We are IntechOpen,
the world's leading publisher of
Open Access books
Built by scientists, for scientists

4,800
Open access books available

122,000
International authors and editors

135M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Chapter

ICT Technologies, Standards and Protocols for Active Distribution Network Automation and Management

Mohd Asim Aftab, S.M. Suhail Hussain and Ikbal Ali

Abstract

The concept of active distribution network (ADN) is evolved to address the high penetration of renewables in the distribution network. To leverage the benefits of ADN, effective communication and information technology is required. Various communication standards to facilitate standard-based communication in distribution network have been proposed in literature. This chapter presents various communication standards and technologies that can be employed in ADN. Among various communication standards, IEC 61850 standard has emerged as the de facto standard for power utility automation. IEC 61850-based information modeling for ADN entities has also been presented in this chapter. To evaluate the performance of ADN communication architecture, performance metrics and performance evaluation tools have also been presented in this chapter.

Keywords: active distribution networks (ADNs), communication standards, communication technologies, co-simulation, IEC 61850, network latency

1. Introduction

With increasing impetus towards use of cleaner energy, power utilities are increasingly integrating renewable energy resources (RER) at distribution level. High penetration of RERs and distributed energy resources (DERs) in the distribution network poses the challenge of reliable operation, control and quality power supply. The concept of active distribution network (ADN) will allow distribution networks to integrate DERs efficiently by addressing the above challenges by incorporating Information and Communication Technologies in distribution systems [1]. The management of ADN with penetration of DERs and RERs, which are highly intermittent, can be achieved by coordinated operation of different components of ADN such as distribution system operator (DSO), control centers, DERs, distribution substations and other components. In ADNs the different components are geographically distantly placed, thus for coordinated operation a wide area communication infrastructure is required. For stable, reliable and efficient management of distribution network, this communication is required to be standardized, interoperable, securable and scalable [2].

To facilitate standard communication in the power distribution networks, various standards and protocols such as IEEE P2030, IEC 60870-5, IEEE C37.118.1/2, Distributed Network Protocol (DNP3), IEC 61850, IEC 61970 and IEC 61968, OpenADR, etc., have been developed. This chapter will present a comprehensive analysis of these state-of-the-art standards and protocols for application in ADNs. The challenges presented by these standards are of feasibility, flexibility and interoperability. In this regard IEC 61850 is emerging as one of the most popular and widely accepted solutions since it is based on the interoperability approach and provides flexibility in implementation [2].

For information exchange between different components of ADN different communication technologies have been explored in literature [3, 4]. This chapter enlists and provides a detailed study of different communication technologies that can be employed in ADNs. The presence of RERs and DERs in ADNs introduces intermittency, thus the communication architecture for ADN must be highly scalable. To address the scalability issue in the smart grid communication architectures Web protocols have been employed. The proposed chapter will present a detail study of the different Web protocols and their suitability for ADNs [5].

The performance of different communication network architectures is evaluated for network latency, quality-of-service (QoS), robustness, reliability and data security to determine its applicability and suitability in ADNs. This chapter will discuss the different simulator tools for evaluating the performance of ADN communication networks. An overview of different real-time test beds and state-of-the-art co-simulation platforms of interfacing power system simulators and ICT simulators will be presented.

2. Active distribution networks: the concept

With the integration of large amount of renewable energy sources into the distribution network, the current distribution network has evolved into an active network from a passive network. The high penetration of DGs into the distribution system introduces bidirectional power flows in the distribution network and also causes voltage rise and increased levels of fault currents. The major challenge is to monitor, control and manage the ADN in order to supply reliable and clean energy to the consumer.

2.1 Challenges with traditional distribution system

In traditional distribution system, the DSOs operated in a top down approach in which the electricity from the transmission system operator (TSO) was received at the DSO level and was transferred to distribution network operator and finally to the end consumer. Since the distribution system operated as a radial network with the source supplying the loads at the end consumer in a unidirectional fashion, there were predictable electricity flows in the network which does not require extensive management and control.

However, with the proliferation of DGs in the distribution network introduces new challenges in management and control of the network and in ensuring reliable power and quality power supply to the consumer. Also increasing number of these DGs are being connected to the distribution network, both in capacity and numbers, leads to unpredictable power flows in the network, wide voltage variations, changed network reactive power characteristics and increased levels of fault current. This has resulted in profound implications on the operation of DSOs.

Thus, the DSOs are expected to operate the modified distribution network (i.e., ADN) in a more secure and reliable way and provide high service quality to the end consumers.

2.2 Evolution of active distribution network

The growing impetus towards renewable energy sources (RESs) like wind power plants, photovoltaic power (PV) plants, fuel cells, electric vehicles (EV) supporting vehicle to grid (V2G), combined heat and power (CHP) plant, etc., is expected to increase their share in total power generation capacity worldwide. This has evolved the concept of Distributed Generation (DG) which involves small or medium generating units usually located on-site. These DGs meet the local power needs and dispatch the remaining power to the electric grid. In a move to reduce carbon footprints and increase supply flexibility and reliability these DGs are getting largely integrated into the distribution system and changing its very nature from passive to active which evolves the concept of active distribution network (ADN).

