

Communication in substation automation systems

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Abstract

Recent developments in communication media and networking technology have offered a wide range of new opportunities for utilities to improve their electric systems, operations, and process automation. The Intelligent Electronic Devices (IEDs), communication protocols, and communication methods work together as a system to perform power system automation. The paper discusses the evaluation of IEC 61850 communication protocol, the standard for “*Communication Networks and Systems in power utility automation*” in designing modern digital substation automation systems. Based on a detailed literature survey, the key technical features, major benefits, as well as technical challenges related to the IEC 61850 standard in substation automation are also presented in this paper.

Keywords: Communication, substation automation systems

1. Introduction

The introduction of communicable IEDs and advanced digital communication in substations has offered a wide range of opportunities for utilities to improve and facilitate the effective substation monitoring, local & remote, protection and automation applications that couldn't be realized with conventional electromechanical principle based protection and control devices. These multifunctional IEDs are becoming the standard protection, control, monitoring and recording equipment in new and existing substations. They provide increased capabilities to measure and monitor different operation, administration and maintenance related analog as well as status signals. Automatic processes can be run in IEDs, and communications are handled through a serial port like the communication ports on a computer [1]. There exist great benefits to the user, if these IEDs could be integrated and made interoperable in the substation environment [2].

Thereby, the major challenge was to determine the standard integration and automation architecture which must allow devices from different suppliers to communicate using a standardized communication protocol [3]. To reduce the complexity and the amount of cables in traditional substations and to develop an economical and high performance integrated substation automation system, interoperability was desired to enable IEDs from different vendors to communicate without gateways.

The success of a substation protection and automation system relies on the use of an effective communication system, incorporating state-of-the-art information and communication technologies, to link various protection, control, and monitoring devices within an electric power substation [4]. Modern substation automation system uses IEC 61850, the standard for “*Communication Networks and Systems in power utility automation*” 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 Profibus,

Modbus, Modbus Plus, DNP3.0, and IEC 60870-5 [6-10].

The paper has discussed the evaluation of IEC 61850 communication protocol in designing modern digital substation automation systems. Based on a detailed literature survey, the key technical features, major benefits, as well as technical challenges related to the IEC 61850 standard in substation automation are also presented in this paper. The rest of the paper is organised as follows: Communication requirements and the supporting protocols for SAS are discussed in Section 2. IEC 61850 communication protocol key components and features are described in section 3 of the paper. Section 4 discusses the approach and impact of IEC 61850 standards in designing copper-less substation automation system. Major benefits of IEC 61850 based SAS are presented in section 5. Finally, concluding remarks are provided in section 6 of the paper.

2. Communication requirements and the supporting protocols for SAS

The communication needs and requirements of each substation level vary according to the type of data and its size. Communication requirements are of different types like Real-time operational data communication that includes power system control, have “hard” real time requirements. Administrative operational data communication that keeps the event history of the power system has moderate time requirements. Administrative communication includes voice communication and facsimile.

Performance requirements for the SAS are special, as the functions performed by SAS are highly time-critical. Moreover, communication among IEDs, which are part of the SAS, should be highly reliable and fast, as for protection purposes, reaction times of the complete system must be in the order of 4-10 ms, between fault occurrence and Circuit Breaker (CB) reenergizing [11-12]. Performance requirements for the substation were generally achieved using techniques such as point-to-point and field bus systems, especially of the type MODBUS.

Industrial Ethernet entered strongly into this field, and the

unified efforts of different organizations resulted in the development of the international communication standard IEC 61850. Ethernet technology, since its inception in the early seventies, has experienced wide acceptance and exhibited exponential growth. It was only recently that Ethernet managed to virtually displace competing process bus and LAN technologies like Token ring, Profibus, Modbus Plus, Lon Works etc., most of which had to switch to the Ethernet-based physical layer and Transmission Control Protocol/Internet Protocol (TCP/IP) based protocols (Modbus TCP/IP, Profibus TCP/IP, and Distributed Network Protocol (DNP) TCP/IP).

