




Article

Communication Network Standards for Smart Grid Infrastructures

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Abstract: Upgrading the existing energy infrastructure to a smart grid necessarily goes through the provision of integrated technological solutions that ensure the interoperability of business processes and reduce the risk of devaluation of systems already in use. Considering the heterogeneity of the current infrastructures, and in order to keep pace with the dynamics of their operating environment, we should aim to the reduction of their architectural complexity and the addition of new and more efficient technologies and procedures. Furthermore, the integrated management of the overall ecosystem requires a collaborative integration strategy which should ensure the end-to-end interconnection under specific quality standards together with the establishment of strict security policies. In this respect, every design detail can be critical to the success or failure of a costly and ambitious project, such as that of smart energy networks. This work presents and classifies the communication network standards that have been established for smart grids and should be taken into account in the process of planning and implementing new infrastructures.

Keywords: smart energy grids; smart substation automation; process bus; interoperability standards; industrial communication networks; TCP/IP



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1. Introduction

Electricity networks are a point of friction in the current era which is characterized by the waste of natural resources, the destruction of the climate and economic austerity, as they can be a starting point for the beginning of a new era. Therefore, it is extremely important to support the transition from the outdated infrastructure of the existing electricity transmission networks to a new smart model of production, management and distribution of electricity [1].

Smart grids use digital technology, artificial intelligence, and advanced communication techniques to monitor, control, and manage electricity to meet the varying needs of their customers. In particular, smart grids are able to coordinate the needs and capabilities of all the market entities (i.e., producers, network operators, consumers), so that all parts of the system operate optimally, thus minimizing the financial and environmental costs and maximizing, at the same time, the stability and reliability of the provided services [2].

In this regard, the design and implementation of a secure and cost-effective electricity supply network requires the integration of an efficient, reliable, and interoperable communication system [3–5].

Based on the semantic approach of smart grids, standardization organizations guided by the object-mapping processes have adopted a holistic conceptual model of architecture, which classifies energy networks into seven sub-sectors. Specifically, these sectors are the generation (bulk and non-bulk), distribution, transmission, operation, service providers, customer, and markets. This conceptual approach provides the architectural background for describing and analyzing the interoperability of current standards, as well as for developing new ones. A conceptual representation of smart energy grid architecture based on distinct operating areas is shown in Figure 1.

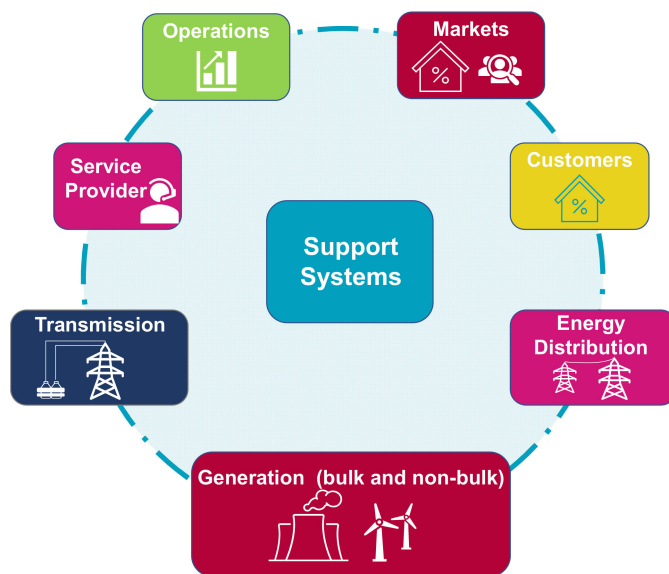


Figure 1. Smart Grid Domains.

Within this architecture, the individual domains interact with each other, respectively, through electrical or communication flow, and by using several available communication architectures, including wired, wireless, or power line communication infrastructure networks, the corresponding interfaces, and the appropriate protocols. A brief description of the interconnection modes is shown in Figure 2.

