Decentralised Hybridised Energy Management Systems (DHEMS) in power grids

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Abstract. The integration of electric batteries along the power supply chain is crucial for the transformation of the energy sector towards a new flexible grid that allows the penetration of renewable power generation while ensuring stability and supply security. Batteries penetration in the grid can be boosted through an efficient management of heterogeneous generation sources, controllable loads and batteries, according to different criteria of stability, efficiency, cost, maintenance and power flow requirements. The Distributed Hybrid Energy Management System (DHEMS) is a management software tool able to solve an optimization problem maximizing renewable energy sources exploitation. The DHEMS has been designed with two control layers. First, the Cloud DHEMS layer accepts external setpoints (from a VPP, DSO or TSO) and dispatchs the total active and reactive power to be exchanged with the grid by a set of distributed plants. Second, the Local DHEMSs are in charge of distributing received set points and commands among the local sets that form each power plant. Different real control and communication tests have been done, in La Plana facility (owned by Siemens Gamesa Renewable Energy).

1 Introduction

The transition towards a decarbonized power sector calls for integrating higher shares of renewable energy generation, which introduces variability and instability in the grid due to the fluctuations in the supply and demand of energy. To properly balance electricity supply and demand on the power grid, grid operators must be aware of how much renewable energy is being generated, how much is expected and how to respond to changing operation. The

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intermittent nature of renewable power hinders this process and flexibility is needed both on the supply and demand sides [1]. Energy storage integration in the form of batteries can be paired with variable renewable sources to accommodate fluctuations. A proper control and management system is needed to maximize renewables exploitation, while reducing batteries degradation, ensuring the optimal operation and balancing generation and demand. Commercial energy management software for smart grids do not operate with hardware from different vendors and usually targets one type of customer. Against this, TALENT addresses interoperability between hardware and software by means of an architecture design that allows to connect control and management modules from different owners with a VPP, enabling participation in the electric system. Moreover, TALENT solution addresses a broad spectre of customers (residential, power generation plant, etc.).
This paper shows the deployment of the proposed architecture in a real hybrid power plant demonstrating its capacity of focusing on one hand in the control performance of the local devices, the stability of the produced energy and their safe operation, and on the other hand in the energy management at grid level and support of DSO's or TSO's operation.

2 Distributed hybrid energy control architecture

Several components build the TALENT control architecture presented in Fig. 1. The top part is the CyberGrid's virtual power plant (VPP) solution CyberNoc that enables the cloud control of distributed energy assets and has a role of a market aggregator. This flexibility platform can distribute the market signal among different hybrid power plants, or directly to the connected energy assets. It enables an optimized market operation while leaving the local management of the energy assets to the local controllers.

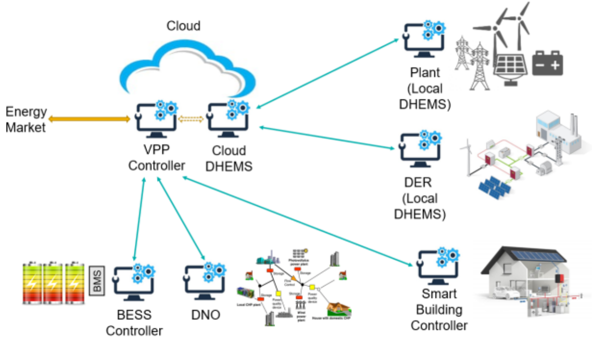

Fig. 1. TALENT control architecture

The Local Distributed Hybrid Energy Management System (LDHEMS) is in charge of the local management of a power generation site that integrates different kinds of assets (e.g.: PV, wind generation, batteries…). It also monitors all the units state and collects the power meters and other sensors measurements. It has been designed to enable control of the following devices in a power plant: up to 32 Photovoltaic inverters, 32 Wind turbines, 32 Gensets, 32 Lithium Storage Systems and 32 Flow Storage Systems. The LDHEMS solution has the following main control objectives: (1) to guarantee the active and reactive power at the plant Point of Common Coupling with the properly dispatching of the plant devices and following external setpoints and command, (2) guarantee voltage and frequency stability, (3) energy storage and spinning reserve management based on economical and operational criteria, (4) to control the normal operation and alarm and emergency situations of all assets of the generation venue, and (5) to send all relevant information (such as active and reactive power capacity or the power measurements) to the VPP and other high-level controllers. The control loop of the LDHEMS is 20 ms executed in a PLC. Apart of the stand-alone operation of the plant in offgrid and ongrid modes (that includes a list of control modes to meet the grid code requirements), this LDHEMS may be controlled by the VPP set-points. The LDHEMS uses standard communication protocols, such as ModbusTCP, SunSpec or ProfiNet, to command the power generation assets, the power meters, the protections and other systems such as meteorological stations. LDHEMS also includes a local SCADA where the operator can check the status of each power generation unit and command locally the power plant.

