Advanced Research in Electrical and Electronic Engineering
p-ISSN: 2349-5804; e-ISSN: 2349-5812 Volume 3, Issue 2 January-March, 2016, pp. 82-86

http://www.krishisanskriti.org/Publication.html

IEC 61850 Substation Automation Systems and Smart Grid

Sunil Gupta[1], Ikbal Ali[2] and Mini S. Thomas[3]

[1]*Maharaja Surajmal Institute of Technology*
[2,3]*Faculty of Engg. & Technology Jamia Millia Islamia*
E-mail: E-mail: [1]sunil.gupta_eee@msit.in, [2]iqali_in@yahoo.com, [3]min_st@yahoo.com

Abstract—*In Smart Grid, a substation needs to connect a large number of components from distribution side like Distribution Automation (DA), Feeder Automation (FA), Distributed Energy Resources (DER) and smart meters etc. at the customer end. To overcome the shortcomings of conventional power grid and to increase the automation facilities in distribution system, there is a need to automate substations that should cover all aspects of intelligence in distribution substation operations. For this, a standardised communication infrastructure is desired in Substation Automation System (SAS) to perform automation functions for the efficient power flow operations and management. IEC 61850, the standard for 'Communication Networks and Systems in Substations' is designed primarily to introduce interoperability between multi-vendor systems, simplify integration and commissioning of data communication networks, reduce the overall SAS costs, and allow for independent testing and validation. This paper discusses the scope of IEC 61850 communication standard which helps not only to develop cost effective and efficient substation automation systems but also provides various opportunities to realize smart grid applications and objectives.*

1. INTRODUCTION

Substations are the crucial nodes of a power system hence its increased capabilities and intelligence in its operations will play an important role to realize the concept of Smart Grid. In Smart Grid, the main focus is on smart distribution. It includes advanced technologies such as Distribution Automation (DA), increased interconnection and effective utilization of Distributed Energy Resources (DER) and customer participation in distributed applications by means of innovative methods. To realize these functions in Smart Grid, a substation needs a fully integrated and fully automatic system that performs data acquisition and processing, protection & control functions accurately, and delivers quality power efficiently with minimum environmental impact of green house gases. Demand response, reduction in peak load demand and power losses, improved power quality with less outage and hence, overall improvement in distribution system reliability and performance are the main objectives that could be achieved by automating substations using advance networking technology.

Substation automation functions can add more intelligence to the grid operations and make it more efficient. To implement various functions of the future Smart Grid at the distribution level, supportive substation architecture is to be designed. Thus modern substation architecture should include following characteristics for Smart Grid functions [1-3].

- To achieve communication interoperability, it must possess seamless communication in power system that provides an open communication interface not only among the Intelligent Electronic Devices (IEDs) but also for inter-substation communication, and linking substations to control centers. It enables plug and play design of substations to handle different functionality effortlessly at the distribution and feeder level.
- High quality of power supply could be achieved by installing de-centralized controllers for corrective or predictive actions, or for normal optimization.
- A future Smart Grid supportive substation is required to be resilient to any physical and cyber attacks. It needs a self healing mechanism to automatically identify, isolate, and rectify the abnormal conditions in a power network based on fast, reliable, and accurate data from the monitoring systems at substations. Fault detection, isolation and restoration algorithms are required which maintain the system security by detecting, and clearing or isolating the faults within time constraints, thus restoring the supply for the healthy feeders in a system. It should lessen interruption frequency and duration of outages in system with minimal customer impact. It improves demand and load side management by reducing response time.
- A distributed data management system is indispensable in substations to deal with all the environmental, operational and non-operational data. An expert system could be developed to deal with non-operational data for asset management in an optimized way. Secure substation architecture is also desired to control and manage the data and information flow. Besides this, it will also help in

prevention of any unauthorized access of data and devices in substations.

- In general, cost reduction, improvement in operational efficiency, and interfacing with other transmission and distribution systems in grid are some of the features which modern substation architecture is expected to possess for transforming an existed power grid into Smart Grid. So they are desired to incorporate various technological features like DA, Demand Response (DR), Demand Side Management (DSM), Outage Management System (OMS), AMI, Fault Detection and Isolation (FDI), Distribution State Estimation (DSE) and others.