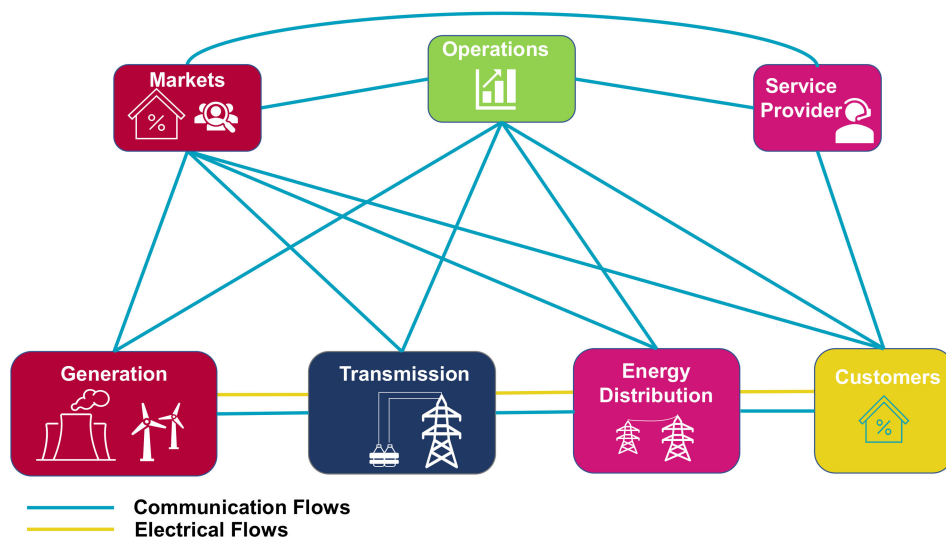


Figure 2. Communications paths between Smart Energy Grid domains.

The five basic principles of designing an integrated and technically sound communication system for the application in smart grid networks are [2,6,7]:

1. **Interoperability:** The architecture of smart grids and their components, both in terms of hardware and software, and refers to their ability to interact directly with each other. This allows easy and efficient exchange of information without disturbing the end user.
2. **Interconnectivity:** The ability to communicate through all available means of participants in the energy ecosystem (stations, substations, machines, devices, sensors, applications, and people).
3. **Classified access to information:** The provision of easy and instant access to useful information, to and from all points of the energy process.
4. **System monitoring:** The cyber-physical systems that support all processes, collecting and visualizing information in almost real-time.
5. **Decentralized decision-making:** The cyber-physical systems that usually take optimal decisions autonomously. A hierarchically higher level usually intervenes only in cases of conflicting objectives.

Taking into account the above design principles, we can conclude that tasks such as data analysis, remote preventive/predictive maintenance, and on-demand use of equipment are essential functions for smart grids [5,8,9]. The work aims to clearly identify all the issues regarding the communication standards that have been established for smart grid networks in order offer interoperability, privacy, and confidentiality among their functional components.

The study is organized as follows: Section 2 gives a detailed description of the network standards that support communication in smart grid infrastructures. Section 3 presents a discussion on our study, and finally, the last section draws the conclusions and outlines future research directions.

2. Network Standards That Support Communication in Smart Grid Infrastructures

Given the constantly evolving field of telecommunications, standardization organizations provide standards that clearly define the communication parameters between all the key components in a smart grid network [2,7,10]. The various smart grid applications and the specific features of the employed telecommunication technologies are presented in detail below.

2.1. Smart Transmission Systems

The objective of power transmission systems is to transmit power from one point to another in a reliable, safe, and environmentally friendly way [2,3,11]. Typical transmission systems include the flexible AC transmission systems (FACTS) [3,12] and the high-voltage direct current [1,3,6,13]. FACTS technology is used for the reliable transfer of large amounts of energy. However, in cases where technical or economic expediencies require the transmission of energy over long distances as well as the interconnection of asynchronous electrical networks, the use of HVDC technology is mandatory. Thus, the main requirement that must be met is the complete integration of the advanced technology equipment of the FACTS and HVDC transmission systems towards the optimization of the load flow and stability of the overall network.

