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Leveraging Power SAS Simulation Modelling in Power System Skill Development

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ABSTRACT

The study explores the incorporation of simulation modelling into power system training programs using a thorough literature analysis and qualitative research methodology. As used in this study, Power SAS refers to Substation Automation Systems (SAS), most commonly standardised through the IEC 61850 communication protocol. It investigates how Power SAS may increase the accuracy of substation monitoring and protection, looks at the obstacles that organizations have when implementing the technology, and suggests strategic ways for its inclusion. According to this study, Power SAS helps close the gap between theoretical ideas and actual implementations while also improving practical comprehension of power system operation. The results also point to institutional obstacles that prevent complete adoption, such as high implementation costs, a lack of technical know-how, and change aversion. To address these issues, the research ends by suggesting that focused training, industry-academia partnerships, and legislative assistance be the main approaches. Additionally, institutions may greatly enhance the capabilities of aspiring power system experts and guarantee more readiness for managing contemporary energy systems by utilizing systems such as Power SAS.

Keywords: Power SAS (Substation Automation System); IEC 61850; Simulation modelling; Power system training; Skill development; Energy systems education

INTRODUCTION

Idema and Domenico (2014) define a power system as one that facilitates the production, transfer, and distribution of electrical energy. The biggest and most intricate man-made systems are thought to be power systems. Power systems must meet the strictest security and dependability requirements since electrical energy is essential to our society (Idema and Domenico, 2014). Power system analysis, according to Garip et al. (2022), entails assessing the electrical behaviour of a power network under many operating situations to guarantee efficiency, stability, and dependability. Nonetheless, the production of skilled engineers and technical experts who can manage, operate, and optimize power systems depends on skill growth in this area (Arcelay et al., 2021). Centralized generating, unidirectional power flow, and predictable demand patterns were the traditional characteristics of power systems (Delboni et al., 2018).

However, there is now more complexity and unpredictability than ever before due to the combination of distributed generation (DG), smart grid technology, and renewable energy sources (RES). Paradigm change from deterministic models to probabilistic techniques that can take into consideration the intrinsic stochasticity of contemporary grids is required in power system analysis and skill development due to this dynamic environment (Iweh et al., 2021). The growing demands for energy usage worldwide and the growing use of a wide range of new power system devices and parts are driving modern power systems to adopt increasingly complicated model configurations (Makolo et al., 2021; Gilmore et al., 2022). Futuristic electrical systems will include additional DC interconnections, microgrids, battery energy storage systems (BESS), renewable energy sources (RES), and flexible AC transmission systems (FACTS) (Farivar et al., 2022; Peyghami et al., 2019; Arrano-Vargas et al., 2022). Considering this, taking decisions for the design, management, and operation of such energy systems presents new difficulties, as it calls for a thorough examination of system operation prospects in a shorter amount of time (Ma et al., 2018; Zeng et al., 2022).

Power system modelling, analysis, and optimization require a highly qualified workforce because of the fast development of power systems brought in by grid modernization, renewable energy integration, and rising electricity consumption (Prasad et al., 2024). But, according to Shehzad et al. (2023), traditional power system education mostly focuses on theoretical training with little to no practical application, leaving graduates unprepared for the industrial difficulties. The needs of contemporary power systems, which call for knowledge in fields like grid stability, fault analysis, and renewable energy integration, are thus not adequately met by preparation. Though their usage is still uneven, systems such as Power SAS provide an integrated platform for protecting, controlling, monitoring, and communicating with substation equipment, which is a solution (Aftab et al., 2020).

For clarity, and in response to a terminological concern raised in peer review, *Power SAS* is used throughout this paper to mean a *Substation Automation System (SAS)* the integrated system of protection, control, monitoring, and communication equipment that governs a substation's Intelligent Electronic Devices (IEDs), most commonly standardised through the IEC 61850 communication protocol (Aftab et al., 2020). This is distinct from unrelated tools and platforms that share the same acronym, none of which are referenced in this paper.

Notwithstanding its potential, several academic institutions and industry training programs find it difficult to successfully integrate Power SAS because of problems with software accessibility, a lack of faculty experience, and an absence of organized approaches for integrating simulation based learning into courses (Fongang et al., 2017). According to Nyarko et al. (2023), the inability to find qualified workers who can operate power systems and do statistical analysis also makes it difficult to manage increasingly complex grids effectively.

