SPECIAL REPORT FOR SC B5 (PROTECTION AND AUTOMATION)

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SUMMARY

This document is the special report for the two Preferential Subjects (PS) selected for the General Discussion Meeting (GDM) of the CIGRE Study Committee B5 session 2026 in Paris (FR).

PS1: Knowledge management in the field of protection, automation, control, metering and monitoring
Special Reporters: Mladen KEZUNOVIC (US), Caitlin SHORT (US)

PS2: Protection and control in networks with unconventional sources
Special Reporter: John WRIGHT (UK)

0. Introduction

Session Papers
Session papers are focussed on a number of subjects, referred to as "Preferential Subjects", selected in advance by the 16 Study Committees of CIGRE and available in the Call for Papers for the 2026 session.
Session papers have been selected through a two-phase review process – abstracts and full papers.
The Technical Programme lists the selected papers for the session and gives an overview of subjects that will be discussed. It is updated as the review of full papers proceeds.

Format of CIGRE sessions
At CIGRE sessions, authors are given the opportunity to present their paper during half-day specific meetings – the **Poster Sessions**. For SC B5, this Poster session will take place on Tuesday, August 25 afternoon. The first slot will be for posters of PS1 papers, the second slot for posters of PS2 papers. The authors of the papers have received the instructions necessary to prepare and present the papers.
Four days are also dedicated to '**Group Discussion Meetings**' (GDM) organised by Study Committees. Four meetings run simultaneously each day from Tuesday to Friday, under the presidency of the Study Committee chairs. The purpose of these meetings is the discussion of the session papers on the basis of "Special Reports" which resume the

session papers and raise a number of questions for discussion. The GDM of SC B5 will take place on Wednesday, August 26.
The Special Reports are available to all on free access – at the end of May - on the CIGRE website, on the session page.
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 registrations portal. Papers are also readable on the session smartphones application on site in Paris.
Latest news and General Programme are also available on the session website .

Introduction to SC B5
The CIGRE Study Committee B5 (SC B5) – Protection and Automation - 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.

The two **Preferential Subjects** selected by SC B5 for the CIGRE 2026 session are presented in this Special Report:

- PS1 - Knowledge management in the field of protection, automation, control, metering and monitoring
- PS2 - Protection and control in networks with unconventional sources

Participating in the 2026 Group Discussion Meeting of SC B5
All delegates are invited to participate in discussing this Special Report at the SC B5 session held on Wednesday, August 26, starting at 08:45 in the Grand Amphitheatre at the Palais de Congress de Paris. PS1 will be discussed in the morning session, and PS2 in the afternoon session.
The Special Reporters have compiled 18 questions, based on the analysis of 121 accepted papers. These questions are not specifically aimed at the paper's authors but are synthesised from common issues and trends identified across the papers. This provides the opportunity for a broader response and participation from all delegates in the discussion session.
Delegates are encouraged to share their views or experiences in response to the specific questions in this report. During the Group Discussion Meeting (GDM), a presentation time slot will be allocated for each accepted prepared contribution.

Procedure for prepared contributions
Registered delegates wishing to contribute should upload their proposed prepared contributions on the registration portal – section "Contributions to Group Discussion Meetings" - using individual delegate account and credentials preferentially before **3rd August 2026**, in any case before 7th August, for preparation of the Group Discussion Meeting.
The proposed prepared contributions will be reviewed. Delegates are encouraged to upload proposed contributions as early as possible to facilitate this process.

Please note the following points:
1. Access to contribution uploading is given only to duly registered delegates.
    - As a consequence, registration to CIGRE Session should be finalised before uploading contribution(s) online.
    - Contributions uploading will be possible at beginning of June.

2. Special Reporters will review the prepared contributions. For each submitted prepared contribution, a Power point presentation with a maximum of **3** slides and an associated word file with a maximum of 1000 words are to be provided.
   A guide for contributors as well as **templates and sample pages** will be available on the Paris Session webpage.
   Important:
   - Power Point presentations and Word file of prepared contributions **must use the template and respect the instructions in the template**.
   - No commercial names are to be included in presentation or the written summary (even TSO/DSO names).

3. Any recommendations or requests to change the contributions will be provided to the contributors by the special reporters directly on the registration platform after submission of the proposal, and in any case before 14th August 2026. Contributors are encouraged to visit their account on the registrations portal to see the result of this review. Formal acceptance requires implementation of updates requested by the special reporters.

4. All contributors with accepted/finalised contributions will be contacted by the special reporters, to finalise the presentation and receive the instructions regarding the session.

   Important note: The final versions of all contributions must be provided prior to **August, 18**.

5. It is expected that the questions relevant to the Preferential Subjects will attract many prepared contributions. The number of contributions for each Preferential Subject may need to be limited. The selection will be based on relevance, quality and time of submission of the contribution. **Early submission is encouraged to facilitate review by the special reporters**.

