Exploring Digital Substation: A Comprehensive Overview

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Abstract: ***Digital substations are the next generation of power substations that influences modern digital technology to transform the way electricity is transmitted and distributed. It is transforming the electrical power systems industry, implementing advanced technologies such as the IEC 61850 standard and Ethernet communication, offering a wide range of benefits such as enhanced reliability, reduced maintenance costs, and improved efficiency. This paper provides a comprehensive overview of digital substations covering their definition and levels. In addition, real-world case will be addressed as an example of implementing digital substations. The paper also explores the opportunities associated with the implementation of digital substations in real-world case studies. However, the implementation of digital substations also poses challenges that must be addressed to realize the full potential of this technology. Overall, digital substations represent a significant shift in the power industry towards a more advanced, intelligent, and sustainable future.***

Keywords: Digitalization, Power Substation, Process Level, Bay Level, Station Level, system level, IEC 61850

1. Introduction

Digital substations are the modern version of current traditional substations that use digital technology to improve the efficiency, reliability, and safety of power transmission and distribution [1] [2]. These substations use sensors, communication networks, and intelligent electronic devices (IEDs) allowing remote monitoring and control of the electrical systems [1]. Digital substations represent a significant shift in the power industry towards a more advanced, intelligent, and sustainable future.

The copper cables are replaced by fiber optics (figure 1) [3] and conventional CTs are replaced by using optical CTs. These replacements will result in less transportation of materials [1] [4]. The use of digital technology will also benefit in reducing the time and cost by reducing operational expenses (such as installation, maintenance, and replacement [3]). For instance, the necessity to have regular physical maintenance will be reduced since using fiber optic cables will allow the real-time data transmission and, accordingly remote maintenance in support with IEC 61850 testing features. [1]

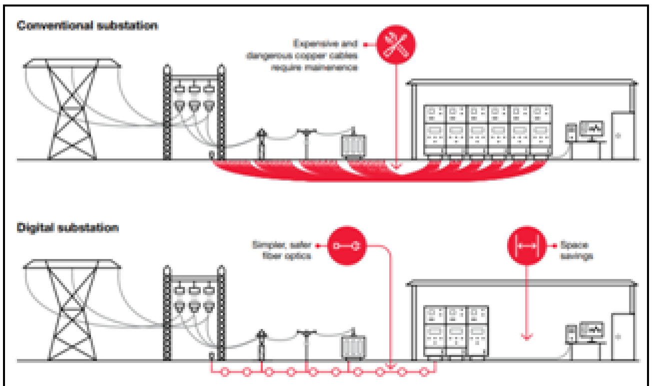

Figure 1: Digital Substations replace copper cables with fiber optic cables

Consequently, reducing maintenance will lead to increase the safety of the operators as result of less connections. The risk of electrical shock by replacing coppers or the harm caused by the unintentionally opened CT circuits during commissioning and site activities will be reduced [2].

Safety is not limited to humans but to the entire system security, too. Digitalization allows increasing the monitored data, which improves visibility of cybersecurity attacks. This helps the system to identify and mitigate the concerns faster before they accelerate and becomes more difficult [4].

Digital substations contribute to the environment by reducing the footprint since less space is required compared to conventional substations. Functions that were implemented by separate equipment can be incorporated in one device in the digital substations by using smart IEDs and sensors [1] [2].

2. Definition and Levels

Substations are the room that comprises the infrastructure of primary equipment, such as transformers, and secondary equipment, such as protection relays [3]. Based on IEC 61850 those substations already been adopting some digitalized solutions such as using digital relays and equipment. However, it is not yet operating as full digital substation solution. A full digitalized substation is the one which will adopt all levels of digitalization. The levels of a digital substation refer to the hierarchical structure that is used to organize the various components and devices within the substation. In a digital substation, the levels are defined based on the functions performed by the devices and the flow of data between them. The levels of a digital substation typically include the process level, bay level, station level, and system level. Each level has its own set of functions, devices, and communication protocols that enable the substation to operate efficiently and reliably. The below figure illustrates and compares the four levels in current and digital substation.

