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Substation Automation in Smart Grid

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Abstract -. *In the smart grid, substations play a significant role in distributing quality power to customers. The intelligence of substations equipment has drawn expanding consideration in the smart grids. Smart Substations are expensive and are challenging to keep up with since they are dispersed in one unit. The functionality optimization and device integration are significant points to be considered in the advancement of a smart substation. This paper reviews the proposed methods mainly based on IEC61850 Standard and communication technologies. The techniques to be assessed are like "three-layer, "SCADA-based substation "with ICS. These strategies manage applications, communication protocols, architecture, and information standards largely focusing on substation automation in transmission and distribution networks. The analysis shows that there is a great exertion from the Smart Grid key stakeholders to develop interoperability across the different components managing an electrical grid, from field processes to market exchanges, allowing the information flow to be more accessible and received across applications and domains, and creating opportunity for new applications in multiple domains*.

Key Words: Smart grids, substation automation, smart transmission and distribution, improved interoperability, standards, grid reliability.

1. Introduction

The conventional electrical grid has undergone essential changes with the introduction of the Smart Grids. Installation of end consumer smart meters distributed renewable power generation deployment, and interconnection of operation and information systems need new solutions that can intelligently monitor and administer the infrastructure.

Early substations include mechanical relays and meters that barely supported recording and had no method for correspondence. The fault recorders primarily captured the information in the form of paper charts, so reading and inspecting the information was not a distinct process. Lack of communication caused any maintenance or troubleshooting to be costly and lengthy due to personnel having to be forwarded to substations that were far away and hard to reach.

With the introduction of High speed, microprocessor-based Remote Terminals Units (RTUs) or Intelligent Electronic Devices (IEDs) are utilized for substation automation and protection. IEC 61850, introduced in 2003, establishes standard protocols for the communication and interoperability of the equipment. SAS is based on decentralized architecture and a bay-oriented and distributed intelligence concept, for security and availability reasons.

Substation automation for power distribution systems is designed to meet two competing design objectives. On one hand, power distribution systems got to be robust to get rid of power outages even in the presence of severe external disruptions, such as natural disasters, equipment breakdowns, or fluctuations in supply and demand. Accomplishing this goal needs redundant hardware and advanced control algorithms. On the other hand, such systems got to be economically viable and supply effective power consumption in corresponding to the newest “green society” trends. This goal requires less redundancy, but more flexibility, adaptability, and reusability of solutions as the electrical grid undergo a major modification with the introduction of the Smart Grid.

Beyond a specific definition, focused on stakeholders (e.g., The Smart Grids European Technology Platform), the smart grid should cover the entire power grid from generation., to the transmission and distribution infrastructure all aside down to a wide array of electricity consumers [1]. A well-designed smart grid initiative builds on existing infrastructure, provides a higher level of integration at the enterprise level, and has a long-term focus. It's not a one-off solution, but it's a change in the way utilities look at different technologies that enable both strategic and operational processes. The design, development, and deployment of smart grids are more important to meeting the ever-increasing demand for electricity [1].

The smart grid is a way to leverage the benefits of the entire application and break down silos of organizational thinking barriers.

2. SA Hierarchy Levels

The International Electrotechnical Commission (IEC) has published the IEC61850 standard, which enhances interoperability between substation equipment and enables the abstraction of communications services. It provides vertical and horizontal communication between devices at three levels:

1. Station level
2. Bay level
3. Process level

2.1 Station Level

Redundant PC-based HMI enables local station control through the MicroSCADA Pro software package, which includes a wide range of SCADA features. The station level includes station-oriented functions that cannot be implemented at the bay level [19]. For example, an alarm or event list related to the entire substation, a gateway for communication with the remote-control centers. A pledged master clock for the synchronization of all entities shall be provided [19].