Key dates for SC B5 deadlines and events for session delegates

- **Friday 7th August 2026, 18:** Latest date for prepared contributions to be submitted for review. Delegates are encouraged to submit at their earliest convenience, preferably before **Monday, August 3rd**.
- **By Friday 14th August 2026:** Authors informed that their contributions will be included in the discussion session, with a time slot, subject to having provided amended files if requested.
- **Tuesday 18th August 2026:** Deadline for providing amended files for prepared contributions.
- **Tuesday 25th of August 2026:** 08.30-10.20: SC B5 Tutorial – "The advancement of PACS architectures with focus on process bus implementation and virtualization of protection IEDs"
- **Tuesday 25th August 2026,** 14.00-18:00: **SC B5 Poster Session**. All paper authors are invited to present a digital e-poster. This is an opportunity for all delegates to meet authors and discuss papers.
  - PS1: 14:00-15:50
  - PS2: 16:10-18:00
- **Wednesday 26th August 2026,** 08.45 – 18.00: **SC B5 Group Discussion Meeting** - Grand Amphitheatre (Level 1). Prepared contributions and this Special Report will be presented and discussed.

1. PS1 - Knowledge management in the field of protection, automation, control, metering and monitoring

1.1 Introduction

The preferential subject PS1 attracted 54 papers from 21 countries. This includes a paper submitted by the B5.82 Working Group titled "Impact of evolving knowledge on professional development of protection, automation, and control engineers" [paper **B5-10689** (US)] summarizing the WG report with the same title, published as TB 977 (January 2026). While some papers are collaborative efforts, the first authors come from utilities (32 papers), vendors (14 papers), universities (3 papers), consultants (3 papers), research institutes (2 papers) and the WG (1).

Papers covered different aspect of the PS1 spanning wide range of issues making it somewhat difficult to group the papers due to overlapping themes. For ease of the discussion, the papers may be categorized as follows.

1. Training Methodology and Tools (**21 papers**)
2. IEC 61850- related Training and Tools (**19 papers**)
3. Use Cases (**14 papers**)
4. WG Report (**1 paper**)

1.2 General Comments

While all the papers are very informative, the first group with most of the submitted papers was focused on the problem of defining the strategy for knowledge management in the context of future Protection, Automation and Control (PAC) workforce training and education (21 papers). The next, also comparatively large, group of papers focused on the problem of similar knowledge management, training and education activities related to at least some aspect of the life cycle of the IEC 61850 solutions (19 papers). A relatively small number of papers were focused on the Use Cases encompassing some aspect of the PS1 but mainly leaving it to the reader to conclude how much of such practice is repeatable through captured knowledge within or outside organizations that originated the paper (14 papers).

Looking holistically at PS1 submissions, several observations can be mentioned:

Only two papers were authored by a research institute, three by a university and three by consultants. While this count relates only to the papers with the first author coming from such organizations, it is understood that utilities, in particular, are collaborating with such institutions more extensively. It is likely that there are additional such experiences and practices that may have not been reported or were underreported in the papers. Most of the papers are written by the first authors coming from utilities (32) or vendors (14). Based on the experience gained so far with the practice of using internal utility resources and plans for knowledge management, training and education may evolve in the same direction over time, or it may increasingly rely on some open-source tools and formal education through university degrees and short courses offered by consultants and universities.

Some of the knowledge management, training and education reported practices depend on sophisticated simulation and modelling resources such as real-time simulators, particularly for some of the Use Case and IEC 61850 needs [Papers **B5-10689** (US)**, B5-11034** (BR)**, B5-11041** (BR), **B5-11110** (IT)**, B5-11182** (RU), **B5-11242** (RU)**, B5-12343** (RS)]. However, such resources are expensive to own and maintain. There may be some national/international or similar collaborative efforts where such resources may be shared across lab consortia among multiple parties, including utilities.

Based on the experiences so far, one option could be to develop internal CIGRE resources such as distinguished lectures, a tutorial repository, and webinar and panel recordings that may be posted for the members, particularly the ones from the affinity groups (Next Generation Network and Women in Energy) or other similar interest groups within CIGRE to use as an additional knowledge management, training and education resource. This practice is well developed within some of the IEEE societies and can be accomplished through joint use of resources as stipulated by the recently signed collaboration Memorandum of Understanding (MOU) between CIGRE and IEEE PES.

Several CIGRE SCs have started focusing on the same discussion as the one initiated by the PS1, and some created WGs with the similar focus, including WGB5.82. It would be beneficial if such efforts are undertaken across several CIGRE SCs.

