People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific research
M'hamed Bougara University, Boumerdes
Institute of Electrical and Electronic Engineering,
Laboratory of Signals and Systems (LSS)

ALGERIAN JOURNAL OF SIGNALS AND SYSTEMS

ISSN : 2543-3792

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Page range: **162- 179**

Volume : 2 Issue : 3 (September 2017)

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A review on Data communication in smart grids

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Abstract: Smart Grids require a complex two-way communication infrastructure, sustaining power flows between intelligent components, and sophisticated computing and information technologies, as well as business applications. Data will flow over generation, transmission, distribution, and user networks in the SG. The amount of data generated by smart devices will experience explosive growth in the future. This tremendous data amount places considerable load on the communications infrastructure of the SG. This paper highlights a review on the smart grid focusing on the communication infrastructure and the data issues. A scan of the most contributions relevant to the topic is presented. The key opportunities and challenges of the communication part of the smart grid are presented for further research.

Keywords: Smart grids, communications, data, PMU, WAMC, Smart metering, Big data management**.**

6. INTRODUCTION

Smart grids incorporate with the electrical grid a data communication infrastructure that gathers and evaluates data in either real- time or offline about power transmission, distribution and consumption [1]. The power grid encompasses four elements: electricity generation plants, transmission substations, distribution substations and customers [2]. Power generated from plants from a variety of sources (including classical fossil fuel, solar, wind and nuclear sources) is attenuated to the voltage fit for residential use. Home appliances power utilization is sensed through their electric smart meters [2–4]. This blend of power levels has to be monitored through the data gathering system. As an example, the power generation can be continually controlled by using the real-time energy consumption of the end users. Similarly, the end user can monitor the real-time power usage of the home and can obtain the real-time cost of the power supplied from the service provider [5]. On the other hand, the users can supply electricity in a smart grid. For example, users having homes equipped with photovoltaic (PV) systems are able to generate electricity and return it to the grid to help balancing the loads by "peak clipping", i.e., sending power back to the grid when the demand is high. This information exchange between different elements provides the smart grid with predictive information and hence, generate recommendations to utilities, their suppliers and their customers on how to manage power in an optimal manner [4].

In the literature, some works attempted to present the smart grid and the communication requirements to enable the functionalities of the smart grid [6]. Authors in [7] provide a comprehensive tutorial about capability and requirements that the smart grid needs from both power and communications perspectives. Authors in [8] summarize application characteristics and traffic requirements of the communication infrastructure in the smart grid, while authors in [9] present a brief survey of selected transmission grid applications in terms of their bandwidth and latency requirements. Although existing wired and wireless communication technologies can be applied to the smart grid, establishing smart grid standards and protocols is an urgent issue for some devices, i.e., smart meters [10]. In the literature, smart grid technologies and standards are discussed to provide an overview of the smart grid paradigm and integration of different communication technologies [11,12]. Some studies focus on a specific standard or communication technologies, i.e., smart metering [13], power line communication (PLC) [14], and wireless communication [15,16]. Authors in [17] evaluate the network performance for a long-distance distribution line and proposed a communication architecture for distribution level applications. Additionally, selection of communication technologies for transmission-level applications has been addressed in [18].

This paper attempts to introduce the smart grid and a systematic presentation of the communication infrastructure needed for its deployment. Focus is put on the data communication and the related standards, requirements and key properties related to this topic.

7. THE SMART GRID

Smart grid is a term referring to the next generation power grid in which the electricity distribution and management is promoted by incorporating advanced two-way communications and pervasive computing capabilities for improved control, efficiency, reliability and safety. A smart grid delivers electricity between suppliers and consumers using two-way digital technologies. It controls intelligent appliances at consumers' home or building to save energy, reduce cost and increase reliability, efficiency and transparency [19].

Several technologies to be taken on by smart grid have already been used in different industrial applications such as sensor networks in manufacturing and wireless networks in telecommunications. These are suitable for use in new intelligent and interconnected paradigm. Generally, smart grid communication technologies can be gathered into five areas: advanced components, sensing and measurement, improved interfaces and decision support, standards and groups, and integrated communications [19].

The smart grid relies on a wide array of technology that has the potential to improve the reliability, security, and efficiency of the electric grid, offering economic and environmental benefits. In Fig. 1, the components of all of the smart grid layers are illustrated from the energy infrastructure to the potential applications.