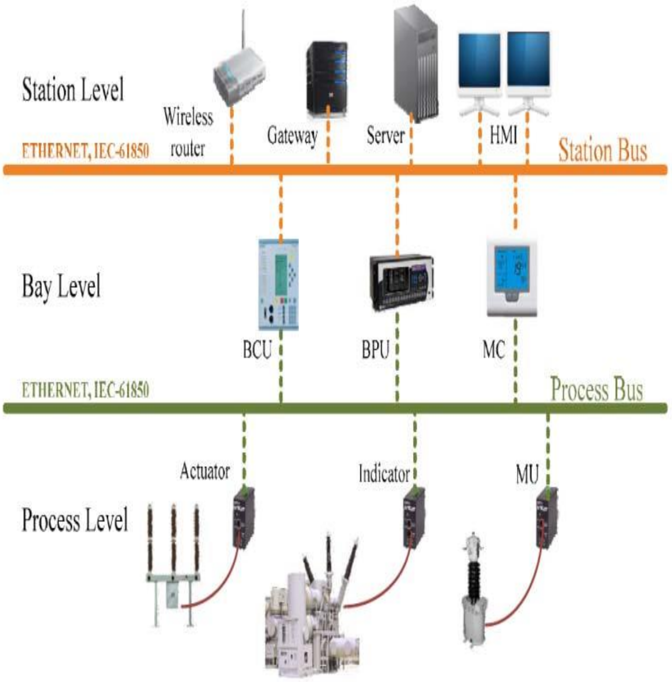

Fig -1: The hierarchy of a substation system with IEC 61850 in three levels [13]

2.2 Bay Level

Bay level comprises circuit breakers and isolators, earth switches, and instrument transformers. At bay level, the IEDs supply all bay level operations such as control (command outputs), monitoring (status indications, measured values), and protection. The IEDs connect directly to the switchgear without the need for additional interposing or transducers. Each bay control IED is independent of the other IEDs and its functionality is unaffected by failures that occur in other bay control units of the station [19].

2.3 Process Level

The process level consists of all substation devices that are routed with copper cables and connect bay-level IEDs used for control and protection using fiber optic cables [19].

3. Components of SA System

From a high-level system perspective, the smart grid can be considered to contain the following key components as illustrated in Fig.2

(i) A microprocessor-based intelligent electronic device (IED) that provides inputs and outputs to the system while performing primary control or processing services. Typical IEDs are protection relays, load monitoring and/or operator indicator meters, revenue meters, programmable logic controllers (PLCs), and power device controllers such as circuit breakers and transformers [1].

(ii) There may also be devices dedicated to specific functions of the SA system, such as transducers, position sensors, and clusters of interposing relays, which may additionally be present [1].

(iii) A dedicated Ethernet switch that connects wired devices such as computers, WiFi access points, PoE lights, and IoT devices to servers on an Ethernet LAN so that they can communicate with one another and to the internet [1].

(iv)There may also be a substation display or user's station (local HMI) connected to or part of the substation host computer (local server) [1].

(v) Common communication links to the outside world such as utility operations centers, maintenance offices, and engineering centers. Most SA systems are connected to SCADA (supervisory control and data acquisition) system master stations that handle real-time requirements for running utility networks from one or more Operations Centers [1].

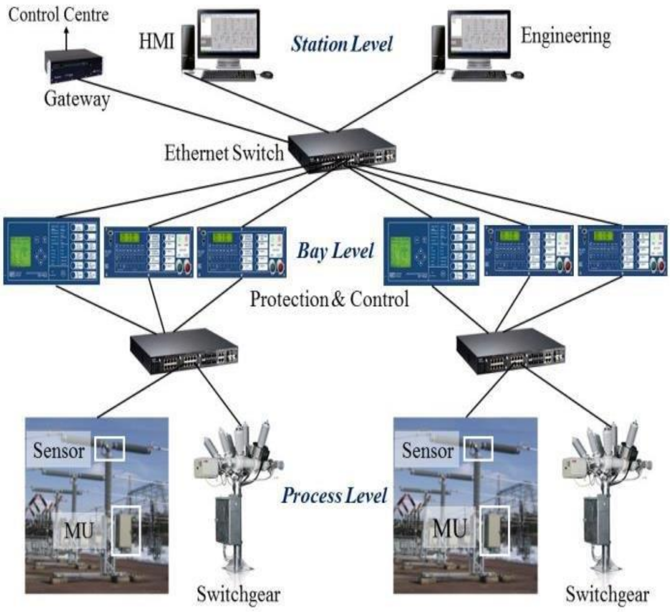

Fig -2: Substation automation system components[5]

Other utility users/services typically connect to the system through a firewall-protected DMZ connected to the SCADA system.

