The Impact of Transmission Technologies on the Evolution of the Electrical Grid

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Abstract. The paper describes the use of the communications technologies in the electrical network in the last decades and it provides a quick look at the significant role of these technologies in the development of new functionalities. Hence, the great evolution of the requirements of the electrical networks is summarized, from the first stages of the remote automation to a new scenario where Smart Grids and demand response will generate a different relation between utilities and final users. Then, a compilation of the main network architectures and communication protocols used in the electrical networks is outlined. Moreover, an evaluation of the benefits and drawbacks of the communication technologies, when they are applied to the last mile connectivity in electrical grids, is described. The paper concludes with a selection of the most relevant challenges of the electrical networks where the communication technologies may ne determinant as an enabling technology. In summary, the paper shows the parallel evolution of the communication technologies and the electrical grid, as a basic aspect for the development of new functionalities and services for all the agents involved in the power generation-transmission-distribution system.

Keywords: Electrical grid · Communication technologies · Wireless communications · Grid automation

1 Introduction

The current electrical model is evolving from a strongly centralized architecture, both in power generation and in management and based on a radial transmission and distribution scheme, to a decentralized structure where new actors arise to develop new or complementary functionalities. Hence, the scheme of a unidirectional generation-transmission-distribution chain will be replaced by a distributed system.

Concepts such as Smart Grids and demand response will generate a different relation between power generation agents, utilities and final users. The user is expected

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to play an active role to become a prosumer due to the promotion of local power generation. The increasing introduction of distributed power generation systems and the active role of a growing number of prosumers will lead to the accomplishment of a real-time demand response. To achieve this goal, more flexible and complex management systems that allow a rapid, efficient and robust control of the electrical network will be required.

This scenario would not be possible without the use of advanced communications system that provide all the high-demanding requirements described in the previous sentences.

2 Automation and Control of the Electrical Grid: Historical Evolution

The proper performance of the electrical infrastructure is a critical factor, because power cuts cause serious economic, social and technical consequences [2]. Due to the expected radical changes in social, economic and demographic areas, the infrastructures of the cities require a radical change [1]. Due to the higher dependence on the electricity, and considering the new functionalities that are being proposed for the city of the future (*Smart City*, *SC*), the electric network infrastructure is a substantial and fundamental part of this process.

The modernization of the electrical infrastructure has not happened overnight. In the 1950s, analog communications were employed to collect real-time data of power outputs from power plants, and tie-line flows to power companies. To achieve this, operators used analog computers to conduct *Load Frequency Control* (*LFC*) and *Economic Dispatch* (*ED*) [3]. *LFC* was used to control generation in order to maintain frequency and interchange schedules between control areas, and *ED* adjusts power outputs of generators at equal incremental cost.

It is from 1960, with the advent of digital computing, when developing the *Remote Terminal Units* (*RTUs*), which were designed to collect voltage measurements, active and reactive power, and states of protection devices in substations. To make this measure possible, the use of dedicated transmission channels was necessary to interconnect the final devices with the computational center. As a consequence of the blackout of 1965 in the USA, a more extensive use of digital computers was highly recommended, in order to improve the real-time operations of the interconnected power systems. The use of computers and digital systems was considerably increased from 1970, with the introduction of the concept of system security, covering both generation and transmission systems [4].

The first control centers were based on dedicated computers, but in the subsequent years, they were gradually replaced by general-purpose computers. It is already from 1980 when the microcomputers were replaced by UNIX workstations, interconnected by means of *Local Area Networks* (*LAN*) [5]. These first networks of interconnected computers allowed a more rapid and efficient data exchange between different parts of the electrical grid.

The real revolution in the electrical system took place in the second half of 1990s, when the electrical industry launched the reorganization of the system. Since then, services ceased to be vertical and the generation, the transport and the distribution of the energy were separated. In addition, monopolies were replaced by competitive markets [6]. The combination of these both aspects marked a turning point in the evolution of the electrical system.

In this new scenario, three clearly differentiated segments were created in the electrical system: *Energy Management System* (*EMS*), *Business Management System* (*BMS*) and *Market*. The above-mentioned segments and the interaction between then are shown in the Fig. 1.