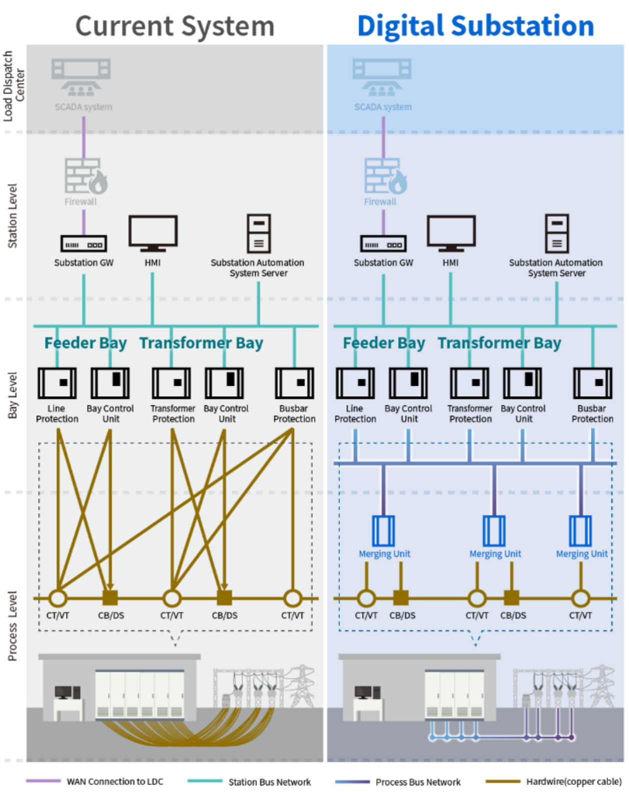

Figure 2: Comparison of levels in Digital Substation and Current Substations

a) Process Level

This is the lowest level in the hierarchy, where the primary equipment is located, such as transformers, circuit breakers, and sensors. The process level also includes the merging units that collect data from the sensors and convert the analog signals into digital signals[3].

b) Bay Level

The bay level is located above the process level and includes bay controllers, which act as interfaces between the process level devices and the station level devices. The bay controllers receive and process the data from the merging units and other devices in the process level, and transmit the information to the station level.

c) Station Level

The station level is the level above the bay level, where the data from the bay controllers are aggregated, processed, and presented to the higher-level control and management systems, such as substation automation systems (SAS) or energy management systems (EMS).

d) System Level

The system level is the highest level in the hierarchy and includes the control center, which is responsible for monitoring and controlling the overall operation of the digital substation. The control center receives and processes the data from the station level and provides the operator interface for the substation.

3. Overview on digital substation examples

Notable examples of such application is the DEWA (Dubai Electricity and Water Authority) digital. Let's explore these digital substation application in DEWA.

DEWA is one of the most innovative companies in the power industry. The organization's mission is to ensure a sustainable supply of electricity and water while preserving the environment for future generations. DEWA has consistently adopted new technologies and best practices to improve its services, reduce its environmental impact, and increase efficiency. the concept of digitally optimized substation (DOSS) is one of the notable initiatives which transmission division in DEWA has adopted. It's important to mention that DEWA has defined a "full digital substation" as a myth since a full digital substation includes nonconventional instrument transformers (NCITs), which are connected to merging units for analog-to-digital conversion and time stamping. The sampled values are then transmitted over an Ethernet network. However, despite these digital components, the fact remains that substations transport analog quantities of voltage and current, making the term "full digital substation" somewhat misleading [5]. Therefore, DEWA has developed an innovative DOSS design which has the following key features:

- Consistent substation design irrespective of the contractors/ OEMs.
- More efficient design approval process for new substation projects.
- Reduction in time required for project design approvals, testing & commissioning.
- Additional benefits such as reduction of maintenance cost, ease of operation and simplification of the substation design.
- Using conventional instrument transformers ensures that protection and control systems can be refurbished in future without the risk of needing to replace instrument transformers or possibly switchgear.

The design optimization focuses on integrating functions, digitizing signals, and utilizing advanced features of IEDs to enhance control and protection in the substation while reducing complexity and improving overall system performance [5].

