Upgradation of Existing Substation into a Smart Substation

Veena Kumari¹* and Preetinder Singh²

¹Punjab Agricultural University, Ludhiana, India.
²Guru Nanak Dev Engineering College, Ludhiana, India.

Authors’ contributions

This work was carried out in collaboration between both authors. Author VK proposed, designed the study, managed the literature searches, performed the simulation, analysis and wrote the first draft of manuscript. Author PS supervised every stage of the work. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AIR/2020/v21i130181

Editors:
(1) Dr. Carlos Humberto Martins, Professor, Department of Civil Engineering, The State University of Maringa, Brazil.
(2) Bruno Miguel Gonçalves Mataloto, Portugal.

Reviewers:
(1) Okure, Inimfon – Abasi George, University of Uyo, Nigeria.
Complete Peer review History: http://www.sdiarticle4.com/review-history/54992

Received 18 December 2019
Accepted 25 February 2020
Published 05 March 2020

Original Research Article

ABSTRACT

The evolution of existing grids to smart grids for power supply is technologically the most prominent research area. It is one of the hot projects considered to contribute in national economy, also at the top priority for the country and involves hefty investments, although the entire research and development area is still immature. The work in this paper describes smart substation and its components which is fully in compliance with IEC61850 standard. It demonstrates a functional architectural framework of smart substation with its three layers. This work compares both systems and proposes a new system in single line diagram. The way to the establishment of smart fully digitized substation is although just in the initial stage in India, but work on improvement must carry on to keep up in pace with the fast growing technology especially integration of information technology for the communication between different entities. This paper presents a model of power system in case of fault how a merging unit can send information with high speed Ethernet in the form of sampled value messages. Intelligent substation can consist of various smart equipments capable of functioning instantaneously replacing the huge web of copper wires with fibre optic cables. Hence Smart substation is the first step in the implementation of smart grid.
Keywords: Grid; IEC61850; smart grid; smart substation; process layer; bay layer; station layer; merging unit; intelligent terminal; modelling.

1. INTRODUCTION

1.1 Existing Conventional Power Grid (Fig. 1)

An electrical grid is a large interconnected network which carries a huge amount of electrical energy and distributes it from the generating stations to the potential customers. It incorporates generating stations capable of producing electricity. Power stations are generally located far from the massively populated areas. The generated power is then stepped up by transformers for transmission. It is stepped down to a low voltage at a substation. Power grid can be categorized into main three parts: generating station, transmission line and distribution system. A distribution system distributes the energy to all the end consumers from the transmission line. Generating stations and Distribution System are linked by the Transmission lines. Step up and step down transformers are installed in the transmission line for the purpose of decreasing and increasing the voltage up to the desired level. In order to minimize the transmission losses, voltage is magnified to a higher level by step-up transformer. At the end spot of transmission line, a step-down transformer decreases the voltage up to a possible level. This lowered voltage is then given out to the distribution system coupled by feeders, sub-stations, distribution transformers, lightning arrestor, utility lines etc. [1].

Though Conventional electrical grid system is efficient, reliable and has good control system, but as it is a well-known fact that technology needs to be updated to help it to be in pace with everyday modern scientific advancements.

1.2 Concept of Smart Grid

Simply, Smart Grid = Digitization + Power Grid

This implies that Smart Grid is the integration of IT (Information Technology) with existing grid to get better flexibility, reliability, resiliency, efficiency and also in order to provide the best services to consumers.

Smart substation is the significant component of Smart Grid. So, this is the main focus of this paper. New generation substation employs hi-tech communication technology to minimize the construction and administrative costs. For the said purpose, IEC 61850 standard has been introduced [2].

1.3 IEC 61850 Standard

In the legacy systems, protocol for substation automation and its layout equipped the power system automation with elementary operation and were introduced to take into account the technical limitation of the complex communication technology. Networking technology has advanced dramatically recently.

---

Fig. 1. Existing conventional power grid architecture
To take benefits from the modern advancements in networking, IEC’s (The International Electrotechnical Commission) technical committee released a universal standard IEC 61850 for substation automation. Mapping of protocols to MMS (Manufacturing Message Specification), GOOSE (Generic Object Oriented Substation Event), SMV (Sampled Measured Values) and to Web Services can be done with standard IEC 61850. The documentation in IEC 61850 describes the networking of communication in 10 sections out of which primary part have been shown in grey fill (Fig. 2). Switched Ethernet is used to get the response time over the internet networks [3].

MMS (Manufacturing Message Specification):
It is a global standard ISO 9506 which deals with the messaging system in the interest of exchanging the information between the networked equipments. MMS describes the following set of standards:

- **A set of standard objects**: It must be in each and every element so that the events like read, write or signalling etc. can be effectively performed.

