

ON THE IMPLEMENTATION OF A MICROGRID PROJECT WITH RENEWABLE DISTRIBUTED GENERATION

Thematic topic 2: Smart grids / Smart Measurement / Microgrids

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ABSTRACT

This paper describes the on-going implementation of a microgrid project with renewable distributed generation under the context of an initiative with demonstration purposes in an university campus. In the actual context of the electrical energy demand increase and limited conventional resources, along with the consciousness of the climate changes and the need to invest in clean energies, microgrids allows the integration of dispersed energy sources, mainly renewable, which make them cost effective, providing a viable alternative to centralized production, transmission and distribution system for remote community areas. The design concept of the microgrid and a description of the base equipment and energy sources already integrated are presented. From the on-going projects to be integrated on the microgrid, it is presented the Grid-to-Vehicle and Vehicle-to-Grid concept, which will provide a second energy storage element using the battery of an electric vehicle. To accomplish this objective, a bi-directional power converter is being developed and simulation results of its power structure and control are presented.

Keywords: Microgrids, Distributed Generation, Self-Sustainable Systems, Vehicle-to-Grid and Grid-to-Vehicle.

1. INTRODUCTION

In a Policies Scenario taking into account both existing policies and declared intentions by countries, world primary energy demand is projected to increase by 1,2% per year, on average, between the current year and 2035. Electricity demand is projected to grow by a higher rate, 2,2% per year, given that it is expected that applications, formerly based on chemical energy, will be based on electrical energy in the following decades (IEA, 2010). At the same time, the need for dependency reduction on imported fossil fuels and decarbonised electricity has arisen and a sustainable energy system is on the agenda of developed countries. On the other hand, in developing countries, there are still 1,4 billion people living without electricity, and many populations are facing recurrent power outages (IHA, 2011).

In context described above, we are witnessing a wide-spread integration of renewable energy sources (RES) in transport and distribution systems and, in the later case, their dissemination in standalone systems, either in small houses or islands and isolated regions. In fact, the electrical power technology is changing

rapidly with the integration of a large number of dispersed generation units based on renewable and non-renewable sources such as wind turbines, photovoltaic systems, small hydro power plants, fuel cells and gas/steam powered combined heat and power stations (Blaabjerg, *et al.*, 2010; Guerrero, *et al.*, 2010). In this perspective, a powerful and flexible energy system is needed, at reasonable prices, aiming to promote the widespread access to electricity. On the other hand, the efficiency of the technology used in production, transmission and/or distribution systems as also in end-users equipment, has to be continuously improved and suitably designed for specific applications. Regardless the energy source, the gross electricity needs to be “processed” and injected into the grid and/or delivered to end users, guaranteeing security and reliability parameters.

There is not a single solution for the problem of energy in the World, but an increasing utilization of available RES and the development of microgrids integrating RES can give a very important contribution to it. A microgrid is a local grid integrating distributed generation (DG) systems, energy storage devices and dispersed loads, which may operate in both grid-connected or islanded modes (Guerrero, *et al.*, 2013a; Guerrero, *et al.*, 2013b). DG is emerging as a new paradigm to produce on-site, highly reliable and with good quality electrical parameters. This concept is particularly interesting when different kinds of energy resources are available and should be integrated, including renewable and nonconventional energy resources (Guerrero, *et al.*, 2010). Thus, microgrids are a key solution for the strategic plans of most countries to address the above mentioned challenges associated with energy management.

This paper describes a laboratory development platform for microgrids in which small distributed generators and energy storage devices are being integrated together into a 5 kW microgrid which has been firstly introduced in (Leite, *et al.*, 2012a). This small microgrid has been developed as a research platform and also for demonstration purposes in the context of an university *campus*, as part of a wider project named *VERCampus – Live Campus of Renewable Energies* – which integrates a set of technologies, infrastructures, and initiatives carried out in the university *Campus* of the Polytechnic Institute of Bragança (IPB) regarding the renewable energies technologies and distributed power generation systems promotion and dissemination for IPB students, stakeholders and all community in general (Leite, *et al.*, 2012a). The paper is organized as follows: section 2 introduces the conceptual design of a microgrid and describes the one that is being implemented into IPB facilities. The following section presents an on-going project for a Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) integration; this concept is illustrated with simulations results aiming at its practical application in a near future. Finally, there are drawn the main conclusions of the paper.