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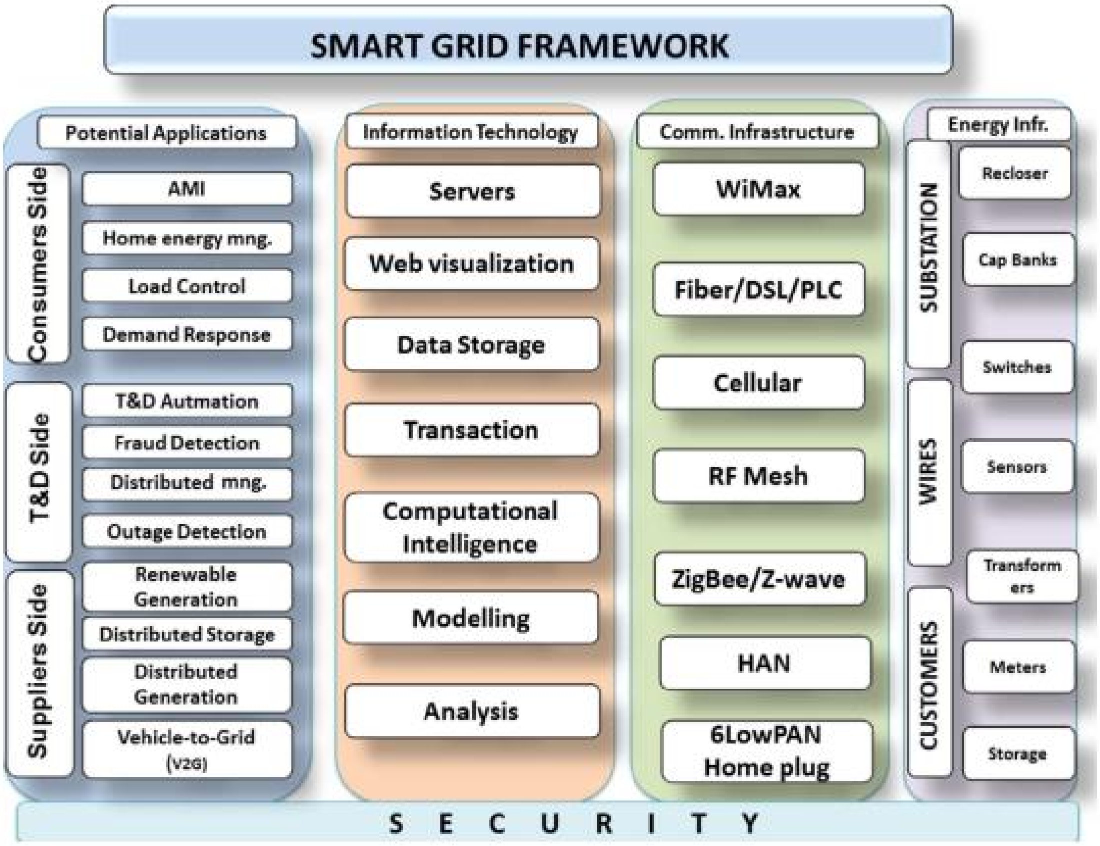


Fig. 1. SG framework depicting the potential applications, information technology, communication, and energy infrastructure of the overall system.

8. SMART GRID COMMUNICATION

Maintaining communication between the components of the smart grid by the communication infrastructure is very essential. Besides the electricity connection, smart grids permit to have data connection to vehicle information over the grid. Hence, there is a need for a secure communication network with high bandwidth capacity and speed.

The smart grid is an interactive platform, consisting of a power system layer, a control layer, a communication layer, a security layer and an application layer. The communication layer is one of the most critical elements that enables smart grid applications. In the smart grid environment, a communication network can be represented by a hierarchical multi-layer architecture classified by data rate and coverage range. According to the smart grid communication, infrastructure can be generally classified into HAN, NAN and WAN based on the data rate and coverage range. Smart grid applications are grouped by their data rate and coverage range required for their successful deployment. A comparison of various communication technologies that can support smart grid applications in terms of data rate and coverage distance is presented in Table 1.

Table 1 Comparison of communication technologies for the smart grid

Technology	Standard/protocol	Max. theoretical data rate	Coverage range
Fiber optic	PON	155 Mbps–2.5 Gbps	Up to 60 km
	WDM	40 Gbps	Up to 100 km
	SONET/SDH	10 Gbps	Up to 100 km
DSL	ADSL	1–8 Mbps	Up to 5 km
	HDSL	2 Mbps	Up to 3.6 km
	VDSL	15–100 Mbps	Up to 1.5 km
Coax. Cable	DOCSIS	172 Mbps	Up to 28 km
PLC	HomePlug	14–200 Mbps	Up to 200 m
	Narrowband	10–500 kbps	Up to 3 km
Ethernet	802.3x 10	Mbps–10 Gbps	Up to 100 m
Bluetooth	802.15.1	721 kbps	Up to 100 m
ZigBee	ZigBee	250 kbps	Up to 100 m
	ZigBee Pro	250 kbps	Up to 1600 m
WiFi	802.11x	2–600 Mbps	Up to 100 m
WiMAX	802.16	75 Mbps	Up to 50 km
Wireless Mesh	Various (e.g., RF mesh, 802.11, 802.15,802.16)	Depending on selected Protocols	Depending on deployment
Cellular	2G	14.4 kbps	Up to 50 km
	2.5G	144 kbps	
	3G	2 Mbps	
	3.5G	14 Mbps	
	4G	100 Mbps	
Satellite	Satellite Internet	1 Mbps	100–6000 km

Generally, there are three types of networks : Home Area Networks (HANs), Business Area Networks (BANs) and Neighborhood Area Networks (NANs) [6]. In the following, each of these types of networks is detailed.

HAN: HAN operates within small area (10 meters)**.** It ensures the transmission of information between different electronic devices that are inside or within close vicinity of the house. From the devices included, we have : smart meter, smart appliances, smart sockets, plug in vehicle chargers. The smart meter corresponds with the rest of devices to gather data as power usage information of energy-consuming devices, the status of renewable energy resources and the produced energy by these resources etc in order to be sent to utility company. HAN permits an efficient home energy management. Wireless and power-line communications are the most fitting options to implement HAN [19-22].

NAN: Neighborhood Area Network comprises multiple HANs. Smart meters (HAN gateways) transfer data of energy consumed by each house and control data to the NAN network. This last sends this data to Local Data Centers for storage [23]. NAN operates within area of hundreds meters, i.e, few urban buildings. The NAN can be implemented by PLC, Wi-Fi, and cellular technologies. Since the deployment environment of NAN in an urban area is complex and harsh, wireless mesh network (WMN) is considered as to be the most suitable technology for NAN [24] .

WAN : Wide Area Network is a link that ensures communications between all entities of smart grid, i.e. power plants, transmission and distribution subsystems, utility companies and customer premises.It is expanded over a wide geographical area. NANs and HANs are incorporated in the WAN [21,25].

