TRANSFORMATION OF A MICROGRID INTO A DISTRIBUTION GRID SUPPORT ASSET

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ABSTRACT

This paper describes the transformation of a microgrid into a grid-support asset, providing services for the electric retail market. Services are designed to be offered at an online platform called EU Marketplace, which has been developed within an H2020 Project. In the framework of the Spanish demo site, in the use case of Malaga city beach promenade (UC-7), an existing microgrid composed of photovoltaic and wind generators, lead acid batteries and consumption points is being converted into a system that works in a coordinated and optimized way that provides flexibility services to the electric grid operator. A remote system has been developed which monitors the entire system via SCADA and operates components based on optimization algorithms, minimizing energy costs and offering auxiliary services to the DSO.

INTRODUCTION

Global energy landscape is changing quickly towards high shares of variable generation, such as solar and wind. This development has been kick-started by low-carbon government policies. Dramatic cost reductions in recent years, especially for solar PV systems, turned them into the least-cost option for newly installed power in many places worldwide [1]. Therefore, responsive intelligent grids with energy storage are needed to balance variable generation and demand. Grid-friendly microgrids [2], [3] with distributed generation, combined with storage and flexible demand seem to be an important piece in the restructuring of electricity markets which is taking place. New market designs are being developed which enable distributed flexibility to be integrated and beneficial for both, grid operators and owners of distributed assets [4], [5].

This paper presents a concept which was developed within the Project, one of the most important European projects in terms of research and application of innovative solutions for the deployment of novel services in electricity retail markets. It deals with management and analysis of real-time electrical data to empower real customers to change their energy behaviour towards more energy efficiency and grid-friendliness. The centrepiece is an online platform called EU Marketplace, which facilitates exchange of energy-related services throughout Europe.

One of the demonstrators is situated in the Spanish city of Malaga. Within the demonstrator, several Use Cases (UCs) were defined to test not only novel data gathering strategies but also the application of advanced optimization rules that would enable new flexibility services. Thus, one of the most advanced Use Cases considered in the Spanish demo is the so-called “Flexibility Service” use case UC-7. The aim of UC-7 is to explore how to further integrate innovative solutions that could enable new flexibility services, such as the optimized use of electrical storage, controlled EV (Electric Vehicle) charging or the modulated injection of power coming from DER (Distributed Energy Resources) systems [6].

The result is a grid-friendly microgrid, which is able to optimize customer bills and at the same time, inherent flexibility is offered as flexibility service to the local DSO.

STARTING POINT

The existing microgrid, located at the Paseo Marítimo of Malaga, was formed by commercial components of renewable energy generation, storage and the associated power electronics converters. Before starting the project, the site contained approximately 20 kW of distributed generation, including wind turbines, four solar pergolas (2x 3 kW and 2x 1.5 kW) and four solar streetlights (475 W each). For energy storage a lead-acid battery pack of 1000 Ah was included and a Vehicle-to-Grid (V2G) charging point allows using electric vehicles as energy sources. All elements were connected to a common 48

VDC bus, ruled by three converters. Renewable devices are controlled by Maximum Power Point Trackers (MPPT). The resulting DC-integrated microgrid is connected to the grid by three bidirectional converters forming a three-phase system.

Operation was not optimised, with components following set-points obtained from voltage control at the DC bus. Energy generation excess was injected into the electric grid and energy stored in the batteries was used to partially compensate demand of the consumption points. The remaining demand was supplied from the grid.

The communication control network was based on Modbus, using a concentrator connected to a programmable logic controller (PLC). Due to the high number of elements connected, the concentrator took about twenty seconds to perform a complete reading cycle. This period is not suitable to perform a real-time control of the system, which was the main reason why a new control system has been developed.

GLOBAL OPERATION OF THE SOLUTION

The main objective of UC-7 was to develop a set of tools, hardware and software, to monitor and operate an existing micro grid reducing the energy bill and providing flexibility services and to demonstrate that a Service Provider (SP) can provide an energy flexibility service to the local DSO, through the microgrid (SP's customer). It is connected directly to a primary substation, allowing the test of different flexibility set-points. The available flexibility is offered by SP (through SP platform) to the DSO (through DSO platform). This service allows improving the stability and safety of the electric distribution network.

To improve the operation of the microgrid different software tools and several hardware devices have been developed, which can be grouped into "local devices" and "remote system" (see Fig. 1). Local devices (grid analysers, inverters, MPPTs, weather sensors and the local SCADA server) are deployed at the demo site, in Malaga. Two servers operating outside of the demo site compose the remote system: CIRCE Web Server and DSO Server (EU Marketplace).