In order to make the most efficient use of the existing network infrastructure and manage DGs for reliable and secure power supply, the concept of ADN management is evolved. ADN will allow efficient integration of DGs to the existing distribution infrastructure by taking maximum advantage of the inherent characteristics of DGs. This requires the planning and operation of the distribution network by taking into account the bidirectional power flows in the network. The system planning and development could happen only by setting out implications for the DSOs, TSOs and for the DG owner/operator.

In an ADN, the DGs provide advantages such as security of power supply, loss reduction in transmission and distribution, peak load and congestion reduction and less network investments. However, most of the DGs are nondispatchable in nature and therefore matching of power production profile with that of the load demand profile cannot be guaranteed at all times. It might happen that the DGs do not generate enough power in cases when the distribution network is constrained while DGs provide abundance power supply when the demand is low. Thus, there remains a challenge in operation of ADN and requires adequate mechanisms to provide solutions to these problems.

2.3 Architecture of active distribution network

The DGs are usually managed and controlled at the individual level and are geographically distributed in nature. The power requirements of the electrical grid are shared with the DG owner via aggregator. Since, management and control of individual DG is not possible due to large number of devices, the concept of aggregator plays a crucial role. Also, since the small scale DGs does not fall under the direct supervision and control of DSOs and thus DSOs acquire services from aggregators for monitoring and control of the DGs. The aggregator manages and controls a group of closely located DGs. The combined demand and supply from the group of DGs is shared with the Distribution System Operator (DSO) via the aggregators. The DSO develops the dispatch schedule for the DGs and provides it to DG owners via aggregators. **Figure 1** illustrates a schematic of ADN architecture including the aggregators and DSO.

The DG operator is in direct contact with the aggregator for providing dispatch schedules. Due to heterogenous nature of DGs in terms of capacity and density, the schedules for different DG owners are different which depends upon the connected sources to the system and the load density. The advantages for having a hierarchical architecture for ADN are as follows:
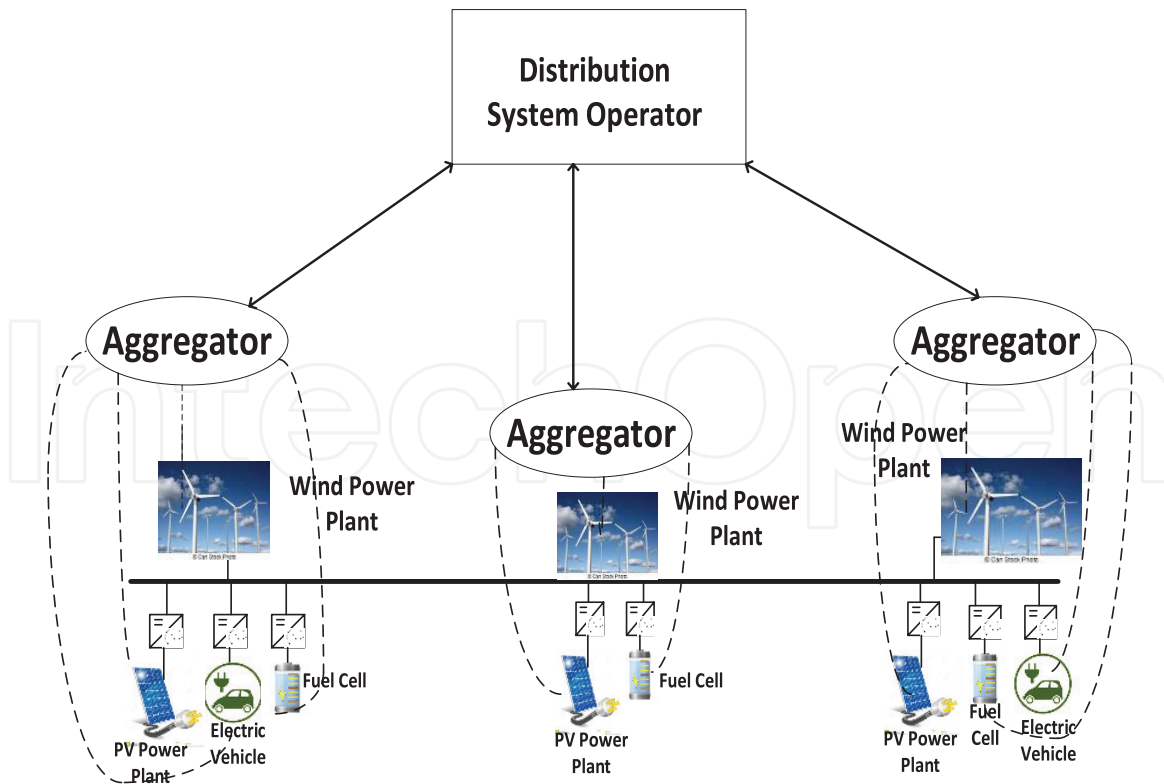
Figure 1.
A simplified schematic illustration of active distribution network hierarchy.

1. Real time information exchange between the TSO, DSO, Aggregator and DG owner.

2. DGs connected through aggregators would provide various services such as power reserves, regulating/balancing power, reactive power support, etc.

