DEMOCRAT: DEMONSTRATOR OF A MICRO-GRID INTEGRATING STORAGE

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ABSTRACT

The increasing integration of renewable energy sources in electrical systems along with the inclusion of recent technologies such as Electric Vehicles (EVs) that require large amounts of energy from the grid in a short period of time lead to additional variability on consumption patterns and the network management becomes more challenging. A micro-grid (MG) integrating Battery Energy Storage Systems (BESS) can contribute to mitigate these challenges, allowing a more flexible, efficient and reliable network operation. Therefore, and in order to meet the identified challenges, Efacec presents an innovative MG demonstration project: DEMOCRAT, with the integration of solutions and technologies in the field of Smart Grids (SG) and storage.

INTRODUCTION

In general, the Distribution Networks (DNs) were not designed to integrate a significant share of Distributed Energy Resources (DER) and, consequently, the challenges in managing and operating the electric grid have been increasing. For that reason, the need to coordinate the new resources, such as renewable generation and EVs, appear as a requirement since their behavior is variable and unpredictable [1]. In order to mitigate periods of high consumption that would require the reinforcement of the existing electrical infrastructures and/or new electric infrastructures, and to maintain high standards of energy efficiency, continuity of service and energy quality, it becomes necessary to change the current paradigm of DNs planning and operation. This new paradigm can be achieved with innovative technologies and solutions that can contribute for the Smart Grid (SG) concept. The SG paradigm enhances the operation of DERs, integrates efficient power electronics components and allows greater involvement from the end-users, since they have access to more information and can make better-informed decisions. All this contributes for an efficient and more flexible power grid, with an upgraded green design and, as a result, the reduction of its carbon footprint [2, 3]. Within the SG concept, micro-grids (MGs) present themselves as an efficient solution to address these new challenges.

MICROGRIDS AND ENERGY STORAGE

A MG consists of a Low Voltage (LV) network encompassing several DERs, including among others photovoltaic (PV), BESS and flexible loads (e.g. EVs) that can be operated in different modes and in a coordinated way. Currently, BESS are a peculiar component to integrate MGs because batteries combine high storage capacity with high charge and discharge rates, and they can easily address the intermittent nature of the renewable production, stabilizing the distribution grids and increasing the flexibility and grid efficiency [4, 5]. MGs can operate both on-grid connected and in an autonomous way, when they are disconnected from the main grid (off-grid mode). Therefore, MGs are considered flexible assets on SG that allow a better management of LV grids. Also, MGs bring several advantages to the system, allowing the minimization of electric consumption on peak periods (smoothing the load profile) and the possibility of avoiding the reinforcement of the infrastructure [6].

In this regard, Efacec presents a project that differentiates itself as a solution applicable not only to LV networks, operated by regulated entities (Distribution System Operators) but also by end users, such as industrial prosumers. The project DEMOCRAT – DEMOnstrator of a miCrogrid integRAting sTorage - comprises several innovative applications, depending on the individual objectives of the solution recipient. This project presents a varied set of functionalities that will be tested in real environment, such as: operation of the LV network in on-grid and off-grid mode; technical integration of renewables through the storage system; optimization of demand from the viewpoint of the end consumer; demonstration of Demand Response (DR) programs and intelligent and centralized control of EV charging stations; as well public lighting as a mechanism of flexibility to MG. The purpose of this paper is to present in detail this pilot project, namely its physical components, the SG architecture designed as well as the several use cases that will be demonstrated.

DEMOCRAT ARCHITECTURE

SGAM and Energy Services Simulator

The SG Architecture Model (SGAM) of DEMOCRAT is depicted on Figure 1. DEMOCRAT follows a hierarchical structure, as its actuation scope covers different layers/levels of electrical power systems -Field and Process levels - where all the installed devices on the field are presented, namely local controllers and communication infrastructures - responsible for ensuring a bidirectional information flow with the MG Management System (MGMS) present at the Station layer. MGMS is responsible for the monitoring and control of all controllable assets and for interacting with corporate system such as SCADA systems.

In addition, DEMOCRAT also comprises a simulation tool - Energy Services Simulator - present at the Market level that will be used as an enabler of the demonstration of some control and management functionalities.