2. DESCRIPTION OF THE MICROGRID

2.1. Conceptual Design

The microgrid illustrated in Figure 1 is based on a bi-directional converter which creates a stand-alone system with standard and stable characteristics as, for instance, 230 V, 50 Hz. It can integrate several distributed energy sources, including photovoltaic, wind, hydro, fuel cells, etc., to generate electrical energy. Microgrids typically use a bank of batteries as the main energy storage device, even though other energy storage elements can be integrated, as the batteries of electric vehicles. This solution is proposed as a viable solution in a near future in the context of V2G and G2V (Ferdowsi, 2007) which will be detailed in section 3.

This system is technically innovative and is particularly well suited for the supply of grid-isolated areas such as remote villages all over the World (Guerrero, *et al.*, 2010). The solution can deliver a new form of unconventional power generation based on a stand-alone, flexible and modular system, which can therefore be easily expanded.

A bi-directional battery inverter is able to convert battery power into alternating current and vice-versa. This inverter is responsible for establishing a single-phase microgrid with stable voltage and frequency, thus enabling the use of conventional loads, providing energy to end users without noticing any difference between the off-grid mode and the public grid.

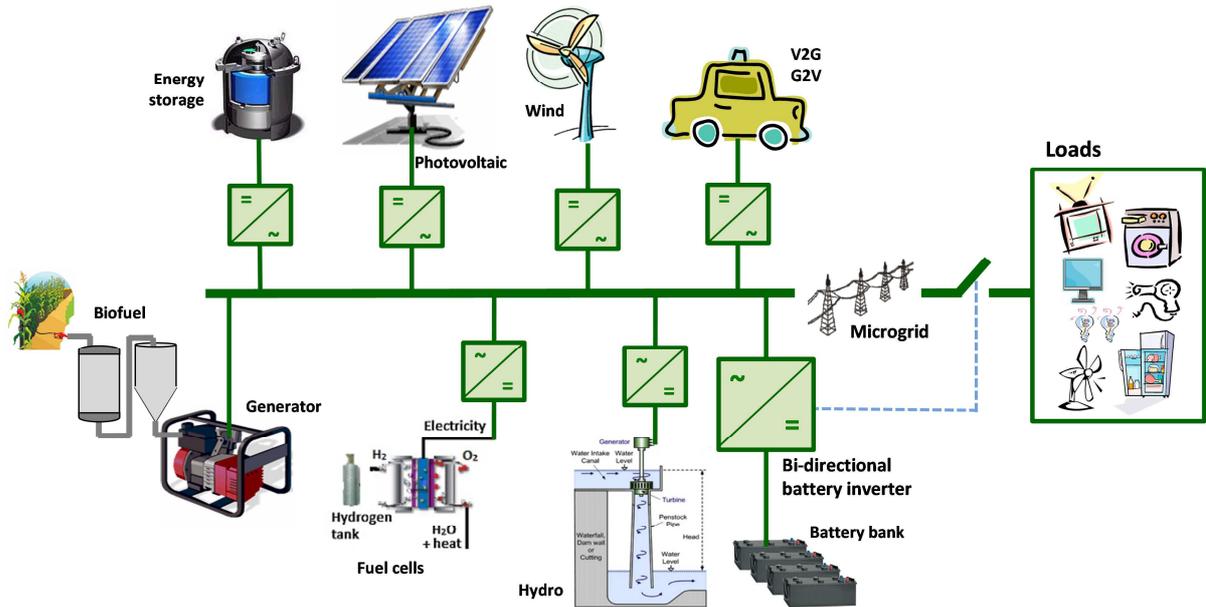


Figure 1.- Illustration of a microgrid integrating several distributed generation systems.