The sub-stations that support the monitoring and coordination processes of FACTS and HVDC technologies typically use serial connections, as defined by the IEC 60870-5-101 & 104 and DNP3 Secure, at low bit rates of 64 kbps. Even when Ethernet technology is used, transmission rates remain at extremely low levels, as no interface is designed to utilize higher bandwidth, which in turn refrains them from sending large amounts of data. In addition, the IEC 60870-5 [14] standard cannot fully cooperate with the range of requirements of IP network technology, which leads to operational incompatibilities. This type of communication is only possible and is covered by IEC 61850, Ed. 1.0–2.009-12

42/136 and later, as the data exchange in these standards is purely based on TCP/IP and provides interfaces for HVDC and FACTS [7,12,13].

2.2. Blackout Prevention Management

Energy transmission networks use mechanisms that process large data sets which, with the help of appropriate algorithms, can make real-time decisions about managing the load flow in the grid. These decisions are then compared with the operational limit values of each individual network equipment to timely inform the operator for overloads, limit value violations or general malfunctions [15]. In addition, the analysis of the load flow provides the mathematical background required by optimization procedures so that appropriate corrective actions can be taken with high accuracy [16,17].

The need for distributed production disperses the energy production centers and, consequently, the exchange of information has to be performed over large geographical areas. Therefore, there is a need for the incorporation of specialized, bandwidth-demanding measurement systems, such as power quality control systems, remote monitoring technologies, and system integrity protection schemes (SIPS) [18], which minimize the possibility of an extended power outage in case of an emergency.

A basic condition for meeting the above requirements is the deployment of a telecommunication protocol that can support broadband communications services. In addition, it is also necessary to have an extensive network of sensors, such as the phasor measurement units (PMU) [19–22], which can be implemented in various topologies and use different data and protocol formats [23,24]. However, IEC 61850 [14] is the only internationally recognized standard used to exchange high-, medium-, and low-voltage metering data with support for broadband TCP/IP connections. In addition, IEC 61850 complies with IEEE C37.118, which allows the integration of synchrophasors [20].

2.3. Advanced Distribution Management

The energy distribution network is the most advanced part of a smart grid as it is supported by information technology on issues such as security and optimization. These networks consist of high-voltage networks, which feed medium- and low-voltage subnetworks through power stations and substations, which subsequently supply electricity to the end consumers [25,26]. The management system includes all the functions required for the distribution network to operate efficiently [27,28] and its main responsibility is the monitoring of the energy demands as well as the control of the energy exchange in the distribution system.

Given the wide coverage area of the distribution networks and the diversification of the employed telecom equipment, the communication specifications for these networks are extremely complex [7,29]. As an example, the control mechanism requires standards that provide operational support to technologies and automation systems including remote control surveillance, geographic information system (GIS), forecasting demand, and fault management etc. [30–33].

These requirements are met by a set of available broadband services that are IEC 61968 compliant [34,35], while this standard also provides compatibility in terms of network optimization, maintenance, and expansion. In addition, the harmonization of IEC 61968 with IEC 61850-7-420 and the adoption of an open architecture improves network scalability, whereas the integration of intelligent measurement models (advanced metering infrastructure, AMI), home networking (home area network, HAN), and their interfaces allows for demand forecasting and modeling of load behavior at the end-user level [36,37].

2.4. Distribution Automation

The electricity distribution system in countries outside Europe includes distribution sub-stations which supply energy through long-distance lines (250 Km or more). As a result, in these systems voltage losses and power outages are very serious problems, which may lead to social problems and significant revenue losses for utilities [38]. To overcome these

problems, over-the-air distribution lines are supported by Sectionalizers & Reclosers [39], which can be used to reshape power in the event of a disturbance. Furthermore, specialized equipment, such as voltage regulators, power regulators, and fault indicators, are utilized to ensure optimal operation and assist troubleshooting [27,35].