3. Easy scheduling between various actors/components of the ADN.

4. Congestion management of the distribution network by active control of DGs.

3. Communication configurations for ADNs: standards and technologies

The cornerstone for the ADN management is the ability of multiple entities such as DG operators, aggregators, DSOs and TSOs to interact with each other for providing monitoring, control and real-time exchange of energy consumption and power usage data. Also, the TSOs and DSOs can retrieve consumer usage data and online pricing and optimize the electricity distribution based on the electricity consumption via a communication network. Thus, a fast, reliable and secure communication infrastructure plays a vital role in management of ADN. With the adoption of information and communication technologies (ICT) in the ADN management it is possible to enhance the efficiency of power generation, transmission and distribution. The ICT helps in accumulating information from every point of ADN and can be used for demand forecasting, network planning, ADN operation, Control and Protection of ADN and in optimizing performance of ADN.

Due to increasing level of DG penetration, real time information about various measurements such as currents, voltage, active power, reactive power, etc., is becoming necessary. These measurements are required to be exchanged

continuously between various components of ADN for overall monitoring and control applications. Also, due to intermittent nature of renewable DGs, these measurements are varying in relatively fast fashion such as like of meteorological data. Thus, a fast and reliable ICT infrastructure is required in order to improve the observability of the whole ADN using real time monitoring of the network. With evolving ICT infrastructure, the future ADN monitoring might not be limited to typical power system data monitoring rather than monitoring of new parameters such as dynamic phasor, dynamic line rating, rate of change of frequency, etc. These new measurements may be then utilized in disturbance management, predictive maintenance and to enhance the stability and load ability of the power system.

The components of ADN are distributed over vast geographic areas and thus in order to have a coordinated operation it requires a wide area communication infrastructure. The wide area network forms a backbone in providing communication between various ADN components to provide a reliable, secure, expedient and trustable service.

3.1 Communication standards for ADN

3.1.1 IEEE 1547

The IEEE 1547 [6] standard provides rules for interconnecting various distributed resources (DRs) to the electrical power systems (EPS). It is characterized by various forms of DRs operations and their interconnecting issues. It sets forth the guidelines for DG participation for voltage regulation, active power management, grounding requirements and integration of DR islands with the existing power systems. The guidelines for monitoring, control and information exchange among the DG and EPS is also provided by the standard.

The IEEE 1547 standard series has various parts dedicated to the issues related to DR interconnection to EPS. These are as follows:

1. IEEE 1547.1: IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems.

2. IEEE 1547.2: IEEE Application Guide for IEEE 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.

3. IEEE 1547.3: IEEE Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems.

4. IEEE 1547.4: Draft Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems.

5. IEEE 1547.5: Draft Technical Guidelines for Interconnection of Electric Power Sources >10 MVA to the Power Transmission Grid.

6. IEEE 1547.6: Draft Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks.

3.1.2 IEEE P2030

IEEE P2030 [7] standard is the first standard drafted by IEEE for providing smart grid interoperability. It provides a roadmap for establishing the framework

for developing IEEE national and international body of standard aimed at development of a standard for smart grid which merges the disciplines in power applications, information technology and control through communications. The IEEE P2030 standard establishes the smart grid interoperability reference model (SGIRM) which develops a base terminology for providing functional performance, characteristics, engineering principle evaluation related to the smart grid interoperability. The SGIRM approach consists of systems of systems and inherently allows for extensibility, scalability, and upgradeability. The SGIRM approach is based on integration of power systems, communication and information technology. Also, it defines tables and data classification flow which are necessary for providing smart grid interoperability. According to IEEE P2030 standard, interoperability is defined as capability of a network, system, device to seamlessly transfer and exchange information with its counterpart in a secure and effective way.

The term Smart Grid interoperability is defined as the ability to effectively communicate and transfer information seamlessly among various devices, organizations even if they are using different variety of infrastructure and are spread along different geographic regions and locations. The smart grid interoperability is associated with three components: Hardware/software component, data formats, interoperability on content level. At the hardware/software level, the interoperability is achieved by developing or designing the devices which follow a standard blueprint and adheres to a common protocol. At the data format level, the messages or information must be encoded in a standard well defined syntax. At the content level, a common understanding of the meaning of the data/content being exchanged must be developed to achieve interoperability at content level. To transform the legacy networks into intelligent devices which can participate in smart grid communication, the standard must address the requirements of stakeholders and develop interoperable solutions and flexible business processes.

3.1.3 IEC 60870-5

IEC 60870-5 [8] standard was developed by IEC Technical Committee 57 to provide protocol for sending basic telecontrol messages from the telecontrol master station to outside stations which are connected through some form of permanent communication link. The telecontrol messages are transferred between the telecontrol equipment in the form of coded serial data which is used for monitoring and controlling of wide are processes. The part 5 of 60870 defines the interoperability among the telecontrol equipment. This standard is a combination of application layer of IEC 60870-5-101 and transport layer of TCP/IP standard. Within the TCP/IP, there is an independent choice of telecommunication networks such as X.25, ATM, and Frame relay.

The IEC 60870-5 supports unbalance and balanced mode of data transfer, provides unique addresses for master telecontrol stations, time synchronization facility, data classification facility and cyclic data updating facility.

