Flexibility services to power systems from smart rural microgrid prosumers

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***Abstract*—The innovation proposed by modern grid paradigms forces to create cutting-edge solutions for managing and integrating software microgrid technologies, as well as hardware ones. In this paper, a smart ICT platform for the management of the flexibility provided by the actors of a microgrid is proposed. Its architecture, functionalities and tools are presented and widely discussed, along with its implementation in a real-life demonstrator located in Terni, Italy.**

Keywords—flexibility-as-a-service; smart control system; RES; distributed generation; …

I. INTRODUCTION

A great amount of innovative grid paradigms is characterizing the evolution of modern power systems. As matter of fact, the implementation of microgrids in different energy contexts, such as urban districts, industrial sites, rural areas, etc., leverages a proper management of the energy resources operated in these grids in order to shape and provide different services to the grid operators, both Distribution System Operators (DSOs) and Transmission System Operators (TSOs). In the view of exploiting the flexibility provided by the energy actors within a microgrid, many approaches and techniques can be implemented for controlling and integrating several flexible behaviors in a unique service [1].

In this study, the implementation of a smart Information and Communication Technology (ICT) platform for controlling the flexibility of the energy resources installed inside a rural microgrid is proposed. This microgrid is composed by different actors that are able to provide flexibility: both generators and loads are in charge of modifying their energy behaviors in this direction. Moreover, a storage system provides its flexibility in generation and absorption for shaping a proper microgrid flexibility.

The research here presented is conducted within the Integrated Smart GRID Cross-Functional Solutions for Optimized Synergetic Energy Distribution, Utilization Storage Technologies (inteGRIDy) project, funded by means of the European Horizon 2020 programme. The inteGRIDy project aims at integrating cutting-edge technologies, solutions and mechanisms in a scalable ICT platform connecting energy networks with different stakeholders, facilitating optimal and dynamic operation of the distribution grid, fostering the stability and coordination of distributed energy resources and enabling collaborative storage schemes within an increasing share of renewables.

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II. FLEXIBILITY SERVICES FOR POWER SYSTEM MANAGEMENT

A. Flexibility of energy actors

The capability of modifying the energy consumption and/or generation pattern is modelled by the concept of flexibility. It is defined as follows: "On an individual level, flexibility is the modification of generation injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system. The parameters used to characterize flexibility include the amount of power modulation, the duration, the rate of change, the response time, the location, etc." [2].

In the context of a typical microgrid, the energy behavior of many actors can be modelled by means of flexibility actions to be structured within a flexibility-as-a-service view. A flexibility service is generally classified by the time response of the energy resources involved [1]: real-time flexibility, short term one, mid-term one, and long term/seasonal one. As such, according to the responsiveness and the dynamics of the flexibility provider, different areas of grid management can benefit from flexibility exploitation: supply and demand balancing; grid operation; user participation; emission reduction. Moreover, the innovative techniques brought by the flexibility open new perspectives for the introduction of tailored flexibility service market places where to trade and give economic values to flexibility. In this view, the figure of the aggregator, in charge of collecting and managing different flexibility contributions in order to give them relevance and effectiveness to the grid, is gaining more and more momentum.

B. Smart control of flexibilty services

As discussed above, the flexibility can be arranged properly in order to provide tailored services to a power system stakeholder, such as a grid operator. The strategies for the control and management of these processes are therefore designed in order to exploit flexibility services at their bests. Firstly, the economic benefit maximization of the actors providing the flexibility is the main driver of almost all the management approaches. Subsequently, the technical aspect related to the control of distributed generation, as well as the storage system, are essential aspects taken into account for establishing a management strategy, along with the improvement of power quality indicators. Some other techniques are directly linked to the service requests of a stakeholder, for instance in terms of power profile or price trend following. Finally, these strategies can be also driven by environmental aspects, such as energy losses reduction, polluting emissions control, energy efficiency, etc.

Due to the high inherent complexity of these management tasks, the platforms in charge of the flexibility management are often based upon dedicated solution methods that allow to take into account several aspects and different trends of the phenomena under study. Some of the most innovative and promising techniques among those employed today are: heuristic optimisation, machine learning, multi-agent systems, etc. In this work, an optimisation framework based upon a heuristic algorithm, in particular a genetic one, is proposed.

