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Experimental validation of smart distribution grids: Development of a microgrid and electric mobility laboratory

C. Gouveia, D. Rua, F. Ribeiro, L. Miranda, J.M. Rodrigues, C.L. Moreira *, J.A. Peças Lopes

INESC TEC – INESC Technology and Science, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal

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ABSTRACT

The development of the Smart Grid concept is the pathway for assuring high reliability, control and management requirements in future electric power distribution systems. The Smart Grid can be defined as an electricity network supported by an intelligent infrastructure, both hardware and software, capable of accommodating high shares of Distributed Energy Resources. Within this line, a Smart Grid laboratorial infrastructure was developed, being dedicated to advanced research and demonstration activities. The adopted laboratorial architecture was developed according to the Microgrid concept, where Electric Vehicles are regarded as active and flexible players. Following the laboratory implementation, this paper provides a detailed description of its infrastructure and experimental capabilities, presenting and discussing different experimental set-ups and associated results.

Introduction

The deployment of the Smart Grid (SG) concept implies major changes in the operation and planning of distribution systems, particularly in Low Voltage (LV) networks. The majority of small scale Distributed Energy Resources (DER) – Electric Vehicles (EV), microgeneration units, energy storage devices and flexible loads – are connected to LV networks, requiring local control solutions to mitigate technical problems resulting from its integration. Simultaneously, LV DER can be aggregated in small cells in order to globally provide new functionalities to system operators [1–4].

Within the SG paradigm, the Microgrid (MG) concept has been pointed out as a solution to extend and decentralize the distribution network monitoring and control capability. A MG is a highly flexible, active and controllable LV cell, incorporating microgeneration units based on Renewable Energy Sources (RES) or low carbon technologies for combined heat and power applications, energy storage devices and loads [5–9]. The coordination of MG local resources, achieved through an appropriated network of controllers and communication system, endows the LV system with sufficient autonomy to operate interconnected to the upstream network or autonomously – emergency operation [6–10].

Following the track record on MG research, significant demonstration activities have been exploited worldwide [11]. In Europe, the Association of European Distributed Energy Resources Laboratories (DERlab) clusters European DER laboratories in order to widen the access to the available testing facilities. In the United States, the CERTS Microgrid Laboratory Test Bed aims to demonstrate peer-to-peer and plug-and-play functionalities for different DER, exploiting the MG islanding operation mode [12]. Large scale demonstration projects can also be found in Japan, with a strong emphasis on the integration of RES in the grid, namely on the development and test of adequate control solutions involving different energy storage technologies to balance RES variability [11,13]. Recently, the Zhejiang Electric Power Test and Research Institute implemented a cluster of multiple distributed generation and energy storage technologies capable of operating in different conditions and involving the testing of control strategies for grid connected and islanding mode, while dealing with protection and power quality issues [13].

Within this framework, the Laboratory of Microgrids and Electric Vehicles presented in this paper aims at supporting the development and testing of SG solutions while promoting an active and intelligent management of electric grids in scenarios with a progressive integration of microgeneration units and EV. A distinct feature of this laboratory relies on the integration of commercially available solutions and in-house developed prototypes. The laboratory allows individual and fully integrated development and testing of concepts, algorithms and communication solutions that will allow the operation of a distribution network under normal and emergency conditions.

* Corresponding author.
E-mail address: carlos.moreira@inesctec.pt (C.L. Moreira).

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In order to provide a detailed description of the laboratory organizational layers and control capabilities, as well as experimental testing capabilities, this paper is organized as follows: Section 'Description of the laboratorial facilities' provides an overview on the laboratorial facilities and its architecture, which is followed by the discussion of different control perspectives for MG operation that are presented in Section 'MG control functionalities'. Finally, Section 'Experimental testing capabilities' highlights several experimental possibilities that can be developed in the laboratory.

Description of the laboratorial facilities

The Laboratory of Microgrids and Electric Vehicles integrates commercially available components as well as hardware and software prototypes developed according to specific strategies envisioned for the active integration of EV and microgeneration units in future distribution grids. The laboratory architecture was specified and developed according to the MG concept, as described in [5–7,8,10] being simultaneously modular and flexible in order to make it a scalable infrastructure.