3.1.4 IEEE C37.118.1/2

The IEEE C37.118 is the standard drafted by IEEE for synchronized phasor measurement in power system. It is the main standard which governs phasor measurement unit (PMU) operation. A PMU is a device which provides accurate time stamping of power system information by performing synchrophasors measurements by incorporating GPS time signal for time reference. It transmits synchrophasors data to remote peers either by unicast or multicast [9]. The IEEE C37.118 standard is split into two parts viz. IEEE C37.118.1 for synchrophasors measurement and IEEE

C37.118.2 for synchrophasors communication. Both these parts of IEEE C37.118 standard form the backbone of PMU operation and communication in power system.

The IEEE C37.118.1 [10] defines synchrophasors, frequency and rate of change of frequency (ROCOF) measurements. IEEE C37.118.1-based measurements made at various locations by the PMU can be readily obtained and interpreted at the Phasor Data Concentrator (PDC) accurately due to the presence of GPS time tagging on PMU information. The IEEE C37.118.1 does not specify underlying hardware or components required for carrying out such synchrophasors measurement. The IEEE C37.118.1 standard specifies certain synchrophasors measurement requirements which are as follows: synchrophasor estimation, frequency and ROCOF estimation, measurement reporting delay, measurement response time and measurement errors.

The PMU must measure the synchrophasor data according to the synchrophasor measurement and estimation as specified in the standard. Measurement latency is the time delay occurred from the instance an event occurs in the power system to time it is reported. Measurement response time is the time transition between the two steady state measurements when an input signal is applied. The purpose of having measurement response time is to ensure that the time tagging is working correctly in the PMU data. The measurement errors are usually computed as the total vector error (TVE) in the synchrophasor measurement by the PMU.

The IEEE C37.118.2 [11] standard defines a method of exchange of synchrophasor data between the power system devices. It provides the guidelines for data message formats which are to be exchanged between a PMU and PDC. It defines various messages which are exchanged for realizing a handshake operation between the PMU and PDC. The following type of messages are employed in synchrophasor measurement viz, data, configuration, header and command.

3.1.5 Distributed network protocol (DNP3)

Distributed network protocol (DNP3) [12] was drafted for providing open, interoperable communication among substation computers, IEDs, remote terminal unit (RTUs) and master stations in the electric utility industry. DNP3 was developed by the combined efforts of IEC TC 57 working group (WG-3) who have been working on OSI three layer "enhanced performance architecture (EPA)" for telecontrol applications. DNP3 is also the recommended practice for RTU to IED communication protocol.

DNP3 was first developed by Harris, Distributed Automation Products (originally Westronic, Inc.) and later it is managed by the DNP3 users group which is composed of vendors and electric utilities which are using the DNP3 protocol. Amendments and modifications in the current draft of DNP3 are carried out by the DNP3 users technical group. To ensure interoperability, longevity and upgradeability of DNP3 protocol, the modifications and recommendations are made open to DNP3 technical group. DNP3 is not limited to serial communication inside the substations but the widespread functionality of DNP3 make it usable with TCP/IP networks having Ethernet, frame relay, fiber-optic-based communication media.

3.1.6 IEC 61850

IEC 61850 has emerged as the global standard for substation automation system since its publication in the year 2004 [3]. The IEC 61850 standard is intended to provide interoperability among substation. The IEC 61850 standard was initially drafted for substation automation system and later on it was expanded to cover power utility system. IEC 61850 adopts object oriented approach for modeling power system components. Due to its worldwide acceptance by the industry and research organizations, it is poised to be the future automation industry standard.

Communication is divided into four main parts viz. Information modeling, services modeling, communication protocols and telecommunication media. Information modeling deals with the type of data that is to be exchanged. It is synonymous with noun in English language. Service modeling deals with reading, writing or other actions taken on data and is analogous to verb. Communication protocol is a way of mapping the data to the required action. Telecommunication media is the physical medium used for data communication.

IEC 61850 models power system components in terms of logical nodes and data objects. This modeling is known as information modeling. Information modeling is a way of exchanging standardized information as per the standard. The group of data objects that serves specific function is known as logical nodes and a group of logical nodes forms a logical device. Logical nodes may reside in different devices and at different levels. The objective of the standard is to specify requirements and to provide a framework to achieve interoperability between the IEDs supplied from different suppliers.

Based upon application, IEC 61850 defines main types of communication services viz. services for real time communication, services for client server communication and services for time synchronization. Services for real time communication are generic object oriented substation event (GOOSE) and sampled values (SVs). Due the time criticality of GOOSE and SV messages, they are mapped directly onto the Ethernet layer of OSI seven layer communication model. The standard specifies the protocol data unit for the GOOSE and SV messages. The SV are multicast in the network.

Whenever a fault occurs, protection devices respond to the fault by generating burst of GOOSE messages. The occurrence of fault changes the periodic heartbeat nature of GOOSE message into burst mode. In burst mode, the transmission interval of GOOSE increases sequentially such that after the certain time of trigger of the event, the retransmission time changes back to normal periodic nature as shown in **Figure 2**. As an event occurs (such as a fault) the retransmission time of GOOSE message is changed from To to T1, T2, T3, ..., Tn such that T1 < T2 < T3 < .... < Tn. The sequential increase in retransmission time ends until Tn reaches to To. The gradual increase in retransmission time in bursts is adopted in order to increase reliability of the network, since the GOOSE message conveys critical commands.