4. The Smart Grid Architectural Model (SGAM)

The Smart Grid Architectural Model (SGAM) Framework of Fig.3 aims at offering advance the design of smart grid use cases with an architectural approach allowing for a representation of interoperability viewpoints in a technology-neutral manner, both for the current implementation of the electrical grid and future implementations of the smart grid [1]. This is a 3D model that combines the dimensions of the five interoperability layers (business, features, information, communications, components) and the two dimensions of the smart grid layer, that is, Zones (representing a hierarchical level of power system management: process, fields, stations, operations, enterprises, and markets) and domains (covering the entire electrical energy conversion chain: mass generation, transmission, distribution, distributed power resources, and Customer premises) [1].

This work provides a state-of-the-art of relevant parts of the smart grid, primarily focusing on the transmission and distribution domain of substation automation, and related protocols, applications, and regulations related to the control center [1].

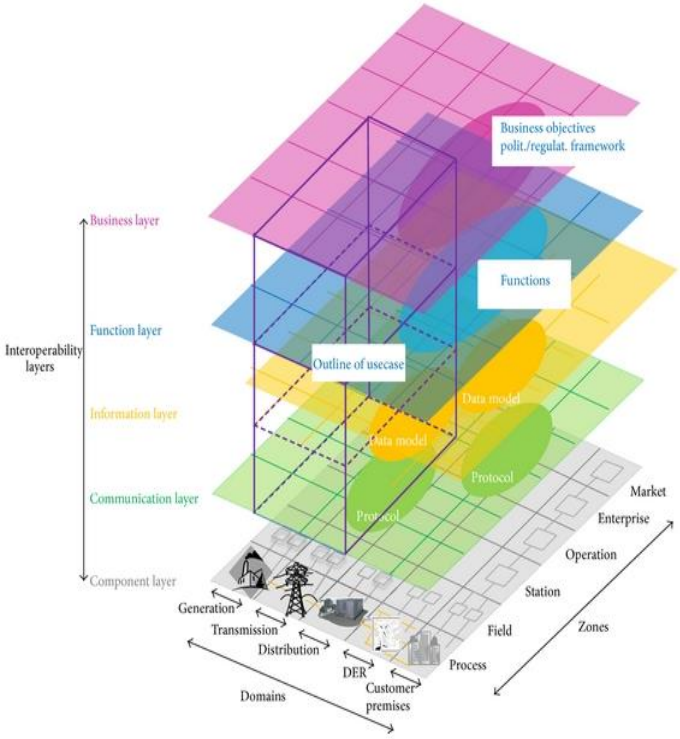

Fig -3: CEN-CENELEC-ETSI Smart Grid plane of domains and hierarchical zones [1]

All over the state-of-the-art analysis, it can be concluded that over there is an enormous effort from the smart Grid key stakeholders to enhance interoperability across the dissimilar components administrating an electrical grid, from field processes to market exchanges. Information can now flow more freely between applications and domains; potentially new applications have an opportunity that is no longer limited to a single domain [1]

5. Applications of SA in Smart Grid

The Smart Grid applications, such as the Integrated Voltage and Var Control (IVVC), Distribution Automation (DA) on Fault Detection Isolation and Restoration (FDIR), and Advanced Metering Infrastructure (AMI), Demand Response (DR), offer increased operational functionality for distribution substation and feeders [15]. To take full advantage of these new applications, a well-designed substation automation architecture provides an enhanced approach to adding new automation functions, providing a common communication infrastructure for feeder automation and AMIs, and offering provision for updates to the network model [15].

