MONITORING SYSTEM FOR THE LOCAL DISTRIBUTED GENERATION INFRASTRUCTURES OF THE SMART GRID

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ABSTRACT

Distributed generation infrastructures based on renewable energies represent a key piece of the Smart Grid puzzle. However, such infrastructures increase dramatically the variability and randomness of energy generation, thus increasing the complexity of the grid management. Therefore, they need to be carefully monitored in order to properly integrate them into the electrical grid. This paper presents the novel monitoring system for distributed generation infrastructures integrated into the M2M-based platform for energy efficiency in energy-positive neighbourhoods which is being developed under the European project ENERsip. The paper describes the overall architecture of such monitoring system, as well as the developed pieces of hardware and software. In addition, the validation of the system is also outlined.

I. INTRODUCTION

The increasing penetration of DG (Distributed Generation) infrastructures introduces novel challenges from both the communications and electrical perspectives [1]. On the one side, these infrastructures involve a wide variety of equipment which runs proprietary protocols. Therefore, interfaces and devices to enable managing all them in a uniform way are required. On the other side, the proper integration of renewables into the electric grid represents a major problem, which becomes even more complex as the more distributed they are. So-called DR (Demand Response) programs and events can be applied to influence the energy demand in such a way that fits the peaks and dips in the energy supplied by renewables [2]. However, this requires of M2M (Machine-to-Machine) communications infrastructures which enable such bidirectional real-time communications.

This paper presents a novel monitoring system for local DG infrastructures that meets the aforementioned requirements. Such a system is integrated at the edge of the service-oriented M2M-based platform for energy efficiency within energy-positive neighbourhoods developed under the EU FP7 project ENERsip [3]. The main goal of the ENERsip project is to create an adaptive, customizable, and service-oriented energy monitoring and control system to reduce the overall electricity consumption in households while integrating the local distributed micro-generation.

The remainder of the paper is structured as follows. Section II outlines the global ENERsip communications architecture and the services that can be provided. Section III presents the developed monitoring system for distributed generation itself. Section IV describes the integration and validation plan of the ENERsip system, with special focus on the validation of the monitoring system for distributed energy generation. Finally, section V summarizes the paper, emphasizing its main conclusions and future work.

II. BACKGROUND: GLOBAL ARCHITECTURE AND SERVICES

Reference [4] details the overall ENERsip architecture as well as the main services such platform can offer. As Figure 1 shows, the ENERsip architecture is conceptually divided into four domains, namely the *Building Domain*, the *Neighbourhood Domain*, the *Information System Domain*, and the *User Domain*. The consumption and generation infrastructures (so-called I-BECI [5] and I-BEGI, standing for In-Building Energy Consumption/Generation Infrastructure) are placed at one edge of the platform; whereas the IS (Information System) - which hosts the intelligence of the electricity grid - is placed on the opposite side. Thus, the platform tightly relies on the hybrid and hierarchical M2M communications infrastructure, spread mainly across the Neighbourhood Domain, which enables the required real-time bidirectional communications. Such M2M communications infrastructure fits typical M2M communications architecture for the Smart Grid, being bounded to the NAN (Neighbourhood Area Network) defined in the CT-IAP (Communications Technology Interoperability Architectural Perspective) from the overall IEEE P2030 SGIRM (Smart Grid Interoperability Reference Model) [6].

Based on this architecture, the system is able to provide several energy services to different users, including not only consumers (energy consumption only) and prosumers (energy consumption and generation) but also other stakeholders, such as local energy producers, aggregators of consumption and generation, and the DSOs (Distribution System Operators). The available services are: *Energy monitoring, visualization, and reporting*, *Remote access and control of appliances*, *Load management*, *Microgrid energy management*, and *Distribution system operation* [4].