Cloud DHEMS (CDHEMS) is an optional controller in the TALENT architecture and is applied in case the plants owners want to implement their own proprietary dispatching strategy for their plants but participate in a VPP as a single unit. It acts as a technical aggregator for plants controlled by LDHEMS. The CDHEMS executes control commands every 100 ms, but communication between VPP and LDHEMS takes place every 2 sec. The CDHEMS receives the set points and commands from a high-level control such as the VPP, DSO, or TSO and dispatches a single set point among the power plants controlled by LDHEMS. The CDHEMS is a software executed in the SGRE cloud system. It receives the set point from the VPP and calculates the power sharing factor for every facility connected and managed by a LDHEMS using two selectable approaches. First, an algebraic proportional dispatching among them, subject to their nominal power and executed within the 100 ms control-loop. Second, an optimal control algorithm that allows power losses minimization (taking into account power losses in cables, transformers and efficiencies of the assets) or profit maximization (based on generation cost and electricity price). The optimization is based in solving a Non Linear Programming (NLP) problem [2] where the restrictions are the devices operation ranges and the energy model of the plant. The objective functions are built with the equations that calculates the previous mentioned power losses and profit. The algorithm is executed periodically (2 seconds at La Plana power plant) calculating the control set-points for every device. Then a closed-loop control executed at a 100 ms control-loop period is in charge of guarantee that the set-points are followed.

The architecture of the Cloud DHEMS solution is shown in Fig. 2, where it can be seen that the control and the database are stored into different machines in the cloud. The Cloud DHEMS Server communicates with all LDHEMS units, the VPP and the Cloud DHEMS Database. The Cloud DHEMS Database only communicates with the Cloud DHEMS Server.

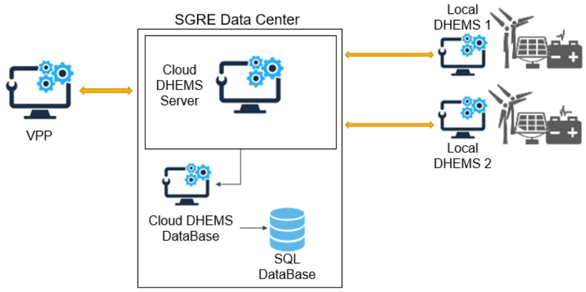

Fig. 2. Cloud DHEMS architecture

The CyberGrid's VPP CyberNoc (Fig. 3) [3], used in this solution is a modular, web-based software tool based on the microservice architecture. It is able to connect various types of assets (e.g. Battery Energy Storage Systems, Renewable Energy Sources, Distributed Generation, Commercial & Industry processes, Electric Vehicles, etc.) and management systems, and connect them to multiple electricity markets (TSO, DSO, spot markets…). The platform supports various communication protocols, e.g., ModbusTCP, SunSpec, IEC 60870-5-104. The VPP has a collection of market strategies, forecasting algorithms, controlling algorithms, and settings with which it can optimally control the connected energy units and distribute the set point.

The TALENT architecture for energy assets and power plants control is based on the System as a Service concept which enables management of decentralized resources and cost reduction for the customers, by reducing the commissioning cost up to 75%. Furthermore, the implementation of the standard communication protocols such as Modbus TCP/Sunspec and IEC 60870-5-104, together with a well-defined data structure for the connection interfaces ensures the interoperability of this solution.

Fig. 3. VPP user interface (CyberNoc)

3 Validation of the DHEMS architecture

The main objective of the TALENT validation campaign is to show that the TALENT solution for VPPs not only works properly but also that is flexible to manage any kind of power generation venue with standard communication protocols such as SunSpec over ModbusTCP and IEC 104. When compared against a standard energy management system, the DHEMS allows a great flexibility since it is able to manage storage systems while enabling connection to the VPP, thus allowing the user to access different energy regulation markets, getting optimal setpoints obtained by the VPP and performing the local dispatching. The testing environment used for the validation of the control architecture was La Plana Hybrid Facility located in Zaragoza (Spain) shown in Fig. 4. , a test site owned by Siemens Gamesa composed by wind turbine, solar plant and a lithium storage system.

Fig. 4. La Plana hybrid facility

La Plana hybrid facility has been divided into two power plants in order to simulate several power generation venues simultaneously connected to the VPP. Each power plant is managed by a LDHEMS, which is further controlled by the VPP or the CDHEMS located in the cloud. The first plant (La Plana 1) includes the wind turbine and the electric battery, and the second plant (La Plana 2) includes the photovoltaic plant and the diesel generators. The wind turbine used for the tests is a G52 legacy Gamesa, which can be controlled when the nominal power exceeds 20% (185 kW of 850 kW). The photovoltaic plant is controlled by a Gamesa Electric 500 kW inverter which provides a very stable power output. Several validation tests have been performed including the main TALENT controllers. Communication and interoperability have been demonstrated in all tests, and control strategies have been demonstrated within the validation tests. Two scenarios have been used for the validation (Fig. 5). Scenario 1 includes the VPP and two LDHEMS units controlling La Plana 1, and Scenario 2 includes the VPP, CDHEMS, and two LDHEMSs controlling La Plana 1 and 2.