Local devices have two main functions: provide field measurements to the remote system and apply operation set-points to the inverters, storage systems and charging point. Grid analysers (from several manufacturers), inverters (CONEXT XW from Schneider), MPPTs (CONEXT MPPT from Schneider), V2G charging point (from MAGNUMCAP) and weather sensors (several manufacturers) gather data from the microgrid. This information is concentrated and stored locally by the SCADA server and sent to the remote system. The CIRCE Web Server receives microgrid data from the local SCADA server via MQTT and stores it in a data base. With this historical data, the server runs two optimization procedures: the first one calculates operation set-points (for microgrid components) that minimize the energy bill of the microgrid and the second one calculates possible flexibility offers. Operation set-points are sent back to the local SCADA server, that applies them to local devices. Flexibility offers are sent to the DSO server, where DSO operators can purchase steps of flexibility. If flexibility is requested, the optimization process is re-launched to calculate new operation set-points for the microgrid.

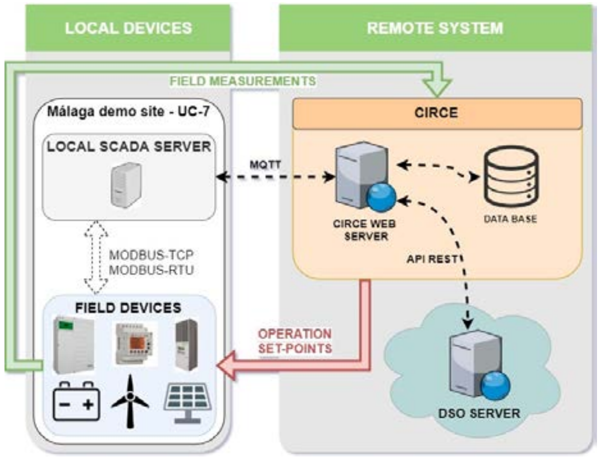

Fig. 1. Global operation schema of the solution.

LOCAL DEVICES: HARDWARE AND SOFTWARE

As remarked before, after the analysis of the existent microgrid, several changes in hardware and a new software were proposed. Hardware changes include new grid analysers to cover all branches of the microgrid, substitution of the largest wind turbine, installation of a new lithium-ion battery system that can work in four quadrants to perform flexibility policies (although not installed at the end of the project the developments can monitor and operate it) and the actualization of the V2G charger to support in these policies.

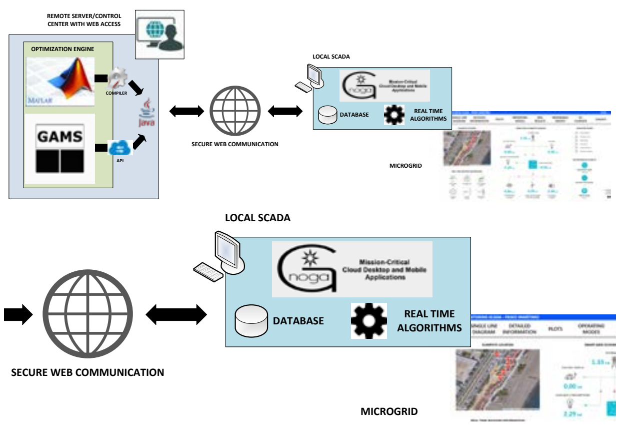

Fig. 2. Local SCADA system in the global communications schema.

The new software solution proposed for local devices (see Fig. 2) is based on the implementation of a SCADA that monitors and modifies operation set-points for the systems components and the development of a group of algorithms that optimize the operation of the components. The use of ADA, a real-time oriented programming language, added to the substitution of the PLC by an industrial PC, allows the new system to read the relevant information in about one second. Additionally, the SCADA system uses GNOGA, an open-source library that provides the latest web technologies (HTML5, WebSocket) to ADA .

Fig. 3. SCADA main page.

The information retrieved from the microgrid is sent to the remote system described in the next section. Additionally, the SCADA presents the state of the system and data from all devices in real time (see Fig. 3) and stores it locally in order to show statistical plots and allow query and export selected data. The SCADA system is designed to allow several operating modes driven by both local and remote algorithms. Implemented local algorithms include peak shaving and the regulation of power factor, voltage and frequency. The remote operating mode applies the set-points provided by the algorithms (described in the next section) to the inverters and the V2G charger. These operating modes can be configured (the local ones only) and selected by the SCADA user in order to change the microgrid behaviour. In addition to the power devices, the SCADA monitors weather parameters such as wind speed, solar irradiance, temperature and humidity. Its Graphic User Interface allows plotting and exporting the weather information in order to correlate it with the grid behaviour.

REMOTE SYSTEM: HARDWARE, DATA BASE AND SOFTWARE

The remote system has four main functions:

- Receive and store information gathered by field devices and sent by the local SCADA via MQTT.
- Execute a programme task to calculate 15-min average values from measurements and to fill slots without information.
- Forecast the state of some microgrid components and execute optimizations to calculate operation set-points and flexibility offers.
- Send optimization results to field devices through the local SCADA.