The DOSS design offers substantial advantages to DEWA as a utility. The re-designed 132/11kV substations incorporate the following benefits:

- Protection & control functions are integrated into a single IED (BCPU1/2): Reduction of 15 IEDs, redundancy in control functions and 18 x control and protection panels removed.
- Hard wired interlocks are replaced with peer-peer GOOSE digital signals: Over 100km of copper cabling eliminated.
- All electromechanical relays were replaced with digital systems: Over 8000 devices were removed.
- Reduction in the number of current transformers: Total 258 units removed.
- Integrated busbar and feeder backup protection for 11kV network.
- Integrated tap change controller (AVR) into BMP IEDs: Panel with 3x controllers removed (digitized).
- Removal of 24x metering units on 11kV.
- Integrated digital fault recorders (DFR's): 3 x DFR panels removed.

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- Optimized SCMS system: 4 x SCMS panels, 5 x computers, 2 x monitors, 20 x network switches, 196 fiber optic cables, 4 x fiber optic patch panels, 1 x GPS clock removed.
- Virtual security, role based remote engineering access through virtual machine is achieved.

All the above will result in:

- The reduction in carbon emissions approximately 37 tons per year for 132/11kV substation due to annual energy saving of 53MWH.
- Reduction in substation building size by 133 m2.
- Savings of 7 million AED per substation due to reduced equipment.
- The new design utilizes, control and protection panels (CPP) developed in the UAE along with local manufacturer.

4. Challenges and opportunities

Digital substations are becoming increasingly popular in the power industry due to the many benefits they offer. However, they also present some challenges that need to be addressed to fully realize their potential. Here are some of the challenges and opportunities of digital substations:

a) Challenges

Cost and Investment

Despite all the costs and time that digital substation benefits to reduce, other costs need to be considered. Implementing digital substations requires significant upfront investments in technology, communication infrastructure, and equipment. The cost of upgrading existing substations to digital substations can be substantial.

Cybersecurity

Digital substations rely on networked communication systems, which can make them vulnerable to cyber threats. Protecting digital substations from cyber-attacks and ensuring the security of critical infrastructure is a major challenge [4].

Interoperability:

Digital substations involve multiple IEDs from different manufacturers. Ensuring seamless interoperability and integration between these devices can be challenging, especially if they use different communication protocols [6].

Data Management and Analytics

Digital substations generate large amounts of data from various sensors and devices. Managing and analyzing this data to extract actionable insights requires robust data management and analytics capabilities.

Skills

Operating and maintaining digital substations require specialized technical skills. Ensuring that personnel have the necessary knowledge and training to handle digital substation equipment and systems can be a challenge.

b) Opportunities:

Improved Monitoring and Control

Digital substations enable real-time monitoring of substation assets, allowing operators to detect and address issues promptly. This enhanced monitoring capability improves the overall reliability and efficiency of power systems [7].

Enhanced Grid Visibility

Digital substations provide detailed data on power flows, voltages, and other critical parameters. This visibility enables utilities to gain better situational awareness of their grid operations and optimize power flow management [8].

Remote Operation and Maintenance

Digital substations facilitate remote monitoring and control, reducing the need for physical inspections and maintenance. Remote operation and diagnostics can improve operational efficiency and reduce downtime [8].

Advanced Automation and Self-Healing

Digital substations enable advanced automation features, such as self-healing capabilities. Fault detection, isolation, and restoration can be performed automatically, minimizing service disruptions and improving power quality [9].

Overall, digital substations present both challenges and opportunities for the power industry. By addressing the challenges and leveraging the opportunities, utilities can modernize their infrastructure, improve operational efficiency, and enhance grid reliability.

5. Conclusion

In conclusion, digital substations are transforming the power industry by implementing modern technology for efficient electricity transmission and distribution. They offer enhanced reliability, reduced maintenance costs, and improved efficiency through advanced technologies like the IEC 61850 standard and Ethernet communication. Real-world case studies highlight successful implementation and associated benefits. Digital substations enable increased monitoring, control, optimized asset management. Challenges include infrastructure upgrades, system integration, and cyber security risks. However, the potential benefits outweigh these obstacles, leading to an advanced, intelligent, and sustainable power industry. Collaboration among governments, utilities, and stakeholders is crucial to overcome challenges, invest in research and development, and prioritize deployment. Embracing digital substations enables the creation of a resilient, flexible, and sustainable power grid that meets present and future needs.

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