The GOOSE messages are LAN-based messages having no Internet or IP layer and is intended for protection purposes. In order to transport GOOSE messages over WAN, tunneling has been employed [13]. Also, differential protection in substations using IEC 61850 has been presented in [14]. Due to presence of distributed generations in a microgrid, the fault current levels increase and a revamped protection strategy is required. This protection scheme must me communication based so that relays are made aware of any addition or deletion of distributed generation. In [15, 16], authors have proposed microgrid protection strategy based on IEC 61850 communication.

The IEC 61850 standard specifies set of abstract services and objects that allows applications to work in a manner independent of the underlying protocol. These services are followed by vendors for invoking any functionalities and are known as abstract communication service interface (ACSI).

3.2 IEC 61850-based communication configuration for ADN

For designing IEC 61850-based communication architecture for ADN, the entities or components of the ADN are modeled as per the IEC 61850 standard.
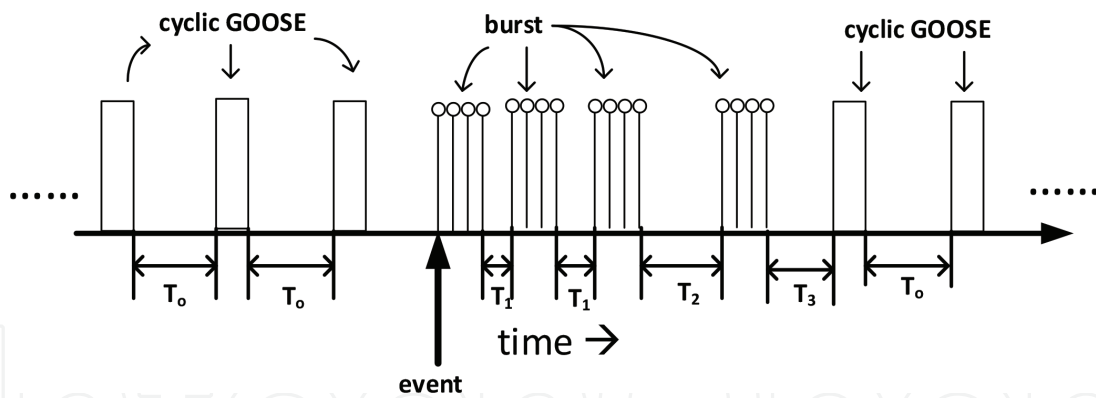
Figure 2.
GOOSE message retransmission in IEC 61850.

There are basically three types of IEDs in a distribution system viz. merging unit (MU) IED, Breaker IED and protection and control (P&C) IED. MU is the main equipment in process level, which receives current and voltage samples from non-conventional instrument transformers and then convert them to digital data packets and communicate to other IEDs, as per communication mechanisms described in IEC 61850-9-2LE [17]. The SV data generated from MUs is time stamped and synchronized using time synchronization source in the substation. A synchronizing accuracy of 1 μs is required by the "IEC 61850-9-2LE" process-bus implementation guidelines to synchronize the MUs in SAS. Breaker IED represents the circuit breaker controlling device, which controls and monitors the status and condition of breaker and also acts as a sink for tripping, close and interlocking commands. P and C IEDs normally receive the SVs data packets from MU IEDs and implement protection and control functions by exchanging appropriate data with other IEDs.

3.2.1 IEC 61850 information models for different components of distribution networks

To enable IEC 61850-based approach for ADN, information models for various entities of ADN are required to be modeled as per IEC 61850 standard. This modeling requires realizing ADN components in terms of logical nodes and data objects. Modeling of various power system components by using relevant logical nodes as per IEC 61850 has been proposed in the standard. The following parts of the IEC 61850 standard are for modeling different components such as,

- IEC 61850-7-420: Information modeling of various DERs such as wind, solar, battery, diesel, etc.

- IEC 61850-90-5: Synchrophasor transmission according to IEC 61850.

- IEC 61850-90-8: Modeling of Electric Vehicle Charging as per IEC 61850.

However, several ADN entities such as phasor measurement unit (PMU), controllable loads, distribution static compensator (DSTATCOM), electric vehicle (EV), solar home system (SHS) are not been modeled in the IEC 61850 standard. Therefore, several researchers have developed information models for all such entities of ADN which are not yet modeled. Authors in [4] have proposed information for IEC 61850-90-5 PMU and provided detailed comparison between the existing IEEE C37.118.2-based PMU and IEC 61850-90-5-based PMU. Performance evaluation in terms of latency, for different network scenario has been presented. Since

the GOOSE and SV type messages are restricted to a local substation and hence cannot be transported in a wide area network (WAN) because of absence of IP layer, modified GOOSE and SV messages have been used. These are known as R-GOOSE (Routable GOOSE) and R-SV (Routable Sampled Values).

Due to absence of any logical node for controllable load, authors in [2] have proposed logical node CNLO by utilizing the generic logical node. The information model for controllable load is also presented. Modeling of Flexible AC transmission system devices is not yet proposed in the standard. Realizing this knowledge gap, authors in [18] have proposed DSTATCOM controller information model as per IEC 61850 standard. The specific information exchanges in the DSTATCOM controller are modeled as instance of logical nodes in their work.