The introduction of microprocessor-based intelligent electronic devices (IEDs), together with cost-effective communication technologies, upgrades and automates the processes of energy distribution and rapid debugging and isolation of malicious material [40–42]. Therefore, based on the effective automation of the distribution process, utilities have the opportunity to create new business models of highly reliable power supply for both critical and industrial applications as well as residential consumers.

Conversely, the structure of the power distribution network in Europe is based on a completely different approach. The backbone of this structure is a very dense grid of a large number of distribution substations while the energy transmission lines typically have a length of 5 to 20 km and the average number of served customers per single distribution feeder is usually less than 1000. Additionally, the connection of the loads to the grid is performed with precise programming and measurements, which lead to highly symmetrical loads. Furthermore, the distribution of substations are fully automated and include microprocessor, protection relays [43], actuators, etc., so that they can be remotely controlled in real time [1,16,32].

Low-voltage transformer stations operate manually, as there is no incentive to automate distribution feeders because, in the event of disruptions, the number of affected customers is low, as is the amount of revenue loss. Nevertheless, the increasing integration of diffuse generation systems, such as low-voltage photovoltaic systems or medium-voltage wind turbines, creates voltage quality problems and makes it difficult or impossible to protect them with conventional non-automatic surge protectors [7,24,38].

For the automation of the distribution systems, the remote control and the supervision of the secondary substations and transformers, is considered vital. Therefore, the exchange of information between them and the management system must be based on common operating protocols, which will provide, among other things, cybersecurity. This directly suggests that they must also support all communication technologies, given the different geographical conditions and infrastructures encountered. Furthermore, the implementation of protection systems should meet the individual specifications of distributed generation systems and, more generally, the automation of the European distribution system and consider the developments in the technological specifications of micro-networks [14,23,44].

IEC 61850-7-4 covers a very large set of use cases for various types of distribution automation and supports the most prevalent information data models. Moreover, for the interconnection of distributed power sources and their remote monitoring, standardizations for the development of a crosslinking profile between IEC 61580-7-420 and IEC 61968, respectively, have been proposed. Finally, IEC 61970 provides a set of guidelines and techniques for active energy distribution and efficient operation of the energy management systems [34,45–47].

2.5. Smart Substation Automation

The technological development of large-scale integrated circuits, which led to the current availability of advanced, fast, and powerful microprocessors, has resulted in the development of automated digital substations which, by utilizing IEDs, are able to perform functions, such as local and remote monitoring, equipment supervision, etc. Furthermore, the use of digital technology improved the interoperability and communication between devices of different suppliers and technological generations [48,49]. The specific technology, which is also referred to as the process bus, contributed to the interoperability between heterogeneous systems and the configuration of functions that are based on open architecture to make the system viable. Regarding the communication between devices, their absolute synchronization is required to perform the exchange of large data sets with small latency

and precision, in addition to the use of open communication standards such as Ethernet, TCP/IP, and XML to achieve interoperability.

The above goals can be accomplished by standardizing the synchronization process of IEC 61850-9-2 functions as well as wideband technologies that support quality of service (QoS), such as 5G telecommunication networks [50,51]. Concluding, IEC 61850 is the only international standard for substation automation that is based on open architecture and incorporates specifications for sampling and timing synchronization based on IEEE 1588 in local and in wide area networks [14,49].

2.6. Distributed Energy Resources

The decentralized production of electricity is paralleled with the so-called virtual power plants, which are a collection of small and very small decentralized power plants, monitored and controlled by a high-quality management system. Successful operation of a virtual power plant requires an efficient and reliable telecommunication network through which the management system monitors, manages, and optimizes the operation of decentralized units [28,48].

In large virtual power stations, control systems based on protocols, such as IEC 61850 and IEC 61400, can be implemented. Given the increasing number of virtual power stations, it is expected that the communication channels and protocols will play a crucial role and the conventional telemetry technique will be gradually replaced by more advanced communication techniques based on TCP/IP protocols. Transmission techniques via the power lines (Power Line Communication–PLC) could also be utilized [44,48,52,53].