The operation of the system, in general terms, can be described as follows. When energy from distributed sources is higher than the consumption, the bi-directional inverter allows the charge of the battery bank and when the availability of the primary resources are not enough for load following, it provides the necessary energy from the batteries. When the energy requested by users is excessive, load shedding can be performed and when consumption is low and the batteries are fully charged, surplus production can be dissipated on heating or ventilation. In cases when the consumption is excessive and load shedding cannot be accomplished, the inverter can automatically start a generator based on fossil fuel. Indeed, the off-grid system should use, with priority, renewable energy sources such as photovoltaic, wind, hydro or other renewable energy resources. In alternative to conventional fuel, biodiesel, which may be produced locally, conveys to an augmented sustainable solution.

This modular system can be easily expanded for grid reinforcement by using inverters in parallel or by creating a three-phase grid, with an inverter per phase and other microgeneration units can be connected directly to the microgrid. This possibility of expanding the grid can be used due to the characteristics of flexibility and modularity of the technology. Thus, it is possible at any time, move from one house to the electrification of a small isolated village.

2.2. The IPB microgrid project

The IPB microgrid, presented in Figure 2, has being implemented in a laboratory of the School of Technology and Management of IPB. It is being developed for isolated and self-sustainable systems up to a rated power of 5 kW, integrating renewable energy sources with the purpose of being a demonstration platform in terms of technology transfer and applied research.

The microgrid uses the bi-directional battery inverter Sunny Island (SI 5048), from SMA, which is the core equipment responsible for the management of the energy flow. Even a small microgrid like this one, for a nominal power of 5 kW, can integrate several distributed power systems and energy storage elements. The following provides a brief overview of the renewable energy systems already integrated in this microgrid (Leite, *et al.*, 2012a):

- A small 1,4 kWp wind turbine, the Passaat WT model from Fortis, with a protection box and the inverter WB 1700 from SMA;

- A solar tracker with a photovoltaic (PV) string of 16 PV modules 190GHT-2 from Kyocera, with a peak power of 3 kWp. This PV string is connected to the microgrid through the PV inverter SB 1700 from SMA;
- A PV string installed on the roof of the laboratory which consists of nine PV modules FTS-220P from Fluitechnik, with a peak power of 2 kWp. The PV string is connected to the microgrid through the PV inverter SB 2100TL from SMA;
- A 5 kW electric generator which uses a percentage of biodiesel produced from wasted oils in the biofuels laboratory. The generator is connected to and controlled by the SI 5048.

Currently, there are being developed additional DG systems to be integrated into the microgrid in the foreseeable future, namely:

- A pico run-of-river hydropower plant (Leite, *et al.*, 2012b) with a 1 kW permanent magnet synchronous generator;
- A photovoltaic glass facade integrated in the Library of the School of Technology and Management of IPB, where 29 of the existing glass were replaced by PV glass. Each one of the PV glass is composed by a set of 24 PV cells connected which account for a peak power of 46,3 Wp and, therefore, the total power of the glass facade is 1 343 Wp (see Figure 2);
- An electric vehicle using state-of-the-art electric propulsion system based on a high performance controller, an axial permanent magnet synchronous motor and a lithium battery (Leite, *et al.*, 2013). This electric vehicle will be integrated with the microgrid as an energy storage element, through a bi-directional power electronic converter, under the context of V2G and G2V as described in the next section.

Several actions addressing energy efficiency in the IPB *Campus* are also being implemented and in this context, the enlightenment of the Library of the School of Technology and Management is using LED technology that will be fed by this microgrid.

