Microgrid Laboratory for Educational and Research Purposes

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***Abstract*— The microgrid concept is widely adopted due to its facilities to mixt the renewable and conventional energy sources with loads and storage elements in an intelligent energy management system. Though, before it can be fully implemented to the real system, the microgrid solutions must be studied and tested in various conditions. This paper presents a DC configurable microgrid laboratory which offers the possibility of implementing the behavior and the control of microgrids, working on-grid or disconnected to the grid. The laboratory consists of three types of "hardware-in-the-loop" emulators which can simulate PV panels, wind and hydro energy generating systems. The conversion and storage elements are implemented with DC-DC and AC-DC converters, rechargeable batteries and supercapacitors. The control is ensured by digital programmable equipment, both for the components and the entire microgrid.**

Keywords—smartgrid; DC microgrid; distributed generation; renewable energy sources; hardware-in-the loop emulators;

I. INTRODUCTION

The microgrid (smart grid) represents a group of interconnected distributed energy resources (including renewables), loads and storage elements, with clearly defined boundaries, that acts as a single controllable entity and can operate grid-connected or/and in island mode [1]-[4].

Compared with the conventional power systems, the main advantages of this concept are related to environmental issues, cost savings, power quality, operation and investment issues [2].

In the last decade, many researchers have been focused on different related aspects to microgrid concept and their design, implementation, operation, integration and interconnection [1]-[5].

A review of microgrid technologies, distributed generation and storage, interconnection and control strategies is given in [5]. In [6] are presented some relevant standards that are intended to regulate the implementation of microgrids. In [7] is given a comprehensive review regarding the integration of renewable energy sources to smart grids, the control systems, and the communication and metering aspects. A microgrid management system, based on intelligent software and "demand side management" functions, using agent technologies, is presented in [8].

One of major importance issue is the student education and the research in the field of implementation of microgrids and renewable energy sources, and their integration in existing power systems. In this respect, some relevant papers are focused on the microgrid laboratory facilities [9]-[14].

In [9] there are presented three microgrid laboratories, installed in different locations, as a result of the European project "Microgrids", with their facilities and some test results.

As is mentioned in [10], it is essential to first test the proposed concept at laboratory level before it can be fully implemented to the real system. It is also very important to have a good handle of microgrid concepts, projects, and control, even as a student.

A very useful presentation about teaching the smart grid fundamentals, using modeling, simulation and hands-on laboratory experiments, is given in [11].

In [12] is presented a smart grid testbed for laboratory research with main components: an intelligent power switch, grid and renewable energy sources as power supply, as well as energy demands and power meter.

A review of recent development smart grid and microgrid laboratories is done in [13].

In [14] is presented an integrated microgrid laboratory, with a configurable structure, designed for experimental and theoretical studies on distributed generations. There are described the physical system configuration, the control system structure and strategy, and the results of an experimental study.

This paper presents the microgrid laboratory designed and implemented at Politehnica University of Timisoara, Romania. In section II the microgrid components are presented, which consists of PV, wind, micro-hydro, conversion and a storage systems. In section III two possible operating modes of microgrid laboratory are described.

II. MICROGRID COMPONENTS DESCRIPTIONS

The topology of microgrid laboratory is shown in Fig. 1 and consists of four modules where are implemented the main components: PV, wind, hydro and storage elements.

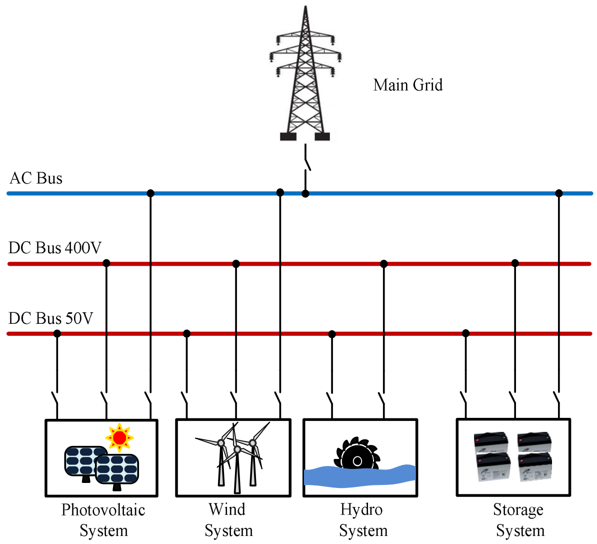

Fig. 1. Microgrid Topology

The microgrid can operate in two modes: on-grid or off-grid. Regardless of the operation mode, by opening and closing switches, the microgrid can have one, two or all renewable energy sources, thus providing different levels of power. The energy is distributed in two DC busses: one with 50V, the second with 400V nominal voltages. The AC connection is used only when the system works on-grid.