The IEC 61850-7-420 standard is compatible with the majority of modern equipment and dispersed energy production systems. However, there is no complete mapping of the IEC 61850-8-x communication protocols, as well as the respective protocols developed for wind energy systems in IEC 61400-25 [54,55]. Furthermore, no system configuration language (SCL) has been developed for the communication between the dispersed energy sources in IEC 61850-6-x, while a major drawback is the fact that the electrical connection points (ECPs) are often of specific configuration and are compatible only with specific systems/regions [7,14].

2.7. Advanced Metering Infrastructure

In the smart grid infrastructure, the system that assumes the special role of interconnecting the distribution network with the systems of smart metering, building automation, industrial automation [56], e-mobility, and distributed energy resources is the advanced metering infrastructure (AMI). It includes data collection and analysis systems as well as energy audit systems, and provides interactive communication between customers, suppliers, utilities, and service providers [9,41]. Among others, AMI includes specifications for network monitoring, power quality monitoring, fraud detection, load leveling, recording of capacity utilization, load/source-shedding, and remote switching procedures.

All available wired or wireless communication systems can be used for the AMI integration (markets, transmission, bulk generation, non-bulk generation, distribution, customer, service provider, building, industry, e-mobility, and foundational support systems) [53,54]. The main standards regarding AMI are IEC/TR 62051, IEC 61968 to 9, and AEIC Guidelines v. 3.0, as well as a vast array of parallel and even conflicting standards with many differences in functionality developed in different countries/geographic areas (e.g., China: GB/Z 20965, USA: ANSI/ASHRAE 135-2008/ISO 16484-5 BACnet), without the clear definition of distinct subsets of common semantics. This makes it difficult to define a common set of cross-cutting requirements between standards to facilitate the exchange of classified information [38].

It should be mentioned that there is a process underway in order to extend IEC 61850 to include the ((DLMS—Device Language Message Specification)/(COSEM—Companion Specification for Energy Metering objects)), thus promoting the coexistence of smart application networks. The extension will include a set of interoperability characteristics of

processes such as energy measurement, load control, pricing, exchange of information, modeling data management events, etc. [7].

2.8. Smart Metering

Smart metering systems allow consumers to play an active role in the operation of electricity markets, as they are the gateway to access the new grid. In particular, they utilize applications which allow interfacing with home automation systems, remote access to energy billing data, collection of additional information on grid operation, power quality and downtime, as well as information on consumption and consumption-based pricing, firmware updates etc. [4,9,41].

Smart metering is based on the IEC 62056-x and IEC 61334-x standards which support the most well-known wired and wireless communication technologies, including IPv6 [7]. It is based on open and flexible specifications, and efforts are made towards the creation of a user-friendly management environment [57,58] as well as to ensure the protection of user privacy and secure data transmission (cryptography integration, blockchain, etc.). Standardization and compliance of equipment and software with specifications of DLMS/COSEM technology is also supported [59].

2.9. Demand Response/Load Management

The demand response and load management mechanisms are related to the rational distribution of electrical loads on the network, taking into account the requirements of the users [58,60]. Therefore, these two mechanisms are directly related to the smart metering system, the automation of home energy management, and especially to the distributed energy production.

Regarding distributed energy production, it should be emphasized that it is a rather complicated process in comparison to the easily regulated production of electricity from measurable natural resources (fossil fuels, nuclear fuel, etc.). The energy production from renewable sources (solar, wind, hydroelectric, etc.) is not entirely predictable as it includes several uncertainty factors. Given also that the worldwide share of the regulated power is constantly decreasing, the challenges in the management system create a new specialized area of study and research. In any case, the management mechanisms that will emerge from the research in this area will benefit from a highly reliable and high-speed telecommunication system.

In conclusion, an optimal load management process requires the modeling of energy data which must be detailed and continuously available including load profile information, production information, etc. [7,61]. These requirements are met by IEC 61968 and IEC 61850-7-420, which support all TCP/IP-based wired and wireless communication technologies including IPv6. A Distributed Energy Management System and a Home and Building Electronic Systems/Building Automation and Control System (HBES/BACS), respectively, are supported by a wide set of standards (ISO 16484 series, ISO/IEC 14543-3, EN 13321 series, EN 50090 series, EN 50428, EN 50491 series, China: GB/Z 20965, USA: ANSI/ASHRAE 135) which require upgrades/modifications in order to enable their interoperability through appropriate interfaces [62].