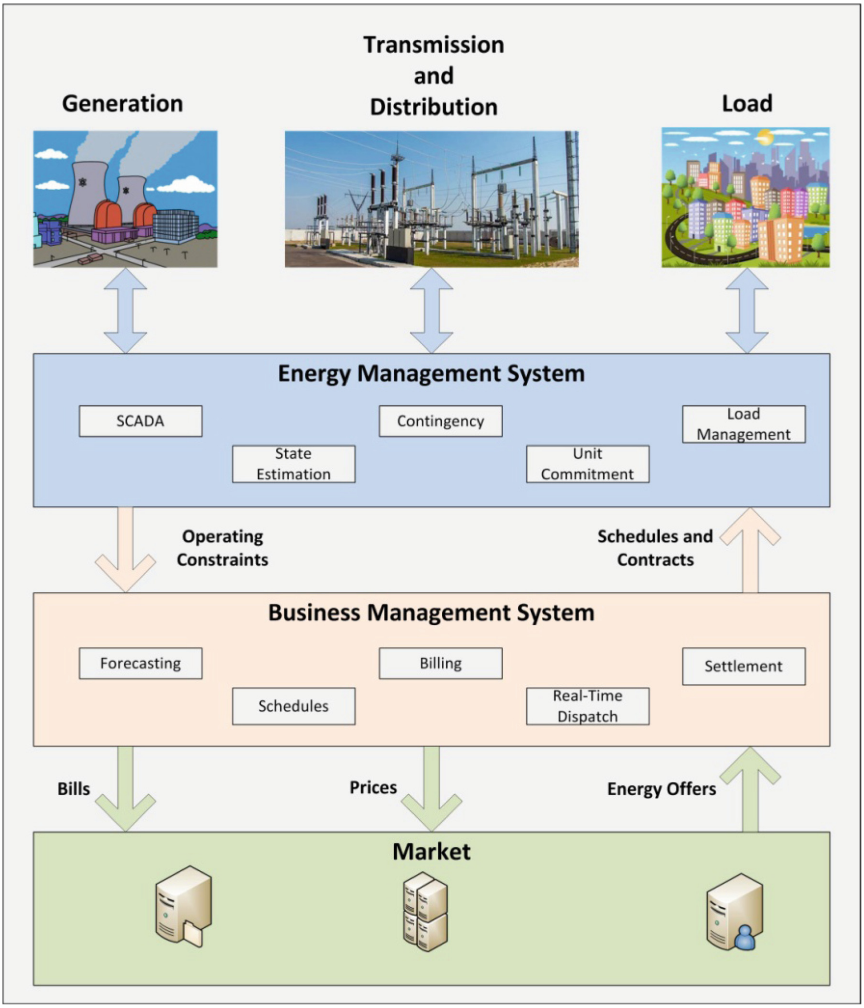

Fig. 1. Segments of the electrical system and interaction between them.

3 The Role of the Communications in the Development of the Smart Grids

3.1 Evolution of the Communication Systems in the Electrical Infrastructure

One of the aspects that enable and foster the great evolution of the electrical system described in the previous section was the development of a robust communications layer. The communication systems used in the electrical infrastructure have also undergone great changes, in order to provide new functionalities adapted to both the evolution of the grid and to the new requirements of the companies in charge of the transmission and distribution services.

Regarding Power Line Communications (the communication technologies based on the use of the electrical cable), the electrical grid was not initially developed as a communication medium, and therefore, the high number of interferences and noise sources, together with the high variability with time and frequency, represent a great challenge for the proper performance of the data transmission.

The strong points for the use of wireless communications have been the higher flexibility, the better conditions of the propagation medium and the potential use of transmission technologies already tested. On the weak side, the difficulties to provide a complete coverage and the need of deploying the complete transmission-reception chain for each link. Nevertheless, these drawbacks were recently overcome by the use of advanced cellular technologies, such as *GPRS* (*General Packet Radio Service*) and *LTE* (*Long Term Evolution* or *4G*), which provide good rates of coverage, availability, data rate and latency. Future Smart Grids functionalities and applications rely on the better performance of wireless technologies, mainly LTE and 5G.

The historical evolution of the wired and wireless communications in the electricity grid is shown in Table 1 [7, 8].

3.2 The Communication Systems in the Structure of the Electrical Grid

The performance of the a communication technology may vary depending on the conditions of the grid, such as the grid topology, the density of communication devices (users, data concentrators or substations) to be connected, the distance between them and the requirements of the communications (data rate, robustness, priority levels) and the presence of interfering electrical noise sources. For example, high-speed communications can be used for the connection of electrical substations in urban areas; however, this solution may not be feasible in other areas, such as rural environments or remote devices.

Table 1. Evolution of the communication systems in the electrical infrastructure.