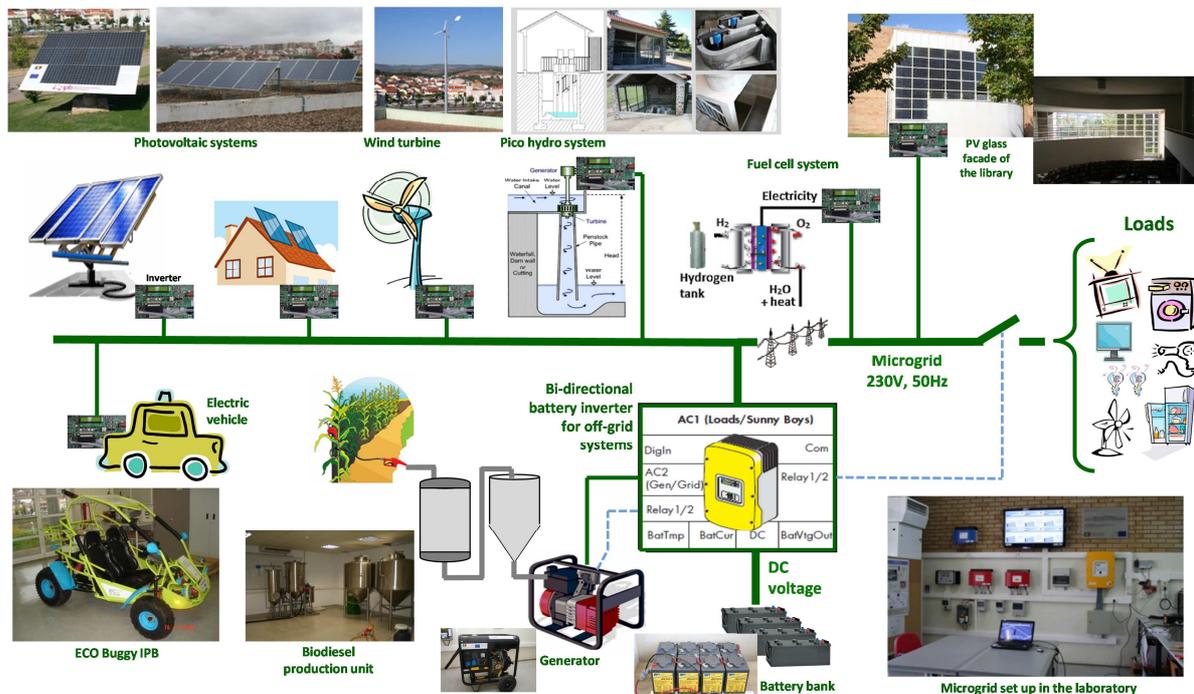


Figure 2.- Illustration of the implemented microgrid.

3. ON-GOING PROJECT FOR V2G AND G2V INTEGRATION

Another initiative developed in the context of VERCampus (Leite, *et al.*, 2012a) is the construction of a light electric vehicle named IPB ECO Buggy (Leite, *et al.*, 2013). This electric vehicle uses state-of-the-art technology with respect to the electric propulsion system and also the battery which will be integrated with the microgrid as an additional energy storage element. A lithium iron phosphate battery was chosen for the IPB ECO Buggy due to its advantages. Indeed, nowadays, lithium iron phosphate (LiFePO₄) is been investigated intensively (Hua, Syue, 2010; Zaghbi, *et al.*, 2004) as a potential cathode material for rechargeable lithium ion batteries because of its low cost of raw materials, long life cycle and superior safety characteristics (Hua, Syue, 2010; Tingting, *et al.*, 2011). Table I shows the main specifications of the battery.

Table 1.- Technical specifications of the LiFePO₄ battery.

Voltage	96 V
Capacity	70 Ah (6.5 kWh)
Weight	90 kg
Charging voltage	109,5 V
Discharging limit	75 V
Maximum current charging/discharging	140 A

The objective is to integrate the IPB ECO Buggy with the microgrid and charge the battery when there is enough energy available and use this energy when needed. By this way the battery becomes another energy storage element. In the future, electric vehicles, plug-in electric vehicles and fuel-cells vehicles will have an enormous distributed energy storage capability with the potential of integration with the electrical grid and the increasing penetration of renewable energy sources (Emadi, *et al.*, 2008; Ferdowsi, 2007; Saber, Venayagamoorthy, 2009; Shafiei, Williamson, 2010; Zhang, Cooke, 2010). In fact, the potential advantages of integrating the electric vehicles with the grid are very attractive. This is especially true in case of the integration with microgrids with high penetration of renewable energy sources due to their intermittency and to the storage capacity introduced by electric vehicles (Saber, Venayagamoorthy, 2009, 2011).