2.10. Smart Home and Building Automation

According to ISO 16484-2 and ISO 16484-3, HBES/BACS refers to the equipment required for automatic control, monitoring, manual intervention, and management of optimization services, including outdoor installations and other equipment [10,63]. The main benefit from the development of smart grids exclusively concerns the distribution and the forecasting of energy loads. A main objective of HBES/BACS technologies is the reduction of the consumed energy through the use of energy optimization functions as well as the cost reduction that can be achieved by appropriate load distribution based on graduated pricing (cost reduction per kWh) and, of course, the conventional power limitations on a case-by-case basis [61,64,65].

In addition, in the context of smart grids and the development of smarter billing methods, the ability to handle additional billing information is a prerequisite. Finally, HBES/BACS systems can handle or integrate in their operation, alternative sources (for instance wind turbines), as well as energy storage systems (for instance electric cars). This leads to a semantic and syntactic compatibility requirement between HBES/BACS systems and AMI technology [10,64].

The operation of HBES/BACS integrates all TCP/IP-based wired and wireless communication technologies through the establishment of the following standards: ISO 16484 series, ISO/IEC 14543-3, EN 13321 series, EN 13757 series, EN 50090 series, EN 50428, IEEE P1701 to IEEE P1705, EN 50491 series, ISO/IEC 15045, ISO/IEC 15067-3, ISO/IEC 18012, China: GB/Z 20965, USA: ANSI/ASHRAE 135 together with other protocols such as OpenHAN, HomePlug AV & C&C, Z-wave, ITU G.9960, etc. [7]. It should be noted that the standardization of common semantics, data models, and cooperation methods between AMI and HBES/BACS is pending.

2.11. Electric Storage

The electric grid operates under the assumption that the energy is produced and consumed at the same time. This means that the transmission and distribution systems are designed to be able to meet the maximum and not the average power flow, resulting in the underutilization of their components. Energy storage can enhance the reliability of the grid, allowing a more efficient use of baseload generation, while facilitating greater penetration of renewable energy sources. Furthermore, it can be implemented on a large, medium and small scale, while it can be distinguished between real electrical storage, (i.e., storage of electricity that can be introduced directly into the system), and storage in an alternative forms in buffers, (e.g., hydrogen, thermal, etc.) [7,66,67].

In electrical power systems, various forms of energy storage can be utilized, with the most common being the use of batteries (for instance lead-acid, lithium-ion, sodium, etc.). Furthermore, in a broader sense, energy storage can be carried out by storing water in hydroelectric power plants or by storing compressed air, or by producing and storing hydrogen, etc. Distributed energy storage can aid towards the efficient handling of load fluctuations, acting as a manageable means of loading and unloading power from the grid, when necessary. Furthermore, distributed energy resources can be connected directly to the distribution network or integrated into HBES/BACS.

A key prerequisite for the various forms of storage is safety in relation to the specifications of the equipment and the way it is handled. Moreover, in order to be successfully integrated and operate in a smart grid environment, including HBES/BACS [62], the latter should be informed on their electrical potential as well as their pricing policy. In addition, effective maintenance planning and scheduling is considered necessary. Robustness, cyclical self-discharge consistency, start-up time, lifespan, and power efficiency are also critical factors for their efficient operation [52,68]. In addition, an essential requirement concerns the communication with the energy resources incorporated in the network, while for the various forms of energy storage, appropriate communication protocols and data modeling for information are required, such as energy storage type, charging status, load history, availability, etc.

The standards that support these requirements are IEC 61850-7-410 and IEEE P2030.2 [67], while there are not any standards for storage devices other than hydroelectric (IEC 61850-7-410) [49]. Moreover, no appropriate specifications have been yet developed regarding the amount and type of data to be exchanged between smart grid and energy storage systems. Finally, specifications for charging storage devices as well as their periodic inspection should also be developed [6,7].