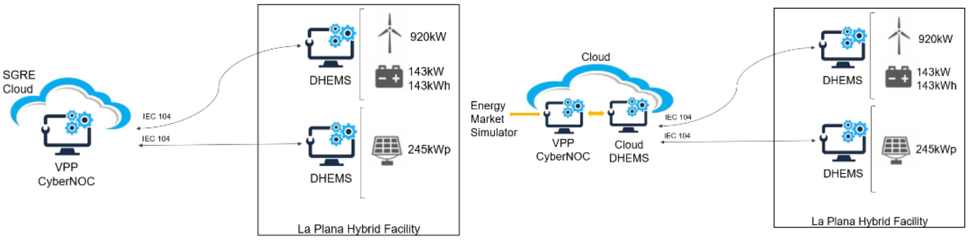

Fig. 5. Validation Scenario 1 (left): VPP controlling both facilities and Validation Scenario 2 (right): VPP controlling the Cloud DHEMS

VPP Control accuracy tests were devoted to check if both plants are able to follow the VPP and the CDHEMS individual set points in Scenario 1 and Scenario 2 respectively with adequate accuracy and response time; also, if the CDHEMS follows the aggregated VPP setpoint in Scenario 2. The control error following the set-points is usually less than 1% but it can be around 3% when the wind turbine is affected by wind gusts. The maximum response time is 8 seconds for steps of 20% of the total available power, being 3 seconds the typical value. This is more dependent on the weather conditions of irradiation and wind than on the control structure. *VPP control dynamic response tests* analyse the response of each plant to large set-points steps (80% of the total power) of the VPP. In this case the response time increase up to 15 seconds in some of the tests, showing that the storage system tanks to the BMS is the main guarantee for plant stability. *Storage, wind turbine and PV unavailability affections tests* checked that the CDHEMS and the VPP are able to manage the plants even though when one of the assets is not available. *LDHEMS affections to the VPP set points tests* showed that the control system is able to dispatch the required set-points at the same time that fulfils local requirements and grid codes such us Power/Frequency control, Power Limitation or Power/Voltage control. Finally, *VPP reactive control tests* showed the capacity of the CDHEMS to control the aggregated reactive power of the plants.

As a visual example of the control performance of the TALENT architecture, a VPP control accuracy test for Scenario 2 is presented, where the set points sent by the VPP to the Cloud DHEMS are 250 kW, 500 kW, 700 kW and 850 kW. It can be seen in Fig. 6 how the VPP set-point is followed by the aggregated power as well as the set-points generated by the Cloud DHEMS for each plant. The Cloud DHEMS is programmed for a proportional dispatching of the power during the test, but the low solar irradiation conditions result in Plant 2 always generating the maximum available power and the power in Plant 1 being regulated to follow the global setpoint. Then, the Local DHEMS in Plant 1 manages the battery storage and wind turbine to follow the local setpoint. The strategy is to charge the electrical battery when possible, which can be seen in the figure where the generated power in the wind turbine is injected in the grid and used for charging the battery at its maximum charging power until the plant setpoint is over 630 kW when the charging power is reduced. The figure shows an example of the cascade control strategy for the VPP, Cloud DHEMS and Local DHEMS that allows different dispatching strategies for different plants or aggregation of plants.

Economic advantages of the proposed architecture working as SaaS in comparison with other VPP developments can be found in [4].

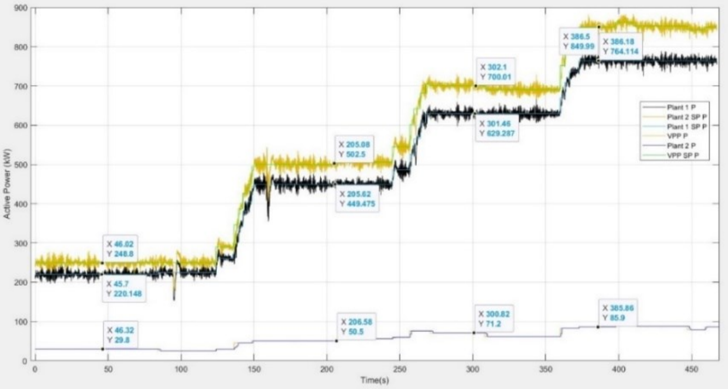

Fig. 6. Scenario 2 set point accuracy test

4 Conclusions

A decentralized hybridized energy management system for power grids has been described, showing its capabilities to control distributed hybrid energy generation, while covering the demand and managing flexibility thanks to the integration of batteries. Three main components constitute the DHEMS architecture: Local and Cloud DHEMS, together with a VPP in charge of enabling the market operation.

The DHEMS architecture has been validated in La Plana hybrid facility, which has been divided into two power plants, allowing the simultaneous control of distributed generation assets. Several tests have been performed in different scenarios where control, communication and interoperability have been successfully checked.

The interoperability approach has allowed that solutions of different companies (Siemens Gamesa Renewable Energy and Cybergrid) can be integrated in a collaborative energy management solution for distributed power plants. This opens a scenario where different companies with specialized solutions at the different levels of the architecture can build a common energy system with reduced cost thanks to the replicability of the particular solutions and the plug and play approach for the whole system.

References

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Acknowledgement

This research has received funding from the EC H2020 project TALENT under GA# 864459.