International Journal of Research in Advanced Engineering and Technology
ISSN: 2455-0876; Impact Factor: RJIF 5.44
www.engineeringresearchjournal.com
Volume 2; Issue 5; September 2016; Page No. 49-53

Impact of IEC 61850 communication protocol on substation automation systems

Sunil Gupta

Maharaja Surajmal Institute of Technology, New Delhi, India

Abstract

The paper investigates the huge potential of IEC 61850 communication protocol to impact the design, operation, testing, and performance of modern substations. The opportunities embedded in the approach, features, and scope of IEC 61850 communication standards to develop cost effective and efficient SASs is explored in depth. It has been identified that the standard begins a new era for the design and operation of Ethernet communication based distributed substation application that cannot be achieved with legacy communication protocols.

Keywords: IEC 61850 communication protocol, substation automation systems

1. Introduction

Substations play an important role in power grid operations and are usually equipped with control, protection and power quality equipments to deliver power to loads reliably and efficiently. In conventional substations, primary equipments are connected to secondary protection and control devices in complex manner through hardwired interfaces using many conventional instrument transformers (CTs/VTs) whose installation, testing and maintenance are difficult and cumbersome. Also rectification of system disturbances is handled manually. To overcome the shortcomings of conventional substations, there was a need to automate substations that should cover all aspects of intelligence in substation operations.

The introduction of communicable Intelligent Electronic Devices (IEDs) and digital communication in substations has offered a wide range of opportunities for utilities to improve and facilitate the effective substation automation applications. However, costly and complicated protocol converters were required to bring the substation devices onto a common physical network and allow everyone to speak a common application layer protocol [1-2]. The major challenges encountered were the successful configuration of the multivendor IEDs, their interoperability and performance tests [3]. Thus, an effective communication system played a key role to link substation devices within an electric power substation for the high reliability and real-time operation of a SAS [4]. Modern substation automation system uses IEC 61850, the standard for '"*Communication Networks and Systems in Substation*" for the real time operation of the power system [5]. Standardized data model, communication approach and the configuration language are some inherent features in IEC 61850 standard that offers various benefits over legacy communication protocols such as Field-bus [6], Modbus, Modbus Plus [7], DNP3.0 [8], and IEC 60870-5 [9-10].

This paper has examined the approach, features, scope and benefits of IEC 61850 communication standards which provides various opportunities for designing communication based distributed substation applications. The rest of the paper is organised as follows: IEC 61850 communication protocol key components and features are discussed in Section 2. The approach and impact of IEC 61850 standards in designing copper-less substation automation system is described in section 3 of the paper. Section 4 discusses the major benefits of IEC 61850 based SAS. Finally, concluding remarks are provided in section 5 of the paper.

2. IEC 61850 protocol based substation automation system

In IEC 61850 based modern substations, the complex network of copper cables are replaced by Ethernet LAN based serial communication links between primary and secondary level devices. IEC 61850 SAS architecture consists of three levels as shown in Fig. 1 [5]. Station level includes Human Machine Interface (HMI) and GateWays (GW) to communicate with remote Network Control Centre (NCC) and integrate IEDs at the bay level to the substation level. Station level functions include event and alarm handling, monitoring, data evaluation, archiving, and status supervision. It also performs different process related functions such as implementation of control commands for the process equipment by analyzing data from bay level IEDs. The protection and control IEDs of different bays of a substation are placed at bay level. The process level equipments are connected to the bay level IEDs through the process bus network for implementing various monitoring, protection, control, and recording functions.