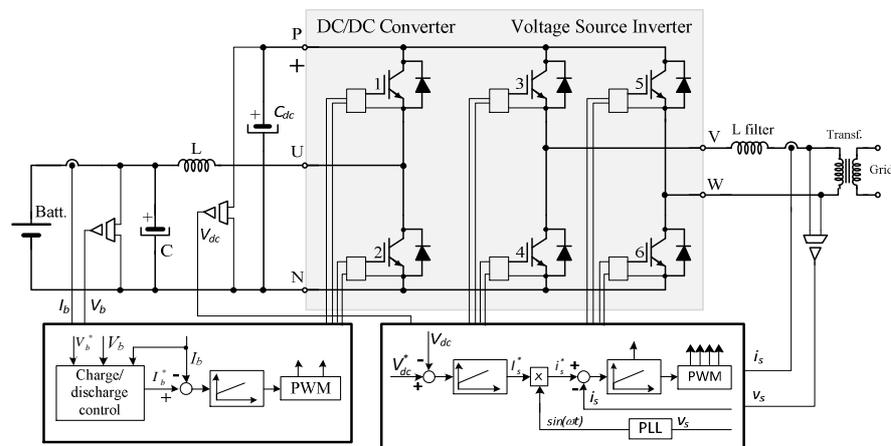


Figure 3.- Bi-directional converter topology.

For the goal above mentioned, a bi-directional power converter is being developed under the context of Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) (Ferdowsi, 2007). The converter topology is based on a

DC/DC converter followed by a full bridge DC/AC converter. The first works as a buck converter for charging the battery (G2V mode) and as a boost converter for injecting current into the grid (V2G mode). The second is a current controlled single-phase voltage source inverter. The converter topology and the basic control schemes are shown in Figure 3. The shadowed area represents an integrated power module from Powerex that will be used in the laboratory. In this case the first leg is used to implement the DC/DC converter and the second and third legs are used as a single-phase voltage source inverter.

3.1. Control of the DC/DC converter

For the control of the DC/DC converter in V2G mode the IGBT 1 is always turned OFF and the IGBT 2 is turned ON and OFF at the switching frequency. The IGBT 2, the inductor L and the diode 1 (of IGBT 1) operate as a boost converter. The reference current, I_b^* , is set according to the power to be injected into the grid and the maximum admissible depth of discharge. On the other hand, to control the DC/DC converter in G2V mode (charging mode), the IGBT 2 is always turned OFF and the IGBT 1 is turned ON and OFF at the switching frequency. The IGBT 1, the inductor L, the capacitor C and the diode 2 (of IGBT 2) operate as a buck converter. In this case, the reference current, I_b^* , and battery voltage, V_b^* , are set according to a three-stage charge curve defined by the battery manufacturer.

The reference current, I_b^* , is positive in V2G mode and negative in G2V mode (charging). A PI current controller compares this reference with the measured current, I_b , and generates the control signal for pulse generation (PWM).

3.2. Control of the Voltage Source Inverter

In the power range of 1-5 kW the most common control structure for the grid converter is a current-controlled voltage source inverter (H-bridge PWM) with a low-pass output filter, typically a L filter but recently LCL filters are being used (Ciobotaru, *et al.*, 2006a). A PLL is used to synchronize the output current of the voltage source inverter with the grid voltage. It provides a unit power factor operation by giving a clean sinusoidal current reference with magnitude 1 which, in turn, is multiplied by the magnitude of the current to be injected into the grid to produce the output current reference, i_s^* . The implemented PLL is a Second Order Generalized Integrator as in (Ciobotaru, *et al.*, 2006b). The magnitude, I_s^* , of the output current reference, i_s^* , is given by a PI controller which controls the voltage at the DC link, V_{dc} , in order to keep it constant and equal to the reference value V_{dc}^* .

3.3. Simulation Results

The above mentioned power structure and control have been simulated in MATLAB/Simulink (Figure 4) and some results are presented in figures 5 to 7. Figure 5 shows the voltage and current of the battery during 4 s. Firstly the battery is charging and after 2 s it starts discharging. The initial voltage and State of Charge (SOC) of the battery are 96 V and 90%, respectively. According to the adopted direction for the current measurement, it is negative when the battery is charging (in G2V mode) and positive in V2G mode. The current reference value is defined by the charging algorithm in G2V mode, and it is set to 8 A in V2G mode.