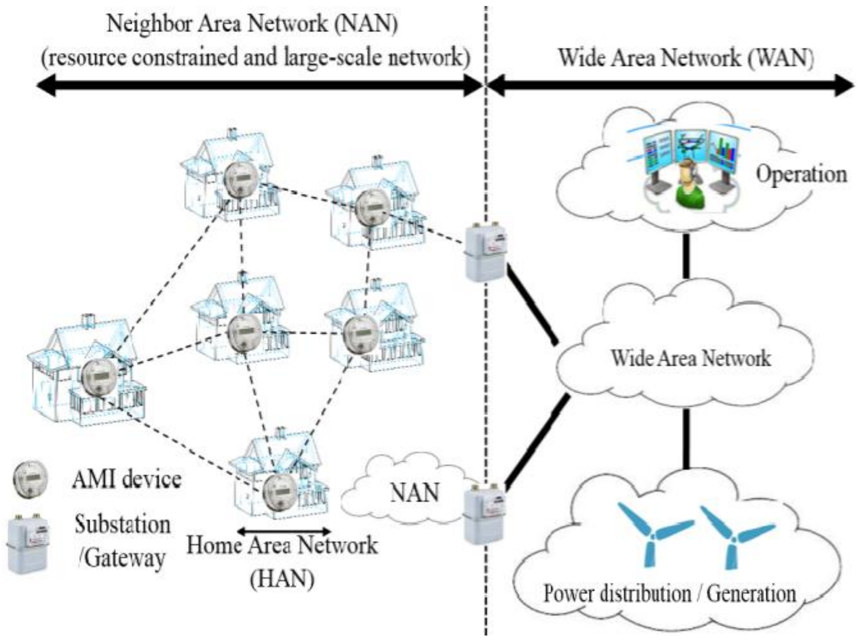


Figure 2: Different parts of Smart Grid communication network

There are several technologies that can be applied to the smart grid:

3.1. ZigBee

Zigbee is classified as wireless communications technology that is moderately low in power usage, data rate, complexity, and cost of operation. It is an ultimate technology for smart lightning, energy monitoring, home automation, and automatic meter reading, etc. it is preferable to facilitate the communication between smart meters, and among intelligent home appliances and in home displays. Zigbee Smart Energy Profile (SEP) allows utilities to transmit messages to the home owners so that they can get the information of their real-time energy consumption.[26] smart grid technologies

1) Advantages: as advantages we can list the low price, small size and it uses relatively small bandwidth. It is ideal to be used in smart grid implementation for mobility and robustness. [27], [28].

2) Disadvantages: some of disadvantages are : the small battery that bound its lifetime, small memory, limited data rate, low processing capability and small delay requirements[26].

3.2. Wireless Mesh

A mesh network is flexible network composed of an assembly of nodes, where new nodes can join the group and every node can operates as an independent router. In PG&E's SmartMeter system, each smart device is suppliedwith radio module that routes the metering data through close meters. Every meter works as a signal repeater until the gathered data reaches the electric network access point. This data is trasmited to the utility via a communication network [29].

1) *Advantages:* we can list its cost effectivenes
with dynamic self-organization, self-healing, self-configuration, high scalability services, that give many benefits as improving the network performance, balancing the load on the network extending the network coverage range and good coverage [30]. home energy management are some of the applications that wireless mesh technology can be used for.

2) *Disadvantages:* as major challenges, we have
Network capacity, fading and interference. There is also the coverage challenge as the meter density is not able to provide complete coverage of the communications network. Providing the balance between reliable and flexible routing, a sufficient number of smart nodes, taking into account node cost, are very important for mesh networks.as the metering information passes through each access point, some encryption techniques are applied to the data for security purposes. besides, while data packets travel around many neighbors, there can be loop problems

causing additional overheads in the communications channel that would result in a reduction of the available bandwidth [31].

3.3. Cellular Network Communication

Cellular networks are widely operated in many countries. They can be used to allow the communication between distinct components and devices in smart grid. The following characteristics that can be achieved using the telecommunication wireless network technologies like 2G, 3G, even 4G that are deployed in smart grid networks : application awareness, support for large numbers of simultaneous cell connections, high service coverage, and prioritized routing of data. The WiMAX is one of the 4G solutions that is most preferable for smart grid implementation. [22].

1) *Advantages* : the already existing infrastructure with wide area of deployment, data transfer high rates, available security algorithms that are already implemented in the cellular communication, Lower cost, better coverage, lower maintenance costs, and fast installation features.

2) *Disadvantages* : cellular networks are joint with other users and are not completely dedicated to the smart grid communications. This may present a serious problem in case of emergency state of the grid [26].

3.4. Powerline Communication

Powerline Communication (PLC) is a technology that makes use of the power lines to transmit data and electrical power [32-35]. This system sends modulated carrier signals on the power transmission wires. There is a variation of few hundred of bits per second to millions of bits per second for data rates on power lines, inversely proportional to the power line distance. Thus, to give an alternative broadband networking infrastructure [36,37] without installing dedicated network wires, power line communication is largely used for in-door environment. a survey of communication network

1) *Advantages:* the wide-spread infrastructure that decreases installation costs. The standardization efforts on PLC networks, the cost-effective, ubiquitous nature, and widely available infrastructure of PLC make it strong and popular [38]. PLC technology is appropriate to urban areas for smart metering, monitoring and control applications.

2)*Disadvantages:* the network topology, the number and type of the devices connected to the powerlines, wiring distance between transmitter and receiver, all of this that have an effect on the quality of signal transmitted over powerlines [29]. All this make PLC technology not appropriate for data transmission. To fix that, some hybrid solutions are proposed like the combination of PLC and other technology as GPRS OR GSM.

9. COMMUNICATION FRAMEWORKS

4.1. IEEE C37.118 Communication System

IEEE C37.118 is the improved version of IEEE 1344 which was the first available synchrophasor communication standard. It defines methods for evaluation of Synchrophasor measurements, time synchronization, application of time-tags and format of messages exchanged over the network. It does not put any restriction on the communication mode, protocol or media and messages can be transmitted in unicast, multicast or broadcast fashion over any communication medium and transport protocol. Originally, IEEE C37.118 addressed the performance of synchrophasors only under steady state conditions ignoring system disturbances and noise. However, a revision of IEEE C37.118 in 2011 accounts for more precision and support for dynamic power system conditions.