The environment technical features are listed below:

- OS Windows 7 Enterprise.
- Machine features:
  - Processor: Intel (R) Xeon(R) CPU E5-2650 v3 @ 2.30GHz (2 processors).
  - RAM: 12 GB.
- App Container: Apache Tomcat 8.5.
- Forecast and other calculations algorithms: Matlab executables.
- Optimization algorithms: GAMS 24.8 running CPLEX solver.
- App Remote Center: java 1.8.

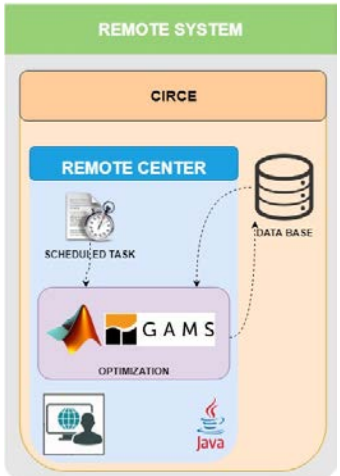

Fig. 4. CIRCE web server the global communications schema.

The information flow of the CIRCE remote system can be explained in these points:

1. Measurements from field devices are sent to SCADA and from there to CIRCE platform (via MQTT protocol) where they are saved in a Data Base.
2. Every 15 min, a scheduled task calculates 15-min averages from measurements averages and completes time slots without information.
3. Every 15 min, a scheduled task calculates the optimized plan using historical 15-min averages (see Fig. 4). The steps in the execution of this task are:
   3.1. Retrieve necessary information for optimization algorithms.
   3.2. Execute several Matlab forecast algorithms.
   3.3. Execute GAMS algorithm to calculate optimal mode operation of UC-7, using Matlab forecasts.
   3.4. Execute GAMS algorithm to calculate flexibility offers. In case an offer is accepted by external user, it will be included in the next execution of step 3.3 using the offer as additional constraint.
   3.5. Save forecast and optimization results in the data base, and create historical log of all results.

3.6. Creates a JSON structure from last optimization result and send it to SCADA using MQTT protocol.

4. Anytime, an external system (i.e. DSO platform) can request flexibility services according to current offers.

As explained before, optimization algorithms provide set-points for manageable devices of the microgrid for the next 72 hours, minimising the energy bill. The objective function is formulated as follows:

$$f = CV_{CS} + CV_{SS} + I + C_{PeajPss} + C_{Pss}$$

Where CV_{cs} is the cost of energy purchased from the grid, CV_{ss} is the cost of using the battery, I is the income from selling energy to the grid, $C_{PeajPss}$ is the cost of grid access tolls (power price) and C_{Pss} is a penalization for high battery power.

Therefore, forecasts for expected demand, distributed generation (wind and solar), energy prices and availability of V2G vehicle battery are needed as model inputs. These forecasts are provided by executables developed in Matlab. A statistical forecast method based on historical data has been adopted, which outperforms more sophisticated models for short-term predictions (several hours). Energy prices are obtained from OMIE (Spanish electric market operator) and weather forecasts (for solar and wind predictions) from AEMET (Spanish weather agency) web pages.

In addition to the dynamic optimization parameters described above, static parameters, such as storage characteristics, grid connection power, nominal device power, are introduced in the data base using the graphical user interface of the SCADA system.

The introduction of a power price ($C_{PeajPss}$) in the objective function provides a means for reducing demand peaks, obtaining a peak-shaving feature without the need of defining a fixed maximum power limit. The same logic is applied by penalization for high battery power, which is aimed to reduce battery charging and discharging power peaks, improving battery life.

The optimization is calculated using CPLEX solver using GAMS software [7]. The GAMS platform has been chosen because it provides a user-friendly environment for programming complex optimization problems. CPLEX is able to solve very efficiently, among others, Quadratic Constraint Programming (QCP), which was required for this application. First results from the demonstrator have shown that the pair GAMS – CPLEX performs stable and efficienty solving optimization problems of this use case.

Additional algorithms have been developed in order to offer flexibility services to the DSO (i.e. increase or reduction of demand at the grid connection point). In order to obtain an indicator of improved system flexibility, available flexibility capabilities are calculated for:

- The original microgrid, offering flexibility capabilities in the operation of the inverters: limiting the energy feed to the grid when the lead-acid batteries are charged and modifying the energy extracted from these batteries to feed microgrid consumptions.
- The whole system, including lithium-ion batteries and V2G charger, based on [8]. In this situation, active and reactive power flexibility is offered.