Electric infrastructure

The main building block of the laboratory includes microgeneration technologies, energy storage devices, controllable loads, EV and the associated chargers as well as the LV grid cable simulators. As shown in Fig. 1, the laboratory comprises several types of microgeneration units. The RES based microgeneration consists of Photovoltaic (PV) panels organized in several strings and having a total installed power of 15.5 kWp. A micro-Wind Turbine (WT) is emulated through a 3 kW permanent magnet synchronous generator (300 V, 330 rpm), which is coupled to variable speed motor drive. Both PV and the emulated micro-WT can be connected to the electric network either through single-phase (230 V, 50 Hz) state of the art commercial inverters (SMA inverters, as exemplified in Fig. 1(b)) or through single-phase inverter prototypes developed in-house and incorporating advanced control functionalities in order to support SG operation, as it will be described in Section 'MG control functionalities'. A state of the art 20 kW/400 V four quadrant back-to-back inverter is also available in the laboratory (see Fig. 1(a)). This inverter is remotely controlled in terms of injected or absorbed power and can be used to emulate a fully controlled microgeneration unit, a load or an energy storage device.

Regarding energy storage units, two Flooded Lead-Acid (FLA) battery banks (50 V, 20 kW h @ 10 h) were integrated in the laboratorial infrastructure, being connected to two three-phase groups of *SMA Sunny Islands 5048* battery inverters (15 kW, 400 V each) represented in Fig. 2. These inverters are mainly used for the electrification of remote areas, being able to operate autonomously in isolated systems, by managing storage and local generation (renewable based and/or small backup generators). However, these inverters can also operate in parallel with an existing grid, while providing a smooth transition to autonomous (islanded) operation [14].

The development of advanced strategies for controlling EV charging such as in [10] is a major concern of the laboratory. As commercial available chargers do not allow controlling the EV charging power, a single-phase DC/AC bi-directional inverter prototype was developed and connected to a bank of lithium-ion batteries (128 cells, 3 V per cell, 40 Ah), thus emulating the operation of an EV when parked and connected to the LV grid [15].

The laboratory also comprises two three-phase-four wire LV (400/230 V) cable simulators (100 A/0.3 Ω and 50A/0.5 Ω), enabling the implementation of different network testing scenarios while considering the resistive nature of many LV feeders. Different unbalanced scenarios can also be implemented, distributing the laboratory electric devices by each phase of the system.

All available devices in the laboratory can be connected to an electric panel equipped with three 400 V busbars (see Fig. 3), with

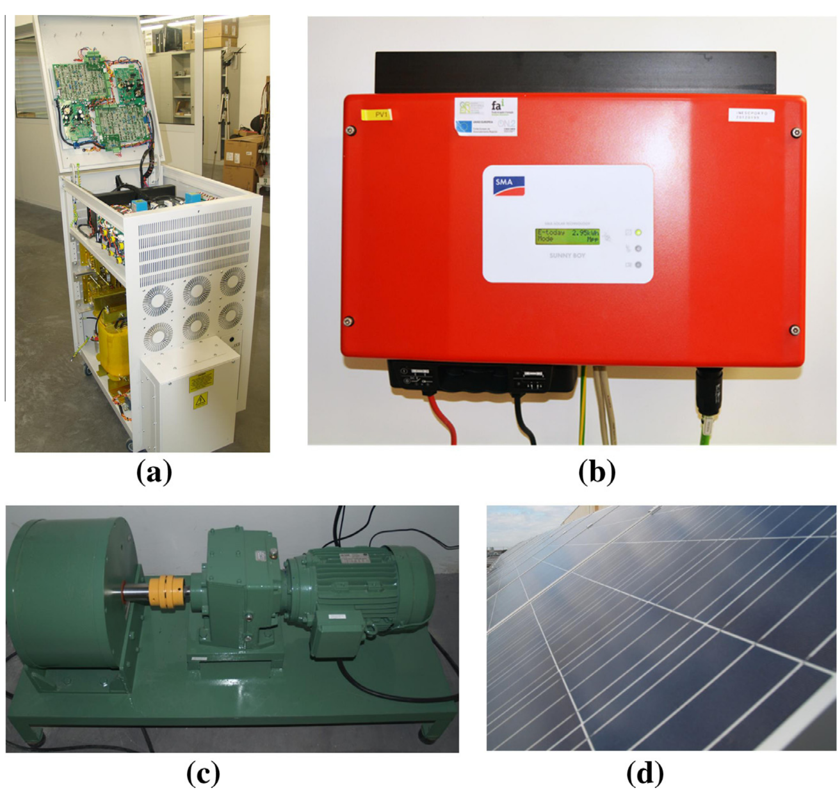

Fig. 1. Microgeneration units available in the laboratory: (a) 20 kW/400 V four quadrant inverter, (b) 1.7 kW SMA solar inverter, (c) micro-WT emulator and (d) PV panels.