The impact on EV on smart grid has been presented in literature [19–22]. Extending the charging support-based information model of EV presented in IEC 61850-90-8, authors in [23], have amended the current information model of EV in order to include the discharging functionality. The proposed information model in their work can support both G2V (Grid to Vehicle) as well as V2G (Vehicle to Grid) functionality.

Solar Home System (SHS) is a small energy system with a PV panel on its rooftop used for energy generation. The IEC 61850-based model of SHS and Smart Meters to manage tariff structure for bidirectional power transfer has been presented in [24].

4. Performance evaluation of ADN

Performance evaluation for a communication network is computed based on certain communication parameters which are discussed in this section.

4.1 Performance evaluation metrics

Various actors involved in ADN operation are geographically distantly located. In order to manage and control the ADN operation, a coordinated action among various ADN actors is necessary. This coordinated action can be realized by a foolproof communication for control and management of a ADN. To ensure this foolproof communication, there are certain communication parameters to which every ADN communication network must adhere. For effective operation, these parameters must be followed. They are as follows.

4.1.1 Network latency

Latency may be described as the delay on the transmitted data between various ADN components. Network latency is the time elapsed in transferring a data packet from source to destination in a communication network. The network latency is also known as End-to-End delay. In certain time critical ADN applications, network latency is not tolerable and a constraint on network latency is defined in communication standards. Applications such as wide-area situational awareness system, protection strategies are highly time critical and hence requires very low latency rates. For other ADN applications, such as data logging, etc., are not very time critical, network latency is tolerable and has larger acceptable limits.

4.1.2 Data delivery criticality

Data delivery criticality is defined based on the type of data which is communicated in a ADN communication network. Certain commands such as trip

signals, critical alarms, etc., are critical in nature and requires guaranteed delivery to the destination. A ADN can operate in grid connected as well as islanded mode. To switch over from one ADN operation from one mode to another requires communication of commands from ADN central controller to point of common coupling circuit breaker. These commands are highly data critical commands and high data delivery criticality is to be ensured for safe operation of ADN.

4.1.3 Quality of service (QoS)

The communication between a power provider and the power consumer is a key aspect in ADN. Degradation in performance due to delay, network outage, jitter may affect the system reliability and thus a QoS mechanism is needed. A continuous cycle is required to achieve effective QoS in a system. QoS implementations in ADN communication networks are of paramount importance. Providing effective QoS in ADN communication network is becoming a prime aspect in today's enterprise of communication network.

A use case for QoS in a smart grid scenario can be considered is the steaming of various smart sensors for large scale Internet of Things project in smart buildings. These smart sensors collect data such as temperature, pressure, and humidity and are highly time critical. Thus, with effective QoS, this data can be efficiently identified, analyzed, marked and queued accordingly.

4.1.4 Interoperability

Interoperability may be defined as the ability of different information systems and technologies to seamlessly exchange data and interact with other system for required application. In order to realize capabilities of a ADN, technology deployments must connect large numbers of smart devices and systems involving hardware and software. These devices are manufactured from a wide range of vendors having little to much differences in their design and capabilities. Thus, these devices are vendor-specific and cannot be seamlessly integrated within one project. This hindrance creates inconvenience to the operator.

To effectively realize the ADN capabilities, interoperability is an important aspect of technology deployment and must be ensured. The prime requirement for a ADN communication network is on deployment of technologies having end to end integration with compatibility among them. A scheme that is driven and sustained by compliance with uniform standards is the prime motive in a ADN communication requirement.

4.1.5 Scalability

Scalability is defined as the capability of a system or network to handle increasing amount of work or sudden growth without any change on its performance. A use case of scalability can be a network switch with multiple devices connected on its ports. As the number of devices which are plugged-in increases, it is required that the performance of the network switch must remain the same. If there is no change in performance, it is said to be a scalable network switch otherwise it is non-scalable.

In a ADN communication network scenario, large number of DERs and other devices are connected to a ADN network. These devices rapidly add and delete in the network architecture. It is required that the performance of ADN communication network must not be altered with the changing network scenario.

4.1.6 Data security

An ADN communication network would be a wide area network and at times would use the resources of a public shared network such as Internet. Data security requires the transferred data to reach from the source to destination securely. The data must not be tampered in the communication path. An end to end cyber secure path must be achieved.

The cyberthreats are on rise in today's scenario and it is required to protect the power system automation data from cyberattacks. Data confidentiality, integrity must be maintained to provide effective services in ADN communication network. A use case can be a scenario in which a fault arises in a part of ADN and respective protection devices issues a trip signal to the breaker. This trip command in form of GOOSE message in an IEC 61850-based ADN must be communicated within a stipulated delay. Any intrusion would lead to tampering of data in such a manner that it becomes illegitimate and is of no use. Thus, failure of protection strategy would give rise to cascading fault which could lead to huge losses in terms of economy.

4.1.7 Reliability, robustness and availability

Reliability is defined as an attribute of a communication network that consistently performs according to the specifications. A communication network must not fail with increasing network traffic and performs consistently. Robustness is defined as the attribute of a communication network in which it is not vulnerable to any kind of faults and its performance is guaranteed. Availability of a communication network is defined as an attribute that a communication network device must be readily available at all times and there should be no denial of service (DoS).

In an ADN communication network, reliability, robustness and availability must be ensured. For ensuring functions such as protection, operation, management and control of ADN a highly reliable, deterministic, robust and available communication network must be developed.

