ABSTRACT

The electric power industry is being shaken by a new idea that is taking shape: smart grids. Nowadays, they appear in all international forums on the future of the electricity grid and many companies show their modernity ensuring they have one or more of these networks in their infrastructure, despite the fact that this concept is still being developed, and it must evolve, because it has major challenges to be solved in several aspects. A traditional distribution network, equipped with smart meters in users' facilities is just that: a network with smart meters. That does not make it a smart grid, although it helps.

Three aspects are considered keys to reach smart grids:

a) The structure of the network must meet the smart grid concept, i.e. it must be resistant to failures, e.g. causing the automatic separation of any broken element without affecting the operation of the other components; it must be flexible to allow the connection or disconnection of loads and distributed generators, it must maintain efficient operation under various load conditions, and so on.

b) The network should open the possibilities of participation of large and small generators as well as users, enabling new business opportunities and active participation, so that "intelligent" generation or consumption may benefit.

c) All participants must have easy access to the information needed to choose the best operating strategy in each case.

In regard to the first condition (a) there are significant challenges to solve: network automation, optimal design, development of new protection and control equipment, etc. To date it cannot be roundly stated whether future networks (hopefully smart grids) will work with alternating current or direct current, as the latter has advantages in many aspects related to operation and control. In any case, it will be necessary to develop equipment adapted to new problems and new needs that will be generated in these networks. Those items of equipment should be standardised, it will be necessary to define tests to take into account issues that currently are not usually needed, such as the presence of disturbances in voltage, or others. In this sense, marginally though, the research team in which the author works has collaborated with a laboratory for electrical testing, the Flex Power Grid Lab Research Infrastructure DNV KEMA in the Netherlands, in the definition and implementation of some tests, as described in *Chapter 3. Smart grids*.

In the second aspect (b), deep social changes are needed and, above all, regulation changes are crucial. In any case, the first step is to know how the consumption of loads is, how can demand be modified, how can small generation (mainly renewable) and energy storage influence generation, and so on. Having accurate models that provide this information is a key factor for network agents to establish their best strategies. It is important to note that a significantly inelastic demand, as presented by most consumers today, leaves the market dominated by large companies, whereas an elastic demand allows demand response actions to offer services to the network, such as removing overloads, voltage control, power reserve, and so on. This dissertation discusses many aspects of energy demand and the problem of controlling several resources and agents in the system operation is addressed and *Chapter 3. Smart grids* shows the management and control software (in which the author has collaborated during the design and development stages) of a small smart grid that exists in LabDER laboratory at the Universitat Politècnica de València (onwards, UPV), where various resources are integrated according to the needs of demand, energy prices, and so on.

In the third condition (c) there are also major challenges to be solved, such as mass information management and the increasing volume of data traffic that it can involve. It is clear that smart meters are an important element to enable the future development of this complex communications system, but it is also necessary to provide the reception facilities with their own communications systems and control centres to manage the facility in an efficient way. Also, small generators and distributed energy storage systems must be equipped with powerful communications systems for large amounts of information and data, as well as with their own control centres to design optimal generation policies. Regarding the use of information, this dissertation proposes several algorithms to facilitate treatment of the available data to optimise the management of the resources in a smart grid or to make decisions about the participation in demand response programs, as shown in *Chapter 8. Energy Management Systems for Smart Customers*.

Energy efficiency and the optimal use of renewable energy resources are important objectives in the operation of smart grids. Energy savings result in lower consumption (thus less generation required and less environmental impact) and a reduction in energy costs for users. It is also a potential source of demand reduction, which could be offered by consumers to the network. But these savings should be quantified, which is not easy. From the consumption data, it is not easy to compute the avoided consumption that is being achieved. Both load models and models of the response of facilities as a result of control actions are necessary. Disconnecting a centralised service in a building (air conditioning, for example) may cause the connection of individual air handling units, which results in a change in consumption much lower than expected. Therefore, a model of the overall response of the building is required, partial models of the elements of the facility are not accurate enough. But, for users it is essential to quantify the savings achieved with each action, to study the profitability, and if power reductions are offered to the network operator, this quantification is critical, since it involves an economical transaction. This is one of the fundamental aspects of this line of research and most of the contributions of this dissertation are related to it. Thus, in *Chapter 4. Energy efficiency and energy management in buildings,* several classifications are proposed in order to facilitate the identification of possible energy efficiency and energy management actions and the quantification of the impact of such actions, showing real examples in various types of facilities. Later, *Chapter 5. Measurement and verification of energy savings* provides a comprehensive review of the framework for measuring savings and it makes some interesting proposals to facilitate the measurement and verification of demand response actions based on the analysis of a practical case. Additionally, *Chapter 6. Consumption forecast* proposes a consumption forecast method that improves the accuracy of other existing methods and *Chapter 7. End-uses disaggregation and forecast* provides a complete methodology for analysing consumption of facilities, disaggregating end-uses and computing consumption forecasts with great accuracy. These tools are of great importance for the measurement and verification of savings.

In regard to the potential savings and the use of renewable energy, we must not forget that electric power is only a part of the total energy used in buildings. The building design and its use of natural resources will have a great influence in its electricity consumption. Smart grids must be developed jointly with smart buildings, not only in the sense that they have control systems, but in the sense that their design allows optimal use of natural resources, thus reducing future energy demand. The study of the main keys to achieve energy efficient buildings is therefore closely linked to the development of smart grids as well as to energy savings. Although in a marginal way, this aspect is also taken into account in this dissertation. The collaboration with the research group CSEF (Centre for Sustainable Energy in Food Chains) during the stay at Brunel University London has enabled a participation in some of the current developments in the areas of intelligent building design and the use of natural energy resources. In *Chapter 4. Energy efficiency and energy management in buildings*, a summary of these aspects is shown.