IEEE C37.118 describes four types of messages: data, configuration, header and command. Data messages are used to send actual real time measurements made by the PMU. Data from multiple PMUs may be transmitted in a single message correlated to a particular time stamp (i.e., PDC functionality).

Header messages contain descriptive information (e.g., filtering, scaling algorithms etc) which is sent by the PMU/PDC but actually provided by the user. Command messages are used to control the operation of device sending synchrophasor measurements. In short, data, configuration and command messages are expressed in machine-readable format while header is descriptive information in human-readable format. Further, data, configuration and header are the message types sent by the data sources whereas command message is received by the data sources [39-40].

4.2. IEC 61850-90-5 Communication System

IEC 61850-90-5 is derived from IEC 61850 which was initially proposed for substation automation. IEC 61850 is a complete communication system that addresses modeling of power system components, abstraction of services and communication protocols and methods [41]. It was designed with several objectives in mind:

(i) interoperability and integration between power system components from different vendors,
(ii) device/service modeling,
(iii) self description and object auto-discovery due to structured meta-data,
(iv) reliability mechanism through retransmission,
(v) reduced substation cost

through multicast and replacing of expensive relay-to-relay wiring with wireless communication, and (vi) support for machine to machine sharing of configuration data using Substation Configuration Language (SCL). However, IEC 61850 also has limitations including lack of security mechanism and restricted communication to only the local network. IEC61850-90-5 inherits all the features of IEC 61850 while also overcoming its limitations. IEC 61850- 90-5 includes a security mechanism based on Group Domain of Interpretation (GDOI) and also allows transmission of time-critical protocols over wide-area networks by relying on transport and network layer protocols.

10. APPLICATIONS AND COMMUNICATION REQUIREMENTS

The SG is the integration of the power grid infrastructure with an advanced communication infrastructure where different types of data can be efficiently moved with varying degrees of security, reliability, QoS, and communication requirements. Hence, an integrated, flexible, interoperable, and secure two-way communication backbone, which meets the communication requirements of each SG component, is critical to the success of the SG. Here, some of the requirements that should be satisfied by the SG communication backbone are listed.

• Latency: Latency can be described as the delay of the data transmitted between the smart grid components. Some mission-critical applications may not tolerate any latency, such as wide-area situational awareness systems or distribution automation systems. For other applications, such as advanced metering infrastructure (AMI) or home energy management (HEMs), latency is not critical.

• Frequency Ranges: SG applications may need lower frequency ranges (below 2 GHz) to provide high-quality and cost-effective communication across the utility's service area. This is because lower frequency ranges can enable radio signals to overcome line-of-sight issues, e.g., foliage, rain fade, and penetration through walls [42].

• Reliability: Reliability is a metric of how reliable a communication system can perform data transfers according to the specific requirements. The communication nodes should always be reliable for the continuity of communications. Some of the SG applications, such as distributed automation, expect highly reliable data communication, and some of them can tolerate some outages in data transfer.

• Data Rate: Data rate is a closely related term specifying how fast the data is transmitted between SG components. The data-rate requirements can be different for each specific SG application. Some of the SG applications that transmit video and audio data, such as wide-area situational awareness systems, require high data-rate values to achieve a reliable and accurate data transfer. On the other hand, the communication data rates for distribution automation and AMI can be low [43]. Hence, the choice for communication technology should be determined according to specific data requirements for each application.

• Security: Security is the ability of the communication infrastructure to combat with physical and cyber security attacks to protect the critical data gathered from various smart grid components. Providing end-to-end security carries the highest priority for almost all SG applications [44]. Especially for mission critical applications, security should be provided on a communication network to prevent any vulnerabilities to the critical assets of the power grid [42].

• Throughput: The estimation of the total throughput that the SG will require for the communication systems of many applications, e.g., AMI, demand response, is Mbps [42]. In the following, the main applications and communication requirements are summarized and analyzed in a structured way.

A. Substation Automation

Substations are key elements of the power grid network and all their devices are monitored, controlled, and protected by substation automation systems (SASs). SAS collects the data and performs actions on it allowing robust routing of power from generators to loads through the complex network of transmission lines. The communication network plays a critical role for SAS to have full control and monitoring of the real-time operating conditions and performances of sub-
stations. A highly reliable, scalable, secure, and cost-effective communication network is a prerequisite to prevent possible disruptions, e.g., power disturbances and outages.
The communication requirements of substation automation are shaped by the hazardous electrical environments. The wired technologies need high protection from the problematic currents on the ground, hence wireless or fiber optic technologies are preferred mostly [45]. On the other hand, the latency requirements must be low, e.g., less than 100 ms, to prevent communication from timing out.

B. Overhead Transmission Line Monitoring

Overhead Transmission Line Monitoring is one of the most important T&D-side smart grid applications since transmissionlines are vulnerable to icing, overheating and lighting strikes, which can adversely affect the lives of citizens. Hence, to monitor T&D systems, wireless sensor nodes are deployed on some parts of the transmission lines and communicate with the relay node to transmit the monitored data. The relay node can be serviced by GSM/GPRS/UMTS as proposed in [46], to send the collected data via cellular communication technologies to the control center.
• Communication Requirements of Overhead Transmission Line Monitoring:
The communication requirements for overhead transmission line monitoring systems depend on the network model, number of nodes and the preferred communication technology. Importantly, a large portion of energy is flowing through the transmission lines, hence, overhead transmission line monitoring systems shouldsupport reliable, secure, effective and real-time communication to respond to emergency situations quickly.
According to the network model that is proposed in [46], it takes 73 s to send information from the relay node to the sink node in a 100 node network model with hybrid communication technologies, e.g., ZigBee, GPRS, etc.