To overcome these crucial skill shortages, this study intends to demonstrate, through synthesis of the existing literature, how simulation-based learning may enhance proficiency in fault identification, operational optimization, and power system analysis by utilizing Power SAS. Therefore, a variety of stakeholders, including academic institutions, business professionals, and legislators, will gain from the research's conclusion. Industry will gain from a highly trained workforce that can handle real-world power system difficulties, while educational institutions may use the insights to improve curriculum by using simulation-based training. Additionally, governments might use the findings to encourage the use of simulation technologies in engineering education.

METHODOLOGY

This study adopts a qualitative, literature-based research strategy conducted within the interpretivist paradigm (Saunders et al., 2019), which stresses comprehending the context and viewpoints offered within a body of existing literature. A deductive approach is used, whereby propositions drawn from prior theory and practice are examined against evidence assembled from the literature (Fife and Gossner, 2024). Rather than generating new numerical data, the study offers a conceptual synthesis grounded in secondary, published sources such as journal articles, conference papers, institutional and industry reports, and technical documentation on Power SAS (Substation Automation Systems) and its use in power system education.

Search Strategy and Sources

The literature underpinning this study was drawn from peer-reviewed journal articles, conference proceedings, and institutional/industry publications concerning power system simulation, power system education, and simulation-based skill development, spanning publications from 2011 to 2026. Sources were retrieved from Scopus, Google Scholar, IEEE Xplore, ScienceDirect, and ResearchGate using search terms including "Power SAS", "Substation Automation System", "IEC 61850", "power system education", "simulation-based training", "skill development".

Inclusion and Exclusion Criteria

Consistent with the study's objectives, sources were considered relevant if they:

- Addressed power system simulation, modelling, or automation tools, including Power SAS (Substation Automation Systems / IEC 61850) or comparable platforms;
- Discussed power system education, engineering skill development, or simulation-based training; or
- Examined organizational or institutional factors affecting the adoption of simulation or automation technology (cost, expertise, change management, integration, security, and regulatory concerns).

Data Extraction and Thematic Analysis

Data extraction and analysis followed the general stages described by Dibekulu (2020): compiling relevant literature, categorizing recurring concepts, and analysing the resulting patterns. In this study, sources were organized around the three objectives set out in Section 1.4 applications of Power SAS in power system studies, institutional challenges to adoption, and strategies for curricular integration and the recurring points raised within each were consolidated into the synthesis tables presented in Section 3, which record, for each theme, the specific application or barrier, a concise description, and the supporting source(s).

Ethical Clearance

According to Greenwood et al. (1993), a researcher is responsible for making sure that study participants, or respondents, are safe. Because this study relies exclusively on published secondary literature, it does not involve human participants, and many of the ethical issues associated with primary data collection do not arise. Nonetheless, ethical practice was observed by ensuring all secondary sources are properly cited and acknowledged, by avoiding plagiarism, and by maintaining transparency in how sources were selected and analysed. The study also respects intellectual property rights by drawing only on publicly accessible or appropriately licensed material, and takes care to interpret the literature fairly, without overstating or misrepresenting the conclusions of the original authors.

RESULTS/DISCUSSION

The Role of Power SAS in Power System Simulation and Modelling

Substation automation systems (SAS) are central to the protection, control, monitoring, and communication of equipment within a power system substation (Aftab et al., 2020). Standardised principally through the IEC 61850 communication protocol, an SAS coordinates data exchange among Intelligent Electronic Devices (IEDs) such as protection relays, digital energy meters, and monitoring devices to support fast, interoperable event and measurement transfer within the substation (Aftab et al., 2020; Mokari-Bolhasan and Taghizadegan-Kalantari, 2016). These functions are summarised in Table 1 and discussed below.

Real-time monitoring of substation voltages and currents is a core function of an SAS. Sampled Measured Values (SMV), one of the principal communication services defined by IEC 61850, transfer continuous current and voltage measurements from merging units to protection and monitoring devices, giving operators a real-time view of power flow conditions at the substation (Aftab et al., 2020). This real-time visibility supports operational decision-making and infrastructure planning, complementing the offline load flow studies that are separately carried out using dedicated power-system-analysis software.

Protection and fault response are central SAS functions. Generic Object-Oriented Substation Event (GOOSE) messaging enables high-speed, high-priority communication of trip and alarm commands between IEDs and circuit breakers, supporting rapid coordination of protection relays during fault events (Aftab et al., 2020). Reliability studies of IEC 61850-based SAS architectures have evaluated how different arrangements of intelligent electronic devices affect the speed and dependability of fault clearance (Mokari-Bolhasan and Taghizadegan-Kalantari, 2016). As digital substations become more networked, protecting this communication layer itself has also become a priority: denial-of-service and other cyberattacks on IEC 61850 messaging can delay or block the very GOOSE and SMV traffic that protection functions depend on, so cybersecurity is increasingly treated as an integral part of substation protection design (Ashraf et al., 2021).

