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Integration and Innovation of Smart Substation Technology in University Electrical Engineering Education

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Abstract: *This paper advocates for the integration of the IEC 61850 standard within electrical engineering curricula, highlighting its critical role in modern substation automation. An innovative teaching methodology is proposed to demystify the IEC 61850 standard's complexities through comparative analysis, visualization techniques, and practical application. The method is designed to enhance students' intuitive understanding of smart substations and to prepare them with industry-relevant skills. Addressing the educational challenges of integrating theoretical knowledge with practical experience, the paper emphasizes the need for strategies that bridge this gap. The methodology's effectiveness lies in its ability to deepen students' comprehension of the IEC 61850 standard, equipping them to meet the evolving demands of substation automation. The conclusion underscores the imperative for educational strategies that align with technological progress and industry requirements.*

Keywords: *IEC 61850 Standard, Smart Substation Automation, Electrical Engineering Education, Teaching Methodology, Curriculum Integration*

1. Introduction

Smart substations represent the integration of advanced technologies such as information and communication technology (ICT), automation, and power systems engineering. They are pivotal in modernizing the electrical grid, enhancing reliability, efficiency, and sustainability. Incorporating smart substation technology into university electrical engineering curricula prepares students for the future workforce. It emphasizes the integration of interdisciplinary knowledge such as electrical engineering, computer science, and data analytics, as well as encouraging students to explore new solutions to existing challenges in the power systems through hands-on experience with smart grid technologies and systems. The IEC 61850 standard emerges as a cornerstone of international communication within the realm of substation automation, underpinning the sophisticated engineering processes that define intelligent substations[1-3]. As its adoption in the industry grows, the knowledge encapsulated within IEC 61850 is progressively being integrated into the academic curriculum of substation automation. The standard employs an object-oriented modeling approach, which, while powerful, introduces a level of abstraction in its definitions and concepts that adds to the complexity of the material.

For students who typically lack hands-on engineering experience, this complexity can pose a significant barrier to mastering the subject matter. The transition from traditional to smart substations is marked by notable shifts in network architecture and communication protocols, which further compounds the learning curve. Traditional teaching methods, which often focus on the theoretical and abstract, have been found insufficient in delivering a clear and intuitive grasp of the IEC 61850 standard to students.

In light of these challenges, this article introduces an innovative teaching methodology that leverages comparison and visualization techniques. This approach is designed to enhance students' comprehension and engagement with the course material. By contrasting smart substations with their traditional counterparts, students are equipped with a framework to quickly identify and understand the distinctive features of modern substation technology.

Moreover, the visualization of information flow, particularly the signals transmitted via optical fibers, provides students with a clear and intuitive model of how data moves within an intelligent substation. This visual representation serves as a powerful tool for demystifying the abstract concepts of the IEC

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61850 standard.

By intertwining these pedagogical strategies with real-world engineering scenarios, the proposed teaching method not only sparks students' interest but also facilitates a deeper and more practical understanding of the course content. The result is an educational experience that is both engaging and grounded in the practical application of IEC 61850, preparing students to meet the demands of the evolving field of substation automation.

The evolution of substation automation has been significantly propelled by the adoption of the IEC 61850 standard, which has emerged as a cornerstone for intelligent substation engineering. As the power industry increasingly relies on this standard to enhance interoperability and streamline operations, it becomes imperative for electrical engineering education to adapt and prepare students for the challenges of modern substation technology. This paper explores the critical need for the integration of the IEC 61850 standard into university curricula and presents an innovative teaching methodology designed to address the complexities inherent in this advanced standard.

2. Evolution of IEC 61850 and Its Integration into Education

In this section, a historical perspective on the development of the IEC 61850 standard is provided, along with an analysis of its progressive integration into educational curricula. The challenges and opportunities presented by this integration are discussed.

The emergence of IEC 61850 has been a significant milestone in the evolution of substation automation, addressing a landscape that was previously fragmented by over one hundred different protocols worldwide. Protocols such as Fieldbus, Modbus, Profibus, DNP, IEC 60870-5-103, and IEC 60870-5-101/4 were all in use before the standardization efforts led by the International Electrotechnical Commission (IEC).

The 1990s marked a significant push towards the development of smart grids, catalyzed by initiatives such as the Smart Grid Interoperability Panel and the Smart Grid European Technology Platform, which sought to harmonize communication protocols within the power sector. These efforts aimed to harmonize the diverse communication protocols within the power system.

A pivotal moment occurred in 2005 when the IEC Technical Committee 57 (TC57) introduced the first edition of IEC 61850, signaling a move towards greater interoperability and standardization. This was followed by the release of the second edition in 2010, which extended the standard's application beyond individual substations to encompass interactions between substations and other domains within the power system.