Figure 6 shows the voltage across the DC link capacitor C_{dc} . The initial voltage of the capacitor is 420 V and after this initial transient the voltage PI controller brings the DC voltage to the reference value. When the power converter changes from G2V to V2G operation, then the DC/DC converter changes from “buck” to “boost” mode of operation. Consequently, the current changes from about -17 A to 8 A and therefore the DC voltage tends to increase dramatically but the voltage PI controller rapidly brings the DC voltage to the reference value once again. This is achieved because the inverter starts injecting current into the grid as can be seen in Figure 7. In fact, looking carefully at this figure, before reaching 2 s, the current is in phase opposition

with respect to the voltage and after 2 s it is in phase. This means that the power flow is, respectively, from the grid to the battery (negative power) and from the battery to the grid (positive power).

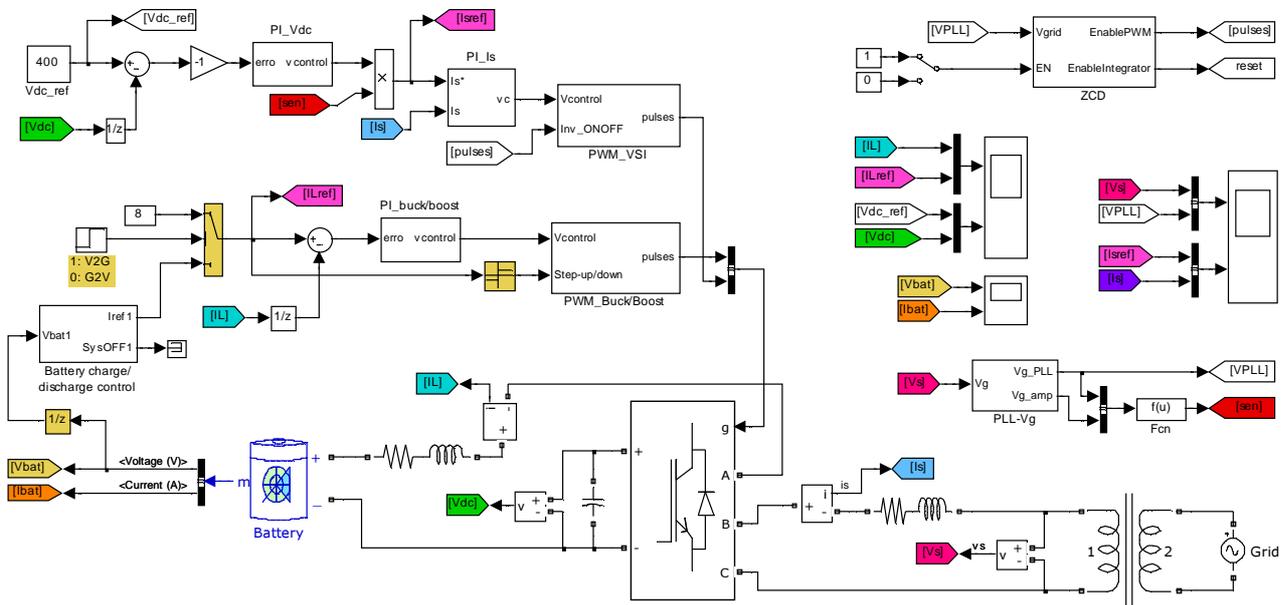


Figure 4.- Bi-directional power converter structure and control simulation in MATLAB/Simulink.