In order to implement the renewable energy systems, hardware-in-the loop emulators are used for the wind and hydro components. For PV can be used real panels or a programmable DC power source.

A. *PV Conversion System*

The PV system is designed to study the behavior of panels arrays connected to microgrid for different conditions and operating modes. The PV system, shown in Fig. 2, is composed of several modules that can be interconnected in various ways in order to simulate different operating modes.

The source consists of 12 x PV panels (Fig. 3) and a programmable CHROMA DC power supply, which can simulate (emulate) various I-V characteristics [15]. In off-grid operation mode S2 is open and the connection between the PV array and the battery bank is made by a solar charge controller (Schneider Electric, Xantrex XW MPPT 80 600) [16]. This controller can charge the battery bank from panels, the DC power supply, or from the 400V DC bus, depending on the S4 switch position. Also, when S1 is closed and S4 is on the first position, the charge controller harvests the energy available from the PV array, regardless of environmental conditions by using the maximum power point tracking (MPPT) method. During on-grid operating mode, the solar source is connected through S3 to an inverter (SMA, Sunny Boy 3000TL) and it is able to send power to the grid, without involving the storage elements [17].

Table I shows the main data of the PV system components.

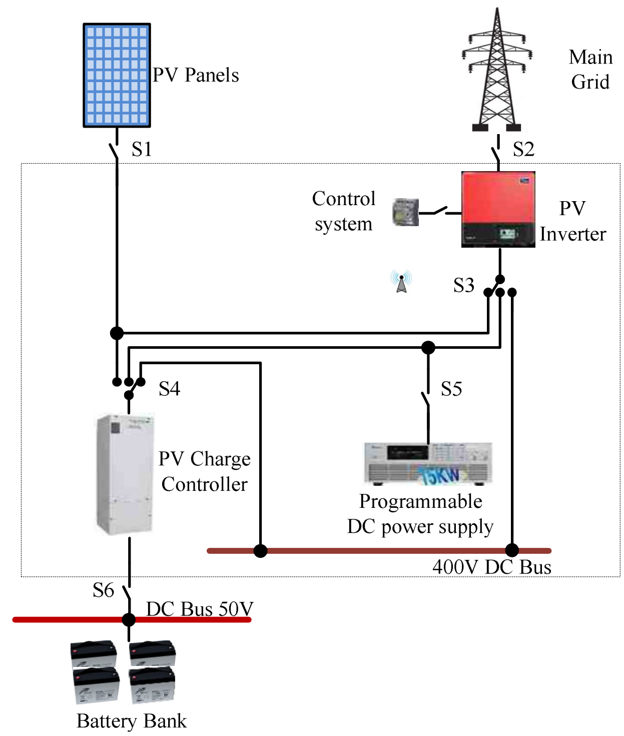

Fig. 2. PV system

TABLE I. THE MAIN DATA OF PV SYSTEM COMPONENTS

Component Name	Main Component Parameters
PV Panels	Renesola JC250M Maximum power voltage=30.1(V), Maximum power current=8.31(A)
Inverter	SMA SunnyBoy 3000TL Input DC Voltage=175…500(V), input current=15(A), output AC voltage=230(V), output current =16(A), output power=3000(W)
Charge controller	Schneider Xantrex XW MPPT 80/600 Input DC voltage=600(V), Output DC voltage=48(V), Output current =80(A), Power = 4.8(kW)
Programmable DC Power Supply	Chroma 62100H 600S Output DC voltage=0-600(V), Output current =0-17(A), Power=10(kW)
Battery Bank	8 x 6 V/480Ah

Fig. 3. The PV panels

B. Wind System

The wind system (Fig. 4) uses a wind turbine simulator (HIL emulator), made by an AC DTC drive (ABB ACS 800 with an induction motor) driven by a controller (dSPACE interface, or Compact RIO from NI) where is implemented the turbine model. The emulator drives a PM synchronous generator (Fig. 5) [18]-[21].