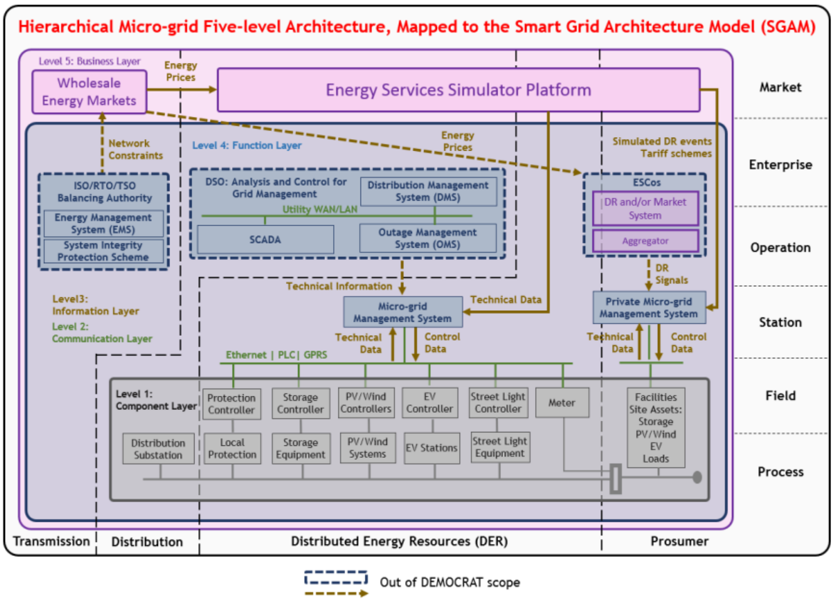

Figure 1- DEMOCRAT architecture based on SGAM

Namely, this platform will encompass:

- Simulation of Energy Markets - introduce different tariffs schemes and energy prices as inputs in the demand optimization of a prosumer with storage;
- Simulation DR: allowing to simulate DR programs and to assess the technical economic feasibility of consumers' participation on supporting system's operators in grid management;
- Technical Simulation: enabling to trigger the MG operation in off-grid mode (e.g. service interruption), assessing the impact of different network operation conditions on system's response.

Architecture

The DEMOCRAT MG, constituted by several generation, consumption and storage resources, is electrically connected in the PCS Block, which also comprises the conversion system of the battery system, integrated in the Battery Block, and allows the exploitation of several use cases, as different grid configurations are possible. The physical architecture is presented in Figure 2, where the main components as well as electric and communication connections are depicted. The approach combines technologies that, enabled by an advanced management scheme, provide an innovative solution. The main components that constitute the pilot project are described below.

Battery Block

The Battery Block corresponds to a containerized battery solution comprising a 200 kW / 200 kWh sizing, battery management system, fire detection and extinction, intrusion detection and a HVAC system for thermal management. Note that the solution is designed to accommodate further storage capacity during the battery system lifetime.

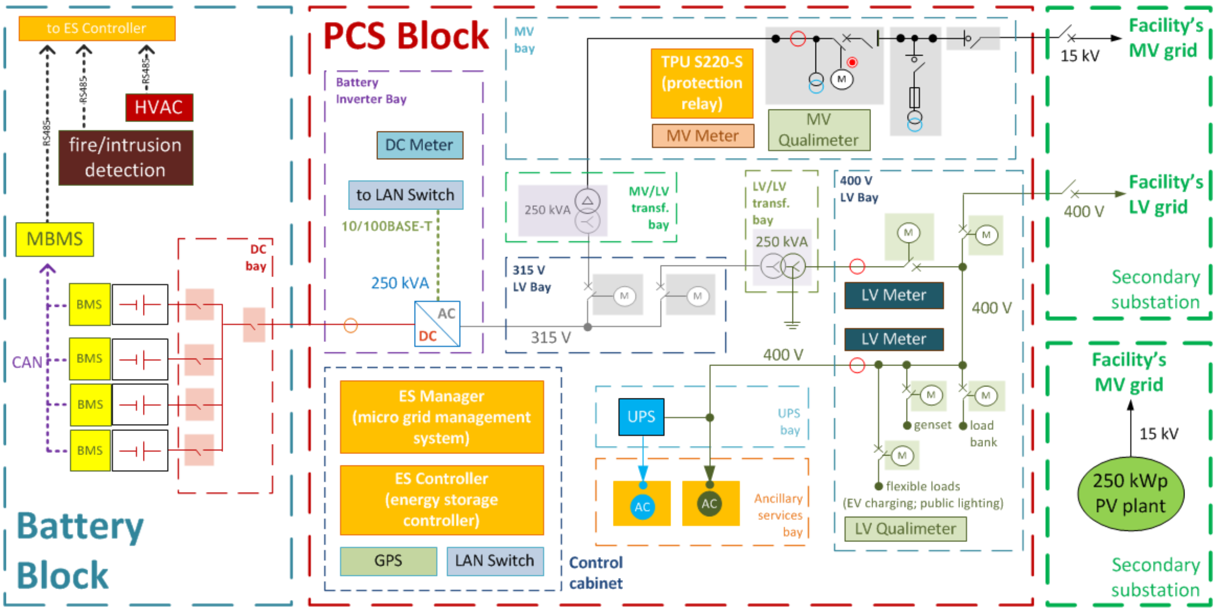

Figure 2- Battery Block, PCS Block and network integration

PCS Block

The PCS Block is a containerized power conversion system, integrating different technologies and enabling the physical connection of the MG:

- The **Battery Inverter** that assures the interaction between the storage system and the grid, providing a set of features and controls that allows a very fast response to power, frequency and voltage changes.
- The **LV/MV** and **LV/LV transformers** connecting to the MV and LV grid infrastructure, respectively. These connections are mutually exclusive, but that enable a flexible operation of the solution.
- The **Control Cabinet** comprises the control and management devices. The **ES Controller** is a smart local control unit that enables the adequate and very fast response of the energy storage system. It enables the continuous monitoring of AC and DC magnitudes from the electric grid and battery system, providing the interfaces with the battery management system and the battery inverter. Its control features ensure the fulfilment of technical and economic criteria that is customizable by the storage system user. Regarding the management system, the **ES Manager** is an innovative platform that integrates advanced algorithms to optimize the operation of the global system. It allows a multi-purpose operation, selecting the most suitable charge and discharge periods, enabling the optimization of batteries useful life time.
- **Metering and Power Quality systems** correspond to several components, namely meters and qualimeters, which are deployed with the objective of systematically analyzing the performance of the MG and the battery system.
- **Active grid components** include EV charging stations and public lighting, genset and load bank. The genset is to be utilized only for use cases demonstration. These components have their connection inside the PCS Block, but they are physically outside of container. They will ensure the provision of flexibility services at the MG level.
- **Uninterruptible Power Supply** to ensure that in case of failure or emergency, the system's critical components have another source of backup power.

USE CASES AND POTENTIAL IMPACT

The DEMOCRAT, since it has been designed with the ability to connect to different voltage levels and with the possibility of enabling different active grid components depending on the operational purpose, involves different Use Cases (UC).

a. UC1: Storage connected to LV grid

This UC corresponds to an on-grid operation of the battery storage system connected to LV grid. The main active elements here are the battery storage system, the battery inverter, the control cabinet and the LV/LV transformer that allows the connection to the LV grid infrastructure (Figure 3). All switches connecting to other components are open. In this case, the battery storage system works mainly to optimize the consumption pattern, supplying a percentage of the total LV load in peak periods while improving network power quality. Through ES Controller, the charging/discharging process is optimally controlled. Besides that, the storage system may provide load following, local voltage control and balancing between phases.

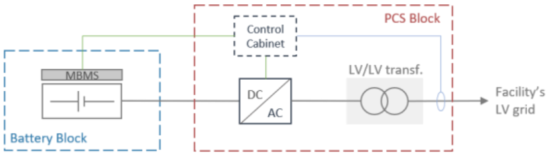

Figure 3- Simplified architecture for use case 1

b. UC2: Storage connected to MV grid

This use case corresponds to an on-grid operation of the battery storage system connected to MV grid. Here, it exists the possibility of interacting with a 250kWp photovoltaic mini-generation plant installed at the MV infrastructure (Figure 4). The capacity of the ES Controller to quickly charge and discharge the batteries compensate the PV power fluctuations will be demonstrated. Also, through the ES Manager and its energy management capabilities the interaction between PV and storage can be scheduled for smoothing the load profile, reducing the load in the peak periods. Moreover, the battery system may provide grid services to the upstream network such as voltage control and reactive power compensation.

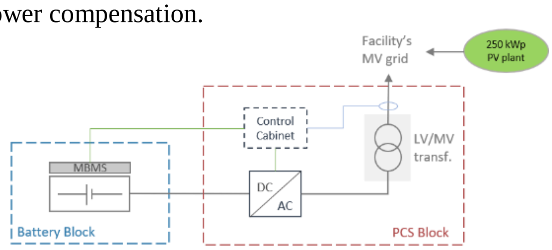

Figure 4- Simplified architecture for use case 2

c. UC3: Storage as an EV charging buffer

In this use case, the main components involved are the battery system, the battery inverter, the EV charging station and the LV/LV transformer or the LV/MV transformer, depending on the type of connection, LV or MV (Figure 5). The BESS can alleviate the peak demand on the grid during the fast charging process, alleviating the electric infrastructure. In this regard, the ES Controller ensures that grid technical limits in terms of voltage and current are not surpassed. The ES Manager can schedule the best periods to charge the battery system ensuring the economic optimization of the process.