III. Cross-functional Modular Platform Solution for Flexibilty Management

In this section, the ICT platform solution proposed by the inteGRIDy project is presented and discussed.

A. Purpose

The main goal of the inteGRIDy project is to provide a complete ICT platform aimed at integrating all the new actors involved in the operations of modern smart microgrids. The integration addresses both new technologies, components, and devices, such as RES, storages, etc., and communication and computational means, such as metering and sensing devices, smart algorithm, and control techniques, etc. In this view, many software and hardware components are going to be integrated in a unique Cross-functional Modular Platform (CMP), an innovative and powerful set of synergetic components relying on openness and interoperability functionalities.

B. Architecture

The architecture of the CMP is structured in three main layers, grouping the main components envisioned for the provision of the different system functionalities. It consists of the different tools, models and mechanisms conceived to support the smartening of distribution services. The CMP consists of the following, hierarchically connected layers of subcomponents:

- Modelling and profiling of grid, Demand Response (DR)/Demand Side Management (DSM) & storage layer: this layer aims at integrating existing models/modelling tools in order to have a wide base of models and profiles characterization able to deliver to the other layers an accurate assessment of the behavior of involved entities.
- Operation analysis framework/simulation layer: this layer produces intermediate results or alternative scenarios, in order to support the decision making and optimisation mechanisms. It integrates current contexts, e.g. current grid conditions or monitoring data, with previously extracted models/profiles in order to use forecasting and prediction techniques.
- Decision making & optimization mechanisms/toolset layer: this layer is in charge of performing all the smart management techniques envisioned for the inteGRIDy system. As a matter of fact, all the information gathered and computed by the other layers of the architecture are conveyed to the Decision making & optimization mechanisms/toolset layer that implements all the functionalities related to the smart control of the energy resources of the system. The adopted approach relies upon several techniques able to optimize, take decisions, and schedule strategies taking into account different sets of criteria or goals to be achieved in particular energy context.

The architecture is enriched with an Integrated Visualization Platform (IVP) that comprises of a set of Human Machine Interfaces (HMIs), tools and services, responsible for enabling access to information of the underlying layers. Moreover, the field middleware modules allow the integration with the physical equipment, enabling access to real-time monitored information, historical data and notifications, suggestions for actuation, as well as the exchange of information with the grid operators. It consist of all the sensors, energy meters, actuators, controllers, etc., that will provide data to the CMP. Finally, the Reference Knowledge Warehouse is responsible for storing the different models, profiles, schemas, indicators, created and maintained by the different CMP components, acting as a common space for sharing and updating information.

C. CMP implementation

The solution proposed in this work allows to manage a rural microgrid described in the next section. The main goal is optimizing the operation of the microgrid taking into account the internal economic benefits of the microgrid and the service request form the DSO.

The envisioned system consists of several components and tools properly mapped over the architecture described above:

- a dashboard put at disposal of the DSO for selecting the typology of service requested;
- a DSO and a microgrid monitoring tool in charge of retrieving real-time data from the field, both regarding grid connection point and internal devices;
- a set of forecasting modules responsible of evaluating the forecasted power profiles of the energy units inside the microgrid;

- a set of modelling modules in charge of simulating the behavior of the energy units inside the microgrids;
- a load flow module aiming at simulating the electrical parameters of the microgrid physical infrastructure;
- an optimization engine responsible of the evaluation regarding all the power profiles, as well as set-points of the system that implements the management criteria;
- a communication module based on openADR [2] in charge of handling the information exchange between all the involved actors.

In Fig. 1, a diagram of the proposed architecture is shown.