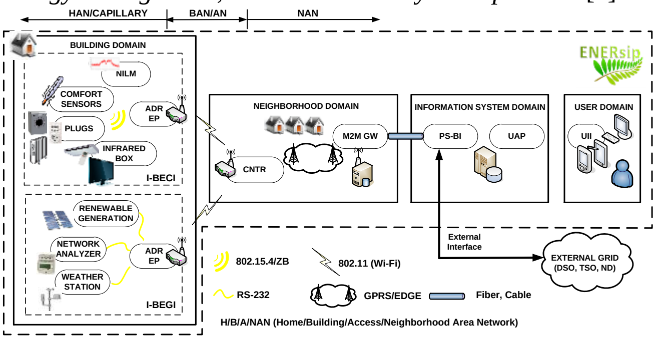

Figure 1. ENERsip overall architecture, communications segments, and communications technologies

The monitoring system for DG infrastructures presented in this paper has a vital role in the provided services. In a scenario of large scale penetration of renewable production from intermittent resources, it is fundamental that the electric system has appropriate means to compensate the effects of the variability and randomness of the generation. Thus, the monitoring system enables, for instance, the real-time identification of sudden reductions of local generation with the consequent activation of a DR event. The forecasting service will also allow the previous identification of unbalances between the generation and consumption, with the consequent request for consumption reschedule.

Therefore, the real-time information and the forecasting of local generation enable the timely identification of intermittence problems, being a very important tool to distribution system operators in its role of generation/consumption matching. Such services are also very important to prosumers, since they allow determining the most profitable option (self-consumption or grid injection of the produced energy), with large economic benefits.

III. MONITORING SYSTEM FOR DISTRIBUTED GENERATION

Figure 2 shows the architecture of the monitoring system for distributed local generation presented hereby, which is composed of: Energy Generation Equipment, Sensors (for gathering both environmental and electrical variables), and the so-called ADR EP (Automatic Demand Response End Point). The Energy Generation Equipment includes Photovoltaic Panels and Micro-wind Turbines, along with additional equipment, such as Inverters, for the connection to the electricity grid (converting DC – Direct Current - into AC – Alternating Current), complementary sensors (e.g., panel temperature sensor), and Energy Meters, to measure the energy that is generated by the installation. The main objective of the Sensors is to measure either variables related to weather conditions (e.g., temperature, humidity, wind direction and speed, solar irradiation) or electrical variables (e.g., DC current or voltage, AC current or voltage) in order to provide the IS with relevant parameters for accurate status monitoring, as well as for accurate generation forecast.

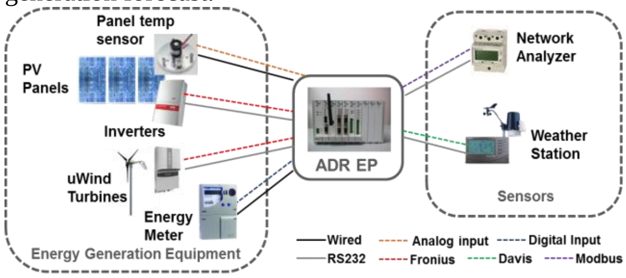

Figure 2. Overall Architecture of the Monitoring System for Local DG Infrastructures

The ADR EP represents the interface between the distributed local generation infrastructures and the remainder of the platform. It works both as a network coordinator and as a communications gateway, forwarding data collected by the sensors and other generation devices (e.g., inverters, meters) to the IS and routing commands coming from the IS to the appropriate devices. Thus, the ADR EP is equipped with multiple hardware interfaces and implements multi-protocol features in order to communicate both with the aforementioned equipment (using proprietary application protocols) and with the IS through the M2M infrastructure (using the ENERsip open protocol, based on XML, thus easing its implementation by a great number of agents).