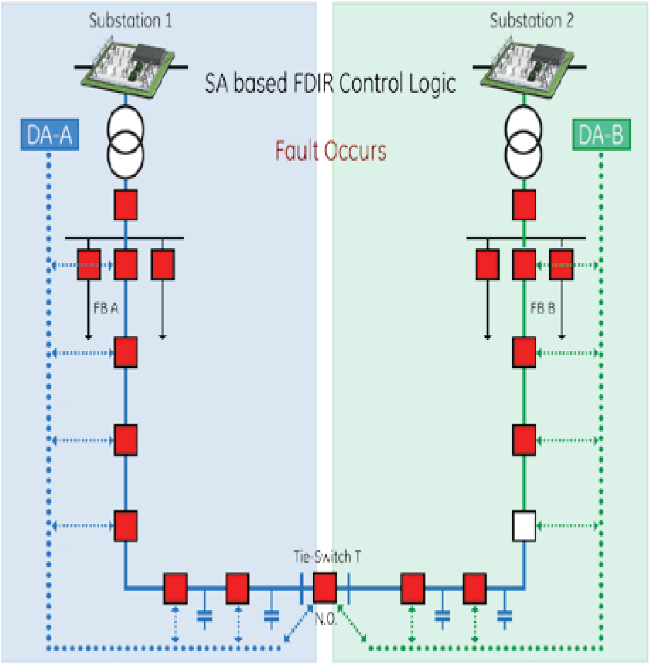

Fig -4: The logic of IVVC operation with the distributed DA system [15]

Fig.4 shows the logic of IVVC operation with the distributed DA system. If part of the substation 2 feeder circuit is supplied from substation 1 via a tie-switch, DA's IVVC logic can handle the case by exchanging data between the two substations. When the DA system in substation 1 detects a fault, the FDIR logic isolates the faulted section and immediately restores the operation of the upstream section, then calculates the total load of the downstream section and limits the load and voltage requirements for substation 2 to pick up. If substation 2 cannot handle the load for recovery, alternative approaches are used for evaluation, including using multiple sources, transferring the load from one feeder in substation 2 to another in substation 2 to increase reserve capacity, or implementing partial restore. Alternative approaches are appreciated, such as restoring as much load as possible to the operation.

Thus, the service scope of SA is expanded to the distribution feeder circuits. Because the feeders may have open ties to other feeders that are served by other substations, the DA system in a substation has to have the capability to support interoperability with the neighboring substations, becoming the real challenge to the distributed DA systems in SA [15].

5.1 IVVC, FDIR - DA Applications

DA is not only an important module in distribution grid operation, but also a hub that connects other important modules and applications in the smart grid such as the Demand Response Management System (DRMS), Advanced Metering Infrastructure (AMI), and Outage Management System (OMS). In general, DA systems include a variety of advanced applications such as Topology Processor (TP), Distribution Power Flow (DPF), Fault Detection, Isolation and Restoration (FDIR), Integrated Voltage/Var Control (IVVC), Optimal Feeder Reconfiguration (OFR), Distribution Contingency Analysis (DCA), Distribution State Estimation (DSE), Distribution Load Forecasting and Estimation (DLF/DLE), etc. Among them, FDIR and IVVC are the primary key applications for real-time operations and are therefore considered typical DA applications for a distributed approach that is simultaneously integrated into the SA solution [15].

IVVC is designed to improve the operational efficiency of distribution systems and serves the following basic objectives:

- Reduce feeder loss by auto-switching ON / OFF of the feeder capacitor bank [15].
- Maintain a healthy voltage profile under normal operating conditions [15].
- Reduce peak load by adjusting the output voltage by controlling the transformer tap settings in the substation and the voltage regulator in the feeder section, achieving automatic voltage regulation [15].

5.2 DR for Load Management

Demand Response (DR) is a relatively new feature of the smart grid. It is designed to directly manage a load of individual customers through two-way communication [15]. The potentially dispatchable part of the individual loads can be aggregated to take part in the system-wide economic dispatch for reduced peak demand and minimize energy costs. On the other hand, the dispatched number of load management can be distributed to the individual loads over disaggregation.

The processes of aggregation and disaggregation need efficient coordination with the DA system for optimal grid operation subject to the constraints on voltage and loading limits [15]. A similar process is needed in the recovery stage while returning to the normal operations for the individual customers. The DA functions in SA can also be designed to play an appropriate role, similar to a centralized DMS system [15].