2.12. E-Mobility

E-mobility includes the use of fully electric or hybrid vehicles and is one of the main perspectives of smart grids both on its own (e.g., a vehicle-to-vehicle energy exchange

scenario, based on cloud technology, can be found at [69]) as well as a method of energy storage, given that the full range of possibilities of this technology can be achieved only after smart grid architecture is fully implemented [7,70].

The specifications of the vehicle's batteries should be standardized and meet the minimum requirements of charging cycle and power stability, which are dictated by the specifications of the overall network to function as an integral part of it. The safety and electromagnetic compatibility (EMC) requirements must also be met in full [71,72].

While two-way communication is not required for electromobility, its integration into a smart grid requires information exchange between the smart grid and electric vehicles. This communication requires the use of appropriate communication protocols and data modeling within a framework that will allow the semantic understanding of the exchanged information.

Although there is a lot of standardization activity as shown in Table 1, the data models and protocols within ISO/IEC 15118-1, -2, and -3 are not precisely identified. The same holds true for the IEC 61851 set of standards regarding the choice of plug and socket (1/3-phase host carrier, 400 V, 63 A) [7,66].

Table 1. E-mobility Standards.

Product and Safety Standards	Smart Grid Standards	Physical Interconnection	Communication	Market Information	General Standards
IEC 61982-1,2,3,4,5 IEC 62576 IEC/NWIP 62619	IEC 60364-5-53		IEC 61850		ISO/CD 12405
	IEC 60364-5-55	IEC 60309 Ed. 4.1	IEC 61968		ISO 6469-1,2,3
	IEC 60364-7-712	IEC 60309-1 Ed 4.1	IEC 61851-31		SAE J1772
	IEC 60364-7-722	IEC 60309-2 Ed 4.1	IEC 61851-32	IEC/TR 62325	SAE J2836/1-3
	IEC/NP	IEC 62196 Ed, 1,0	ISO/IEC 15118	IEC/TR 62325-501	SAE J2847/1-3
	60364-7-760 IEEE P2030.1	IEC 62196-1	ISO/IEC 15118-1,2,3		USA-SAE J1771 USA-SAE J2836

2.13. Condition Monitoring

The electricity grid faces several challenges given the ever-increasing demand, the requirements for continuous improvement of its availability, and the provision of quality value-added services in the most efficient way. Key objectives in overcoming these challenges are the extension of the average life cycle of the equipment and the minimization of its maintenance costs. These objectives are based on smart grid functions such as real-time monitoring of the network, real-time infrastructure quality control, forecasting and early diagnosis of faults, predictive maintenance, etc. Specifically, a condition monitoring function provides all the technical information required for maintaining availability and, at the same time, for maximizing efficiency in the energy supply chain, thus helping to optimize the network by preventing unplanned downtime or hardware failures. The condition monitoring function also includes specialized processes such as monitoring of transformers (refrigeration, lubrication, contact opening speed, switch operating time, etc.), insulators, ground, wiring lines, ARRESTER mechanisms, etc. [52,73,74].

Regarding telecommunications, the deployment of a system that meets the measurement and control procedures requirements is essential, as well as the description of uniform data models for all subsystems of the smart network. Although there is a lot of standardization activity in this field, the basic communication standards are IEC 61970 (EMS) & IEC 61968 and IEC 61850, which are supported by most wired and wireless communications technologies [34,35].

2.14. Renewable Energy Generation

Given the energy crisis, the depletion of natural resources, the destruction of the environment and the growing electricity demand the production of energy from renewable sources seems to be the only feasible solution to the upcoming energy crisis [38,75,76]. However, as such a solution is not based on quantifiable natural resources, it does not

provide a solid basis for planning and leads to performance uncertainty, which in turn creates many and diverse challenges [77,78].