As the power system's demand for digital intelligence has grown, so too has the IEC 61850 standard evolved. Continuous improvements have led to its broader application, reflecting the industry's need for a unified communication framework. The standard has also been proactive in addressing the renewable energy sector, with the release of edition 2.1 in 2018, demonstrating its adaptability and commitment to technological advancement. The overarching ambition of IEC 61850 is to streamline communication protocols across all segments of the power system, embodying the concept of "One World, One Technology, and One Standard." This unification is intended to simplify operations, enhance interoperability, and foster innovation.

The integration of IEC 61850 into the curriculum of university science and engineering departments is a reflection of its growing importance. However, the transition has not been without challenges. Students typically enter these courses without practical engineering experience, and even instructors may not be well-versed in the real-world applications of IEC 61850. This gap between theoretical knowledge and practical application underscores the need for educational strategies that bridge the divide, such as hands-on training, industry collaboration, and curriculum updates that reflect the latest industry practices.

To address these challenges, educators and institutions must strive to provide students with opportunities to engage with the IEC 61850 standard in a manner that is both practical and relevant to the industry's needs. This could involve incorporating case studies, simulations, and guest lectures from industry professionals to enrich the learning experience and prepare students for the realities of working with this critical standard in substation automation.

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3. Enhancing Smart Substation Education: Methodology and Application

The paper presents a detailed description of the innovative teaching methodology, which includes visualization of information flow, and practical application through case studies and simulations.

At the onset of the course, educators have the opportunity to lay a foundational understanding for students regarding the three-tiered structure of intelligent substation automation systems. By drawing comparisons to traditional substations, teachers can help students form an initial conceptual framework of the system's architecture. This approach not only highlights the evolution from conventional to modern practices but also underscores the functional differences that define smart substations.

In addition to the structural overview, instructors can delve into the specific communication networks pivotal to smart substations, such as the Sampled Measured Values (SMV) and Generic Object Oriented Substation Event (GOOSE) networks. These networks are predominantly utilized for the transmission of analog signals and switching or event-based quantities, respectively. By introducing these concepts early on, teachers provide students with insight into the data flow and communication mechanisms that are integral to the operation of smart substations.

To facilitate a clear and accessible learning experience, the basic structural components of both smart and traditional substations can be presented side by side. This comparative analysis allows students to discern the differences and similarities between the two systems efficiently. The juxtaposition of these structures serves as a practical tool for students to grasp the unique characteristics of smart substations, such as the integration of advanced automation, digital communication, and enhanced monitoring capabilities.

Through this methodical introduction and comparison, students are equipped with a solid grounding in the fundamental concepts and structures of substation automation. This knowledge base is essential for their journey through the curriculum, enabling them to build upon these initial understandings as they delve deeper into the complexities of smart substation technologies and applications.

The virtual circuits of smart substations are fundamentally different from the electrical circuits that are traditionally implemented with cables. When it comes to expansion and renovation projects, the abstract nature of virtual circuits poses challenges, as they cannot be easily verified with conventional tools such as multimeters. Moreover, the process of altering and safeguarding configuration files, such as the Substation Configuration Description (SCD), is more complex, increasing the likelihood of errors occurring within the virtual circuits. Consequently, it is essential in the educational process to concentrate on summarizing and encapsulating the virtual circuits that are implicated during the expansion and reconstruction of line and main transformer bays.

Figure 1 depicts the relevant SV and GOOSE virtual circuits for a 220kV line. In this figure, the SV circuits are depicted with solid lines, whereas the GOOSE circuits are indicated by dashed lines. The diagram encompasses five modules: Line Merge Unit (LMU), Bus Merge Unit (BMU), Bus Protection Unit (BPU), Line Protection Unit (LPU), and Line Intelligent Terminal (LIT). In the 220kV smart substation, the LMU and BMU perform critical roles. The LMU is responsible for data acquisition from line sensors, processing and analyzing this data, consolidating signals, monitoring line conditions, and detecting faults. On the other hand, the BMU integrates data from the bus, facilitates network communication, coordinates bus protection, controls operations such as circuit breaker functions, and displays the status of the bus and connected equipment. These units enhance the substation's monitoring, control, and protection capabilities, ensuring greater reliability and stability through their advanced data processing and communication functions.

As can be seen, smart substations focus on synchronization of SV sampling, phase checking practices, ensuring proper connection and testing of busbar protection, utilizing GOOSE networks to improve operational efficiency, employing dual configurations to improve reliability, as well as implementing direct sampling to quickly address faults, and improving grid stability and operational efficiency through digital communications and smart devices. The following aspects require special attention.