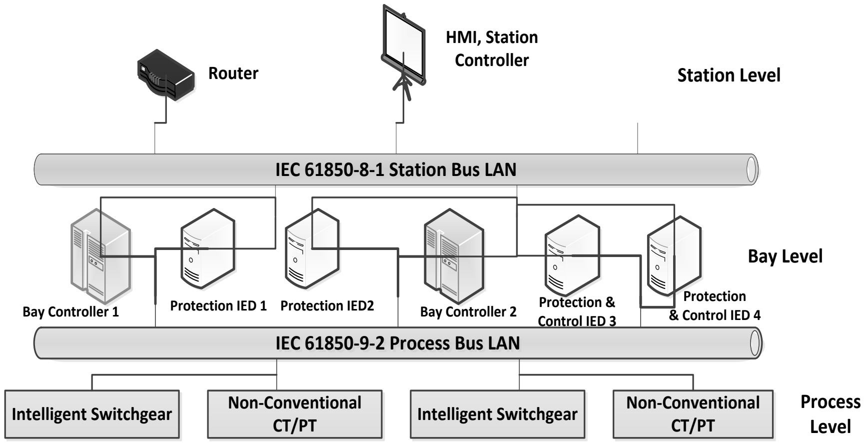

Fig 1: IEC 61850 Substation Automation System

Process level includes the switchyard equipments, remote I/O devices, intelligent sensors and actuators etc. The conventional or Non-Conventional Instrument Transformers (NCIT) are located at the process level to collect system data and send them to bay level devices to perform automatic control & protection operations which are achieved through circuit breakers and remotely operated switches. Station bus exists at the substation level and is used for communication between IEDs at the bay level and the station level. Several redundancy methodologies are usually employed to select station bus architecture for improving the reliability and performance of various protection and control functions carried out by IEDs at the station level. Process bus is serial communication interface between the process level and bay level equipments. It facilitates the time-critical communication such as Generic Object Oriented Substation Event (GOOSE), Sampled Values (SVs), binary status and control signals between switchyard equipment and bay level IEDs through instrument transformers.

The standard uses ISO/OSI seven layers communication stack consisting of Ethernet (layers 1 and 2), Transmission Control Protocol/ Internet Protocol (TCP)/IP (layers 3 and 4) and Manufacturing Message Specification (MMS) (layers 5-7) for satisfying the different communication needs of IEC 61850 SAS [5]. The standard, based on different logical interfaces, defines the different types of communication services for information exchange between the IEDs and towards local HMI and control centre. Client-server communication service model based on MMS over TCP/IP and Ethernet is used for vertical communication between the bay and station level devices. The data transfer is very slow and reliable since the communication is based on seven layers ISO/OSI communication stack model. Thus, client-server communication is not suited for time-critical data.

Substation critical protection and control applications require fast data transfers and are based on horizontal communication network between the IEDs at the same hierarchical level. Both GOOSE and SVs communication are based on '*publisher/subscriber'* communication model consisting of fast communication services. These messages are sent as multicast messages over the SCN. GOOSE messages are event driven and are repeated for high transmission reliability while the SVs are time triggered and possess low transmission reliability over the process bus network. Both require real time performance of the communication network and hence to guarantee a timely delivery, advanced Quality of Service (QoS) features like 802.1X are used in addition [11-12].

3. Impact of IEC 61850 communication standard

The most promising feature of IEC 61850 standards is its object oriented and hierarchical data model, which contains data models of all possible substation automation functions and devices in substations, and standardizes the names of these functions and data. The CDC elements are defined in part 7.3 [13]. The abstraction of the data objects (LNs) is found in IEC 61850-7-4 [14].

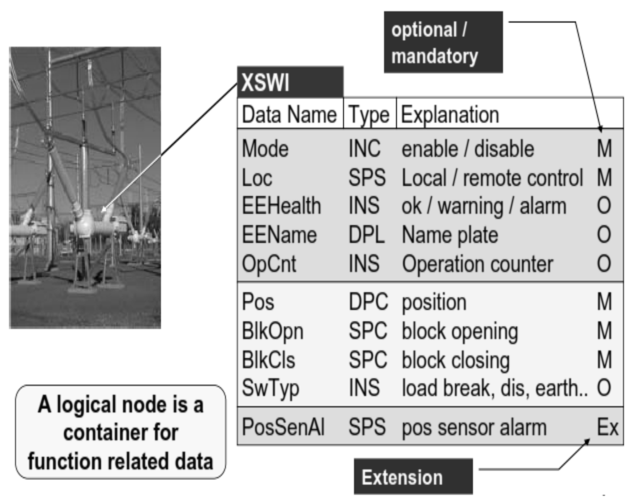

Fig 2: The object model of IEC 61850

The abstract data and object models of IEC 61850, as shown in Fig. 2, define a standardized method of describing power system devices that enables all IEDs to present data using identical structures that are directly related to their power system function. Each functional element is defined as a logical node which again consists of standardized data and data attributes. Thus, LNs represent either the information content of a function or devices in SAS. This information represents the process, configuration, name plate and diagnostic information. Also, the standard has an object model and the set of rules for creating new logical nodes and common data classes. Thereby it enables to extend the scope of the standard, and include new applications both inside and outside the substation.