Ethernet technology was widely believed to be inadequate for mission critical, hard real-time applications, with multiple studies analyzing limitations of the CSMA technique. Recently, however, Ethernet technology has evolved from the initial CSMA/CD (Carrier Sense Multiple Access with Collision Detection) mechanism to native switched Ethernet, which is almost collision free. This advanced networking protocol can now be designed with deterministic transmission times, suitable for real-time and mission-critical tasks. Switched Ethernet LANs is able to create a full duplex and collision free communication environment, by means of twisted paired optical fiber cables and separate Ethernet switch. Switched Ethernet technology support QoS features to satisfy the real time performance requirements of time critical messages in substation automation applications. Multicasting with switched Ethernet allows messages to be sent simultaneously and hence faster. Priority tagging (IEEE 802.1P) enables time critical messages to be sent on a priority basis. Further, the data throughput is higher with Ethernet switch because it entails no collisions. Virtual LANs(VLANs supported by IEEE 802.1Q standard), Rapid Spanning Tree Protocol (IEEE 802.1W), Simple Network Management Protocol (SNMP) and Electromagnetic Interference (EMI) immunity are some other special features of switched Ethernet technology, which can be harnessed for enhanced performance of SCN architecture [13-15]. Redundancy technologies such as RSTP/ Parallel Redundancy Protocol/High-availability Seamless Redundancy/Dual Homing Protocol (PRP/HSR/DHP) facilitate the designing of a suitable substation network topology at various levels in SAS to satisfy different levels of reliability and performance issues. Ethernet provides high flexibility regarding

communication architectures, as well as incorporation of fast growing communication technologies. Therefore, the development of Ethernet technology provides an opportunity to design new and innovative communication systems for power system protection applications.

3. IEC 61850 protocol based Substation Automation System

IEC Technical Committee no. 57 (TC57) Working Group 10 (WG10) introduced international standard-IEC 61850- 'Communication Networks and Systems in Substations' published in 2003 [5]. It provides a set of standards and specifications with a common application layer protocol to ensure interoperability, with Ethernet at the physical layer to ensure everyone resides on the same physical network. The proprietary communications standards such as Modbus, Modbus Plus, IEC 60870-5, and DNP3 in SAS lacks the standardize representation and organization of data in substation devices in terms of the applications. IEC 61850 resolve this issue by separating the data of the functions, services and communication protocols. The approach in IEC 61850 is based on abstracting the definition of the data items and services i.e. creating data objects and services that are independent of any underlying protocols. With standardized object data models of all possible functions in substations and the related generic services, the standard provides standardized communications in substations.

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.

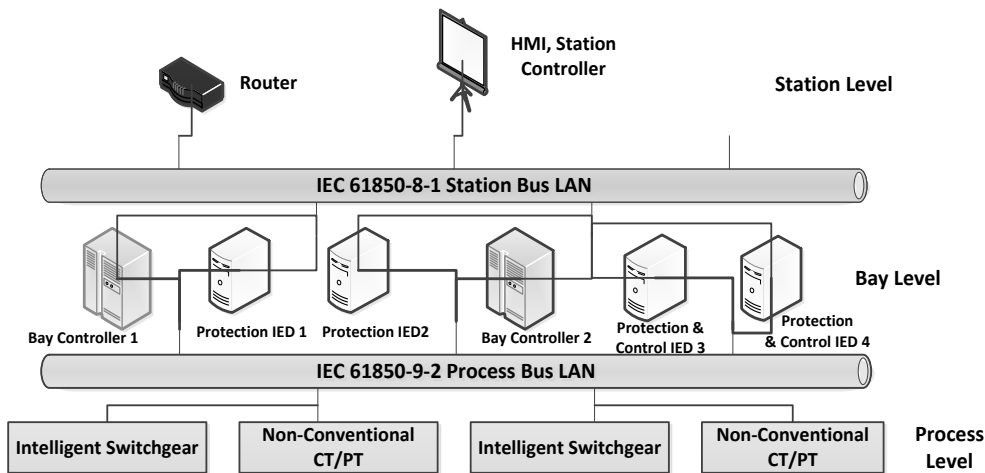


Fig 1: IEC 61850 Substation Automation System

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) ^[16], Sampled Values (SVs) ^[17], 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.

4. Impact of IEC 61850 communication standard on SAS

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. The abstraction of the data objects (LNs) is found in IEC 61850-7-4. 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.

The communication services and data models are defined in section IEC 61850-7-2 of the standard. IEC 61850 uses OSI-7 layers stack for communication and divide it into three groups. 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 ^[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.

The standard specifies an XML based SCL 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. This feature enables automatic configuration of IEDs to share device information among the users and suppliers and allows off-line configuration of 61850 substation applications.

5. 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 ^[19-20]:

- 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.

6. Conclusion

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 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. With these advanced features, it is possible design cost effective, highly reliable and

performing distributed substation protection and automation applications. Also, these features make it possible to extend the scope of the standard beyond the substations.

7. References

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