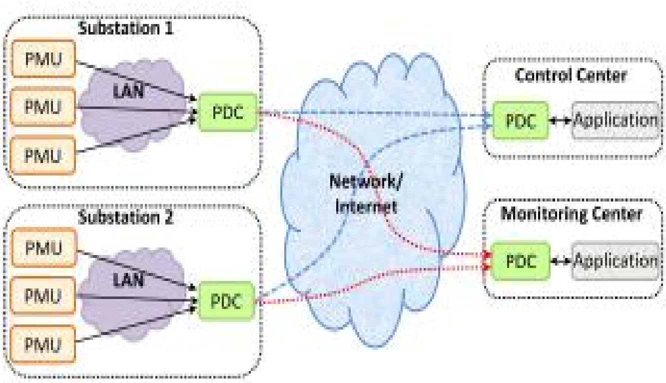
11. DATA COMMUNICATION

In smart grids, the information can be collected at the data server and reproduced by the service provider in order to develop new services and business models. Hence, all electric grid elements must share the common understanding that the smart grid needs to be integrated with a data-networking infrastructure in order to be categorized them as “smart things” [19].
In smart grids, care must be taken to deal with the different data sets. Because of their nature, distribution and real-time constraints of certain needs, big Data techniques are suitable for advance and efficient data management for this kind of applications. The large volume of data will help utilities to do things they never could do before such as better understanding the customer behaviour,conservation, consumption and demand, keeping track of downtime and power failures etc. At the same time, this will present challenges for utilities that lack the systems and data analysis skills to deal with these data. So, the main goal of utilities now is the ability to manage high volume data and to use advanced analytics to transform data collected to information, then to knowledge and finally to actionable plans [47].
As data size, latency and reliability requirements for different smart grid applications vary widely and are not easily obtainable to practitioners, this paper presents a comprehensive compilation of information from various use cases and smart grid-related standards on potential smart grid applications and their associated communication network requirements. These are discussed in terms of typical payload, data sampling requirements, as well as latency and reliability requirements for smart grid applications deployed in a Home Area Network (HAN), Neighborhood Area Network (NAN) and Wide-Area Network (WAN). Additionally, the paper also

discusses, based on selected smart grid projects around the world, various communication technologies that have been implemented to support real-world smart grid applications.
Data quality is a subjective standard used to determine if a set of data is suitable for a particular business purpose. To quantify the data quality problem further, fifteen data quality aspects have been defined in [48]. The suitability of PMU data to the intended WAMC application function is measured by a set of metrics that are referred to as the PMU data quality measures. Three critical PMU data quality attributes including data accuracy, data latency, and data completeness are of great importance.

12. DATA COMMUNICATION AT THE GRID LEVEL

The WAMC system is proposed to enhance the power system operation and control by aggregating the fine-grained and timely information that was originally used for power system protection purposes at higher levels in the system hierarchy [49]. The data accuracy is a relevant quality attribute for all of the computer systems providing services based on measurements. This quality attribute is measured by the discrepancy between the PMU measurements and the corresponding power system states. A set of metrics has been proposed by the IEEE standard C37.118.1 to determine the performance of the PMU measurements under a variety of conditions. For example, the Total Vector Error (TVE) is introduced as a primary tool to evaluate the synchrophasor measurement accuracy in the power system steady state, and the delay time and response time are proposed to evaluate the PMU response to step changes [50].
A prominent feature of the synchrophasor technology is that the PMU measurements are provided with time information, represented by their time-stamps, to track the power system states that change with respect to time. Consequently, neither the inaccurate PMU measurements nor the delayed synchrophasors can represent the true states of the power system.



Generic synchrophasor system.

In [51], a set of delay values was presented to prove the feasibility of transferring synchrophasors over a multicast-based communication infrastructure. In another related project [52], the PMU communication delays in IP networks were examined by performing simulations in ns-2. The extra PMU communication delays due to encryption and decryption of the synchrophasor data streams were highlighted by this paper. A similar work with an extended scope can be found in [53]. Simulations of the IP network was extended by [54] to investigate the PMU data frame losses due to data alignment performed by the PDC. To ensure the timeliness of the PMU measurements, research efforts were also made to implement quality of service mechanisms to prioritize the PMU traffic. Results from simulations of an IP network incorporating the multi-protocol label switching scheme in OMNET++ were reported in [55], and a latter work with a similar concept can be found in [56]. In [57], the challenges posed by a hierarchical infrastructure with multiple layers of data concentrations (performed by PDCs) were discussed.
The empirical results regarding the PMU communication delays or data frame losses are those of [58] from China, [59] from Canada, and [60] from Brazil. The primary contribution of the above works was not to report empirical results. As a result, these works provided neither detailed descriptions of the ICT systems in question nor elaborated discussions on the presented empirical evidence. In [61-62], a comprehensive and detailed description of the utility IP network from where

the empirical results were obtained are provided. Additionally, the research also emphasized on the interpretation of the empirical evidence by analyzing the root causes of the patterns of the studied data. Finally, efforts have been made to generalize the PMU communication delays by identifying distributions that offer the best fit to the empirical datasets.
To account for the challenges posed by the delayed PMU input, or the data frame losses, many delay-robust control schemes have been proposed. According to [63], the delayed input essentially create an excessive time-variant phase-lag to the damping controller, which, in turn, run the risk of deteriorating the control functionality. Such a challenge could be overcome by deploying adaptive compensations calculated from phasors extracted from rotating coordinates. An alternative is to propose control strategies against a set of nominal delays that are modeled using Pade approximations. A typical work along this track is the predictor framework presented by [64]. Following the same principle, a parameter-dependent $H\infty$ controller coupled with scheduled gains, referred to as GSPOD, was proposed to manage the delayed input and model variations in [65]. Though promising outcomes have been presented, these Pade approximation based designs tend to yield conservative control outcome with respect to delays that deviate significantly from the nominal delay horizons. Research efforts were also made to apply the generalized predictive control scheme together with an on-line Kalman filter to manage the PMU input delay as well as the changes of the plant model [66]. Moreover, the robustness of the fuzzy-logic based wide-area damping system was investigated by [67]. The reported simulation results suggested that this design could tolerate PMU input delays to approximately 300 milliseconds without presenting any notable function degradation. To increase the stability margin of the damping control in the presence of input delays, a PMU-based damping system incorporating a band-pass filter was presented in [68]. Finally, a more recent work applying trajectory extrapolation to compensate for the communication network impairments can be found in [69].