- **A set of standard messages**: Includes transfer of a set of information in order to serve the motive of monitoring or controlling the objects between the clients and the server station.

- **A set of encoding rules**: When the transfer of messages occurs, then mapping of these data to bits and bytes is done by virtue of the encoding guidelines [4].

**GOOSE (Generic Object-Oriented Substation Event)**: On the authority of IEC 61850 standard, a control model GSE (Generic Substation Events) produces high-speed, reliable and secure mechanism for the transfer of messages over the whole electrical substation. GOOSE (Generic Object-Oriented Substation Event) and GSSE (Generic Substation State Events) are the two sub-divisions of GSE. GOOSE has the capability to exchange the instructions within 4 milliseconds. GOOSE data is straight integrated into Ethernet. It has enhanced communication structure. IED’s (Intelligent electronic devices) are being installed in the substation that is completely embraced by IEC 61850 without having demand of particular cables or algorithms [5].

2. SMART SUBSTATION SYSTEM

IEC 61850 standard embodies three layers in smart substation architecture (Fig. 3) called process layer, Bay layer and Station layer. Transformers, circuit breakers, isolators, primary equipments and associated intelligent elements are included in the process layer. In the process
bus, the conventional wires are replaced with optic fibres that transmits GOOSE messages and optical fibre sends sampled values. Optical fibre is made up of silica capable of transmitting at higher data rates over large distances. Moreover, just like in case of wires, fibre optics cables are not affected by the electromagnetic interference. The Process Layer consists of merging unit (MU) and intelligent terminal (IT). Data acquisition and execution of command is performed by IT. Digital fortification, processing, and conversion function of protocols are operated by MU. The second layer is the bay layer which is mainly for the protection, control, fault recording, monitoring, data collection, calculation and other services. This layer has many IED’s (Intelligent electronic device). Now comes MMS which is the main integration to the third layer station layer. Time synchronization, communication, proof-locking of disoperation, real time monitoring and immediate decision making all are involved in the station layer.

2.1 Process Bus Layer

In the Process Level of Smart Substation, the data is carried in the form of a cycle from the master (main) switchyard (SW) to the HMI (Human Machine Interface) and vice-versa. The high voltage components of the master switchyard surrounds bus-bars, circuit breakers, isolators, power transformers, current and voltage transformers (CT’s and VT’s) which are confined to merging unit and intelligent terminal in smart substation. The output obtained by CT’s and VT’s are collected (from digital system) and sampled (from analogue system) by means of Merging Unit IED by the way of Sampled Value (SV) messages. The Intelligent Terminal Unit takes up the commands and executes them.

![Smart substation architecture](image-url)
The transfer of these instructions is followed in the shape of GOOSE (Generic Object-oriented substation events) messages. Thus, the communication technology used in this level are SV (Sampled Value) and GOOSE messages. The GOOSE messages involve the functions like indications, tripping signals and alarms etc. On the contrary, SV messages transmits instantaneous current and voltage samples from CT’s and VT’s to HMI. [6]. The Process layer functional architecture is shown in Fig. 4.

2.2 Bay Layer

Historically defined devices known as secondary equipment are connected between the process layer and station layer. This mid-layer is called bay layer (Fig. 5). The smart substation constitutes IED’s (Intelligent Electronic devices) in this level in order to serve the purpose of protection of station level, monitoring, supervising, controlling, instant fault recording, giving quality power, real time invigilation, and more auxiliary operations.

IED consists of protective relays, fault recorders, event recorders, integrated sensors, communication technologies, control and measurement automation systems. The bay level is accounted to have five fundamental functional parameters (MMCPC): Monitoring, Measurement, Communication, Protection and Control. The first function is essential to get the real time status of different associated components in the system for example switches, transformers etc. Precise measurement of electrical parameters comes under the measurement function. Furthermore, the recorded information is to be shared then with Network Control Center that is the master switchyard.

---

**Fig. 4. Functional architecture of process layer**
communication part. In case of outages or faults, protection is the most critical function that a smart substation must have. This operation makes it compulsory to have the measurement of the electrical parameters very precise and accurate. The control function is entailed so as to get the switches performed instantaneously when in need. These have to be automated via suitable communication channels [7].

**Fig. 5. Functional architecture of bay layer**

**Fig. 6. Functional architecture of station layer**
2.3 Station Control Layer

Station Layer (Fig. 6) accommodates the automation system assisted with hi-tech communication system. This layer uses IEC 61850 protocol based MMS service for communicating with other devices.

Substation control bus utilizes Ethernet switches for message transfer which is contrary to process level that uses GOOSE/SV messaging incorporating two-way communication. Station Layer consists of unicast method. Unlike process layer, it does not employ fiber optic cables, mostly double stranded wires have been adopted for interconnection in control level. However, network analyser including additional cutting-edge applications are prefixed to this layer extending data scrutiny functionality to tackle any kind of fault occurring [8].

