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Smart Grid and Computer Network: How Analogous Are They?

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Abstract

Technological advances allowing optimal exploitation of renewable energy sources and the development of new information and communications technology (ICT), have led to the appearance of a new network so-called Smart Grid. This article is dedicated to the study of similarities and differences between the smart grid and the computer network, thus, in order to better carry out this comparison. Firstly, we present the structure, operational model and benefits of smart grid. Secondly, we identify analogous quantities and similar parameters between the two networks.

Keyword: *smart grid, computer network, electrical network, analogy*

1. Introduction

With the invention of the microprocessor by Marican Hoff in 1971, the miniaturization of components of the computer has allowed the appearance of personal computers and, therefore, the development of a new industry promoting the emergence of computers and the appearance of computer networks. The computer network has appeared in 1969 by Advanced Research Project Agency (ARPA), whose goal was to build an indestructible and reliable network, linking academic centers and military installations. Over time, this network has evolved to give birth to the INTERNET [1]. With the appearance of the Web [2], the computer network which was originally intended to transport information from one company to another, has become accessible to the greatest number of people, facilitating access to sites and offering users the possibility to consult online a wide range of information. This new purpose has helped to improve the quality of life of individuals around the world.

Today, with the use of renewable energy sources [3], similar developments were observed in electrical networks, giving birth to a smart electrical network, called Smart Grid [4-8]. According to official projections, the global energy expenses will be doubled by 2030, in parallel, emissions of greenhouse [9] will increase. So, it became necessary to introduce the various sources of renewable energy in the production process of electrical energy.

However, these energy sources are intermittent and not synchronized with the consumption. It is therefore necessary to deploy meters and communicating devices, in the drive to optimize production and distribution of electrical energy between producers and consumers. The conventional electrical grid is paired with a communication network taking advantage of the development of new information and communications technology (ICT). This modernization of the electrical grid, affecting production and consumption, will lead to a bidirectional exchange of electrical energy. Thus, it will profoundly transform the power grid architecture.

The establishment of such a network has engaged a lot of researchers from different disciplines, some of them like Jeremy Rifkin [10], project in the near future, the emergence of an "energy internet" [11], which could also be extended to networks and intelligent transport systems, a concept that is often associated to a "smart-city" [12]. In this context, in order to better carry out this research, it is more appropriate to take inspiration from computer network. Indeed, the new architecture of power grid allowing a bidirectional flow of electricity, imposes the study of a possible analogy with the computer network. This analogy will allow, firstly to better use of information technology for electricity distribution network and, secondly, to draw

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the most reasonable and the most optimal way to develop the smart grid network in addition to the ability to inherit efficient computer network protocols.

This article is devoted to a brief description of the structure, operational model and benefits of smart grid. In addition, we will study two systems, physically different, namely the smart grid and the computer network where we will attempt to show the similarities and differences between the two networks. Furthermore, analogous quantities and similar parameters are also identified, and finally, we present an example of smart grid implementation using the computer network.

2. Smart Grid

In order to understand the similarities between the Smart Grid and the computer network, we will in this section study the major technological advances which succeeded the smart grid, its structure, Operating principle and its different advantages.

2.1. Major Technological Advances

As a global model of energy management, this vision has emerged in the first decade of the 2000s [4-7]. However, It has older roots, since it is made possible by innovations which are prepared in the 1970s, followed by the appearance of new information and communications technology (ICT) which quickly earned a large part of the economy, research and leisure (personal computers). This new network could not exist without microprocessors which have prepared the advent of computers, and then the creation of Internet, or without home automation and broadcasting of hundreds of millions of mobile objects interconnected by wireless technologies. Memories of oil crises, severe nuclear accidents (Three Mile Island, Tchernobyl, Fukushima) and the prospect of Peak Oil have also guided the principles of energy independence and distribution of resources. Production, distribution and control of such a decentralized energy cannot be achieved without the convergence of various communication technologies and different renewable energy (wind, solar, geothermal). Network "City in Transition" is one of the fastest solutions to apply all or part of this approach.

2.2. Structure of the Smart Grid

Production units. This new network, which one of the main objectives is to ensure a continuous balance between production and consumption, consists mainly of centralized production units (nuclear, thermal, hydro, etc.) and decentralized production units from renewable sources, installed at the consumers premises (residences, public buildings, etc.), this structure is illustrated in Figure 1.