3.1 Communication Approach

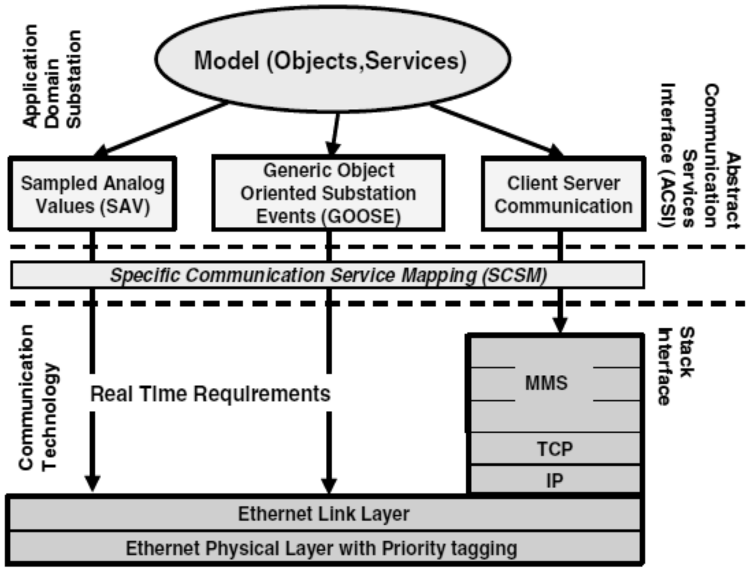

Fig 3: Overview of IEC 61850 functionality and associated communication profiles [5]

The communication services and data models are defined in section IEC 61850-7-2 [15] of the standard. IEC 61850 uses OSI-7 layers stack for communication and divide it into three groups as shown in Fig. 3. Here, seven types of messages are mapped to different communication stacks. In client-server communication that involves medium speed messages (type 2), command messages with access control (type 7), low speed messages (type 3), and file transfers (type 5) is used for applications in managing switchgear equipments at process level.

IEC 61850-8-1 defines the mapping of abstract object models and its services to the application layer of MMS, which has a TCP/IP stack layers on the top of the Ethernet layer. In addition to client/server services by mapping to MMS (connection oriented) stack, the standard provides peer-to-peer services for the transmission of fast, real time information exchange between IEDs, such as GOOSE and SVs. SVs (type 4) messages from Merging Units (MU) and GOOSE messages (type 1, 1A) like interlocking or trip commands are mapped directly to the link layer of the Ethernet thereby eliminating the additional upper layer protocols overheads involved in the transmission [16-18]. This improves the transfer time performance for mission critical messages by reducing the processing time of Ethernet frames, but reduces the reliability in GOOSE and SVs transmission. To increase the transmission reliability of GOOSE messages, the data transmission is repeated. Also for some specific applications like protection tripping, IEEE 802.1Q services of data link and physical layers are used. Time Synchronization messages (type 6) are broadcasted to all substation IEDs in substation based on UDP/IP.

3.2 Substation Configuration Description Language (SCL)

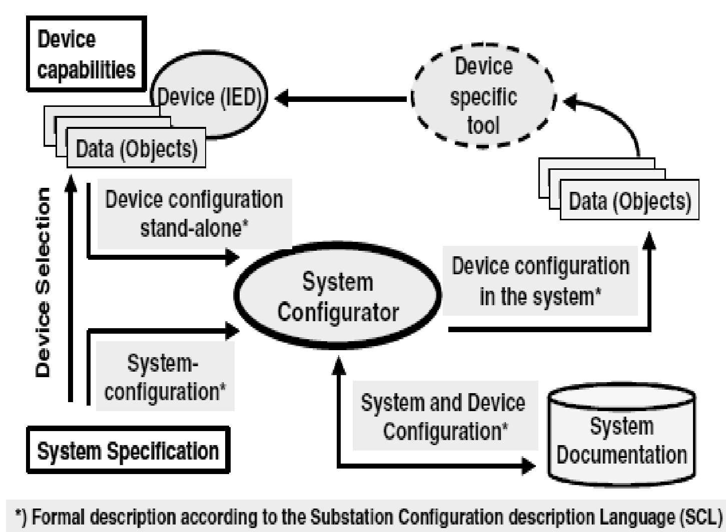

Fig 4: The use of SCL for system engineering

The standard specifies an XML based SCL, as shown in Fig. 4, which includes the data representation for substation IEDs including all relevant services based on IEC 61850-7-X, their interconnection and the substation automation functions to achieve communication interoperability and reduction of design efforts. These files allocate substation automation functions to the IED that contain logical nodes along with their data and data attributes. The standard IEC 61850-6 defines four types of SCL files considering their tasks as follows:

a. Data exchange from IED configuration tool to the system configuration tool is defined using *IED Capability Description files (ICD).*
b. Data exchange from substation specification tool to the system configuration tool is defined using *System Specification Description (SSD).*
c. Data exchange from system configuration tool to the IED configuration tool is described using *Substation Configuration Description (SCD)* files. The system configuration tool requires ICD and SSD files to generate SCD files.
d. Data exchange from IED configuration tool to IEDs is defined using *Configured IED Description (CID)*.