This gives raise to the following questions:

Q1.01 – *Very few papers (less than a dozen) are mentioning the use of Artificial Intelligence (AI) for any of the PS1 topics (knowledge management, training or education).* ***Are there corresponding experiences, or are there plans for a more elaborate use of AI tools for this purpose?***

Q1.02 – ***What is the experience gained so far with the practice of using internal utility resources and plans for knowledge management, training and education? Are there plans to increasingly rely on some open-source tools, formal education through university degrees or short courses offered by universities, consultants or other organisations? How is the outside knowledge from such resources captured for future internal utility uses?***

1.3 Training Methodology and Tools

21 papers, i.e. over 40% of the papers submitted to PS1, fall into this category [Papers **B5-10293** (NL)**, B5-10607** (IN)**, B5-10689** (US)**, B5-10844** (FR)**, B5-10865** (US)**, B5-10879** (US)**, B5-11034** (BR)**, B5-11038** (BR)**, B5-11039** (BR)**, B5-11041** (BR)**, B5-11110** (IT)**, B5-11182** (RU)**, B5-11189** (RU)**, B5-11191** (RU)**, B5-11242** (RU)**, B5-11254** (RU)**, B5-12060** (TH)**, B5-12343** (RS)**, B5-12383** (DE)**, B5-12387** (DE)**, B5-12480** (DE)].
They provide comprehensive utility perspective on the future needs, some of which share experience collaborating with universities, and some reporting various challenges. All provide their vision on how to deal with the knowledge management, training and/or education issues now and some reflect on possible solutions in the future.

The most comprehensive reports came from utilities, mostly larger or nationally dominant, which are often well supported internally by the needed resources and/or rely on government

support [Papers **B5-10293** (NL)**, B5-10607** (IN)**, B5-10844** (FR)**, B5-10879** (US)**, B5-11038** (BR)**, B5-11041** (BR)**, B5-11110** (IT)**, B5-11242** (RU)**, B5-11254** (RU)**, B5-12060** (TH)].

Several of such programs are developed in collaboration with local universities [Papers **B5-11034** (BR)**, B5-11036** (BR)**, B5-11189** (RU)**, B5-11242** (RU)], most often also well-funded and quite often, also supported by the government. Some papers, particularly the ones written by universities, present interesting but not yet well-established advances in the science of education. This rich set of shared experience raise a few observations and questions (below).

In many of the comprehensive plans, the knowledge management includes documentation comprising vendor, utility, and often consultant-originated instructional materials [Papers **B5-10607** IN)**, B5-10844** (FR)**, B5-10865** (US)**, B5-10879** (US)**, B5-11039** (BR)**, B5-12343** (RS)**, B5-12383** (DE)**, B5-12387** (DE), **B5-12480** (DE)].
There is a trend and firm plan to make the entire process paperless going forward and perhaps turned into a collection of the AI-compliant digital files that can be easily access by Large Language Models (LLM) or some other emerging forms of AI tools for future use and expansion [Paper **B5-11039** (BR)**, B5-12480** (DE)]. If a utility project involves contractors, the outside knowledge from such resources should be captured for future internal utility uses. There are also issues related to cyber security and confidentiality that must be considered.

It is widely agreed that grid digitalization is imminent and, in many cases, well underway. Such developments can be met with a full digital twin replica of both the PAC infrastructures and decision-making processes, which perhaps will be the most comprehensive way to manage knowledge and implement training and education tasks [Paper **B5-12480** (DE)].

Since the knowledge management, training and education may require substantial funds to develop and maintain, the smaller utilities in less developed countries that may also have limited academic resources may have to rely on national or international collaboration to fulfil Knowledge Management System (KMS) needs rather than developing in-house capabilities. CIGRE might find ways to help the professional community in this process.

The following questions can be formulated for this section:

Q1.03 – ***When making comprehensive knowledge management plans, and gathering the instructional material, how are confidentiality, cyber security and privacy issues addressed when the process involves internal vs external contributors using paperless cyber-based approaches?***

Q1.04 – ***Understanding that the required skillset for PAC engineers may be dynamically and rapidly expanding, what methods should be employed to keep up? How can we incentivize the employees to take additional academic or professional degrees/certificates? Have employers encouraged very close collaboration of the PAC group with several utility departments with specialized skills such as OT, IT, communications, etc.? Something else?***

1.4 IEC 61850-Related Training and Tools

The deployment of IEC 61850 solutions across utilities worldwide is not equally distributed, so the related papers came from parts of the world with varying stages of implementation, some in initial stages, others well underway [Papers **B5-10225** (US)**, B5-10390** (AU)**, B5-10595** (AU)**, B5-10611** (IN)**, B5-10842** (FR)**, B5-10946** (JP)**, B5-10947** (JP)**, B5-10948** (JP)**, B5-10983** (SA)**, B5-11031** (BR)**, B5-11063** (BR)**, B5-11478** (ES)**, B5-11778** (PY)**, B5-11847** (GB)**, B5-11930** (SE)**, B5-12013** (AT)**, B5-12033** (CO)**, B5-12475** (DE)**, B5-12639** (RS)].
This is reflected in the maturity and comprehensiveness of the issues being tackled. The vendors and consultants' contribution here are visible making it a true partnership among all the organizations involved.

The focus on most of the reported experiences is on the complexity of the design specification and verification of the IEC 61850 solutions [Papers **B5-10611** (IN)**, B5-10842** (FR)**, B5-10948** (JP)**, B5-11031** (BR)**, B5-11063** (BR)**, B5-11847** (GB)] , and the issues associated with commissioning and periodic testing aimed at verifying the initial design to managing the design changes in the future [Paper **B5-11478** (ES)**, B5-11778** (PY)].