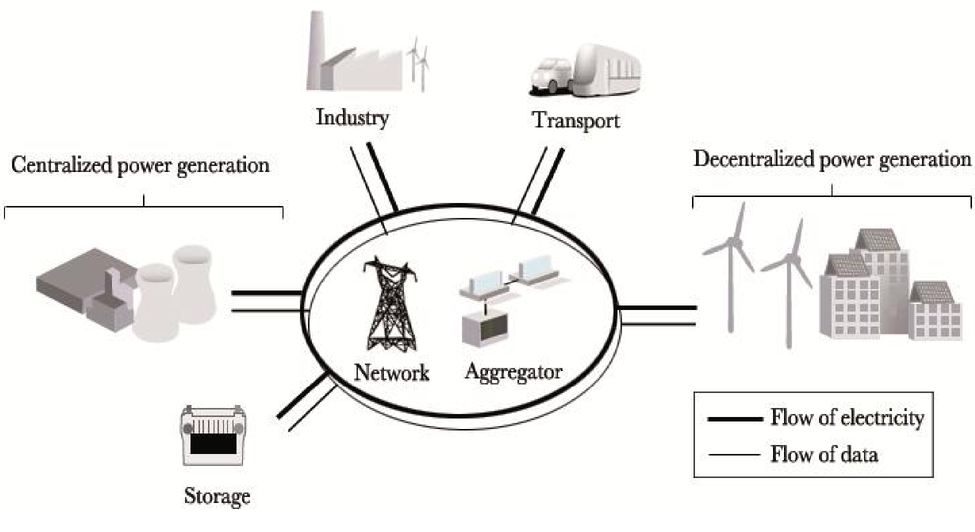

Figure 1. Structure of smart grid

Communication layers. The smart grid also includes communicating devices (meters, regulators) installed at different points of consumption and production, so constituting a communication network allowing efficient electricity management. As a platform enabling a connection between the electricity market and the internet, will allow consumers to know their real-time energy consumption and participate in the optimization of energy flow.

The equipments constituting this new layer can be connected directly to the computer network as they can communicate via the power grid itself. The first approach is based on the use of existing computer network, thus, it will allow to take advantage of the various existing protocols (TCP/IP, UDP, FTP, etc.) to develop real-time protocols adapted to the smart grid. The second approach is based on the development of new communication protocols allowing the use of electrical network itself via power line communication (PLC) as in G3-PLC [13] for circulating information in low, medium and high voltage. This technique has several advantages: it is inexpensive, reliable, optimal in resource allocation, however, like all technologies, it has some limitations, which requires the use of complementary solutions. The schema of the Figure 2 shows a model using PLC technology combined with the computer network, thus forming an evolved metering system.

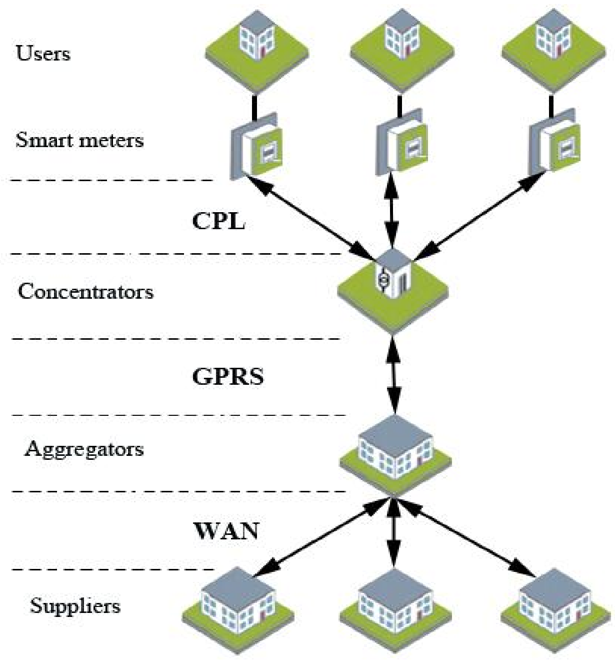

Figure 2. Evolved metering system using PLC technology

Storage. Renewable energy sources are always fluctuating and not synchronized with consumers' needs, which requires the implementation of mechanisms to store energy during periods of low consumption and high production. So different researches [14-16] have been carried out to develop efficient storage solutions, for example, electrochemical batteries [see] and Fuel Cells using Hydrogen, methanol or methane as fuel. This storage system is an essential piece of the smart grid because it will allow it to become more flexible and also promote the development of renewable energy.

2.3. Operating Principle

The current network has been built on an architecture based solely on thermal, hydro and nuclear power plant. Producer provides the total energy required to the network without having to worry too much about the needs and behavior of consumers. With massive implementation of renewable energy sources, consumers become producers of electricity for their own needs, the smart grid must therefore be designed to make maximum use of local production, this will help to optimize energy flows by avoiding the routing of electricity over long distances through distribution and transmission network.