The system can work on-grid, without storage, when S2 is connected to the wind interface (a three phase rectifier with overvoltage protection). If the storage elements are connected, the generator gives power in a supercapacitor (Maxwell) through a hybrid DC-DC converter, in order to ensure enough power capability [22]. The stored energy in the supercapacitor can also charge the same battery bank (described in Fig. 2), with a charge controller.

The hybrid inverter (Xantrex) has the possibility to work in both, on-grid/off grid modes, through switch S3, and it is responsible to feed the AC loads [23]. In on-grid mode, the inverter can charge the battery bank, pass AC through to the loads or send power to the grid. In off-grid mode, the inverter produces power to the loads from the battery bank. The main data of wind turbine system components are shown in Table II.

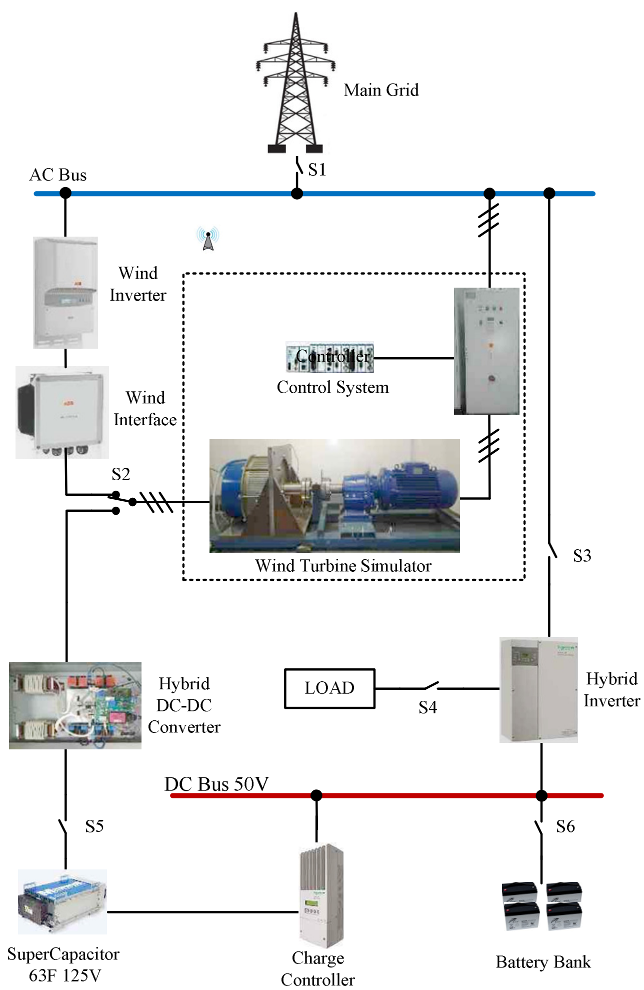

Fig. 4. Wind System

Fig. 5. The Wind Turbine Simulator

TABLE II. THE MAIN DATA OF WIND TURBINE SYSTEM COMPONENTS

Component Name	Main Component Parameters
Wind Turbine Simulator	Induction Motor: Power=7.5 kW/750rpm, with 1/6 gearbox PMSG, Power= 5kW/120rpm
Wind Inverter	ABB Wind Inverter 4.2 Input DC Voltage=140-530(V), input current=32 (A), output AC voltage=230(V), output current=20(A), output power=4.2 (kW)
Wind Interface	ABB Wind Interface Input AC voltage=400(V), input current=16.6 (A), output DC voltage=600(V), output current=6 (A), output power=4 (kW)
Hybrid Inverter	Schneider Xantrex Hybrid Inverter Input DC voltage=48(V), input current=96(A) output AC voltage=240(V), output current=40 (A), output power=4.5 (kW)
Charge Controller	Xantrex XW MPPT 60/150 Charge Controller Input voltage=400 (V), input current=16.6(A), output voltage=600 (V), output current=6(A), output power=4 (kW)
SuperCapacitance	3x36 (F), Rated voltage=125(V)
Hybrid DC-DC converter	Input Voltage=400 (V_{dc}), input current=16 (A), output voltage=50 (V_{dc}), output current= 100 (A), output power (5kW)

C. Hydro System

The (micro) hydropower system structure is presented on Fig. 6. It consists of three modules (HTS1, HTS2, HTS3), with three types (induction, synchronous with DC excitation and multiphase reluctance synchronous) electric generators, driven by same AC DTC drives as described in the wind system. These drives can also emulate turbines.