5.3 AMI – End of Line Measurements

AMI systems are getting more and more attention about smart grids. In addition to the conventional roles in accounting and customer billing, the AMI data from the individual customers can also be utilized to make better the distribution entity in operation and management, containing the historical load profiles for more exact load forecasting and estimation, as well as the real-time information at the endpoints of feeders to feed DA functions[15].

The SA operation in distribution substations can include the key DA functions, which include IVVC and FDIR, and can incorporate the AMI and DR data in addition to improving the operation performance [15]. A general review of the conventional SA functions is presented and the extended SA functions in distribution substations are discussed with AMI, DR, and DA functions incorporated in Smart Grid operation [15].

6. Advantages of SA for the Smart Grid

The latest SAS is smarter with software-enabled devices, digital sampling, and seamless communication networks. These systems provide useful information for smart grid applications and components. This information includes measurements for metering, protection, and a wide range of control applications. Reliable construction and use of these systems require ensuring reliability, including safety and security [20].

In addition, smart substations got built-in control and automation capabilities. This dual capability reduces the opportunity for communication failures and the effects of power outages and can decrease development and maintenance costs [20].

The smart grid can use SAS functionalities to rapidly deploy multiple services and functions in transmission and distribution networks and control centers. The function is mainly to protect the network of connected renewable energy resources. Therefore, the grid will be scalable with these new SAS features. The following points highlight the main benefits of the evolution of the smart grid.

6.1 Accessibility of Massive Data for Metering and Measurement

Digital measurement and metering are available in modern SAS systems to provide accurate information about the state of the grid when these parameters are collected at the regional or national level. Substation status data availability also helps to connect or disconnect any energy source according to a demand response scheme [20]. The SV (Sampled Values) service sends analog measurements values in digital format, and SVs can send digital device measurements such as currents and voltages embedded in multicast Ethernet frames to SAS devices. A good example of this communication service is sending data at a specific sampling rate, for example, 80 samples/cycle with a 50 or 60Hz cycle. According to the standard, protection, automation, and coordination need to reverence time-critical constraints to make better reliability, e.g. accurate time synchronization of this sampling mechanism to avoid security issues [20].

6.2 Readiness of Data for Maintenance

Network maintenance should benefit from up-to-date substation data, for example, the IEC 61850 object model provides records containing the status of devices at many levels of substations. Generic Object-oriented Substation Events (GOOSE), defined in IEC61850 Part 7-1, is a high-speed message for communicating status and event changes. GOOSE datasets are embedded in Ethernet frames with priority tagging capabilities to improve time-sensitive priority requests [20]. These messages can be routed externally of the substation to supply helpful information for maintenance planning and follow-ups. These datasets assist to schedule preventive maintenance policies and extending the life of grid assets (e.g. Switchgears, transformers, and capacitors). Another important dataset is the communication network and interfaces status that can provide assistance to diagnose failures and differentiating between cyber and physical ones. Testing can be accomplished with these datasets moreover automatic diagnostics shall aid disclose hidden failures [20].

6.3 Estimation Overall Grid Status

Data collected locally from modern smart substations via routed messages (routed GOOSE and SV) helps to manage real-time protection and control strategies in large power grids [20]. Therefore, the overall state of the grid can be estimated before the appearance of reliability issues, such as cascaded failure or blackouts. In addition, grid expansion can be planned seamlessly utilizing the status information from SAS [20].

6.4 Real-time Monitoring of Electrical Network

The digital sampling-related parts, of the IEC 61850 standard, provide recommended sampling rates to draw a useful shape of the grid [20]. These samples represent the amount of frequency, current, and voltage that is used to determine status and metering values. With additional data from generators, power plants, renewable resources, and other DERs (Distributed Energy Resources), the Control Center can automatically provide detailed information about the grid. Therefore, the reliability of the electrical power service can be monitored in real-time [20].

7. SA Security and Regulation

Security in Smart Grids is a critical factor as interruptions in these systems can lead not only to the destruction of expensive equipment but also to interruption of serious operations that can include significant risk to the health and safety of human lives, thoughtful damage to the environment, and financial issues such as production losses and negative impact to a nation's economy[1].