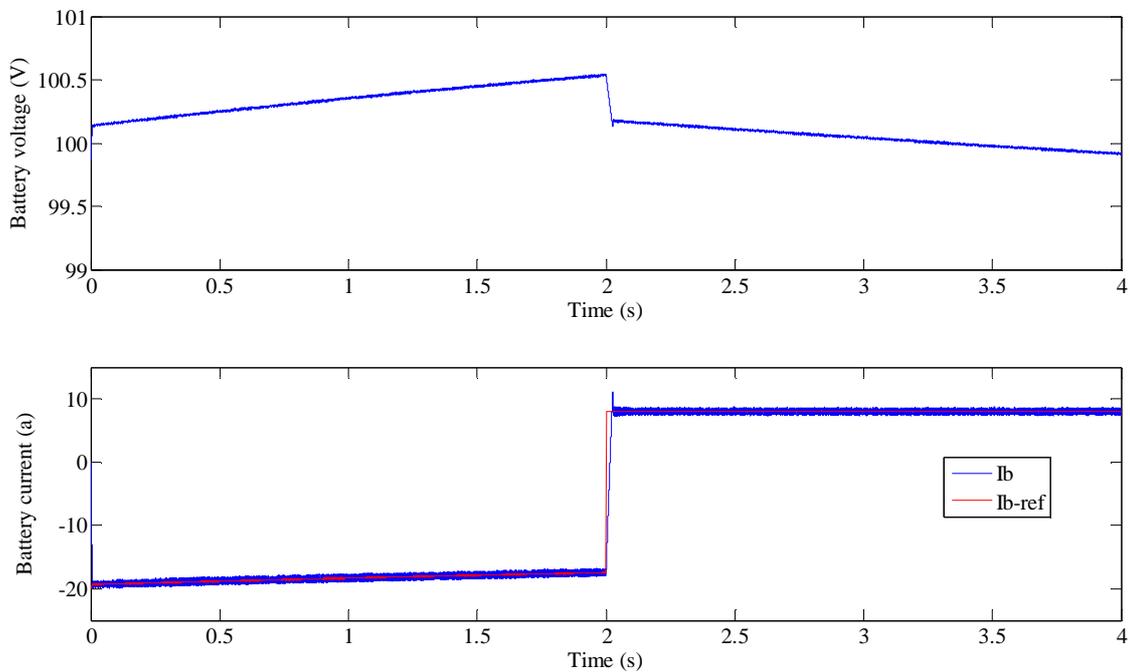


Figure 5.- Voltage (above) and current (below) of the battery.

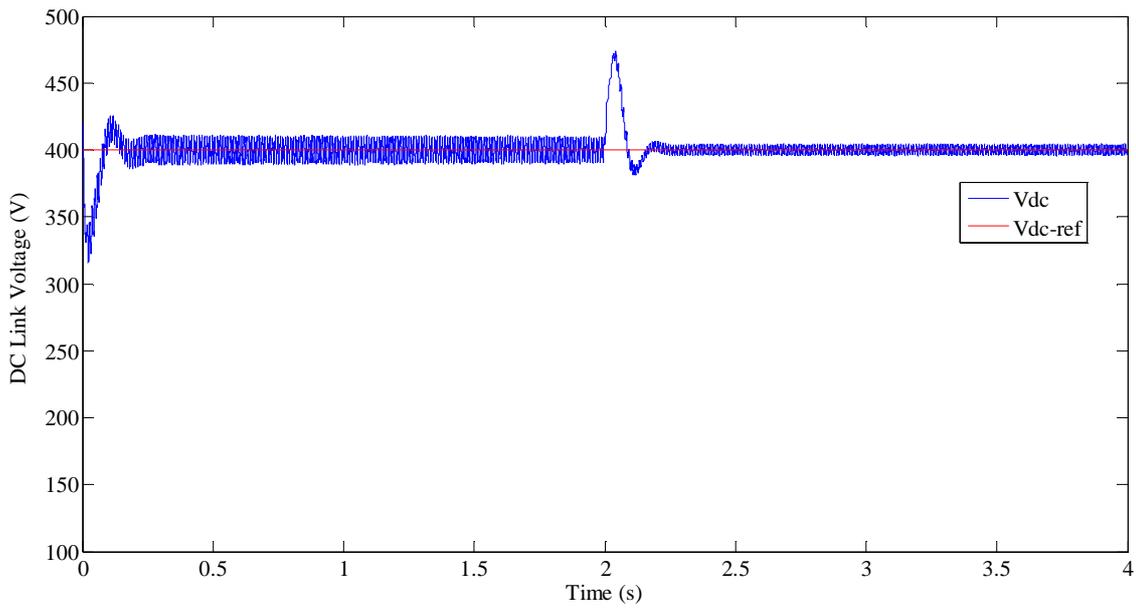


Figure 6.- Voltage across the DC link capacitor.