This feature enables automatic configuration of IEDs to share device information among the users and suppliers and allows off-line configuration of IEC 61850 substation applications.

3.3 Switched Ethernet Technology Support and Benefits

Modern managed Ethernet switches offer advanced features which allow SCN to be optimized to deliver consistent, real time performance that are critical for substation protection, control and automation application [19-20]. SCN infrastructure satisfies the real time protection over switched Ethernet with the advanced mechanisms. Switched Ethernet provides high speed data rate in the range of 100 Mbps/1 Gbps. IEEE 802.3x provides full duplex operation and collision free environment to ensure deterministic delivery. IEEE 802.1p allows prioritizing IEC 61850 SCN message frames with different priority levels and thus providing a delivery guarantee for the high-priority traffic. IEEE 802.1q Virtual LAN (VLAN) allows the segregation and grouping of IEDs into Virtual LANs in order to isolate real time IEDs from data collection or less critical IEDs. This feature ensures that real time traffic always makes it through the network even during high periods of congestion. IGMP (Internet Group Management Protocol) layer 2/3 snooping/multicast filtering allows for multicast data frames, such as GOOSE/SVs, to be filtered and assigned only to those IEDs which request them to listen. IEEE 802.1w Rapid Spanning Tree Protocol (RSTP) allows managing redundant paths in a layer 2 network and hence makes it possible to create fault tolerant SAS architecture that will re-configure in milliseconds (10-500 ms) depending on the SCN topology and size. Ethernet allows for a wide variety of network topologies providing different levels of reliability, availability, and performance. Component redundancy and/or communication path redundancy can be chosen to improve reliability at the physical and data link layer of OSI model. Availability of EMI (Electromagnetic Interference)-hardened, extended temperature range Ethernet switches for operation in the substation environment. Following subsection has discussed the major benefits of IEC 61850 on substation performance.

4. IEC 61850 communication standard benefits

IEC 61850 defines and offers much more than just a protocol. Several inherent features in IEC 61850 communication standard, as discussed in the previous section, provide various opportunities and benefits over legacy substation communication protocols such as IEC 60870-5, DNP3.0, and Modbus. Some of the benefits offered by IEC 61850 include [21-23]:

a) Simple and cost effective substation architecture: In IEC 61850 based modern substations, costly and complex network of multiple copper cables, both at the station and bay level, are replaced with a few shared Ethernet communication links between process level and bay level equipment. It allows integrating multiple functions in a single IED, and also the replacement of a number of convention instrument transformers at the process level with a few optical/electronic technology based NCITs. It results in very significant improvements in the designing, safety, reliability and performance of substation applications. Further, it allows IEC 61850 SASs to have low installation, commissioning, maintenance, testing and life-cycle costs which bring the long-term economical benefits needed by the utilities to stay competitive in an energy market.

b) Future proof standard: The standard follows progress in main-stream communication technology as it advances due to future developments. With this, it only needs to map the abstract data models are services onto new communication protocols.

c) Benefits of Switched Ethernet technology: Switched Ethernet is used as a mainstream communication technology in IEC 61850 SAS that offers various benefits such as full duplex operation without collision, high data transfer speed among IEDs, supports peer-to-peer communication model like GOOSE and SVs instead of master-slave communication in legacy protocols, permits scalable and redundant architectures etc. Further, the use of IEEE 802.1x network traffic management features such as priority queuing, VLANs, RSTP, IGMP etc., enhances the real time performance of communication based protection and control applications in 61850 substations.

d) High level engineering support based on SCL: The standard supports self-description of device in terms of ICD file that contains data models and its associated functional and communication capabilities. The XML based SCL files contain all information that is relevant to build the SAS and supports the automatic configuration of devices and the system. This feature also makes any future extension of the SAS easier and economical.

e) Standardized data modeling: Data is defined based on an advanced object oriented hierarchical structure, which contains whole data specifications instead of single-oriented model where data is defined by numeric addresses (indexing) as in legacy protocols.

f) High level communication services: IEC 61850 standard supports peer-to-peer communication services like GOOSE and SVs for real time data transfer instead of master-slave model for communication in legacy protocols.