IEC 61850 requires exceptional skills in fundamentals of communication engineering such as time synchronization, latency, error management, etc. [Papers **B5-10595** (AU)**, B5-10983** (SA)**, B5-11031** (BR)**, B5-12639** (RS)]. The PAC engineers and technical staff are in general well versed in many communication issues from existing practices but lack broader experiences from the telecom industry.

In many countries, IEC 61850 considerations are still at the cost-benefit analysis stage [Papers **B5-10390** (AU)**, B5-11847** (GB)**, B5-12033** (CO)). It would be useful for CIGRE to maintain a well-organized library of technically focused testimonies about the IEC 61850 experiences associated with evaluation of the benefits [Paper **B5-11478**(ES)].

Comprehensive design testing at the model level has proven to be very effective in identifying potential deployment issues. The industry is developing very detailed open-source digital twins of the IEC 61850 solutions, and there are the examples of such a proactive methods used for knowledge management [Papers **B5-11031** (BR)**, B5-10225** (US)**, B5-10611** (IN)**, B5-12475** (DE)**, B5-11778** (PY)].

Several utilities with a mature and well proven legacy substation automation systems are looking at transitioning to IEC 61850 based solutions gradually over time [Papers **B5-10946** (JP)**, B5-10390** (AU)**, B5-12033** (CO)]. They must capture fundamental knowledge through years of using legacy solutions and to transfer and complement it with the knowledge emerging from the IEC 61850 experiences.

Interoperability demonstration events at various industry conferences supplying IEC 61850 products were instrumental in the early stages of the IEC 61850 adoption [Papers **B5-11778** (PY)**, B5-11930** (SE)**, B5-12013** (AT)**, B5-12475** (DE)**, B5-10947** (JP)]. Such practices should be continued by industry vendors supplying major regional universities with full suites of products and demo kits. Such elaborate labs should be non-profit and offer services to the industries in the region, as well as serve the students' hands-on experiences for the classes and short courses.

A few questions motivated by the papers in this section are:

Q1.05 - What would be the best way of sharing experiences from the telecom industry regarding knowledge management?

Q1.06 – *The curriculum for training and educating PAC professionals in the skills needed for understanding and deploying IEC 61850 solutions has become very elaborate.* ***How can such training be complemented with the knowledge readily available online, and in most instances, free of charge?***

1.5 Use Cases

This group of papers illustrates different knowledge management, and training and education approaches focused on a selected problem, in many cases something specific to a given utility that may have been already solved by other utilities around the world [(Papers **B5-10125** (BE)**, B5-10598** (IN)**, B5-10603** (IN)**, B5-10604** (IN)**, B5-10616** (IN)**, B5-11036** (BR)**, B5-11046** (BR)**, B5-11750** (BA)**, B5-11180** (RU)**, B5-12010** (AT)**, B5-12127** (CO)**, B5-12152** (CO)**, B5-12198** (CO)**, B5-12474** (DE)].

Examples are automated analysis of relay operation [Papers **B5-11036** (BR)**, B5-11180** (RU)**, B5-11750** (BA)] relay testing and certification [Papers **B5-10616** (IN)**, B5-12152** (CO)], and some issues associated with communication-based protective relaying schemes [Papers **B5-10604** (IN)**, B5-12198** (CO)].

The key observation based on several papers in this group is an attempt to demonstrate how an automated process for analysis of the power grid event detection, classification and characterization, or protective relaying equipment operation can be utilized in training and education [Papers **B5-10603** (IN)**, B5-11750** (BA)**, B5-12010** (AT)**, B5-12127** (CO)]. While automated analysis may bring continuity to knowledge management, the methodology itself cannot translate easily to a training or education tool, and that process requires further efforts. In general, the full benefit of such individual Use Cases would be more apparent if there was a broad international repository of such cases made available online as an open source.

Several papers pointed out the value of collecting substation data and data across other PAC assets [Papers **B5-11046** (BR)**, B5-10125** (BE)**, B5-12474** (DE)**, B5-12010** (AT)**, B5-10603** (IN)].
It was hinted that such data may be used to enhance the knowledge base about system dynamics and PAC equipment behaviour during such dynamic events, but very few papers elaborated on how such data may be used efficiently.

The topic of life cycle management of certain PAC assets resurfaced across a few papers [Papers **B5-10598** (IN)**, B5-12474** (DE)] which also suggested recording the performance data for future uses. While important in some cases, the suggestions to also collect environmental data such as weather (wind speed, temperature, participation, lightning, etc.) was missing.

Examples of automated analyses of PAC system operation clearly indicate the benefits in reducing the time of analysis resulting in quick decision-making and reducing the workforce

hours of their involvement in this process. There are benefits of such solutions to other utility groups such as system operators and/or asset and outage management crews that can offer leveraged investment in such solutions making them a more desirable practice [Papers **B5-10603** (IN)**, B5-12010** (AT)**, B5-12127** (CO)**, B5-12152** (CO)].

While the various instances of protective relay misoperations under heavy IBR penetration have been well document in the past, the focus in the Use Cases did not emphasise such concerns except in a couple of instances (Papers **B5-10125** (BE)**, B5-11046** (BR)]. However, the IBR penetration impact on protective relaying is probably a worthy subject for enhanced knowledge management, training and education focus going forward.