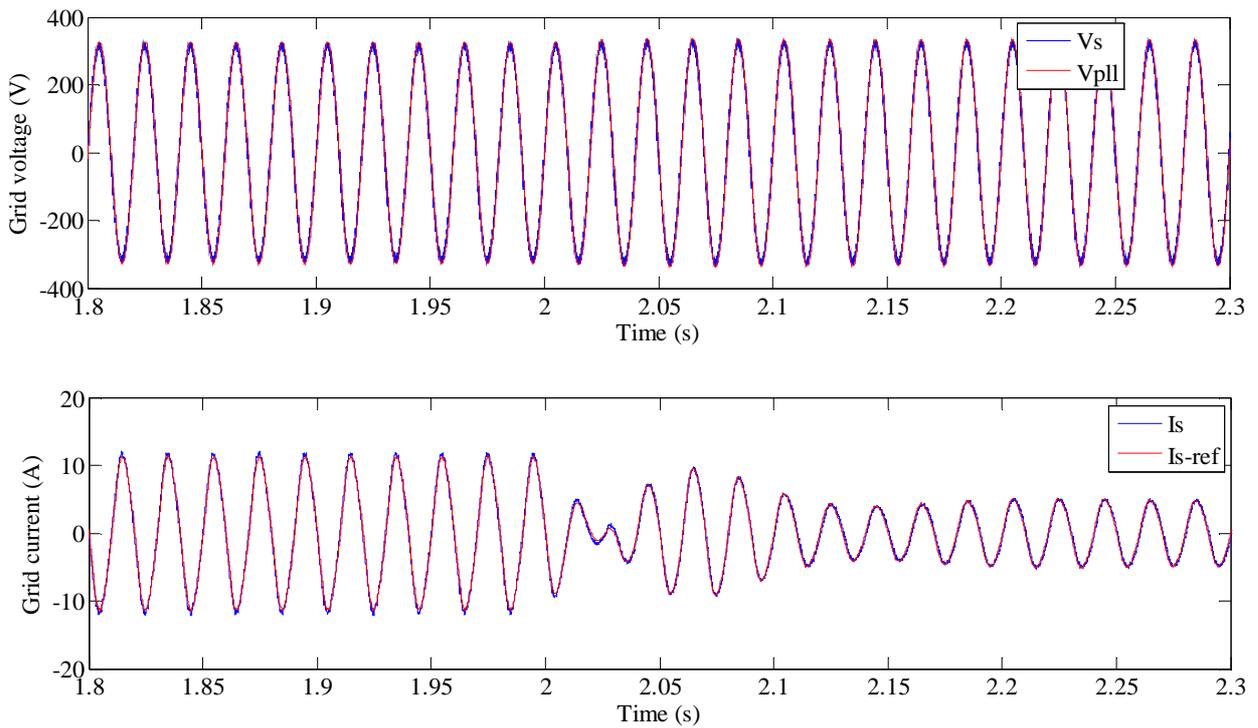


Figure 7.- Grid voltage and PLL output voltage (above) and grid current (below).

4. CONCLUSIONS

In the actual global energy context, the integrated use of key existing technologies allows the reduction dependency on fossil fuels, decarbonise electricity, enhance energy efficiency and reduce greenhouse-gas emissions. Renewable distributed generation systems integrated into microgrids play an important role on the

necessary mix to enhance energy solutions, dampening surging energy demand and promoting the widespread access to electricity. The microgrid concept design and main features were introduced, followed by the description of the micro grid that has been implemented in the IPB facilities. This project has been developed as a research platform and also for demonstration purposes in the context of an university *campus*. This microgrid is characterized by its modularity and flexibility on integrating various renewable energy sources. From the ongoing projects under the initiative *VERCampus* and the microgrid implementation, the project of the V2G and G2V integration is presented, and will provide another energy storage element to be integrated into the microgrid in a near future.

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