Besides the operation modes that follow set-points calculated remotely, local operation modes have been developed. Local operation is fast (real-time) and thus, can reduce grid impacts of the microgrid and support the operation of the electric grid:

- Peak Shaving, to reduce consumption peaks.
- Reactive power compensation, to reduce losses and increase grid capacity.
- Frequency regulation, supporting the grid when frequency is out of standard limits.
- Voltage regulation, supporting the grid when voltage is out of standard limits.

FIRST OPERATIONAL RESULTS

The local SCADA has been monitoring and managing the microgrid and communicating it with the remote system successfully for some months. As an example, Fig. 5 shows photovoltaic generation (blue line), lead-acid batteries (orange line), wind generation (green line), energy exchange with de grid (red line), lighting demand (purple line) and auxiliary consumption points demand (brown line).

During the demo period, an average of 22.9 h per day the system has been offering flexibility to the DSO to support in the grid operation. Fig. 6 shows an analysis of the Flexibility offered by the microgrid to the DSO on 19/12/2018 at 10:00h. There are two moments to increase demand, P_up (blue line), reducing excess solar PV energy feed to the grid (green line) and reducing the energy extracted from the batteries to feed street lighting (brown line). There is a moment to reduce demand, P_down (grey line), increasing the energy extracted from the batteries to feed street lighting (brown line).

CONCLUSIONS

The developed monitoring and control system has transformed a simple microgrid into a distribution grid support asset with optimised operation and the ability of offering flexibility to the grid operator. Field tests are ongoing, but some conclusions can already be drawn:

- The SCADA system monitors the entire microgrid and

can manage inverters and V2G charging points following optimized set-points.
- Optimization tools calculate set-points for manageable components to minimize energy costs.
- Developed tools calculate and offer flexibility to the DSO supporting distribution grid operation.
- The tools are stable, as most of the time are able to offer flexibility to the DSO

Next steps in the development of these tools are to continue with field tests for debugging and improvements, finish a smartphone app to see the state of the microgrid and the installation of a second storage system to test all the capabilities of the tools.

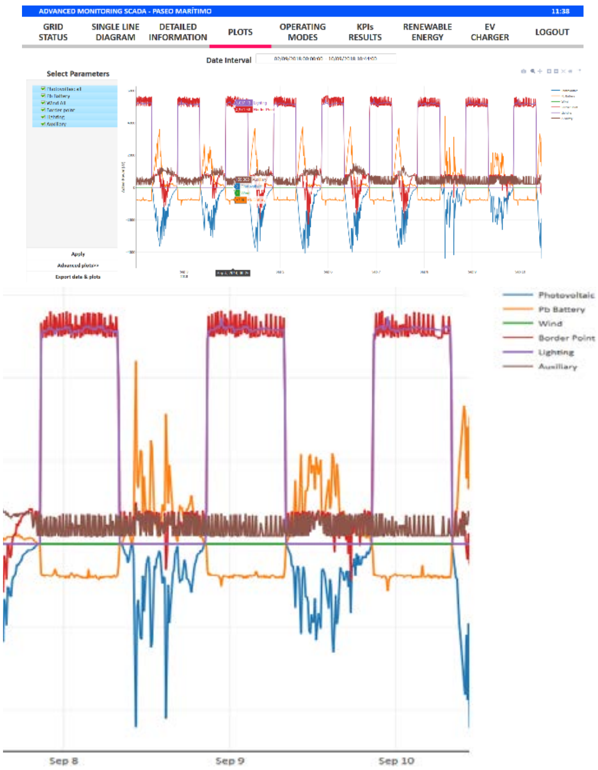

Fig. 5. SCADA showing the operation of the microgrid operation (general view and detail).

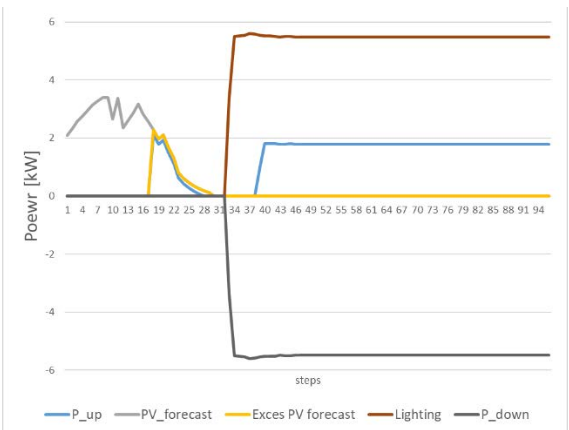

Fig. 6. Flexibility offer analysis.

ACKNOWLEDGMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646482.

DISCLAIMER

This paper reflects the FLEXICIENCY [9] consortium view and the European Commission (or its delegated Agency INEA) is not responsible for any use that may be made of the information it contains.

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