The need to standardise procedures and processes involved in design and deployment of PAC solutions has surfaced from several Use Cases reported in this group of papers. The lack of a standard or set of standards for digital formats for storing, managing and using such design information has been pointed out [Papers **B5-12474** (DE)**, B5-12010** (AT)**, B5-10603** (IN)]. This may look similar to practices used in some licensing agreements for open-source software where each party that uses the results of others is required to deposit back their contributions to such developments.

The following questions can be formulated for this section:

Q1.07 – The *knowledge base management and utilisation of Use Cases in training and education of the workforce should be made more efficient, cost-effective and affordable across the board.* ***While the specific Use Cases are an important instance for capturing knowledge, how can such developments be documented through some well-known AI, digital twin, and/or virtualization tools widely used across other industries?***

Q1.08 – ***How can collecting environmental and monitoring data be useful in the PAC tasks, including knowledge management and related training and education about the causes of outages? Should there also be a standard or set of standards for digital formats for storing, managing, and using such information?***

1.6 B5.82 Working Group Paper

The working Group B5.82 titled "Education, qualification and continuing professional development of engineers in protection, automation and control," completed its work recently and published the TB 977 (January of 2026). It was tasked to review and update the WG B5.40 brochure (TB 599) published in November 2014 with focus on "…new topics, technologically aware means of delivering knowledge including web-based learning approaches, internal utility training and skill updates, and formal education certification processes that will enable new and existing Protection, Automation and Control (PAC) workforce to achieve, maintain, and enhance the skills required to support technological changes for the next generation of the electric grid assuring that it is safe, secure, reliable, environmentally friendly, and socially equitable." Hence, the new report provided an update reflecting the industry practice changes over the last 10+ years. A TB summary is provided in the paper submitted under the PS1 (**B5-10689** (US): Impact of Evolving Knowledge on Professional Development of Protection, Automation, and Control Engineers).

While the WG was not tasked explicitly with the knowledge management focus, but was mostly dealing with the training and education needs, due to its comprehensive assessment of the industry changes, it made some pointed recommendations that are perhaps worth exploring through several synergetic questions that may be raised around complementing issues between the PS1 papers and WG TB findings.

The TB 977 raised the issue that training and education should undergo an abrupt, fundamental change due to its urgency rather than depend on incremental adjustments occurring naturally to education and training over time, which takes much longer. The need for immediate adjustment is driven by the overwhelming and rapidly emerging knowledge needs stemming from profound changes in power systems. In the context of fundamentally changing existing practices, it has to be determined how the relationship between formal (academic) fundamental education and practice-driven (industry) pragmatic education should be complemented [Papers **B5-10125** (BE), **B5-11034** (BR), **B5-11036** (BR), **B5-11038** (BR), **B5-11750** (BA), **B5-11189** (RU), **B5-11242** (RU), **B5-12013** (AT), **B5-12343** (RS)].

The TB 977, and subsequently the papers submitted for the PS1, are recommending deeper insights into the role of AI and LLM in the training and education process [Papers **B5-10225** (US), **B5-10879** (US), **B5-11750** (BA), **B5-12010** (AT), **B5-12127** (CO), **B5-12480** (DE)]. The PAC industry will have to embrace such opportunity while at the same time keeping human-in-the loop, assuring the tools are used safely and ethically, particularly in the case when the workforce is using widely available online tools.

In synergy with some of the papers discussed under the PS1 [Papers **B5-10595** (AU), **B5-11031** (BR), **B5-11038** (BR), **B5-11063** (BR), **B5-11242** (RU), **B5-11254** (RU), **B5-11182** (RU), **B5-12060 TH**)], the TB also raises an issue of adding certification and quality control of the training and education process of the employees through a diverse set of resources, some internal and some external, to the company's quality control means.

It has been clearly noted that the PS2 topic (Protection and control in networks with unconventional sources) deals with one of the most profound changes in the PAC area. This was also emphasized by the TB 977, representing a synergetic issue that bridges the PS1 discussions with the PS2 experiences regarding PAC knowledge management, training and education.

The TB brochure 977 compares the finding on the same topic of training and education against the status 10 years ago reported in TB 599 and illustrates visible expansion of knowledge facing PAC personnel. This exponential expansion of knowledge might lead to fundamentally different workforce hiring practices, investments in knowledge management, training and education, and different regulatory practices.