7.1. Supervisory control and data acquisition (SCADA)

Communication between multiple automation components is important in any smart grid implementation. SCADA system has a role at the core of smart grid system to maintain the real-time monitoring and control of power distribution [70]. A standard SCADA system comprises the following components [71]:
_Control Servers: hosting control software and accessing subordinate control modules.
_ Human-Machine Interface (HMI): it permits operators to monitor the system states; changes control settings, and manually overrides automatic control operations in emergencies.
_ Remote Terminal Unit (RTU): with wireless radio, it interfaces to conduct data acquisition and control.
_ Programmable Logic Controller (PLC): that performs the logic control functions performed by electrical hardware.
_ Intelligent Electronic Devices (IED): a smart sensor and actuator to acquire data, communicate to other devices, and perform local processing and control.
As it is illustrated in Figure 3, the control center holds the control server, the HMI, engineering workstations, and the data historian, which are all connected by a LAN and exposed through a router. It collects measurements and logs information from the field devices, visualizes them to the HMI, and may generate actions based upon detected events. The wide area networks enable the communication protocols between the control center and the field sites, which are typically implemented using power/telephone line, cable, radio microwave and satellite [72].

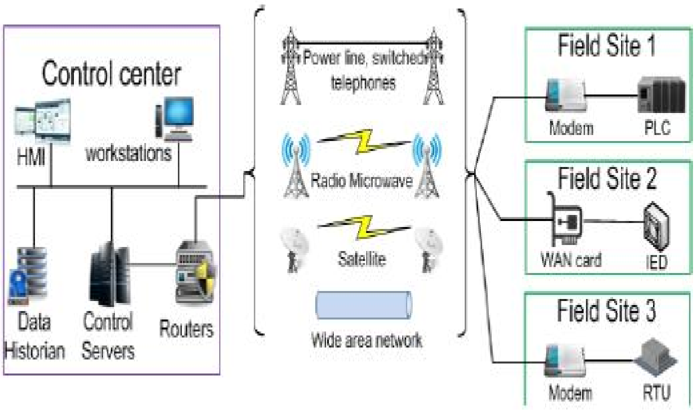


Fig. 3. SCADA system general layout [72]

7.2. Synchronized Phase Measurement Unit (PMU)

PMU is a monitoring device that uses synchronization signals from global positioning system (GPS) satellites. It affords the phasors of voltage and currents computed at some substation. PMUs will be used at control centers for energy management system(EMS) not only for substation applications [73].The energy management system (EMS) uses the information received from PMUs at control centers for improving state estimation, monitoring, control a,d protection. When the PMUs are effective utilized, they will be useful in mitigating blackouts and learning the real time behavior of the power system [74].

13. DATA COMMUNICATION AT USER LEVEL

Smart distribution grids's enablers are automated meters and smart meters. The term smart grid is used broadly to refer to the next generation of electrical energy transmission and distribution infrastructures, which will be characterized by a tight integration with Information and Communication Technologies (ICT). Automated meter term is used for a device that can (i) measure consumption of electric energy with a variable time granularity and (ii) report the measured consumption to a Meter Data Management System (MDMS).

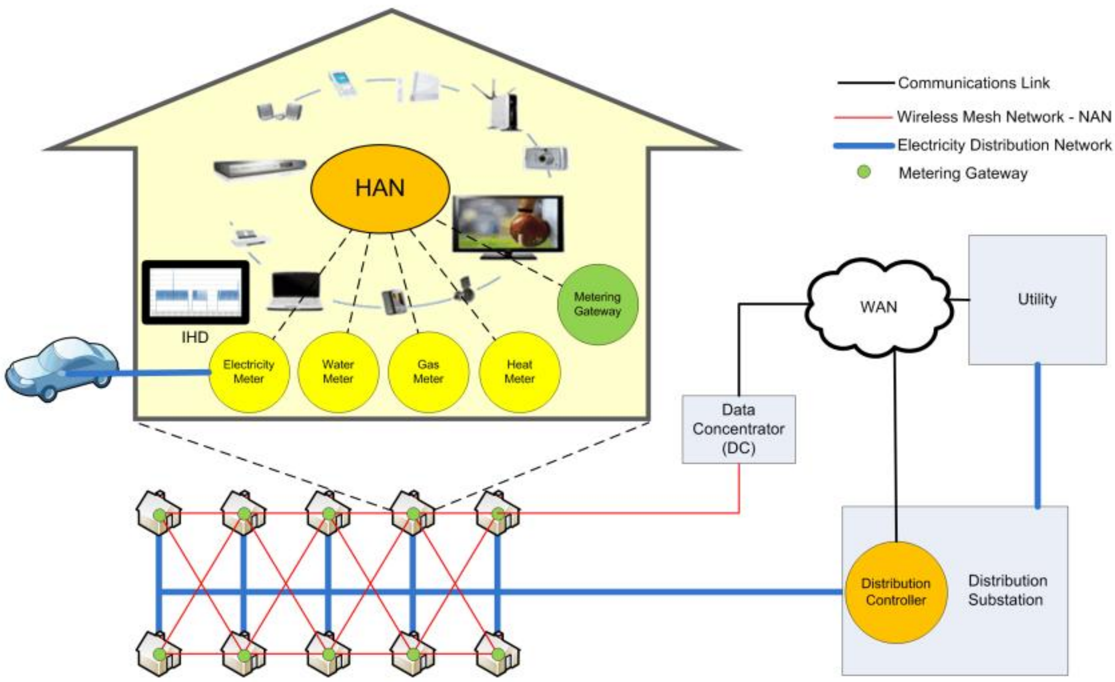


Fig. 1. Typical smart metering architecture

Smart meter are used for an automated meter that can also (iii) receive pricing information or direct load control commands and can (iv) exchange information with smart home appliances, that permits to optimise energy use and to participate in demand response [75].