Year	Achievement	Network architecture	Communication protocols and standards	Communication media
Before 1985	Without standardization	Isolated substations Hierarchical tree Single master	Conitel 2020 ModBus SEL WISP	RS232 RS485 Power-line carrier Dial Up Trunked Radio Speed below 1,200 bps
1985–1995	Standardization begins	Redundant links Hierarchical tree Multiple master	TASE 2 IEC 60870 DNP3 Serial	Packet Radio Leased lines Speed between 9,600 and 19,200 bps
1995–2000	Local Area Network (LAN) and Wide Area Network (WAN)	Substations with peer-to-peer communications Interconnected substations via WAN	TCP-IP Telnet HTTP FTP DNP3 WAN/LAN	Ethernet Spread Spectrum Radio Frame Relay Megabit Data Rates
2000 to present	Integration within the business	Use of Internet Utility connection with business network Extension of network to customer premises	TCP-IP IEC 61850 XML Power Line Communication (PLC)	Digital Cellular IP Radios Wireless Ethernet Gigabit backbones

Accordingly, the network infrastructure can be separated into two zones [9]:

- Last mile connectivity: it can be understood as the high-speed communications between the substations and the control center. There are wired communications (*PLC* and fiber optic) and wireless communications (via satellite and wireless in general).
- High speed communication core network: this network can be private or public. A high-speed network for the automation of substations is Internet based on Virtual Private Network.

Although everything is important, perhaps the last mile communications are crucial for the operation of the electric network. In this sense, one type of communications or others will bring advantages or disadvantages, as can be seen in Table 2.

Table 2. Advantages and disadvantages of possible communication technologies for last mile connectivity.

Communication technology	Advantages	Disadvantages
PLC	• Wide coverage, due to the existence of already deployed power lines (distribution and transport) • Investment in infrastructure is more economical	• Electric cables conduct noise and interferences, which degrade communications [10, 11] • As the power line is a shared medium, the data rate per user is lower than the nominal capacity, depending on the number of users simultaneously transmitting • The switches, inverters and other protection devices degrade the quality of PLC, [8] • The impedance varies with time, network topology and devices connected at each moment, which causes that the attenuation and distortion of the signal are high and changing • Power cables are not twisted and use no shielding, which may cause significant *Electro Magnetic Interference* (*EMI*)
Satellite communication	• Satellite communication has wide coverage, which allows communication between remote substations without additional infrastructure [12]	• The latency in the communications is quite large due to the long distance between satellite and devices on the ground • Protocols such as TCP/IP are not suitable for satellite communication, because the TCP/IP speed settings can cause a lot of delay [13] • The use of satellite communication for remote substations may be justified, but its use for the entire electrical infrastructure can be excessively expensive
Optical fiber communication	• It provides high bandwidth, required by applications such as electrical automation • There is no EMC problem • Immune to interferences from external sources	• The cost of devices and installation is more expensive
Wireless communication	• Wireless communication is quick to install • In case of cellular network, the cost of infrastructure is low, since the existing infrastructure can be used	• IEEE 802.11b presents the limitation of coverage (100 m), although other technologies such as WiMAX do not have this limitation • However, technologies such as WiMAX can have the drawback of the absence of infrastructure in remote areas

3.3 A Representative Example: Wireless Communications Applied to Automation Tasks

The *Wireless Sensor Networks* (*WSN*) can be used in automation tasks [14]. Specifically, *WSN* is used in *Wireless Automatic Meter Reading* (*WAMR*) systems, for reading consumption/generation in *Smart Meters* (*SM*). *WSN* presents some benefits in automation, namely:

- The sensors used in *WSN* are reliable, self-configurable, robust and are not affected by climatic conditions (pressure, temperature, etc.).
- The coverage of a sensor is low, but the entire network of sensors converts the network into an extensive communications network.
- The *WSN* is a redundant network, due to the intervention of all the sensors.
- The sensors perform a pre-filtering, so that the network presents an efficient data processing.
- The *WSN* presents self-configuration and automatic organization of the devices.
- The *WSN* has low installation and maintenance costs.

4 Conclusions

An essential feature in the evolution of the Smart Grids is the use of information and communications technology to gather different types of data from a distributed network of sensors and take fast decisions according to the analysis of this information. The final purpose is the improvement of the efficiency, reliability, economics, and sustainability of the production, transmission, and distribution of electricity.

The conversion of the user from a consumer to a prosumer, together with the new generated distribution systems, will change completely the architecture and the procedures to manage the electrical grid. This will lead to employ two-way communication systems in the smart grid.

In parallel, the recent developments on the wireless technologies, mainly in cellular systems, providing higher data rates, much lower latency values and the possibility to provide simultaneous service to a high number of devices, will open the door to innovative services for the users and the rest of the agents related to the electrical grid.

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