The following questions can be formulated based on the findings from TB 977:

Q1.09 – ***Is the industry ready for and in need of fundamental changes in how it handles PAC workforce training and education, and if so, what are the key components of such an approach?***

Q1.10 – ***What are the examples and which is the experience feedback of approaches for quality control of the training and education process of the employees?***

1.7 Conclusions

Based on the accepted papers for PS1 several conclusions may be drawn:

- With the PAC knowledge base expanding, utilities are facing a well-recognized challenge of managing the knowledge base going forward. While many good practices are in place, the use of advance tools based on LLM and generative AI are still in infancy even though they are expected to significantly reduce the cost and improve efficiency in workforce training and education.
- Most of the knowledge management practices reported by utilities and some reported by universities, consultants and vendors are primarily focusing on the utility needs. The internal knowledge management practices, particular by vendors, would benefit the industry if shared widely in the form of open-source on-line resources as widely available digital twin libraries, and repositories of webinars and tutorials
- Based on the university involvement reported in the papers, some utilities and even vendors use the formal educational experiences in defining knowledge management practices, but the support of universities to offer comprehensive lab facilities that may be used widely for workforce development and PAC curriculum enhancements is rather limited as reported in the PS1 papers.
- While the papers spanned many important emerging areas of interest to PAC engineers and support staff, it was somewhat surprising that the impacts of Inverter-based Resources (IBRs) on PAC system performance has not taken more central role particularly knowing how limited the overall PAC engineers knowledge may be in the area of power electronics and interfacing of the electrical vehicles, hyperscale loads, and large scale batteries.
- To manage the quality of the knowledge acquisition and practice by the workforce, it was emphasized that some sort of certification program, hopefully managed internationally may be beneficial. The open question remains who the organizations are best fit to issue such certificates, and how such certificates program may be managed and acknowledged by the industry for advancing the staff careers.

While not emphasized by many, it still remains interesting to investigate the role of CIGRE and its partners such as IEEE PES in defining cross-committee efforts to streamline the knowledge management process since many tasks such as use of open source tools, use of AI, and development of repositories of the artifacts from previous experiences (videos, webinars, tutorials, keynotes, etc.) are somewhat transparent irrespective of the specific technical areas.

2. PS2 - Protection and control in networks with unconventional sources

2.1 Introduction

The preferential subject PS2 of CIGRE Paris session 2026 is titled “Protection and Control in Networks with Unconventional Sources”. This area of power system protection has attracted considerable interest of late, mainly due to the increasing integration of such sources into the electrical grid and the corresponding noticeable challenges facing established protection systems. Compared to synchronous machine dominated grids, where the fault signatures and subsequent protection responses are well understood, unconventional sources present a new set of complexities for protection engineers. Varying and dynamic fault signatures, influenced by factors such as the type of source, control strategies, and associated connection standards are impacting current protection philosophy. The result is an increasing number of impact studies and a growth in the exploration of ways to mitigate such challenges, for instance, by modifying the existing protection system or by implementing a new one, along with the adoption of new standards, tools, and testing strategies.

A total of 67 papers on PS2 from 21 different countries have been reviewed for PS2. These papers can be broadly classified into 5 groups. It is worth noting that several papers span multiple groups. For example, modelling is often used to determine new techniques. However, for this report, a broad categorisation has been adopted in the grouping to allow sufficient comparison for the purposes of the prepared contributions.

1. Impact on Existing Protection Techniques **(14 papers)**
2. New Protection Technologies and Strategies **(25 papers)**
3. Standards, Regulations & Grid Codes **(3 papers)**
4. Modelling and Testing **(17 papers)**
5. System or Wide Area Approach **(8 papers)**

2.2 Impact on Existing Protection Techniques

A total of 14 papers addressed challenges and opportunities for protection of networks with unconventional sources, implying that the level of impact is dependent upon the protection philosophy adopted. However, due to the prolific use of distance protection in electrical grids, specifically at higher voltages and its reliance on certain predictable power system quantities for secure and repeatable operation, it is not surprising that it has been under the most scrutiny. There are numerous documented cases where its decision, along with the response of other types of protection has resulted in undesired operation. Since we are in a transitional phase and this protection function is not practical or necessary to replace the complete installed base, we have witnessed accelerated progress finding ways to either modify the existing protection algorithm or develop alternatives. The papers investigate the impact on current protection techniques, focusing collectively on a range of topics from the influence of controls strategies, types of unconventional sources, grid codes, variations in fault signatures and system inertia.

[Paper **B5-10628** (IN)] investigates the use of time domain distance protection. [Paper **B5-11839** (UK)] proposes an innovative approach that is independent of Inverter Based Resource

(IBR) type, control strategy, or the proprietary controller design and [Paper **B5-10640** (IN)] goes no to highlight the benefits of alternative advanced protection, such as line current differential and travelling wave-based fault detection, whilst considering the influence of power-quality issues including harmonics and transient overvoltages. [Paper **B5-11484** (ES)] investigates the behaviour under off-nominal frequency conditions in networks and proposes improvements to reactance line polarized directional elements.
[Paper **B5-11192** (RU)] details the operating principles of a hybrid algorithm for transmission lines adjacent to IBRs, using high frequency (HF) transceivers for exchanging, enabling and blocking signals between protection devices.

[Paper **B5-10395** (AU)] highlights that while traditional protection principles remain viable, they must be carefully parameterised and supported by additional logic to accommodate the characteristics of inverter dominated networks.

[Papers **B5-10629** (IN), **B5-10630** (IN)], utilising return on experience, propose that undesired results are intrinsically linked to the current-limiting and sequence-selective fault response behaviour of IBR. [Paper **B5-10632** (IN)] goes on to describes operational experience from multiple utility-scale plants and presents three detailed case studies along with a mitigation framework comprising of multiple protection techniques.