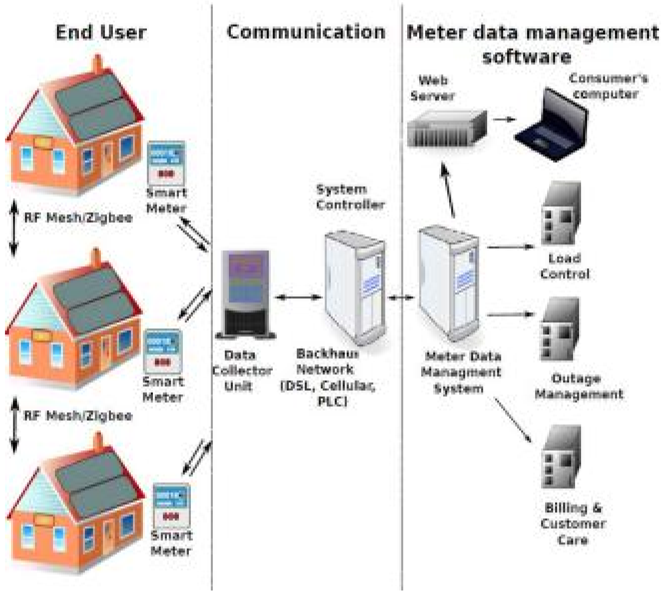


Fig. 4. Detailed architecture of an AMI

Unfortunately, the data collected by smart meters may also serve for invading consumers' privacy. Several recent works have pointed out that electricity consumption data may allow one to reveal private information, such as household occupancy or economic status [76]–[80]. As a consequence, smart meter data are subject to serious privacy and security concerns. The privacy concerns and their perception within the public have delayed the roll out of smart metering in a number of countries [81], and call for new technical solutions.

What makes the problem different from standard data security and privacy is the combination of three factors: the legacy of energy technologies that are based on closed systems, the interweaving with legal and regulatory aspects that introduce additional constraints, and the complex structure of the energy sector, with a variety of interconnected stakeholders, thus requiring more standardized solutions.

There has been significant recent works showing that individual appliances (based on their load signatures [82]) can be identified from the detailed analysis of energy consumption traces [83]–[90]. Frequent meter readings can also be used to infer the occupancy of a household, and data mining algorithms can also be used to invade the privacy of consumers in more sophisticated ways, e.g., by revealing their life-styles and economic status [76]–[80]. Recent work also shows that fine enough measurements could reveal consumers' interests as well, e.g., Greveler et al. [91] show that they can estimate the displayed TV channel from the electricity usage profile with a sampling period of 0.5 s. Privacy is thus a serious concern, and calls for a data governance framework tailor-made for the smart grid.

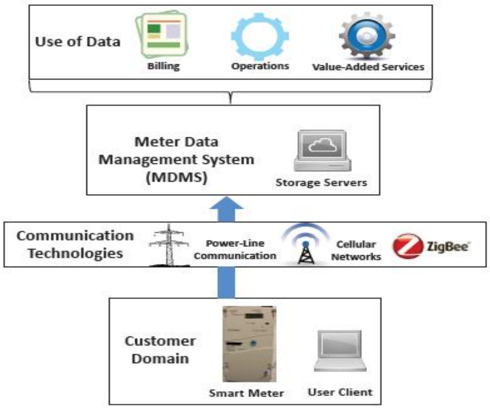


Fig. 4. Different domains of the smart metering infrastructure [75]

A number of recent articles survey security issues in smart grids [92]–[100]. Lu, Wang and Ma [93] provide guidelines on designing security schemes for smart grids. Baumeister [94] reviews and categorises the literature on smart grid security. In [96], Anderson and Fuloria discuss the security economics of electricity metering, while the potential effects of hacking have been reviewed by several security specialists. Mo et al. [99] discuss security approaches for smart grids. Privacy challenges in the smart grid have been considered recently in [100]–[106].

14. BIG DATA MANAGEMENT

9.1. Cloud computing

Several problems related to big data management for smart grids are solved by cloud computing. It allows utilities to guarantee the flexibility, agility and efficiency in terms of saving cost, energy and resources [32]. Using cloud computing in smart grid has huge advantages as a result of redundancy, rollback recovery and multi-location data backup that augment data fault tolerance and security [22].

Cloud computing is based on service models that can be proposed in public, private, or hybrid manner: (1) software as a service (SaaS) that gives applications and make them available to customers over the Internet, (2) platform as a service (PaaS) delivers hardware and software tools and gives customers the ability to create their own applications, (3) infrastructure as a service (IaaS) offers hardware, software, servers, and other IT infrastructure components over the Internet, (4) data as a service (DaaS) permits customers in addition to run applications to store data on-line, (5) communication-as-a service (CaaS) is useful for messaging tools including voice over IP (VoIP), instant messaging (IM), and video conferencing, and (6) monitoring as a service (MaaS) is used for security services to ensure a third party security [26].

challenges of using Big Data technologies are satisfied by Cloud computing frameworks. there are several cloud solutions that can hold Big Data such as Amazon Elastic Compute Cloud (Amazon EC2), Google Compute engine, Microsoft Azure Cloud, IBM Docker Cloud, etc.