As a result, the ADR EP enables the management in a uniform way of the wide variety of devices of such infrastructures, i.e., it hides this complexity and heterogeneity to the IS, which is able to manage whatever equipment within such infrastructures using the same protocol. The ADR EP aims at being a Smart Grid oriented device. In that sense, focus has been put on flexibility (different kind of generation infrastructures to be monitored and controlled), scalability (different sizes of installations), performance (wide range technologies deployment), and aggregation capabilities (based on open communications protocols). Next subsections elaborate on the main features of the ADR EP, as well as on its hardware and software design and development.

A. ADR EP Functionality

The main functionalities supported by the ADR EP are data acquisition and communications management. Data acquisition involves managing digital and analog inputs appropriately. Communications management includes the configuration of the modem for RS-232 communications, the configuration of the ADR EP from an external PC

(Personal Computer) through HMI (Human Machine Interface), and the support of different proprietary application protocols, such as Modbus, Davis, and Fronius.

Modbus is a serial communications protocol widely used in industry for connecting different devices, which thus has become a *de facto* standard [7]. Davis application protocol is a serial proprietary protocol used to communicate with Davis Weather Stations (via RS-232 connection) [8]. Lastly, Fronius application protocol is a serial proprietary protocol used to communicate with Fronius International Gmbh inverters (via RS-232 or RS-485 connection) [9].

The ADR EP could not only implement different protocols for the communication with other commercially available devices from other vendors, but also be adapted to the use of different communications technologies, such as ZigBee, PLC or Z-Wave. Potential capabilities of the ADR EP associated with its integration into the Smart Grid of the future are those related with DR automated actions (not only monitoring but also controlling), storage system management based on real-time pricing information, and other.

B. ADR EP Architecture

Hardware Architecture

The ADR EP hardware architecture is based on a CPU (Central Process Unit) and a group of peripheral boards. It has been foreseen that different kinds of boards, with complementary functionalities, will be arranged in the Bus Board in order to accomplish the specific requirements of the distributed local generation equipment (i.e., number and types of sensors and actuators). Thus, the minimum number of boards needed for the ADR EP to provide the described functionality is: 1 SB (Supply Board), 1 CPUB (CPU Board), 1 IEEE 802.11 Board, 1 Serial Board, 1 AIB (Analog Input Board), and 1 DIB (Digital Input Board). Figure 3 shows a typical hardware configuration.

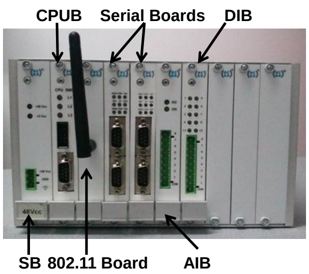

Figure 3. ADR EP Typical Hardware Configuration

Software Architecture

Figure 4 shows the ADR EP software architecture, including the main functional blocks and the relationships between them. ADR EP Core, Database and Real Time Module are the main parts of the system. They are responsible for managing the operation of the other ADR EP blocks, the data processing, and the internal clock operation. Analog, Digital and Counter Input Reader are responsible for gathering periodically every input coming from the different field sensors. Inverter, Energy Meter and Weather Station Communications manage the communications with installed inverters, energy meters, and weather stations through *RS-232 Interface* and using different protocols, depending on the manufacturer. CNTR and HMI Communications modules process the queries and receive commands and transform them into orders for the ADR EP Core. Also they transmit the cyclic data messages generated by the ADR EP Core. Finally, IEEE 802.11, RS-232, Analog Input, Counter Input and Digital Input Interface are drivers to control the physical interfaces present on the ADR EP. These drivers are used by the communication blocks and input reading blocks to send and receive information.