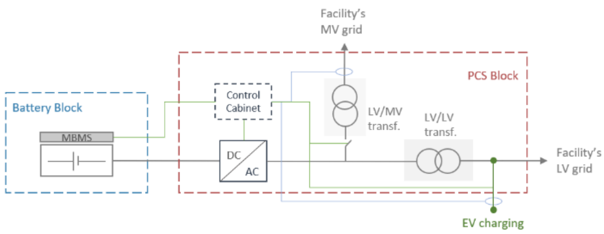

Figure 5- Simplified architecture for use case 3

d. UC4: MG connected to LV or MV grid

In this use case, a MG (battery system, flexible loads and load bank) is connected to the LV or the MV grid infrastructure (Figure 6). The main feature of this use case is the possibility of MG separation and resynchronization with the main grid. This separation can be planned (opening a switch) or not planned (trip of a protection relay). In this way, the MG operates in off-grid mode and the battery system stays responsible for the supply of load bank and flexible loads. Here, the ES Controller holds as main features the MG separation control (transition from on-grid to off-grid), the black start mode, the backup power and the resynchronization mode (transition from off-grid to on-grid). The most important requirement in this use case is keeping voltage and frequency inside the technical limits during the transition modes, even when the transition occurs in an unpredictable way, meaning that the battery system needs to perform grid forming.

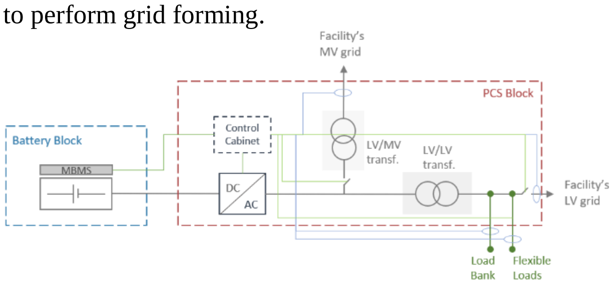

Figure 6- Simplified architecture for use case 4

e. UC5: Hybrid off-grid system

This use case comprises a hybrid off-grid system with two main operational strategies. The hybrid system consists of diesel genset, battery storage system and load bank, while not being interconnected with the main grid (Figure 7). In the first operational strategy, the diesel genset works as the single voltage source of the MG under isolated mode. The battery storage system as well as the other controllable resources are managed to optimize the genset fuel consumption and, therefore, minimize environmental impacts. Thus, it is possible to avoid the waste of energy, handle with peaks in demand without burning extra diesel and improving the system operation.

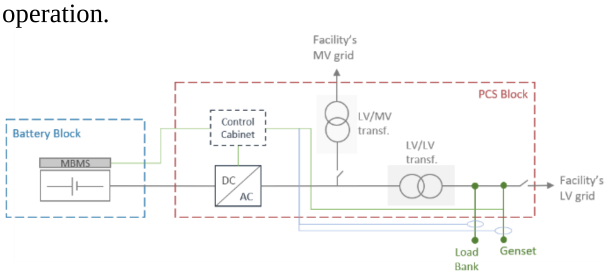

Figure 7- Simplified architecture for UC5: first hybrid system

In the second operational strategy (Figure 8), the battery system imposes voltage and frequency, while the diesel genset is offline for the maximum extent of time. This means that it is responsibility of the battery system, in a first instance, to compensate voltage and frequency excursions derived from other MGs resources. Different performance objectives are defined to the battery system and MG management in order to demonstrate the benefits of the proposed approach in these applications.

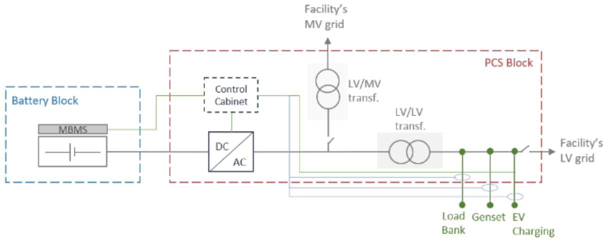

Figure 8- Simplified architecture for UC5: 2nd hybrid system

CONCLUSIONS

The contribution of DEMOCRAT to increase the efficiency and overall operation of electric power systems and consequently represent an effective transition to the SGs paradigm make this solution unique and with a high market potential. The DEMOCRAT aims to create the necessary conditions for MGs to be able to manage with local constraints, to increase the renewable energy penetration and to operate more efficiently, providing a great flexibility to the grid in benefit for SGs. The integrated solution enables the coordination of diverse network assets with high security and energy efficiency, enabling sustainability and decarbonization of energy services.

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