At the production level, there are significant challenges ahead. The smart grid must take into account a set of parameters related to different mode of production, for example: irregular aspect of solar and wind production, the make-ready time to achieve the optimal level of production at nuclear power plants. To attain these objectives, the smart grid must be very reactive. For that, it must be equipped with a set of smart devices distributed on all levels: low, medium and high voltage. These equipments allow it to have a flexibility in control through a self-control at the local level and a centralized control at the national or international level.

2.4. Major Advantages

Today, we are on the verge of an unprecedented economic, energetic and ecological crisis. Given this situation, the smart grid is an indispensable solution with benefits for the various actors in the electricity market: consumers, producers and aggregators, it offers many advantages, we can mention, for example:

a) Development of renewable energy on a large scale which will reduce production based on coal, oil or gas causing greenhouse gas emissions.

b) Interconnection of electricity demand at market prices, which will reduce peak demand and lead to a more efficient economic equilibrium.

c) Real-time supervision and control of the network, which will help to avoid congestion and reduce economic losses related to network failures.

3. Comparison with Computer Network

Progress and development in power systems, giving rise to the smart grid, are similar to those that took place in the computer network [17]. For these reasons, since the first decade of the 2000s, a new vision began to emerge which is the Internet of energy [11], it is essentially based on the combination of the internet and renewable energies. According to Rifkin [10] this new approach will contribute to a Third Industrial Revolution. The rapidity with which the two networks are becoming increasingly similar, opens the door to great opportunities. Indeed, on the one hand, the development of a protocol based on the power-line communication (PLC), allowing bidirectional data exchange on the power grid itself, and on the other hand, the development of the power over ethernet (PoE), which involves passing electrical power via an ethernet cable, shows the existence of a strong analogy between smart grid and computer network.

The many results owe their success to the analogy, in fact, in the story, the analogy has always contributed directly and indirectly to the development of science, the examples are numerous. As a case in point, the unification of laws governing the infinitely small and the infinitely large in physics and behaviour modelling of TCP/IP network, using the following fluid-flow model:

$$\begin{cases} \dot{W}(t) & = & \dfrac{1}{R(t)} - \dfrac{W(t)W(t-R(t))}{2R(t-R(t))} p(t-R(t)) \\ \dot{q}(t) & = & \dfrac{W(t)}{R(t)} N(t) - C \end{cases}$$

Where W, N, C, p, q and R(t) are respectively the TCP window size, number of TCP sessions, link capacity, probability of dropping packets, queue length and the round-trip time (RTT),

This model was completely found by analogy with the fluid mechanics. By combining this model with an Active Queue Management (AQM) mechanism, we have developed a state feedback control law ensuring stabilization of the network and congestion avoidance, for details see [18-19].

Therefore, inspired by the importance of analogies, we will devote this section to study the similarities and differences between the two networks. This comparison will allow us to develop a smart grid as reliable and efficient as the computer network.

3.1. Similarities

The study of the structure and operation of the two systems, has allowed to identify a set of similarities, Table 1 illustrates the various similar elements.

Table 1. Similar elements in the two grids

Element	Smart grid (Energy aspect)	Computer network
Resources	Hydro, thermal, nuclear, solar, wind, biomass, etc.	PCs, workstations, smartphones, tablets, etc.
Network	Transmission lines	WAN, LAN, MAN.
Analogous quantities	Energy transmission Aggregator Voltage Cable W-hour	Data transmission Router Bandwidth Cable Bit/s
Storage	Electrochemical batteries, Fuel Cells.	Magnetic tapes, hard drives, optical storage devices (CD-ROM, DVD-ROM, Mini-Disk).
Transmission direction	Bidirectional	Bidirectional
Protocols	G3-PLC	TCP/IP, FTP, POP, SMTP, HTTP, etc.
Connection	Plug and play	Plug and play for some types of networks, for others, it requires an authentication.
Load type	Heterogeneous: refrigerators, air conditioners, washing machines, hair dryers, games console, electric cars, mobile phones, etc.	Heterogeneous: TV, games console, cars, mobile phones, computers, tablets, etc.
Security	Disconnectors, fuses, breakers, etc.	Firewall, PKI, Antivirus, TLS and SSL protocols, etc.
Transmission capacity	Depends on the type of transmission line (low, medium and high voltage).	Depends on the bandwidth of the line.