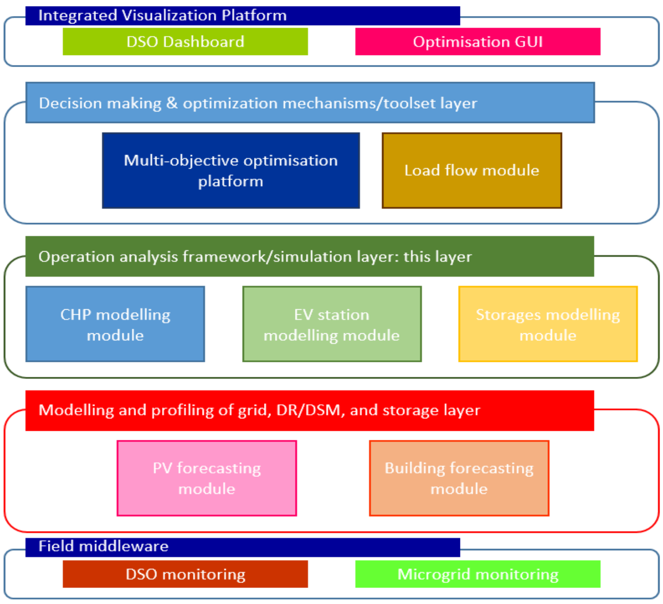

Fig. 1. inteGRIDy Terni implmentation ICT architecture.

IV. Demonstrator Test Site

The demonstrator test site comprises a smart rural microgrid, named “Il Moggio” and located in Terni, Italy. The local energy infrastructure is managed by ASM Terni S.p.A., the DSO in Terni. “Il Moggio” is a farm that covers an area of 14 hectares, in which 9 buildings are devoted to agricultural and commercial activities. The microgrid is characterized by a considerable amount of Distributed Generation (DG), as well as a Battery Energy Storage System (BESS), more precisely:

- a 29,4 kWp rated PV plant, connected through a static inverter both to the microgrid load and the BESS;
- 2 biomass (dry organic materials, as agricultural waste, walnut shells, wood chips) Combined Heat and Power (CHP) generators, each 31 kVA – 25 kWt rated and connected without a static converter;
- a 60 kWh rated BESS, consisting of 50 series-connected 12 V - 100 Ah lead batteries.

At present, “Il Moggio” is a stand-alone microgrid and will be connected to the Terni medium voltage distribution network through a 250 kVA secondary substation under construction. The DSO monitoring tool is basically composed by a SCADA system, a network calculation platform able to perform state estimation and a database storing network historical data. A power quality analyzer forwards voltage, current and active/reactive power measurements from the field to the SCADA.

According to the reference inteGRIDy architecture, the field equipment of the microgrid belongs to the field middleware layer. A PC Server interconnects the CMP layers with the microgrid, forwarding measurements from the field to the CMP and forwarding commands and settings from CMP to a Programmable Logic Controller (PLC), which supervises the microgrid components. The PC server is also in charge of storing measurements from the field, in order to assemble a microgrid historical database. Each component is connected to the PLC: the inverter controller, which commands the static inverter connecting the PV plant and the BESS; the DSE generator controller and the Arduino controller, which monitor and control the CHPs generators; the load controller, which forwards measurement of active/reactive power and active/reactive energy absorbed by the microgrid loads. Fig. 2 evidences the structure of the test site and the data flow between CMP, DSO monitoring and microgrid components.

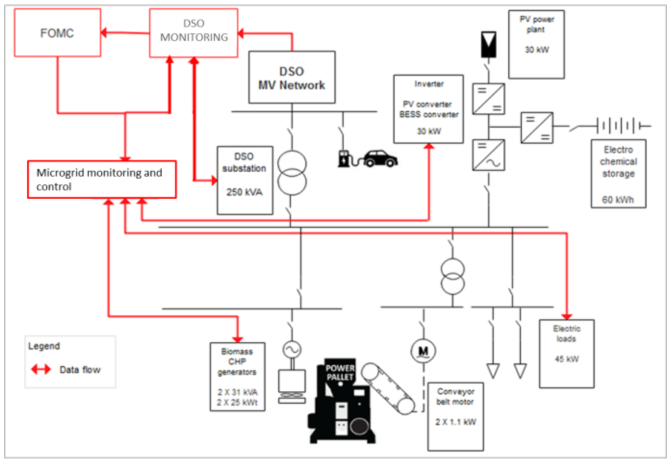

Fig. 2. inteGRIDy Terni pilot site structure and data flow.

V. Conclusions

This paper demonstrates how many different energy actors providing different flexible behaviors can be integrated and managed by a unique ICT platform in charge of performing the monitoring, modelling, simulation, forecasting, optimization, and visualization tasks related to the energy processes of a rural microgrid. Moreover, the structure and the features of the real-life demonstrator where the platform is going to be implemented are reported as well.

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