This paper discusses the scope of IEC 61850 communication standard which helps not only to develop cost effective and efficient substation automation systems but also provides various opportunities for smart grid applications and objectives. The rest of the paper is organised as follows: Smart Grid key features and objectives are discussed in Section II. The major technical features of IEC 61850 based substation automation system are described in section III of the paper. Section IV discusses scope of IEC 61850 communication protocol based substation automation system in realizing smart grid goals. Finally, concluding remarks are provided in section V of the paper.

2. SMART GRID KEY FEATURES AND OBJECTIVES

The European Technology Platform defines the Smart Grid as "An electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both, in order to efficiently deliver sustainable, economic and secure electricity supply" [4]. Smart Grid is expected to include the following main objectives/features for transforming an existing grid [5-8].

- Smart Grid should provide an opportunity to generate, transmit and distribute the energy optimally, achieved through technological innovations, energy efficient management, healthy market competition and intelligent decisions in management and operation. Smart Grid technologies like Advanced Grid Assets (AGA) and Advanced Asset Management (AAM) reduce losses and improve asset utilization which allows energy to be utilized efficiently with longer life of equipments.
- Smart Grid should provide an ability to detect, analyze and rectify the faults. It monitors and controls the system disturbances to avoid or mitigate power outages and power quality problems. It should maintain the power supply capacity through quick fault detection, rectification and thus restoration of services instead of a prolonged large area power outage in conventional power grid. In Smart Grid, power system is self-correcting such as it detects overloading situation in network and reroute the supply to prevent outages. It results in reduced power losses and improved system performance.
- Smart Grid empowers the consumer through smart metering that allows two way interaction of energy and information flow between the utility and end consumers. It manages their energy use and thus reduces the energy cost. Advanced Metering Infrastructure (AMI) is a key technology where end consumers participate in grid operations for enhancing the distribution system operations and management. The energy management system functions help consumers to choose among the various tariff plan options, reduce peak load demand and shift usage to off-peak hours, save money and energy by using more efficient appliances and equipments. It also improves customer satisfaction with increased reliability in grid operations and reduced outages.
- Smart Grid should provide an ability to protect the grid from cyber attacks and unauthorized access by deploying new technologies. Data acquisition, handling and processing operations must be secure from any external attack. The system must possess the capability to deal with any corrupt data effectively to avoid any disoperation or damage of equipments.
- Smart Grid accommodates distributed generation and storage options. It makes use of various forms of clean energy technologies to reduce the burden on fossil fuels and the emission of green house gases. Smart Grid not only provides a means of distributed green power generation but also helps in load balancing during peak hours through energy storage technologies and applications such as Plug-in Hybrid Electric Vehicles (PHEV).
- Smart Grid facilitates integration of power system components and techniques such as process optimization, information flow, infrastructure, and market structure and management policies for reliable, economical and secure operation of the power grid. It integrates advanced communication technology and automation infrastructure to the existing power system network for real time monitoring and analyses of data from all parts of the electric grid. Advances in the field of power electronics, grid control, wireless sensor networks, intelligent scheduling technologies and AMI, are inculcated in Smart Grid to provide intelligent decision support.

Thus, the primary objectives in Smart Grid are to optimize assets usage, reduce overall losses, improve power quality, enable active customer participation, make energy generation, transmission and distribution eco-friendly and to make detection, isolation and rectification of system disturbances automatic. To achieve these objectives, the Smart Grid utilizes technological enhancements in equipments and methodologies that are cost effective, innovative, and reliable.

3. IEC 61850 SUBSTATION AUTOMATION SYSTEM

A number of standard communication protocols are designed for information exchange between process level equipments and devices in SAS. However, data sharing is possible only if devices are protocol compatible. Modern substation automation system uses IEC 61850 for the real time operation of the power system. IEC 61850, the standard for '*Communication Networks and Systems for Substation*' was introduced primarily to permit interoperability between the IEDs for performing a variety of protection, control and automation functions in substations [9-10]. Thereby no costly and complicated gateways are required for information exchange between devices from different manufacturers as it is required in case of legacy protocols. Standardized data model, communication approach and the configuration language are some inherent features in IEC 61850 standard that offers various benefits over legacy protocols such as Modbus, Modbus Plus, DNP3.0, and IEC 60870-5 [11-13].