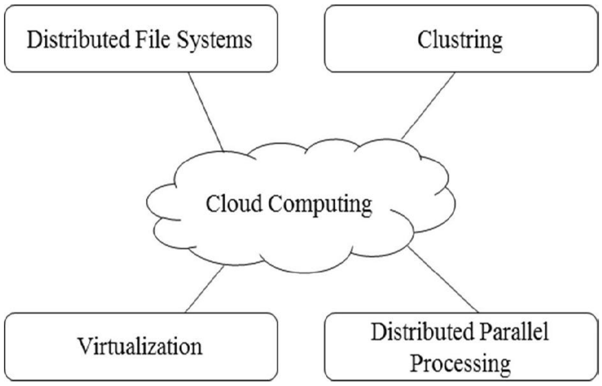


Fig. 5 Cloud computing components. Cloud computing relies on several concepts that are required for Big Data management in smart grid[]

15. KEY CHALLENGES AND OPPORTUNITIES

The development of the Smart Grid will mean a drastic change in power use and administration. Users will become active participants in energy management and will be able to control their consumption. On the other hand, utilities will be able to control demand peaks and manage the grid efficiently from generation to distribution.

Different types of wireless networks are available, but which one is the suitable for a SG, depends on the system architecture and varieties of communication modules and links. The multihop wireless networking is definitely necessary, as electric equipment out of range of each other need to exchange information. First of all, in order to simplify network organization and maintenance the entire environment needs to be self-organized. Moreover, communications modules may pertain heterogeneous nature in terms of coverage, computing power and power efficiency. Wireless mesh networks (WMNs) are considered as important networking for SG. However, when WMNs are applied in SG wireless infrastructure, a few challenging issues still remains (e.g. security level). Without effective measures to prevent security attacks, the primary of users and confidentiality of grid information cannot be guaranteed.

advanced technologies and applications offered by smart grid will shave the energy consumption behaviors of consumers, and hence, a considerable reduction in energy consumption will be achieved. The integration of SG technology into the existing system has been accelerated with the SG standardization efforts of different organizations, government regulations, and SG solutions of technology and solution providers as depicted in Tables I and II. A description of communication requirements, potential applications, and the SG roadmap has been presented in this paper as the keys to SG development.

The challenges include the deployment of large-scale embedded computing, legacy power grids, intelligent appliances, and next-generation communications and collaborations that will provide the foundation for a post-carbon society. In this section, we discuss the context that gives these challenges urgency as well as the technical challenges that need to be addressed by smart grid communication infrastructures.

Modeling, analysis and design a suitable communication infrastructure meet many new challenges. The models to be used must be capable of accounting for uncertainty as a way to simulate emerging behavior. The numerical tools to perform the analysis must be capable of solving very large scale problems. In fact, the power system is tightly coupled and non-linear [78] and does not benefit from the sparsity that typically characterized this problem. The control system and particularly communication infrastructure must be designed to manage uncertainty and inconsistencies to be resilient or gracefully degrade when necessary. Finally the performance metric must be adjusted to the new nature of the power system.

Communication infrastructure should be capable of providing fail proof and nearly instantaneous bidirectional communications among all devices ranging from individual loads to the grid wide control centers including all important equipment at the electricity distribution and transmission system. This involves processing vast number of data transactions for analysis and

automation. It requires a high performance communication infrastructure capable of providing fast intelligent local subsecond responses coordinated with a higher level global analysis in order to prevent or contain rapidly evolving adverse events [86].
To address the variability of the net demand, as renewable resources growing over the long run, efficient communication infrastructure for information exchange among demand response, storage devices and utilization of plug-in electric vehicles (PEVs)/plug-in hybrid electric vehicles (PHEV) will complement the remedies [92].
Demand response can be implemented through either automatic or manual response to price signals, or through a bidding process based on direct communications between the consumers and the market/system operators or through intermediaries such as aggregators or local utilities.

16. CONCLUSIONS

Smart Grid is a foundational technology that will provide considerable changes to the existing power grid, consumer lives, the quality of power delivery, and traditional energy resources. Traditional energy sources produce energy with high environmental damage, as opposed to renewable energy sources (solar,wind, waves, and biomass), which do not present this problem, but have remarkable different dynamic characteristics than traditional ones. An integration of these into the existing energy grid is necessary and involves new technologies. The information flow is an important concept to define these technologies.
Information and communication technologies (ICT) represent a fundamental element in the growth and performance of smart grids. A sophisticated, reliable and fast communication infrastructure is, in fact, necessary for the connection among the huge amount of distributed elements, such as generators, substations, energy storage systems and users, enabling a real time ex-change of data and information necessary for the management of the system and for ensuring improvements in terms of efficiency, reliability, flexibility and investment return for all those involved in a smart grid: producers, operators and customers.
The WAMC systems offer many opportunities to improve the real-time situational awareness of the power system. Essentially, these systems are built following a similar principle as the conventional SCADA systems but with continuous streaming of data frames at high resolutions. The functionality of the WAMC applications running on top of them are heavily, but not exclusively, dependent on the capabilities of the underlying ICT systems. The design of the ICT systems supporting the WAMC applications, i.e., selecting the communication protocols, architecture and configurations need to be coordinated with the design and parameterization of the application algorithms.
Smart meters are supposed to help transform the delivery network into a two-way information system which can signal price changes to the customer; the customer in turn will be able to set rules so that heavy-load appliances such as cars and dishwashers work when the electricity is cheapest. This 'demand response' will help cope with a growing number of fluctuating energy sources such as solar and wind. Peak demand shaving will help governments meet energy security goals and will also save utilities money, as customers on day-night tariffs are typically paying less then the wholesale cost of energy during the peak.
IEEE C37.118 is a weak communication framework from a security point of view due to no built-in security mechanism. On the other hand, IEC 61850-90-5 provides strong protection against cyber attacks by relying on GDOI based security mechanism. However, this assumes the KDC and communicating devices secure from unauthorized access. In terms of required network resources, IEEE C37.118 is highly efficient with very small packet size compared to IEC 61850-90-5. This results in much lower bandwidth requirement for IEEE C37.118 compared to IEC 61850-90-5.

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