Beyond routine operation, an SAS supports visibility into system disturbances as they occur. Event and disturbance data captured through GOOSE and SMV messaging can be logged, time-stamped, and reported to control centres, giving operators a real-time record of how the system responded to a fault, load change, or protection operation (Aftab et al., 2020). Machine-learning-based approaches have also been proposed to use this SAS-generated data to detect anomalies and support automated restoration following a disturbance, extending the substation's role from passive data capture to active resilience support (Park et al., 2024).

As distributed energy resources (DER) such as rooftop solar and small-scale wind are increasingly connected at the distribution level, an SAS plays a growing role in integrating them safely into the grid. IEC 61850 has been extended to standardise communication with DER and active distribution network equipment, allowing substation automation systems to monitor and coordinate distributed generation alongside conventional loads (Ustun et al., 2019). This depends on the same evaluation of intra-substation communication performance that underpins other SAS functions, so that DER integration can be managed reliably as substations take on a more active role in distribution-level operations (Ustun et al., 2019).

Table 1: Core Applications of Power SAS in Power System Studies

Function	What it enables	Evidence type / Key sources
Real-time voltage/current monitoring	Sampled Measured Values (SMV) transfer continuous current and voltage data from merging units to IEDs, providing real-time visibility of power-flow conditions.	Peer-reviewed journal: Aftab et al. (2020)
Protection & fault-response coordination	GOOSE messaging enables high-speed trip/alarm communication between IEDs and circuit breakers, supporting rapid and coordinated fault clearance.	Peer-reviewed journals: Aftab et al. (2020); Mokari-Bolhasan & Taghizadegan-Kalantari (2016)
Disturbance event logging & anomaly response	Time-stamped GOOSE/SMV event data supports post-disturbance analysis; ML-based methods use this data for anomaly detection and automated restoration.	arXiv preprint: Park et al. (2024)
DER / renewable integration	IEC 61850 extensions standardise communication with distributed energy resources connected at the substation/distribution level.	Peer-reviewed journal: Ustun et al. (2019)
Cybersecurity of substation communications	Protecting GOOSE/SMV traffic from denial-of-service and other attacks is treated as an integral part of substation protection design.	Peer-reviewed journal: Ashraf et al. (2021)

Challenges Faced by Organizations in Adopting Power SAS

Organizations face several difficulties in incorporating Power SAS into their processes, summarised in Table 2 and discussed below.

High Initial Costs: Businesses frequently encounter substantial cost obstacles when implementing Power SAS. Software licensing, infrastructure upgrades, and staff training can be costly (Morgan and Ngwenyama, 2015). In practice, cost is a commonly cited reason many utilities delay SAS adoption: new substations below the extra-high-voltage class are often still built without an SAS, and older substations frequently go without retrofits, owing to the substantial cost implications involved (Asian Journal for Convergence in Technology, 2021). Utilities have explored lower-cost implementation approaches for smaller or older substations to make adoption more affordable, though the scale of investment required can still be unaffordable for smaller operators, preventing them from using the system even where it would offer advantages (Asian Journal for Convergence in Technology, 2021).

Lack of Technical Expertise: A significant degree of technical proficiency is required to use Power SAS effectively. Utilities and institutions frequently face internal skills shortages and steep learning curves when adopting IEC 61850-based automation, particularly around process bus configuration, data modelling, and changes to established engineering workflows (PAC World, 2026). This shortage of expertise can result in the system's capabilities being underutilised, reducing its overall effect on organizational performance; organizations that lack the necessary skills may therefore be unable to fully realise the technology's potential.

Resistance to Change: The transition to Power SAS may encounter resistance from staff accustomed to conventional, hard-wired protection and control methods (Alvarez-Alvarado et al., 2022). In North America specifically, adoption has lagged behind Europe and Asia, with hesitancy attributed to unfamiliarity with the standard, concerns over reliability, and resistance from field technicians accustomed to traditional methods (Burns & McDonnell, 2025). Management and staff may be hesitant to adopt new technologies due to unfamiliarity, fear of disruption, or scepticism about the technology's benefits (Edwards, 2019), and this resistance can slow adoption and limit Power SAS's ability to support organizational objectives.