In IEC 61850 based modern substations, copper cables are replaced by communication links between primary and secondary devices. It results in very significant improvements in both cost and performance of electric power system. IEC 61850 based SAS reduces operational and maintenance expenses by integrating multiple functions in a single IED. These functions are distributed among IEDs on the same, or on different levels of the SAS [14-15]. It enables distributed intelligence in a network for developing various new and improved applications. This improves the functionality, design and construction of modern substations [16-17]. Hence IEC 61850 communication standard allow the substation designer to focus more attention on other important issues like intelligence, reliability, availability, security, and efficiency of the power network. Although various standard protocols exist for communication outside the substations, the features possessed by IEC 61850 may also be utilized to enhance the performance of applications beyond the substation such as in Distribution Automation (DA) applications and for communication with other substations and control centres [18].

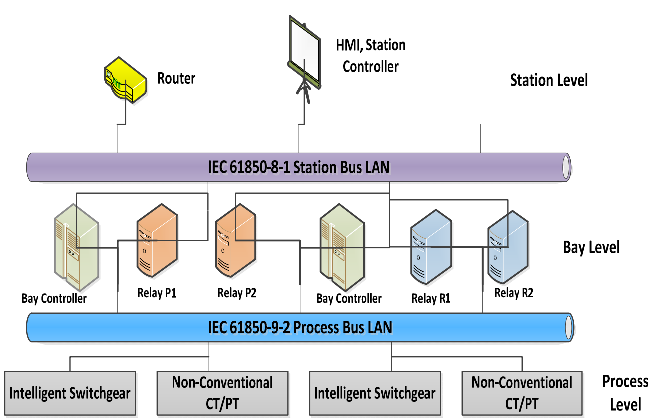

Fig. 1: IEC 61850 substation automation system

Fig. 1 shows IEC 61850 based substation automation system architecture which generally consists of three levels [19].

Station level: It includes Human Machine Interface (HMI) and gateways to communicate with remote control centre and integrate IEDs at the bay level to the substation level. It also performs different process related functions such as implementation of control commands for the process equipment by analyzing data from bay level IEDs.

Bay level: The process level equipments are connected to station bus via IEDs at the bay level that implement monitoring, protection, control and recording functions.

Process Level: It includes switchyard equipments, sensors and actuators. The current and potential transformers are located at the process level to collect system data and send them to bay level for automatic control & protection operations which are achieved through circuit breakers and remotely operated switches.

4. IEC 61850 SAS AND FUTURE SMART GRID

The standard possess object oriented data models and the set of rules for creating new Logical Nodes (LNs) and Common Data Classes (CDC). It also supports peer-to-peer communication based publisher-subscriber communication mechanisms such as Generic Object Oriented Substation Event (GOOSE) and Sampled values (SVs), and has Substation Configuration Description Language (SCL) for the automatic configuration of systems and devices applied in the whole electrical energy supply chain. With these advanced features, it is possible to extend the scope of the standard beyond the substations either downstream at the feeder level or upstream, at a higher level of a network management. Thereby, it supports various Smart Grid functions such as in distribution automation, feeder automation, distributed generation, and for communication outside the substations in the following manner.

Distribution automation is the most complex part of the power system that exhibits advance distribution tools and technologies to carry out control, protection and power quality operations in an efficient way. It can bring down operational and capital expenses in power system through reduced power losses and peak load demand. Therefore, it is absolutely necessary for IEC 61850 based SAS to support DA functions for achieving the goals of Smart Grid [20]. IEC 61850 standardized, semantic object models can be effectively utilized to model the various components of FA and DA systems for Smart Grid functions. It is possible to define the Logical Nodes (LNs) for performing various control and automation operations such as power flow control, voltage control and fault clearance at the distribution level for voltage control and fault handling applications in DA [21-22]. For instance, the standard can be used for modeling DA system components such as Auto-Reclosers, Shunt Capacitors, and Tap Changer Control.

IEC 61850 can also be utilized in different multi-agent systems for monitoring, protection, control, and recording in substations as discussed by [23]. References [24-25] have discussed that IEC 61850 lacks the specification of functions and IEC 61499 lacks "standard" communication services. The combined use of both the standards provides a high level of function and communication interoperability. Therefore, it is possible to enhance the flexibility and adaptability of automation systems in Smart Grid by implementing standardized functional models of IEC 61850 using IEC 61499 based distributed control architecture.