4.1.8 Standardization

There is a great effort for standardizing the smart grid communication. The benefits of standardization include easy integration of devices, a holistic framework for working and application, a larger business perspective for new entrants. For cost effective and wide spread deployment of smart grid/ADN, interoperability and open interfaces for future extensions standardized solutions are a necessity. The standardization of ADN is driven by government's worldwide by defining new policies and framework. Also, a large number of standardization organizations from ICT and energy industry are considering ADN standardization a priority issue.

For ADN standardization there are various standardization committees working in this direction. Some of the major standardization players are International Electrotechnical Commission (IEC), National Institute of Standards and Technologies (NIST), ISO/IEC JTC1, German Commission for Electrical, Electronic and Information Technologies (DKE), etc. Due to presence of multiple vendor devices in a ADN communication network, the activities of standardization are necessary to provide seamless deployments. The existing smart grid standards are from multiple standardization organizations and have to be developed continuously to deal with changes within regulatory, technical, political and organizational aspects.

4.2 Performance evaluation tools

For carrying out performance evaluation of ADN communication architecture before its actual deployment in field, software tools are employed. These tools help to present the performance of the communication network in terms of latency, throughput, jitter, etc. An emulated system can be developed with the help of performance evaluation tools. The following software-based evaluation tools are used for testing communication configuration of ADN. OPNET/Riverbed Modeler [25], OMNET++ [26], OMNEST, NS2/3 [27] and Qualnet [28].

OPNET/Riverbed Modeler: It provides a comprehensive simulation environment for modeling the communication network and distribution network. It can be used to analyze the performance and behavior of communication network. It provides a Graphical User Interface (GUI) and uses C programming language. It is now known as Riverbed Modeler.

OMNET++: OMNET++ is a component based, modular and open architecture discrete event simulator framework used for simulation of communication networks. Eclipse-based simulation library is used for OMNET++ simulation. Latest version of OMNET++ is OMNEST.

Network simulator (NS2/3): It is discrete event simulator which provides substantial support for TCP simulations, routing simulations and multicast protocol simulation for wired and wireless network. It is an open source freely available software which is designed specifically for computer network simulation. NS3 is the advanced version of NS2.

Qualnet: It is a commercial (licensed) network simulator from scalable network technologies (SNT) which was initially developed for defense project. It is used to predict performance of wireless and wired networks and is a ultra-high fidelity software.

5. Cybersecurity in IEC 61850-based ADN

The IEC 61850-based communication for ADN relies on data transfer in terms of IEC 61850-based messages over a wide area network to realize various features of smart communication. This wide area network is usually a public network like Internet and hence demands proper message security. Ensuring cybersecurity in smart grids employing IEC 61850 requires implementation of IEC 62351's guidelines for different power system operations. However, IEC 62351 cannot handle communications in WANs with several nodes exchanging information at the same time. Therefore, scalability is the bottleneck of cybersecurity in smart grids. Mapping XMPP to IEC 61850 messages can solve this problem. Very recent IEC 61850-8-2 provides these mappings only for MMS messages. There is an immediate need to study feasibility and performance of these mappings. Furthermore, to fully implement XMPP in IEC 61850-based networks, it should be mapped to other IEC 61850 messages, namely R-GOOSE and R-SV. A study for the assessment of delays caused due to processing probabilistic signature scheme (PSS) as per IEC 62351-6 standard in IEC 61850-based GOOSE messages has been presented in [29]. It was concluded that the existing security scheme does not meet the time criticality of GOOSE messages and there is a need of amendment of IEC 62351-6 for providing effective cybersecurity and timing requirements for IEC 61850-based messages.

6. Conclusion

This chapter presents communication technologies and standards which can be employed in an ADN. Role of information and communication technology is inevitable in management of ADN. Thus, this chapter presents communication technologies and protocols which can be adopted for communication configuration of ADN. Among the existing communication protocols for ADN, IEC 61850 is found to be most suitable and acceptable worldwide for communication standardization of ADN. Also, software tools which are employed for simulation of communication architecture of ADN have been discussed. Also, cybersecurity needs for IEC 61850-based ADN has been discussed in this chapter.

Conflict of interest

Authors declare no conflict of interest.

Author details

Mohd Asim Aftab[1]*, S.M. Suhail Hussain[2] and Ikbal Ali[1]

1 Department of Electrical Engineering, Jamia Millia Islamia (A Central University), New Delhi, India

2 Fukushima Renewable Energy Institute, AIST (FREA), Koriyama, Japan

*Address all correspondence to: mohdasimaftab4@gmail.com

IntechOpen

References

[1] Koutsoukis NC, Siagkas DO, Georgilakis PS, Hatziargyriou ND. Online reconfiguration of active distribution networks for maximum integration of distributed generation. IEEE Transactions on Automation Science and Engineering. 2017;**14**(2):437-448

[2] Ali I, Hussain SMS. Communication design for energy management automation in microgrid. IEEE Transactions on Smart Grid. 2018;**9**(3):2055-2064

[3] Communication networks and systems for power utility automation-IEC 61850. 2nd ed. International Electrotechnical Commission; 2013