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.

5. Conclusion

The IEC 61850 standard possesses various advanced features which makes it possible to design cost effective, highly reliable and performing distributed substation protection and automation applications. It facilitates 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 GOOSE) and SVs, and has Substation Configuration Description Language (SCL) for the automatic configuration of systems and devices applied in the whole electrical energy supply chain. These features also make it possible to extend the scope of the standard beyond the substations.

6. References

1. Shephard B, Janssen MC, Schubert. Standardized communications in substations, Seventh IEE International Conference on Developments in Power System Protection. 2001, 270-174.
2. Chaturvedi M. Substation IED communications," IEEE Power Engineering Society, winter meeting. 2002; 1:596. DOI: 10.1109/PESW.2002.985070.
3. McDonald JD. Substation automation, IED integration and availability of information, IEEE Power and Energy Magazine. 2003; 1(2):22-31.
4. Gungor VC, Lambert FC, A survey on communication networks for electric system automation, Computer Networks. 2006; 50(7):877-897.
5. IEC 61850: Communications Networks and Systems in Substations, 2002-2005, Available [Online]: http://www.iec.ch./
6. Zhang SW. Field bus technology overview and its impact on industrial automation, Field Comms USA, Boston. 1997.
7. MODBUS, MODBUS-IDA, Modbus application protocol specification, 2006. [Online]. Available: http://www.modbus-ida.org/.
8. DNP USERS GROUP. Distributed Network Protocol. [Online]. Available: http://www.dnp.org/.
9. IEC Standard for Telecontrol equipment and system: Transmission Protocols- Companion standard for the informative interface of protection equipment, IEC 60870-5-103, 1996.
10. Mohagheghi S, Stoupis J, Wang Z. Communication Protocols and Networks for Power Systems- Current Status and Future Trends, IEEE/PES Power Systems Conference and Exposition (PSCE), 2009, 1-9.
11. IEC 61850-5: Communication Requirements for Functions and Device Models, IEC INTERNATIONAL STANDARD, 2003.
12. Brunner C. IEC 61850 for power system communication, IEEE/PES Transmission and Distribution Conference and Exposition, Chicago, 2008, 1-6.
13. IEC 61850-7-3: Communication Networks and Systems in Substations, Part 7-3: Basic Communication structure for substations and feeder equipment- Common Data Classes. Available: http://www.scribd.com
14. IEC 61850-7-4: Communication Networks and Systems in Substations, Part 7-4: Basic Communication structure for substations and feeder equipment- Compatible logical node classes and data classes. Available: http://www.scribd.com
15. IEC 61850-7-2: Communication Networks and Systems in Substations, Part 7-2: Basic Communication structure for substations and feeder equipment-Abstract Communication Service Interface (ACSI). Available: http://www.scribd.com
16. Communication Networks and Systems for Power Utility Automation-Part 8-1: Specific Communication Service Mapping (SCSM) –Mappings to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IEC 8802-3, IEC 61850-8-1 ed2.0, 2011.
17. Communication Networks and Systems for Power Utility Automation-Part 9-1: Specific Communication Service Mapping(SCSM) –Sampled Values Over Serial Unidirectional Multidrop Point to Point Link, IEC 61850-9-1, First edition. 2003, 05.
18. Communication Networks and Systems for Power Utility Automation-Part 9-2: Specific Communication Service Mapping (SCSM) –Sampled Values Over ISO/IEC 8802-3, IEC 61850-9-2 ed2.0, 2011.
19. Decotignie JD. Ethernet-Based Real-Time and Industrial Communications, Proceedings of the IEEE, 2005; 93(6):1102-1117.
20. Puzzuoli MP, Moore R. Ethernet in the Substation," IEEE Power Engineering General Society Meeting, 2006, 1-7.
21. Hoga C, Wong G. IEC 61850: Open Communication in Practice in Substations, IEEE PES Power Systems Conference and Exposition. 2004; 2:618-623.
22. Mackiewicz RE. Overview of IEC 61850 and benefits, IEEE PES Transmission and Distribution Conference and Exhibition. 2006, 376-383.
23. Vadiati M, Ghorbani MA, Ebrahimi AR. Arshia M. Future trends of substation automation systems by applying IEC 61850, 43rd International Universities Power Engineering Conference, UPEC. 2008, 1-4.