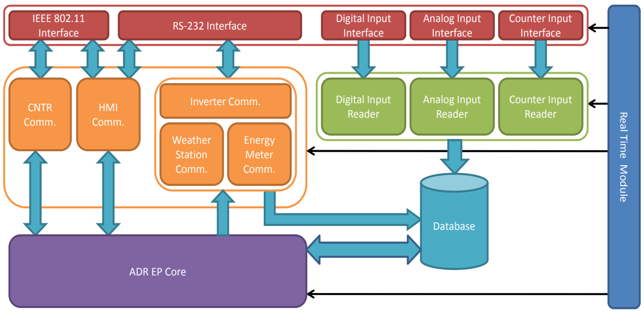

Figure 4. ADR EP Software Architecture

IV. SYSTEM VALIDATION AND EVALUATION

The integration phase of the hardware and software modules developed within the scope of the ENERsip project, comprises three phases: *Hardware Integration*, *IT Integration*, and *ENERsip System Integration* phase. Once the system is properly integrated and debugged, it is validated using 4 different and complementary strategies, namely by means of simulations of the communications infrastructure and of the energy services, and by means of pilot schemes, the first one focusing on the consumption infrastructure (*Consumption Pilot*) and the latest one addressing the overall system (*Demonstration Pilot*) [10]. This section focuses on the qualitative tests that were carried out to check that both the hardware and software developed worked as expected both as a stand-alone device and integrated into the remainder of the platform. Such tests were divided into two sections: Data acquisition tests and Integration tests.

A. Data acquisition tests

The tests to validate data acquisition were developed in the photovoltaic plant located at ISASTUR premises. This plant is formed by a set of solar panels with a total installed capacity of 5.55 kW, equipped with an inverter. In addition, the plant has a weather station, a temperature sensor, which measures the surface temperature of the panels, and an energy meter. An ADR EP was added to the installation to make the monitoring tests, using the same hardware configuration shown in Fig. 3.

The data acquisition tests included the acquisition of the generation electrical variables as well as the environmental variables. The tests allowed validating the following capabilities: *real time data acquisition for each device in the installation, detection of communication failures and operating abnormalities of the devices*, and *scalability to different sizes of generation systems*.

Performance tests were conducted to check the refresh and processing capacity of the ADR EP working with different sizes of the generation installation. Since it was not possible to have different installations, they were simulated using both commercial simulators and simulators developed specifically for these tests. As a result of the tests, it can be concluded that the ADR EP was capable of processing information at least from 20 devices connected with an information refreshing period below 1 second. Moreover, the capture frequency of wired signals could reach 100 Hz.

B. Integration tests

The integration tests with the ENERSIP platform were carried out in Israel, in two different locations. In each of these locations several ADR EPs, both for generation and for consumption, and one CNTR were installed. The tests consisted of validating data communication with the CNTR and the data flow through the platform, with particular emphasis on the communication performance the Wi-Fi (IEEE 802.11) link connecting the ADR-EPs and the CNTR.

The tests validated the following use cases: *registering a new generation end-device, deregistering a generation end-device, sending periodic measurement*, and *changing the sampling frequency*. The tests allowed showing that a wireless communication can be established to distances of 100 meters and data collected by ADR-EP can be sent with periods lower than 1 minute. Complementing these tests, a set of simulations was developed to determine the throughput of the IEEE 802.11 interface in different scenarios [11].

V. CONCLUSION

This paper presents the main features of the novel monitoring system for distributed generation infrastructures developed under the ENERsip project, as well as the practical experiences obtained during its testing and validation. The proposed system was integrated and validated under real conditions and all the test cases were successfully completed proving the effectiveness of the system.

The monitoring system presented in this work provides relevant information to guarantee proper electrical grid management and can be easily extended by including energy storage and control capabilities, thus also ensuring the on-site optimization of the local generation. The system can also be adapted to other types of generation equipment and to large scale facilities (not only in buildings) enabling the monitoring of all kind of DER (Distributed Energy Resources) infrastructures. In addition, this system may be upgraded by using communications technologies which are winning momentum within this area, such as Zigbee or PLC (Power Line Communications). This can be done just by using off-the-shelf modems from RS-232 to one of these communications technologies. In this case, the ADR EP will need only to be equipped with one additional communications interface to manage the entire DER infrastructure.

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