3. DATA TRANSFER METHOD

In IEC 61850, voltage and current samples are transmitted to protection IED by making use of Merging Unit in the process layer. This data is in the form of SV messages. The protection and control equipments analyses the received samples and if any fault is spotted by it, then it signals the breaker via trip GOOSE message. P&C (Protection and Control) IED’s in the bay layer functions in the form of logic nodes.

Logical devices in IED’s in Fig. 7 are TCTR, TVTR, PDIF, PTRC and XCBR. The first letter indicates the logical nodes. The smallest part of a function that exchanges data is called logical node (LN) in IEC 61850. Logical node is a container that holds data objects and each data object has a data attribute. Logical node C is used for Supervisory Control, likewise G for Generic Functions, I for Interfacing and archiving, L for System logical nodes, P for Protection, R for Protection Related, S for Sensors and monitoring, T for Instrument Transformers, X for Switchgear, Y for Power Transformers, and Z for further Power System equipment. TVTR node connects to voltage transformer. TCTR node links to current transformer. PDIF is a logical node for differential protection and is used to analyze the samples received. PTRC stands for protection trip conditioning; this logical node carries the trip information to XCBR. XCBR signifies circuit breaker which performs the action to control the received commands [9].

![Fig. 7. Data transfer method](image-url)
4. DESCRIPTION OF MAIN INTELLIGENT COMPONENTS

Merging Unit: Merging Unit (Shown in pilot installation - Fig. 8) is mainly constituted of non-conventional instrument transformers (NCIT’s) capable of measuring current and voltage. NCIT’s are well trusted with the objective to facilitate and close-pack the primary components. To facilitate relays, meters and bay devices, NCIT’s are the basic fundamental equipments which are essential for measurement, control and giving protection to the energy network because a precise modification of secondary components is crucial to deliver to Intelligent Electronic Devices (IED’s) and digitated relays. Digital interface is a necessity to communicate with digital relays and IED’s and NCIT’s only support the measurement of high transmission analogue current and voltage signals.

Fig. 8. Merging unit
(Courtesy: ABB)

Fig. 9. Integrated smart terminal
However, IEC 61850 necessitates digital interface in the form of smart devices. Therefore, Merging Unit can be described as an interface IED that receives multiple sampled values from...
CT’s/VT’s (Optical / Conventional) and delivers multiple digital point to point unidirectional time-synchronized output. The use of Electronic CT’s and VT’s is highly recommended because of no saturation effect, no effect of electromagnetic interference and no flammable insulation material such as oil, etc [10].

**Smart Terminal (Intelligent Terminal):** Conforming with IEC 61850, Intelligent Terminal features an interface which acts as a nexus between process level bus and bay layer devices for data exchange. Synchronous sampling is obtained through input interface for protection and measurement equipments. The design of intelligent terminal supports further update and can be configured as per need. GOOSE messages and MMS are received in milliseconds through optical fiber linked to smart terminal (Figs. 9 and 10) [11].

**Intelligent Electronic Device:** Monitoring, safety and supervision control are the most important functions to facilitate the automation of substation. Each function has specific tasks and is called as logical node as according to IEC 61850 standard. IED is formed of many such nodes. These nodes are further parted into naming structures, data objects, data attributes, services, and commands etc. Interoperability is the most profitable characteristic of IEC 61850 standard, so IED supports it for further integration and reconfiguration with latest communication systems.

6. **SIMULATION MODELLING OF POWER SYSTEM**

6.1 **Complete Power System Modelled in Matlab/Simulink**

The modelled power system is composed of 220kV programmable voltage source, 4 buses, one 220/66kV step down transformer, 10 km transmission line, three phase fault exerted between bus 2 and bus 3 and load. The complete modelling of power system is shown in Fig. 15.

Simulation results of three-phase fault has been briefed in result section for the fault current between bus 2 and bus 3. But in order to test the Merging Unit whether Sampled Value message is sent to process bus by MU, further signal arrangement has to be done with MU.

The power system with MU’s attached is presented in Fig. 16.
Fig. 12. SLD of 220kV substation

[Divided into 4 sections]
Fig. 13. Complete SLD of system
Fig. 14. Simple power system model

Fig. 15. Power system modelling in Matlab/Simulink

After the conversion of NCIT signals to a single vector, it is to be fed into the Merging Units. The configuration of Merging Unit is given in Fig. 18.

6.2 Complete System Integration

The developed model in order to test various protection functions is shown in the screenshot where the formulated power system has been merged with NCIT. The subsystem has been created indicating ECT and EVT (Electronic Current and Voltage Transformers) model integrated with Merging Unit to convert the analogue signals into digital signal. The signal is to be transmitted to Ethernet. Process bus receives the information in the Sampled Value form.