3.2. Dissimilarities

The study showed a strong resemblance between the two networks, however, they are not completely identical. We have thus identified some aspects of non-similarity that should not be overlooked. For example, the excess electrical energy fed into the grid is routed according to the need, in contrast to the computer network in which the information is usually accompanied by a destination address. The second example of non-similarity concerns the storage, indeed a battery runs out after a certain time of use. Conversely, at a computer storage medium, the data are not exhausted.

4. Example of Smart Grid Implementation

As shown in the previous sections, we have put in evidence the similarities and differences between the two networks. Indeed, we are convinced that this approach by analogy is the best way to take advantage of current technological advances and to build a smart grid that meets our needs perfectly.

In the same context, some companies have already started to propose their smart grid model. This is the case of Alcatel-Lucent [20] which proposes the model shown in Figure 3, a model that integrates the different sources of energy and completely adaptable to the requirements of the current power network. Thus allowing to create a smart grid enjoying all advantages of the current computer network, namely reliability, availability, security and efficient network management tools.

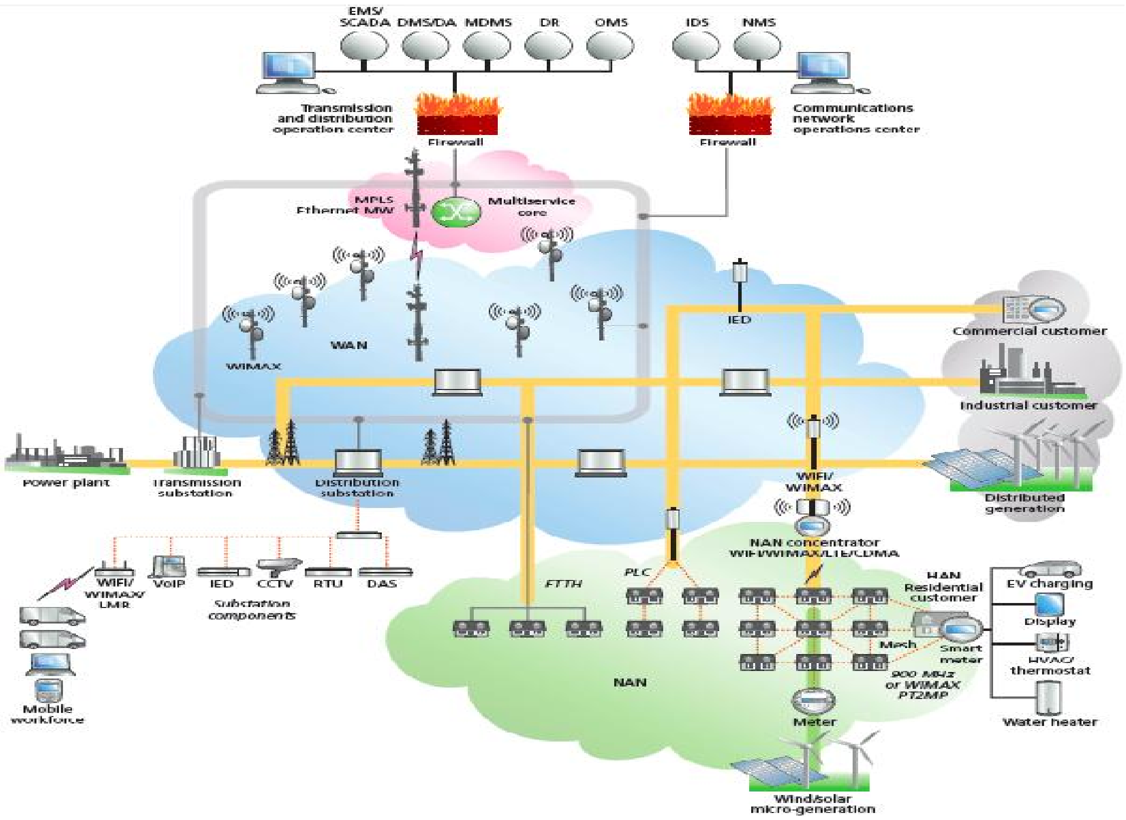

Figure 3. Smart grid model proposed by Alcatel-Lucent

5. Conclusion

A few years ago, the advances in the information and communication technologies have revolutionized our world. Today, we are witnessing a similar change through the emergence of the smart grid, a new concept that will profoundly transform the current power grid architecture. In this article, we presented the structure and operating principle of the smart grid. Subsequently, a comparison with the computer network has enabled us to identify the various similar elements. In perspective, a thorough study of the interactions between these elements is necessary, to fully capitalize on this analogy.

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