Several information models are defined or are under way:

- For substation and feeder equipment (-7-x)
- For power quality monitoring (61850)
- Control centre (61970 CIM)
- IEC 61850-7-410 "communications system for hydroelectric power plants": This series is to be used for the control and supervision of a hydro power plant. The standard defines LNs for electrical functions, control functions, mechanical functions related to the turbine and associated equipment and LNs for hydrological functions.
- IEC 61850-7-420"communication system for distributed energy resources [26]: This series is to be used for information exchange between DER devices and any systems which monitor, control, maintain, audit , and generally operate the DER devices. The standard defines LNs for a DER system, as well as for the models of DER equipment.
- IEC 61850-25-1 "communications for monitoring and control of wind power plants" [27]: The series defines LNs for the communication between wind power plants components like wind turbines, a SCADA systems or a condition monitoring system. Impact of GOOSE Communication on Substation Performance. IEC 61850 for wide area communication like communication between substations or communication between substation and control centers.
- IEC 61850-90-1 for communication between substations: Following applications are considered-

Protection functions like current differential line protection, distance protection with permissive and blocking schemes, directional and phase comparison protection, transfer tripping, protective wide area protection and substation integrity protection schemes. Control functions: auto reclosing, interlocking, cross triggering, generator or load shedding, topology determination of high voltage networks. AHWG 07 of TC57 has proven the feasibility of using IEC 61850 for the communication from the substation to the NCC and other system level applications. It will be discussed in IEC 61850-90-2.

- IEC 61850-90-2: Using IEC 61850 for the communication between substations and control centres.
- IEC 61850-90-3: Using IEC 61850 for Condition Monitoring.
- IEC 61850-90-4: IEC 61850 - Network Engineering Guidelines.
- IEC 61850-90-5: Use of IEC 61850 to transmit synchrophasors information according to IEEE C37.118.
- IEC 61850-90-12: It covers Wide Area Network (WAN) engineering guidelines.
- IEC 61850-90-14: It covers FACTS (Flexible AC Transmission Systems) data modeling.

Feeder automation can be in the form of using the same logical nodes defined in the standard, or applying the fast messaging techniques such as GOOSE message for protection and control, and SVs for transmitting the measured data from the feeders to the substation. One way is to GOOSE messages for fast transfer of critical information between IEDs or Phasor Measurement Units (PMUs) at the transmission level [28].

The plug and play design feature using SCL in IEC 61850 substation environments support the effortless testing and commissioning of Smart Grid components. Also as the reconfiguration of equipments is not required while adding new devices and applications in a system, it makes any future extensions easier and economical for developing Smart Grid applications. Intelligent switchyard equipments such as non-conventional current and potential with optical outputs in IEC 61850 based SAS can replace the conventional current and potential transformers to achieve high bandwidth, better accuracy and low maintenance costs for handling voluminous data efficiently in Smart Grid.

Further, to achieve the objectives of future Smart Grid, it is planned to launch another series of IEC 61850 to include device models for different Smart Grid components like IEC 61850-90-7 for inverter based applications, IEC 61850-90-8 for electric vehicles and IEC 61850-90-8 for battery storage devices. Integrating the DERs, energy storage devices and support to other advanced components of Smart Grid in SAS, using a standard data model of IEC 61850, helps in green power generation and improved power quality.

5. CONCLUSION

This paper has presented an important extract of the major technical features possessed by IEC 61850 communication standard and investigated the opportunities on the design and operation of economical and efficient SAS applications. Further, the paper has also focused on how IEC 61850 capabilities can be utilized to extend the scope of standard in applications outside the substations, which support smart grid objectives. IEC 61850 has different series of standards that define communication system for monitoring and control of hydroelectric power plants, distributed energy resources, wind power plants, and also for wide area communication.

REFERENCES

[1] J. Heckel, “Smart substation and feeder automation for a smart distribution grid,” *20th International Conference and Exhibition on Electricity Distribution - Part 1, CIRED*, pp. 1 – 4, 2009.

[2] Li, Fangxing, Wei Qiao, Hongbin Sun, Hui Wan, Jianhui Wang, Yan Xia, Zhao Xu, and Pei Zhang, “Smart transmission grid: Vision and framework,” *IEEE Transactions on Smart Grid*, vol. 1, no. 2, pp. 168-177, 2010.

[3] M. Sooriyabandara and J. Ekanayake, “Smart Grid – Technologies for its realisation”, IEEE, 2010

[4] C. Cecati, G. Mokryani, A. Piccolo, and P. Siano, “An overview on the smart grid concept,” *36th Annual Conference on IEEE Industrial Electronics Society, IECON*, pp. 3322-3327, 2010.

[5] E. Santacana, G. Rackliffe, L.Tang and X. Feng , “Getting smart,” *IEEE Power and Energy Magazine*, vol. 8, no. 2,pp. 41-48, 2010.