Smart Grids, in terms of their interconnection with renewable energy sources, are facing various operational issues per sector of operation such as:

1. Wind energy (control, certification, wind-generator design requirements, measurement, and evaluation of generated energy, etc.).
2. Solar energy (testing, certification, interconnection, protection of photovoltaic systems, measurement, and evaluation of produced energy, etc.).
3. Marine power (design requirements for marine energy systems, wave performance evaluation, energy converters, etc.).
4. Fuel cells (safety of fuel cell power generation systems, fuel efficiency and testing, etc.).
5. Pumped storage (hydraulic turbine tests, storage pumps, etc.).

Overall, given the tremendous development of the sector and its standardization process, we can conclude that smart grids include technical standards that enable the interconnection of different scale systems as well the procedures of testing, maintenance, and management of these systems as shown in Table 2. Although wired communications are adequately supported, it is recognized that most telecommunication solutions are provided through wireless systems [7,38].

Table 2. Renewable Energy Generation Standards.

Wind Power	Solar Voltaic	Fuel Cells	Pumped Storage	Distributed Generation	Nuclear Generation	Conventional Power
IEC 61400 series ISO 81400-4	IEC-60904 series	IEC 62282-x		IEC		
	IEC 61194	IEC 62282-1		62257-1,2,3,4,5,6,7		
	IEC 61724	IEC 62282-2		IEC 62257-7-3		
	IEC 61730 series	IEC 62282-3-1	IEC 60193	IEC 62257-8-1	NERC/NUC-001-1	IEC 60308
	IEC 61730-1	IEC 62282-3-2	IEC 60041	IEC		IEC 61850-7-410
	IEC 61730-2	IEC 62282-3-3		62257-9-1,2,3,4,5,6		
	IEC/TS 61836	IEC 62282-5-1		IEEE 1547		
	IEC 62446	IEC 62282-6-200		IEEE 1547.3		
	IEC/TS 62257	IEC 62282-6-300		MAIN Guide NO3B		
	IEC 61727					

3. Discussion

Sustainable energy infrastructure design must be based on interoperable, standardized technologies, which ensure the quality of services provided, energy, information, security, and privacy [41]. A key condition is overcoming competitive monopoly efforts for the prevalence of business solutions or standards and, respectively, the full consensus in the establishment, development, and support of existing energy standards. Coordinated efforts should be made to address the gaps and problems identified in existing standards and develop new ones, which will ensure the further adoption of smart grid technologies [7].

An important fact that confuses energy infrastructure designers when it comes to communications is the multiple choices in existing standards and rules that can determine the form, timing, order, control, and correction of errors during information transmission [79]. The fact that the established standards overlap themselves creates serious confusion which lead to functional gaps.

A significant process which is currently at an initial level but is estimated to contribute greatly to the further development of intelligent energy infrastructure in terms of communications is the process of their certification based on an international ISO standard. This standard will provide a set of policies, guidelines, and documented procedures to ensure that no key elements required by an intelligent network to be successful are omitted. This process will consider evaluation criteria and provide documentation of communication standards mapping, thus providing the essential framework for further developments.

4. Conclusions

The development of smart grids necessarily goes through the provision of integrated technological solutions that ensure the interoperability of the components of the electrical

system and reduce the risk of devaluation of various technologies. The heterogeneity of infrastructures and the dynamics of their operating environment requires the continuous reduction of complexity, the faster processing of expansion works, and the addition of new ones. Integrated management requires a clear, and unequivocal way of providing end-to-end communication services based on active and interoperable standards, to ensure quality based on strict policies.

This paper presents the institutionalized and active standards of communication related to the specific issues of smart grid applications, which are necessary and should be taken seriously in the process of architectural design and implementation of energy upgrades of the existing infrastructure.

Future extensions concern the validation of active standards which are constantly changing and rearranging, as well as the inclusion of new standards that have recently been certified. Finally, an important development concerns the recording of the general recommendations by the standardization bodies by sector of operation of the smart networks, as well as the corresponding gaps that may have been identified and concern further development and evaluation procedures.

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