Integration with Legacy Systems: Many organizations rely on older, hard-wired substation protection and control systems that may not be compatible with Power SAS. Utility deployments of IEC 61850-based automation have documented real integration challenges, including impacts on existing operational systems such as energy management systems and data historians, which required new interfaces to accommodate the additional data generated by the automation system (EPRI, 2020). The time, cost, and effort required to integrate the system with existing infrastructure remains a significant obstacle to smooth adoption (Bhatt, 2023), and utilities are typically advised to secure stakeholder buy-in early and identify affected systems before beginning implementation (EPRI, 2020).

Data Security and Privacy Concerns: Power SAS must implement strong security measures when processing critical power system data, particularly given growing interconnection and smartgrid technology, to guard against cyber risks and unauthorised access (Achaal et al., 2024). The digitalisation of substations increases their exposure to cyberattacks; denial-of-service attacks against IEC 61850 messaging, for example, have been shown to significantly delay or block the GOOSE and SMV traffic that protection functions rely on, underlining the need for robust cybersecurity measures in any SAS deployment (Ashraf et al., 2021).

Ethical and Regulatory Concerns: Ensuring compliance with data-protection regulations and addressing ethical issues around data use is a crucial, though sometimes overlooked, part of the adoption process (World Bank, 2023). Organizations implementing Power SAS must also navigate related ethical and legal considerations.

Table 2: Institutional Barriers to Power SAS Adoption

Barrier	**Nature of the barrier**	**Evidence type / Key sources**
High initial costs	Licensing, infrastructure, and training costs can be prohibitive, especially for smaller substations/operators.	Peer-reviewed (Morgan and Ngwenyama, 2015); peer-reviewed case study (Asian Journal for Convergence in Technology, 2021)
Lack of technical expertise	Skills shortages and steep learning curves slow adoption of IEC 61850-based automation.	Industry publication (PAC World, 2026)
Resistance to change	Staff familiarity with legacy tools and regional unfamiliarity with the standard slow adoption.	Peer-reviewed (Alvarez-Alvarado et al., 2022); industry analysis (Burns & McDonnell, 2025); academic thesis (Edwards, 2019)
Integration with legacy	Compatibility and back-office integration demands complicate adoption alongside existing	Institutional case study (EPRI, 2020); practitioner (Bhatt, 2023)

systems	infrastructure.	
Data security and privacy	Digitalisation of substation communications increases exposure to denial-of-service and other cyberattacks.	Peer-reviewed (Achaal et al., 2024); peer-reviewed (Ashraf et al., 2021)
Ethical and regulatory compliance	Data-protection regulation and ethical data-use considerations must be addressed.	Institutional report (World Bank, 2023)

Strategies for Integrating Power SAS into Training Curricula

Several strategic approaches for integrating Power SAS into training curricula emerge from the literature, summarised in Table 3.

Equipment vendors offer structured training programs covering substation automation products and standards; for example, Siemens' Power Academy and GE Vernova's Protection & Control and Substation Automation learning portfolio combine self-paced e-learning, virtual classroom sessions, and hands-on workshop training (Siemens, n.d.; GE Vernova, n.d.). Higher-education institutions can access relevant resources by forming alliances with equipment vendors and organizations in the power sector, gaining access to training material and real-world case studies. However, many institutions lack the facilities to run dedicated automation laboratories at scale (Khmelnytska and Tkachenko, 2023); self-paced e-learning and virtual training modules can allow learners to build foundational knowledge remotely before undertaking hands-on laboratory work.

Faculty training programs are crucial for ensuring that teachers are properly prepared to teach substation automation concepts; vendor-run courses and university-industry partnerships can support this preparation (Siemens, n.d.). Rather than developing entirely new courses, institutions may embed Power SAS within existing electrical engineering and power system curricula — as seen, for example, in dedicated grid-digitisation and automation courses now offered at graduate and undergraduate level (George Mason University, 2026; University of Washington, n.d.) — using it to create simulation-based projects that let students model real-world substation scenarios and strengthen hands-on learning (Junaidi and Rahmaniar, 2022), an approach that helps close the gap between theoretical understanding and real-world implementation (Bompard et al., 2023).