[6] H. Farhangi, “The path of the smart grid,” *IEEE Power and Energy Magazine*, vol. 8, no. 1, pp. 18-28, 2010.

[7] J.R. Roncero, “Integration is key to smart grid management,” *SmartGrids for Distribution, IET-CIRED, CIRED Seminar*, pp.1-4, 2008.

[8] J. Fan and S. Borlase, “The evolution of distribution”, *IEEE Power and Energy Magazine*, **vol. 7** no. 2, pp. 63 – 68, 2009.

[9] IEC 61850: Communications Networks and Systems in Substations,” 2002-2005, Available [Online]: http://www.iec.ch./

[10] R. Kirkman, “ Development in substation automation systems,” *IEEE International Conference on intelligent systems applications to power systems,* ISAP 2007, pp. 1-6, 5-8 Nov. 2007.

[11] IEC Standard for Telecontrol equipment and system: Transmission Protocols- Companion standard for the informative interface of protection equipment, IEC 60870-5-103, 1996.

[12] DNP USERS GROUP. Distributed Network Protocol. [Online]. Available: http://www.dnp.org/.

[13] MODBUS, MODBUS-IDA, Modbus application protocol specification, December 2006. [Online]. Available: http://www.modbus-ida.org/.

[14] J. D. McDonald, “Substation automation, IED integration and availability of information,” *IEEE Power Energy Mag.*, vol. 1, no. 2, pp. 22–31, Mar./Apr. 2003.

[15] A. Apostolov, "Disturbance Recording in IEC 61850 Substation Automation Systems," *Transmission and Distribution Conference and Exhibition*, Dallas: IEEE, pp. 921-926, 21-24 May 2006.

[16] M.C. Janssen and A. Apostolov. "IEC 61850 Impact on Substaion Design," *IEEE/PES Transmisssion and Distribution Conference and Expositio,* Chicago,pp. 1-7, 21-24 April 2008.

[17] R.E. Mackiewicz, "Overview of IEC 61850 and Benefits," *IEEE Power Systems Conference and Exposition, PSCE’06.* Atlanta, pp.623-630, Oct.29-Nov.1 2006.

[18] S. Mohagheghi, J. Stoupis and Z. Wang, “Communication Protocols and Networks for Power Systems- Current Status and Future Trends,” Proc. *IEEE PSCE*, Mar. 2009.

[19] C. Brunner, "IEC 61850 for Power System Communication," *IEEE/PES Transmission and Distribution Conference and Exposition*, Chicago, pp. 1-6, 21-24 April 2008.

[20] C. Smallwood and J. Wennermark, “Benefits of distribution automation,” *IEEE Industry Applications Magazine*, vol. **16**, no. 1, pp. 65-73, 2010.

[21] S. Mohagheghi, J. C. Tournier, J. Stoupis, L. Guise, T. Coste, C. A. Andersen, and J. Dall, “Applications of IEC 61850 in distribution automation,” *IEEE/PES Power Systems Conference and Exposition (PSCE)*, pp. 1-9, 2011.

[22] Z. Xue-Song, C. Li-Qiang and M. You-Jie , “Research on smart grid technology,” *International Conference on Computer Application and System Modeling (ICCASM)*, pp.599-603, 2010.

[23] A. Apostolov, “Multi-agent systems and IEC 61850,” *IEEE Power Engineering Society General Meeting*, pp.1-6, 2006.

[24] V. Vyatkin, G. Zhabelova, N. Higgins, K. Schwarz, N. Nair, “Towards intelligent smart grid devices with IEC 61850 interoperability and IEC 61499 open control architecture,” *IEEE PES Transmission and Distribution Conference and Exposition*, pp.1-8, 2010.

[25] N. Higgins, V. Vyatkin, N.-K.C. Nair and K. Schwarz, “Distributed power system automation with IEC 61850, IEC 61499, and intelligent control,” *IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews,* vol. 41, no. 1, pp. 81-92, 2011.

[26] Part 7-420: Basic communication structure - Distributed energy resources logical nodes, 2009, IEC 61850-7-420, 1st ed.

[27] IEC, Wind Turbines—Part 25: Communications for Monitoring and Control of Wind Power Plants, IEC Std. 61400-25, 2006.

[28] C. Brunner, “IEC 61850 for power system communication,” *IEEE/PES Transmission and Distribution Conference and Exposition*, 21-24 April 2008, Chicago, 1-6.