In addition to the modification of the protection system, [Paper **B5-11045** (BR)] expresses that continued development and sharing of knowledge within the industry is critical. This paper details an event held by the Brazilian CIGRE B5 in June 2024, emphasising the need for constant dialogue and collaboration amongst all stakeholders in the search for more comprehensive solutions. [Papers **B5-10126** (BE), **B5-10864** (US), **B5-11035** (BR), **B5-11040** (BR)] detail the importance of considering how the primary plant operating mode and requirements can impact and support the protection system in correct fault identification. Collectively, they consider the impact of the mode of operation of the inverter, namely grid forming or grid following, along with fault ride through obligations.

Question 2.01 – Utilising return on experience, what is the impact of unconventional sources on existing protection systems and what new techniques and strategies can be employed to support the installed base in correct fault identification and operation?

Question 2.02 – How can the use of primary plant, such as grid forming convertors, HVDC and battery energy systems, along with modified operating conditions, support the existing protection installed base in correct fault identification without the need to modify the current algorithms and techniques?

2.3 New Protection Technologies and Strategies

By utilising advancements in technology and communications, 25 papers proposed several innovative techniques and strategies to improve fault identification and protection response. This is particularly prevalent in the area of adaptive protection. Whilst this concept is not new to the field of protection, it is ideally suited to the varying nature of unconventional source connections and the associated changes in grid dynamics.

To limit the challenges associated with fixed settings, [Papers**B5-10171** (EG),

B5-10181 (US), **B5-10949** (JP), **B5-11037** (BR), **B5-11097** (PT), **B5-11190** (RU), **B5-11468** (CN), **B5-12216** (CO), **B5-12448** (DE), **B5-12530** (CN), **B5-11033** (BR), **B5-10644** (IN), **B5-10639** (IN)], collectively address numerous strategies around real time setting and scheme modifications, such as adaptive: polarising, voltage protection and generator control block settings. They also investigate the use of fuzzy logic and a centralised platform, in addition to focusing on specific applications such as static synchronous series compensators, micro grids and a modular toolset approach.

In addition to an adaptive approach, it is apparent that the use of artificial intelligence, particularly deep and machine learning is gaining interest, as emphasised in [Papers **B5-11488** (ES), **B5-12071** (UK)]. As we accelerate towards digitisation, [Paper **B5-10226** (US)], explores the use of R-GOOSE and [Paper **B5-11370** (FN)] investigates the impact and practical challenges of the digital substation.

[Papers **B5-11639** (QA), **B5-11640** (QA), **B5-11714** (DK)] highlight the importance of considering the DC component in the fault signatures and the impact of HVDC, Battery Energy Storage and specific applications such as offshore wind.

Furthermore, to understand the restrictions imposed on the protection system by the adoption of unconventional sources, there is a recognition of the need to realise the limitations of the existing fault detection techniques and subsequently ensure correct fault location and restoration. To address these complexities, [Paper **B5-10631** (IN)] presents an intelligent fault classification solution that adopts a dynamic switching approach for enhanced independence from grid operating conditions.
Four papers investigate the challenges with traditional fault location and restoration techniques, collectively proposing alternatives. [Paper **B5-10636** (IN)] introduces two novel compensation methodologies based on the estimation of a non-homogeneity factor, [Paper **B5-11186** (RU)] looks at a practical implementation of a wave-based method, [Paper **B5-11255** (RU)] presents a dynamic programming and graph-based algorithm, and [Paper **B5-12623** (RS)] proposes a technique based on controlled signal injection and frequency-domain sensitivity analysis.

Question 2.03 – How can digitisation and advancements in communication technology be utilised to improve the protection response for networks with unconventional sources? – *Please also consider any cyber security implications.*

Question 2.04 - How can real time monitoring and an adaptive approach to protection be used to improve fault detection and system resilience in networks with unconventional sources? *Please also consider the application and adoption of artificial intelligence.*

Question 2.05 – What new strategies and techniques can we use to enhance and improve the location of faults in networks with unconventional sources? - *Please consider both the AC and DC part of the system.*

2.4 Standards, Regulation and Grid Codes

It is important to recognise that the connection of unconventional sources to the grid is governed by policy, such as, guidance documents, grid codes, regulations and standards. Policy, therefore, dictates the operating requirements and obligations of the unconventional sources and thus impacts the behaviour of the grid and in turn the protection during system disturbances. In addition to the connection and operational requirements, the protection and control systems themselves are also subject to and influenced by standards such as IEC 60255 and IEC 61850, in some cases these standards are still evolving and under development, which can lead to both opportunities and challenges. Three papers focus on this area.

[Papers **B5-10193** (US**)**, **B5-10866** (US)] look at the influence and impact of IEEE 2800-2022 (IEEE Standard for Interconnection and Interoperability of IBRs Interconnecting with Associated Transmission Electric Power Systems) on protection operation. Notable discussion points include.