1) **SV Sampling and Zero-Sequence Voltage:** The potential omission of the rated delay in SV sampling and the connection of zero-sequence voltage in the bus voltage measurements. It refers to the response time that sampling devices need to consider when recording voltage changes. Correctly accounting for the rated delay is crucial to ensure that the sampling data is synchronized with the actual voltage waveform. On the other hand, in the measurement of bus voltage, to measuring the three-phase voltages, it is also necessary to measure the zero-sequence voltage, which is the vector sum of the three-phase voltages. The measurement of zero-sequence voltage plays an important role in fault diagnosis,

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accurate operation of ground protection devices, and monitoring the symmetry and stability of the system. Normally, the zero-sequence voltage is zero, but a ground fault will cause it to change.

2) **Phase-Checking with A-Phase Voltage:** The practice of using only the A-phase voltage for phase-checking in electrical systems is a simplified method for verifying phase sequence accuracy. It's essential for ensuring the proper operation of three-phase equipment, balancing the system, and facilitating maintenance. It is key to preventing operational disruptions due to phase-related issues, making it an indispensable part of electrical system management.

3) **Trip Jumper Relay (TJR) Connection in Bus Protection:** Ensuring the correct connection of the virtual terminal of the tripping TJR in bus protection is crucial for the reliable operation of the electrical system. This involves verifying that the TJR is accurately linked within the bus protection scheme to manage and control the tripping signals effectively. Additionally, conducting a bus differential transmission test is essential to confirm the integrity and proper functioning of the connections. This test helps ensure that the protection system can detect and respond to faults accurately, maintaining the stability and safety of the power network.

4) **GOOSE Network in Merge Unit:** The merge unit employs a GOOSE network for voltage switching operations involving the isolating switch, offering a distinct advantage over the direct sampling technique used in bus protection. This networked approach ensures swift communication for timely fault detection and system response, boosting substation automation efficiency.

5) **Dual Setup in 220kV Line Bay:** In the 220kV line bay, dual configurations are standard for protection, merging units, and intelligent terminals, with a critical design feature being the parallel connection of the closing outputs between Set A and Set B of the intelligent terminals.

6) **Direct Sampling and Tripping of SV and GOOSE Signals:** Apart from the isolating switch for voltage switching in the merge unit and GOOSE network links responsible for fault initiation, remote tripping, and interlocking between line and bus protection, direct sampling and tripping are implemented for all other SV and GOOSE signals. This setup necessitates the construction team to confirm the optical cable paths and the integrity of spare fiber splicing.

7) **Advanced Fault Management in Smart Substations:** A significant departure from conventional stations, smart substations have streamlined their operation by eliminating the need for three-phase malfunction initiation on the line. This advancement reflects a move towards more efficient and sophisticated fault detection and management systems that can identify and address issues more precisely and rapidly. The reliance on advanced technologies and algorithms allows for quicker isolation of faults and a reduction in the potential impact on the overall grid stability. This innovation is part of a broader trend towards enhancing the resilience and responsiveness of power systems, leveraging the capabilities of digital communication and intelligent electronic devices within the smart grid framework.

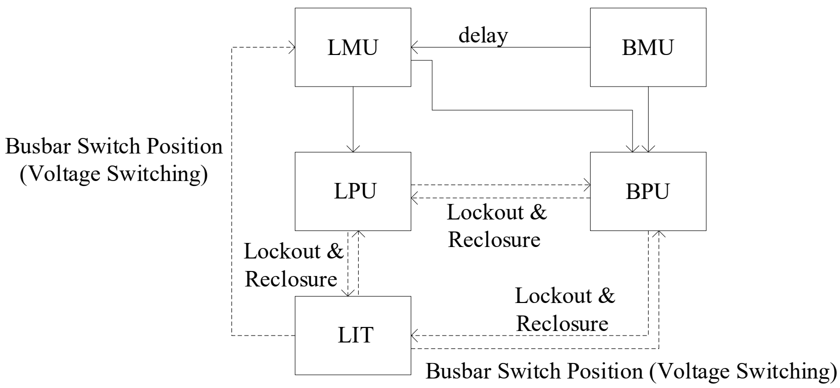

Figure 1: SV and GOOSE virtual circuits for a 220kV line

These measures are distinct from conventional methods, designed to clarify and streamline the original text for enhanced readability and comprehension. Such innovative teaching methods can assist students in effectively engaging with the study of smart substation technology.

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4. Conclusions

The pedagogical approach outlined in this paper effectively bridges the theoretical-practice divide, equipping students with the acumen to navigate and master the complexities of smart substation technology, thus preparing them for the dynamic landscape of the modern power industry. By focusing on comparison, visualization, and practical application, the methodology fosters a deeper understanding of IEC 61850 and equips students with the skills necessary to meet the demands of the modern substation automation field. The paper concludes with the necessity for ongoing educational strategies that keep pace with technological advancements and industry needs.

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