Investment in seminars and training courses helps familiarise teachers with the system's features and applications (Annuš, 2024). Dedicated substation automation laboratories such as one designed and commissioned specifically to address the shortage of personnel skilled in IEC 61850based tools allow both students and working engineers to gain hands-on experience with real intelligent electronic devices in a realistic environment (Victoria University, n.d.). Students can work on practical problems that replicate substation challenges, such as protection coordination or DER integration, an approach that builds problem-solving skills and workplace readiness (Chiou et al., 2013). Blending digital tools with conventional teaching methods can further strengthen the learning process (Lisachenko et al., 2017), and an interactive virtual substation simulation training system has recently been shown to measurably improve students' practical competence compared with conventional teaching alone (Wang et al., 2026).

Effective integration requires adequate resources hardware, IEDs, and technical support so institutions should allocate sufficient funding and establish dedicated laboratories equipped to support simulation-based learning, as demonstrated by existing SAS training laboratories built specifically for this purpose (Victoria University, n.d.). Simulation and virtual-training performance metrics can help institutions assess student comprehension and identify areas for improvement (Steenhuis et al., 2011; Wang et al., 2026), sustaining the effectiveness of Power SAS integration over time. Certification in substation automation competency, whether through vendor programs or professional training courses, can also improve learners' job prospects and give them an advantage in the labour market. Ultimately, successfully embedding Power SAS in power system training programs supports the goal of closing the gap between theory and practice.

Table 3: Strategies for Curricular Integration of Power SAS

Strategy	Description	Evidence Type / Key Sources
Vendor–institution partnerships	Alliances with equipment vendors and power-sector organizations provide access to training materials, technical resources, and industry case studies.	Vendor training programs (Siemens, n.d.; GE Vernova, n.d.)
Remote/self-paced access	E-learning and virtual training modules enable learners to develop foundational knowledge without requiring substantial investment in physical hardware.	Institutional (Khmelnytska & Tkachenko, 2023)
Faculty training and curriculum embedding	Vendor courses and dedicated grid-automation courses prepare instructors and facilitate the integration of automation content into existing curricula.	Siemens (n.d.); George Mason University (2026); University of Washington (n.d.)
Embedding within existing curricula	Automation concepts are integrated into existing power-system courses rather than being taught exclusively as standalone modules.	Peer-reviewed (Bompard et al., 2023)
Simulation-based, hands-on projects	Students use simulations and practical projects to address real-world substation problems, such as protection coordination and distributed energy resource (DER) integration.	Peer-reviewed (Junaidi & Rahmaniar, 2022; Chiou et al., 2013)
Blended digital and traditional teaching	Combining digital and virtual training tools with conventional classroom instruction can strengthen learning outcomes.	Peer-reviewed (Lisachenko et al., 2017; Wang et al., 2026)
Dedicated resourcing and laboratory facilities	Institutions allocate funding for hardware, intelligent electronic devices (IEDs), technical support, and dedicated automation laboratories.	Institutional lab case study (Victoria University, n.d.)
Performance-based assessment	Simulation- and virtual-training performance metrics are used to evaluate student comprehension and identify areas for improvement.	Peer-reviewed (Steenhuis et al., 2011; Wang et al., 2026)
Competency certification	Certification in substation automation competencies can strengthen graduates' technical credentials and employability.	Vendor/professional training programs

CONCLUSION

Power SAS (Substation Automation System) is an effective technology that meaningfully supports the development of power system skills. Learners may improve their problem-solving abilities, gain a stronger grasp of power system dynamics, and become better prepared for the changing needs of the energy industry by using its capabilities. Power SAS also helps educational institutions produce graduates who are more capable and employable, by bridging the gap between academic theory and industrial practice. Although there are difficulties in implementing Power SAS including budgetary limitations and resistance to change, these issues can be addressed through focused strategies. Industry engagement, faculty training, and resource allocation are essential to successful implementation, and the tool's impact can be further increased by encouraging multidisciplinary research and learning.

The following recommendations are proposed based on the findings of this study to maximise the application of Power SAS in power system skill development:

- The purchase and upkeep of Power SAS licenses should be supported by subsidies, grants, and financing from government, academic institutions, and industry players.
- Institutions can improve proficiency in Power SAS usage and application by investing in seminars, certification courses, and faculty development initiatives.
- Institutions should collaborate with industry participants to offer special events, apprenticeship opportunities, and practical examples, so that training remains aligned with industry demands.
- Organizations should keep their Power SAS installations up to date to take advantage of the newest features and improvements, for more effective power system simulations.
- Organizations and businesses using Power SAS should implement strong cybersecurity measures to safeguard sensitive information and ensure secure operation.
- Power SAS should be incorporated into electrical engineering and power systems courses, enabling students to gain practical experience through simulation projects and laboratory activities.

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