The vulnerabilities disturbing the SCADA system regard mainly the following equipment [1].

1. IEDs and RTUs in the substations;
2. Substation LAN and firewall;
3. Communication network between substation and control center;
4. SCADA LAN and firewall;
5. Corporate (office) LAN and firewall;

Different regulatory mandates exist or are arising that require energy utilities to secure, monitor, and manage their critical sites and data networks by regulatory requirements and standards. These vary in granularity and rank, positioning from process-oriented to technical standards [1].

7.1 Security Threat in SA

Fig.5 represents an outline of potential targets for cyber-attacks (indicated by yellow exclamation marks) on the communication infrastructure of SCADA frameworks [1]. The primary issue in most of the existing systems derives from the fact that SCADA frameworks were not intended to be associated with the external organization foundation and thus security perspectives were not considered during the development phase [1]. The messages that IEDs exchange with the outside world are often transmitted over communication channels that are potentially open to eavesdropping or active intrusions [1]. An enormous possible threat to these frameworks is gotten from unauthorized users on the corporate channel or any other network that has an association with the SA [1].

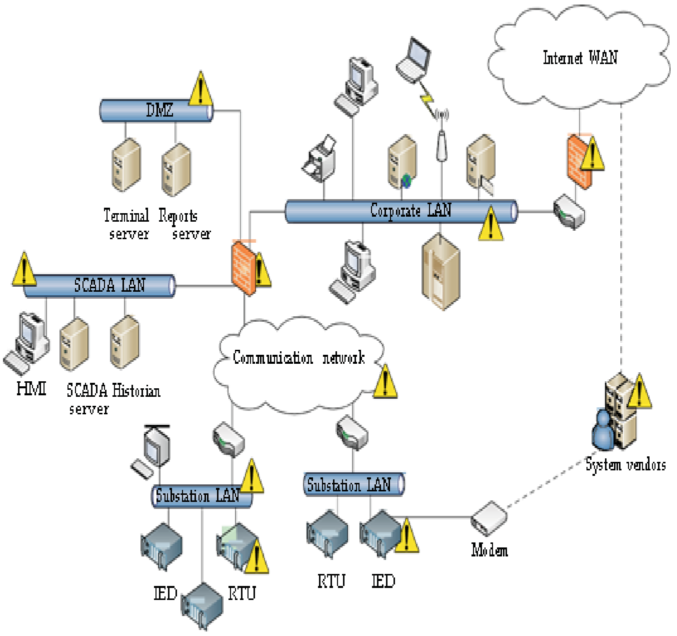

Fig -5: The SCADA system vulnerabilities [1]

7.2 Security Measures in SA

The initial phase in securing substation assets is separation from the SA system network by utilizing suitable firewall rules and other known cyber-security measures [1]. Assuming remote innovation is sent at the substation, it can make another assault vector if no appropriate safety efforts, for example, access control and encryption are in place[1].IEEE Standard 1402-2000 recognizes and arranges the sorts of "intrusions" into a substation and examines some security techniques to be taken on for moderating risks[1]. NERC in "Security Guidelines for the Electricity Sector" has developed a comprehensive set of guidelines methods to be applied in safeguarding the electric infrastructure systems [1].

8. CONCLUSIONS

Conventionally, SA has been focused on automation functioning for instance monitoring, controlling, and gathering information inside the substation. This is a narrow margin to allow effective control of the automated equipment inside the substation fence, but the automated feeder devices cannot be used effectively. The smart grid can extend the distribution stations in the SA system to include the automated feeder devices distribution circuits supplied by the substation. The noticed improvements in the Smart Grid domain raise several security perspectives which were discussed and most likely will acquire significance in the future.

In this paper, an attempt was made to give an overview of important smart grid-related standards. These standards developed should be reviewed and revised regularly based on lessons learned from real-world use cases and feedback from smart grid implementations. As a continuous learning process, standardization plays a key role in building a secure, reliable, advanced, and smart electric power grid with bidirectional communication, interoperability between different devices, and control capabilities.

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