JP) details the development of the Integrated Stability Control (ISC) system in Japan. The ISC system integrates the functions of the previous System Stabilizing Controller (SSC) and Transient Stability Control (TSC) systems, reducing the number of devices by about 40% and lowering costs. Additionally, the ISC system adopted a ring-type communication topology, which reduced the number of communication paths required while maintaining high reliability. This new communication method, along with the use of modern protection IEDs, further streamlined the system and reduced both engineering and maintenance costs. The ISC system automatically recognizes grid configurations and adapts control actions in real-time, improving grid operability and consistency in response to faults.

The capacity of the power system is needed more in the electrifying societies. Investments are increasing in the electricity systems, and more infrastructure is built each year. Load and generation profiles seem to be fluctuating more which means a higher need for transmission and distribution capacity. There is a need for more efficient and cost-effective use of the electrical infrastructure in many countries and, thus, more special protection actions and schemes are introduced into the network. This leads to the following questions:

Question 3.05: **How can we ensure the proper coordination and security of different special protection schemes applied more widely into the network?**

Question 3.06: **How should we prepare the protection and automation community to be ready for more complex networks which are pushed more to their limits?**

3.5 Revising protection and maintenance related principles

The following six papers provide an overview of recent advancements and challenges of protection and maintenance related principles in power systems across various countries. The papers present examples and discussion about protection principles, how they could be modified and what should be taken into consideration. The papers also discuss about the challenges related to configuration and setting management of the modern IEDs. Also, the importance of cybersecurity is discussed in some of the papers.

Paper B5-1116 (JP) discusses the development of a 275kV line differential protection Intelligent Electronic Device (IED) with distributed and integrated functionality by a utility in Japan. The paper addresses the limitations of the current single-series primary protection devices and explores a dual redundancy configuration to improve redundancy of the primary protection. The paper introduces a developed prototype system using IEDs and Merging Units

(MUs) for digital substations, highlighting the benefits of function distribution and integration. The study identifies challenges such as processing time and cost, emphasizing the need for low-cost, high-performance hardware for practical application.

Paper B5-1122 (BR) examines the cybersecurity risks and operational impacts on microgrids, which integrate distributed energy resources (DERs) like photovoltaic panels, batteries, and generators. It highlights the vulnerabilities of microgrids due to their reliance on communication networks and Energy Management Systems (EMS) for real-time control. Cyberattacks can disrupt synchronization with the main grid, leading to voltage instabilities, unintentional islanding, and cascading failures. In isolated mode, attacks can cause load shedding, blackouts, and resource mismanagement. The paper proposes robust cybersecurity measures, including encryption protocols, multifactor authentication, and real-time intrusion detection systems to mitigate these risks.

Paper B5-1124 (JP) explores the use of Intelligent Electronic Devices (IEDs) as protection relay devices in Japan. It highlights two main considerations: the Main Relay and Fault Detection Relay (M/FD) configuration, and the operation time of protection relay devices. The M/FD configuration separates the hardware of the main and fault detection relays to prevent malfunctions but using IEDs from outside Japan may increase costs. The paper discusses the importance of meeting regulated operation times and the challenges posed by process bus systems. In a process bus system, delays can occur due to the added transmission and processing times compared to conventional systems. The paper suggests specifying the operating time for each device, including IED operating time, process bus transmission time, input/output time to the merging unit (MU), and trip time. Solutions include consolidating functions and adopting static trip methods to address these delays.

Paper B5-1148 (CO) addresses the challenges in managing and configuring Intelligent Electronic Devices (IEDs) in power systems due to the lack of standardization and technological diversity. It highlights the issues of manual processes, which are error-prone and compromise system reliability. The paper proposes a methodology for optimizing IED settings and configuration management, emphasizing standardization, automation, and the use of advanced tools. Case studies from Colombia demonstrate successful implementations of centralized management platforms and commercial applications that enhance interoperability, reduce human errors, and improve the reliability and safety of electrical systems. The paper also discusses the importance of cybersecurity in protecting these systems.

Paper B5-1154 (BR) examines best maintenance practices adopted by Brazilian Transmission System Operators (TSOs) for modern Intelligent Electronic Devices (IEDs) in high-voltage transmission systems. It highlights key challenges, strategies, and solutions, emphasizing the importance of planning, factory tests, field commissioning tests, and continuous training. The paper presents an overview of an Inspection and Test Plan (ITP) for validating relay settings and stresses the need for robust cybersecurity measures. A case study over five years demonstrates significant improvements in system performance and reliability through these practices. The paper underscores the importance of integrating modern technologies and maintaining operational excellence.

Paper B5-1164 (AU) presents a case study on the implementation of a Protection Configuration Management System (PCMS) by Endeavour Energy (EE) in Australia. The transition from electromechanical relays to digital Intelligent Electronic Devices (IEDs) began in 2015 and was completed by 2020 to enhance safety, fault detection, and compliance. The

PCMS, implemented between 2020-2022, centralizes protection relay settings, integrates with the Advanced Distribution Management System (ADMS), and automates workflows. This integration improves fault response, asset management, and regulatory compliance while reducing operational costs and enhancing system reliability. The paper highlights best practices and lessons learned from this transition.

Many of the principles and policies related to protection and maintenance derives from the era of electromechanical devices. These principles and policies have been guiding the use of modern IEDs also. Changing the principles and policies can be difficult when the change has happened slowly over many decades. The slow change also means that people working with the principles, policies and protection systems are changing during that time. The previously mentioned aspects lead to a situation where it may be difficult to analyse what principles and policies are relevant in modern protection systems. This leads to the following questions:

Question 3.07: What changes in our principles could lead to major benefits or cost savings in the design and maintenance of protection and automation systems?

Question 3.08: What measures can be taken to effectively identify and revise our protection and automation principles and utilize the modern assets to their full capabilities?