Ph.D Thesis Abstract

# *Bidirectional Metering Advancements and Applications to Demand Response Resource Management*

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The power grid is an electric system capable of performing electricity generation, transmission, distribution and control. Nowadays it has been subjected to a deep transformation, which will reshape it completely. In fact, growing electricity demand and consequent increase of power losses in transmission and distribution grids, the increase in prices of fossil fuels and the diffusion of renewable resources, the need for a more effective and efficient grid management and use of energy, the availability of new technologies to be integrated into the grid, they all push for a modernization of the power grid. Integrating technology and approaches typical of different areas (i.e. power systems, ICT, measurements, automatic controls), the aim is to build a grid capable of engulfing all types of sources and loads, capable of efficiently deliver electricity automatically adapting to changes in generation and demand, ultimately empowering customers with new and advanced services. This paradigm is known as *Smart Grid*.

In this context, the role of measurement theories, techniques and instrumentation is a fundamental one: the automatic management and control of the grid is a completely unfeasible goal without a timely and reliable picture of the state of the electric network. For this reason, a metering infrastructure (including sensors, data acquisition and process system and communication devices and protocols) is needed to the development of a smarter grid. Among the features of such an infrastructure are the ability to execute accurate and real-time measurements, the evaluation of power supply quality and the collection of measured data and its communication to the system operator. Moreover, a so defined architecture can be extended to all kinds of energy consumption, not only the electricity ones. With the development of an open energy market, an independent entity could be put in charge of the execution of measurements on the grid and the management of the metering infrastructure: in this way, “certified” measurements will be guaranteed, ensuring an equal treatment of all grid and market users.

In the thesis, different aspects relative to measurement applications in the context of a Smart Grid have been covered.

A *smart meter* prototype to be installed in customers’ premises has been realized: it is an electricity meter also capable of interfacing with gas and hot water meters, acting as a *hub* for monitoring the overall energy consumption. The realized prototype is based on an ARM Cortex M3 microcontroller architecture (precisely, the ST STM32F103), which guarantees a good compromise among cost, performance and availability of internal peripherals. Advanced measurement algorithms to ensure accurate bidirectional measurements even in non-sinusoidal conditions have been implemented in the meter software. Apart from voltage and current transducer, the meter embeds also a proportional and three binary actuators: through them is possible to intervene directly on the monitored network, allowing for load management policies implementation. Naturally the smart meter is only functional if being a part of a metering and communication infrastructure: this allows not only the collection of measured data and its transmission to a Management Unit, which can so build an image of the state of the network, but also to provide users with relevant information regarding their consumptions and to realize load management policies. In fact, the realized prototype architecture manages load curtailments in Demand Response programs relying on the price of energy and on a cost threshold

that can be set up by the user. Using a web interface, the user can verify his own energy consumptions, manage contracts with the utility companies and eventually his participation in DR programs, and also manually intervene on his loads.

In the thesis storage systems, of fundamental importance in a Smart Grid Context for the chance they offer of decoupling generation and consumption, have been studied. They represent a key driver towards an effective and more efficient use of renewable energy sources and can provide the grid with additional services (such as down and up regulation). In this context, the focus has been on li-ion batteries: measurement techniques for the estimation of their state of life have been realized. Since batteries are becoming increasingly important in grid operation and management, knowing the degradation they are subjected has a relevant impact not only on grid resource planning (i.e. substitution of worn off devices and its scheduling) but also on the reliability in the services based on batteries. The implemented techniques, based on Fuzzy logic and neural networks, allow to estimate the State of Life of li-ion batteries even for variation of the external factors influencing battery life (temperature, discharge current, DoD).

Among the requisites a Smart Grid architecture has, is the integration into the grid of Electric Vehicles. EVs include both All Electric Vehicles and Plug-in Hybrid Electric Vehicles and have been considered by governments and industry as sustainable means of transportation and, therefore, have been the object of intensive study and development in recent years. Their number is forecasted to increase considerably in the next future, with alleged consequences on the power grid: while charging, they represent a consistent additional load that, if not properly managed, could be unbearable for the grid. Nonetheless, EVs can be also a resource, providing their locally stored energy to the power grid, thus realizing useful ancillary services. The paradigm just described is usually referred to as Vehicle-to-Grid (V2G). Being the storage systems onboard the EVs based on li-ion batteries, starting from the measurement and estimation techniques precedently introduced, aim of the thesis work will be the realization of a management systems for EV fleets for the provision of V2G services. Assuming the system model in which the aggregator not only manages such services, but can also be the owner of the batteries, the goal is to manage the fleets so to maximize battery life, and guarantee equal treatment to all the users participating in the V2G program.