[4] Ali I, Aftab MA, Hussain SMS. Performance comparison of IEC 61850-90-5 and IEEE C37.118.2 based wide area PMU communication networks. Journal of Modern Power Systems and Clean Energy. 2016;**4**(3):487-495

[5] OpenADR [Internet]. 2019. Available from: http://www.openadr.org/ [Accessed: March 14, 2019]

[6] IEEE Application Guide for IEEE Std 1547, IEEE Standard for Interconnection Distributed Resources with Electric Power Systems-IEEE 1547. Institute of Electrical and Electronics Engineers. 2008

[7] Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), and End-Use Applications and Loads-IEEE 2030. Institute of Electrical and Electronics Engineers. 2011

[8] Telecontrol Equipment and Systems-Part 5: Transmission Protocol. IEC 60870-5-101. International Electrotechnical Commission. 2018

[9] Ali I, Hussain SMS, Aftab A. Communication modeling of phasor measurement unit based on IEC 61850-90-5. In: Annual IEEE India Conference (INDICON). New Delhi; 2015. pp. 1-6

[10] IEEE Standard for Synchrophasor Measurements for Power Systems-IEEE C37.118.1. Institute of Electrical and Electronics Engineers. 2011

[11] IEEE Standard for Synchrophasor Data Transfer for Power Systems-C37.118.2. Institute of Electrical and Electronics Engineers. 2011

[12] Distributed Network Protocol (DNP) [Internet]. 2019. Available from: https://www.dnp.org/ [Accessed: March 14, 2019]

[13] Aftab MA, Roostaee S, Hussain SMS, Ali I, Thomas MS, Mehfuz S. Performance evaluation of IEC 61850 GOOSE based inter-substation communication for accelerated distance protection scheme. IET Generation Transmission and Distribution. 2018;**12**(18):4089-4098

[14] Ali I, Hussain SMS, Tak A, Ustun TS. Communication modeling for differential protection in IEC-61850-based substations. IEEE Transactions on Industry Applications. 2018;**54**(1):135-142

[15] Ustun TS, Ozansoy C, Zayegh A. Modeling of a centralized microgrid protection system and distributed energy resources according to IEC 61850-7-420. IEEE Transactions on Power Systems. 2012;**27**(3):1560-1567. DOI: 10.1109/TPWRS.2012.2185072

[16] Ustun TS, Ozansoy C, Ustun A. Fault current coefficient and time delay assignment for microgrid protection system with central protection unit. IEEE Transactions on Power Systems.

2013;**28**(2):598-606. DOI: 10.1109/
TPWRS.2012.2214489

[17] 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, Ed. 2.0. 2011

[18] Hussain SMS, Aftab MA, Ali I. IEC
61850 modeling of DSTATCOM and
XMPP communication for reactive
power management in microgrids. IEEE
Systems Journal. 2018;**12**(4):3215-3225.
DOI: 10.1109/JSYST.2017.2769706

[19] Ustun TS, Zayegh A, Ozansoy C.
Electric vehicle potential in Australia: Its
impact on smartgrids. IEEE Industrial
Electronics Magazine. 2013;**7**(4):15-25.
DOI: 10.1109/MIE.2013.2273947

[20] Hussain SMS, Ustun TS, Nsonga P,
Ali I. IEEE 1609 WAVE and IEC 61850
standard communication based integrated
EV charging management in smart
grids. IEEE Transactions on Vehicular
Technology. 2018;**67**(8):7690-7697. DOI:
10.1109/TVT.2018.2838018

[21] Ustun TS, Ozansoy CR, Zayegh A.
Implementing vehicle-to-grid (V2G)
technology with IEC 61850-7-420.
IEEE Transactions on Smart Grid.
2013;**4**(2):1180-1187. DOI: 10.1109/
TSG.2012.2227515

[22] Ustun TS, Hussain SMS,
Kikusato H. IEC 61850-based
communication modeling of EV
charge-discharge management for
maximum PV generation. IEEE Access.
2019;**7**:4219-4423. DOI: 10.1109/
ACCESS.2018.2888880

[23] Aftab MA, Hussain SMS, Ali I,
Ustun TS. IEC 61850 and XMPP
communication based energy
management in microgrids considering
electric vehicles. IEEE Access.
2018;**6**:35657-35668. DOI: 10.1109/
ACCESS.2018.2848591

[24] Hussain SMS, Tak A, Ustun TS, Ali
I. Communication modeling of solar
home system and smart meter in smart
grids. IEEE Access. 2018;**6**:16985-16996.
DOI: 10.1109/ACCESS.2018.2800279

[25] OPNET [Internet]. 2019. Available
from: https://www.riverbed.com/in/
products/steelcentral/steelcentral-
riverbed-modeler.html

[26] Omnet++ [Internet]. 2019. Available
from: https://www.omnetpp.org/

[27] NS2 [Internet]. 2019. Available
from: https://ns2tutor.weebly.com/

[28] Qualnet [Internet]. 2019.
Available from: https://web.
scalable-networks.com/
qualnet-network-simulator-software

[29] Farooq SM, Hussain SMS, Ustun
TS. Performance evaluation and analysis
of IEC 62351-6 probabilistic signature
scheme for securing GOOSE messages.
IEEE Access. 2019;**7**:32343-32351. DOI:
10.1109/ACCESS.2019.2902571