The purpose of modelling a power system is to test the merging unit by simulation if it sends the Samples Values. This needs to be connected through fibre optic cables enabling IEC61850 protocol signals. The performance can be analyzed using the modelled power system. The network packet analyzing software Wireshark has been used to capture SV from the connected MU’s.
Fig. 16. Model of power system with NCIT's

Fig. 17. RT-LAB OpIEC61850 merging unit block
This tab is to specify the name of the ethernet adapter interface.

This specifies the system-wide unique identifier (string, 10 characters min., 35 characters max.). IEC 61850-9-2:LE recommends using the format ‘xxxxxMUxxx’ where xxxx is the concatenation of the substation name, voltage level and bay and where xx identifies the measuring point.

This is to specify the MAC multicast destination address where the sampled values will be published (e.g. ‘01-0C-CD-00-00-00’).

This gives the option to specify the number of samples to be transmitted per cycle.

Each MergingUnit block has a 50-element circular buffer. During each calculation step, it fills up one entry. Depending on the extrapolation method, the driver uses a number of known values from the circular buffer and predicts the block input value that will be sent on the network at that moment.

This specifies the clock of MU. On selecting external clock, the MU will be synchronized with an external clock. Otherwise the block uses internal clock of the system. This option allows us to use Spectracom TSync PCIe board along with MergingUnit block to synchronize the time with GPS instead of system time.

Fig. 18. Configuration of RT-LAB OpIEC61850 merging unit block

Fig. 19. Complete system integration
7. RESULTS AND DISCUSSION

7.1 Comparative Analysis of Smart Substation and Conventional Substation

Table 1. Comparative analysis of smart substation and conventional substation

<table>
<thead>
<tr>
<th>Smart substation</th>
<th>Conventional substation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart substation is IEC 61850 standard compliant that is fully advanced with upgraded communication.</td>
<td>Conventional substation is complied with Indian Electricity Act, 2003.</td>
</tr>
<tr>
<td>Electronic current transformer has no saturation effect and immunity to electromagnetic interference.</td>
<td>Conventional CT installed causes saturation in the core leading to non-linear excitation. It is affected by the electromagnetic interference.</td>
</tr>
<tr>
<td>Non-conventional instrument transformers can be integrated into Merging Units. The other secondary equipments can be merged into Intelligent terminal. Then both can be formulated into Integrated Intelligent Terminal. So compact size reduces space and lowers maintenance.</td>
<td>Conventional current and voltage transformers and secondary equipments are used which are not efficient enough and occupies large space.</td>
</tr>
<tr>
<td>Hence compactness is bound to reduce cost.</td>
<td>Heavy cost is imposed on the system.</td>
</tr>
<tr>
<td>Fiber Optic Cables to be replaced with copper wires with no electromagnetic interference plus it has the capability to transmit at higher data rates over long distances. Less cost.</td>
<td>Large cabling required, generally copper wires are used. Hence costing is enormous.</td>
</tr>
<tr>
<td>It uses high speed Ethernet generally with 100 MBps enabling SV, GOOSE and MMS and integrated with existing SCADA system.</td>
<td>Power Line Carrier communication have been installed for the communication purpose. SCADA is being used.</td>
</tr>
<tr>
<td>Monitoring, protection and immediate decision making functions completely digitized making the system more stable, reliable and cost-effective.</td>
<td>Used method of communication causes delay in the safeguarding of equipments in case of outages because of slow communication.</td>
</tr>
<tr>
<td>Intelligent Electronic Devices are employed in intelligent substation which uses logical nodes. It employs protection and control function digitally with improved operation.</td>
<td>Not so efficient protection and control system is available in existing substation system.</td>
</tr>
<tr>
<td>Automatic fault clearance capability within few milliseconds.</td>
<td>Fault clearance time is large.</td>
</tr>
</tbody>
</table>

8. CONCLUSION

A Smart substation, an indispensible part of the smart grid, is latest technology and the hot topic being discussed around. The main components of smart substation to be initially used and developed is discussed in the paper. The integrated intelligent terminal and intelligent electronic devices blocks were used in single line diagram of 220 kV Ferozepur Road substation. The three layers of the smart substation are described, and functional architecture of substation is designed using AutoCAD software. The proposed model of power system created in MATLAB/Simulink has been used to understand the behaviour of system in case of fault. At last, a comparative analysis has been penned to show the contrasting features between the existing and intelligent substation. Though communication part still needs to be worked upon a lot and the time synchronization can be a good research for further work to test between different Merging Units and Intelligent Electronic Devices. The merging units can be more technologically advanced (standalone merging units) in near future for interoperability which is the main focus of IEC 61850.

COMPETING INTERESTS

Authors have declared that no competing interests exist.
REFERENCES


© 2020 Kumari and Singh. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/54992