- Requirement for fault current characteristics that enhance fault identification and polarization under evolving grid condition,
- Ability of IBRs to inject negative-sequence current. This is identified as a key enabler for reliable directional protection and stability,
- Fault ride-through (FRT) behaviour,
- Post-contingency recovery.

[Paper **B5-11042** (BR)] looks at the impact of grid code across multiple countries. The comparative review of international grid codes highlights that the primary challenge for protection systems in IBR dominated networks is not the absence of FRT requirements, but rather the degree of explicitness with which inverter fault-current behaviour is defined and standardised.

Question 2.06 – For networks with unconventional sources, what is the impact of current connection standards, grid codes and protection and control standards, such as IEC 61850 on protection design and operation? What changes in such standards are in development or required to improve protection performance and efficiency?

2.5 Modelling and Testing

Modelling and testing are key elements in the critical path for the successful validation and implementation of any protection and control scheme. 17 papers focused on modelling and testing, proposing that this is even more evident with the adoption of unconventional sources and the need for verification of existing and new protection techniques, as the traditional methods may not be optimised.

Several papers utilise a range of techniques, including steady state analysis, Electromagnetic Transient (EMT), Model Based State Estimation (MBSE), Hardware-In-Loop (HIL) testing, along with real time simulators to demonstrate the behaviour of protection and highlight some of the contributing factors to undesired operation and confirm correct response [Papers **B5-10626** (IN), **B5-10643** (IN), **B5-10719** (US), **B5-10845 (**FR**), B5-12357 (**DE**), B5-12442** (DE)**, B5-11638** (QA)**, B5-11183 (**RU)**, B5-11184** (RU)].
[Paper **B5-11112** (IT)] employs a component-level model, which directly represents physical behaviour and [Paper **B5-11372** (FN)] proposes a model-development method, in which a

discrete Fast Fourier Transformation (FFT) algorithm is used to estimate the amplitude and the frequency of the sub-harmonic perturbation. [Paper **B5-11032** (BR)] shows that, depending on the IBRs control strategies, traditional differential protections can lose sensitivity, leaving the system exposed and [Paper **B5-10392** (AU)] concludes that while desktop studies using relay models are useful for identifying potential miscoordination, it may not be sufficient to draw definitive conclusions regarding actual relay performance, arising largely from proprietary algorithms.
[Paper **B5-11840** (UK)] goes on to showcase how significant improvement can also be made in different stages of the protective relay development, as well as in simulation studies using model-based relay design. [Paper **B5-10683** (US)] proposes digital twin technology and IEC 61850-based communication schemes to be executed and tested in a fully virtual environment.
In addition to verifying correct relay behaviour, modelling can be utilised to refine engineering process and reduce errors. [Paper **B5-12173** (CO)] presents a methodology designed to identify protection risks utilising a framework that automates the transfer of protection settings, avoiding manual data entry and eliminating transcription errors. After data integration, the methodology performs automated protection simulations across multiple fault scenarios and [Paper **B5-12275** (CO)] presents a structured method to define optimal protection schemes.

Question 2.07 – In order to ensure a reliable protection response in a grid incorporating unconventional sources, what are the challenges, requirements, tools and techniques necessary for modelling and testing?

2.6 System or Wide Area Approach

With the proliferation of unconventional sources connected at differently voltage levels to support the grid, there is a recognition that whilst traditional local based protection schemes are still critical, a wide area or system-based protection approach provides additional supporting benefits, particularly from a network visibility and stability point of view, 8 papers proposed such strategies.

Several papers focus on the use of Phasor Measurement Units (PMU). [Paper **B5-10601** (IN)] demonstrates the feasibility of estimating and validating transmission line sequence parameters under actual operating conditions. [Paper **B5-10722** (US)] proposes a probabilistic fault-risk forecasting framework. [Paper **B5-11111** (IT)] provides real-time visualisation, intelligent analytics, and automated notifications enabling operators to rapidly detect and respond to dynamic power-system conditions. [Paper **B5-11185** (PT)] covers a study conducted to evaluate and test the applicability of the existing power swing function and proposes for future work, advanced monitoring and control solutions should be considered. [Paper **B5-11681** (UK)] presents WAMPAC solutions to enhance the stability of South Australian power grid by defending against separation from its neighbouring states.

In addition to the application of PMUs, [Paper **B5-11911** (JO)] focuses on a wide area protection scheme for radial active distribution networks based on fault current component analysis. [Paper **B5-12458** (DE)] focuses on a centralized intelligence for co-located solar, wind, and pumped storage assets, thus, demonstrating the wide range of potential applications and solutions available at a system or wide are level to support the introduction of unconventional sources and the subsequent protection.

[Paper **B5-11467** (CN)] investigates both the construction modes and framework of a hierarchical protection system adapted to renewable energy integration. The novel hierarchical relay protection system is structured into three protection levels: local-level, station-level, and wide-area protection, demonstrating that a combined strategy may bring operation advantages and efficiencies.

Question 2.08 – For networks with unconventional sources, what are the advantages of adopting a system or wide area-based protection and control strategy, not only to protect the system but also to support grid resilience?