The system has three AC-DC power converters made by commercial (Danfoss) inverters, with a modified control board and the DC link connected to the 400V DC bus [24].

A bidirectional DC-DC converter connects the 400V DC bus with the 50V DC Bus, creating the opportunity to transfer power in both directions [25]. The photos of the hydro turbine HIL emulators and the power converter systems are shown in Fig. 7 and Fig.8 respectively.

The main data of wind turbine system components are presented in Table III.

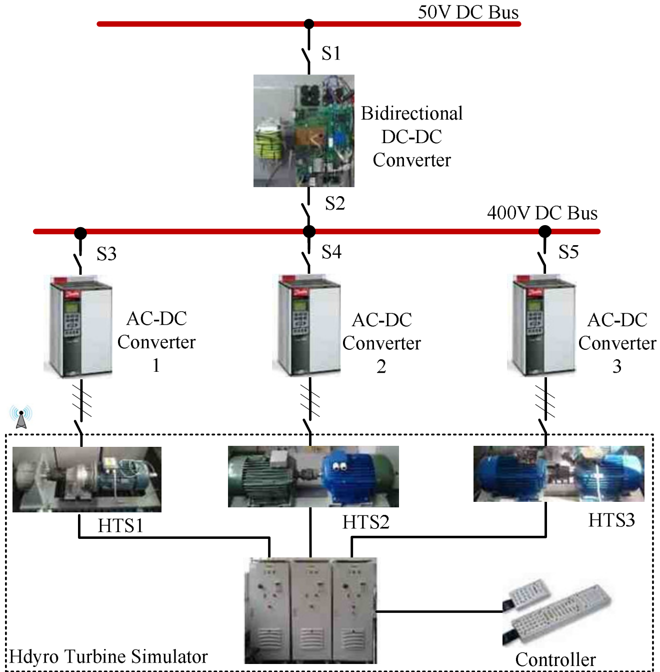

Fig. 6. Hydro System

TABLE I. THE MAIN DATA OF HYDRO SYSTEM COMPONENTS

Component Name	**Main Component Parameters**
Bidirectional DC-DC Converter	Low voltage DC=50(V), high voltage DC=400(V), rated power = 5(kW)
AC-DC Converter	Danfoss FC-302 Input AC voltage=3x380(V), input current=7.4 (A), rated power=4 (kW) output DC voltage=400 (V), output current=8.2 (A)
Hydro Turbine Generator 1	Reluctance synchronous generator Rated power = (kVA), rated voltage = 3x220(V), poles number = 11, rated speed=200 (rpm)
Hydro Turbine Generator 2	Synchronous generator with DC excitation Rated power = 2 (kVA), rated voltage = 3x220(V), rated speed =250 (rpm)
Hydro Turbine Generator 3	Dual stator windings induction generator Rated power = 2.5 (kVA), rated voltage = 3x220 (V), rated speed =250 (rpm)

Fig. 7. Photo of the Hydro Turbine Simulators

Fig. 8. The power converters systems

III. OPERATING MODES

The presented microgrid structure can operate in on-grid or off-grid modes. By opening and closing switches, the microgrid can have as inputs one or multiple renewable energy sources. If the microgrid is connected to the grid the power can be transferred in both directions. The structure of this operating mode is presented in Fig. 9.

The wind system is connected directly to the grid through the wind interface and the wind inverter.

Depending on S6 position, the PV inverter provides energy to the grid from the PV panels, or from the programmable DC power supply. Also this inverter can link the 400V DC Bus with the grid.

A bidirectional DC-DC converter links the 400V and the 50V DC Busses, in order to charge or discharge the storage system. The energy from the 400V DC Bus is provided by hydro system through the AC-DC converters.

The hybrid inverter is used to send/receive power to/from the grid and to feed the AC loads. Also the inverter can charge the batteries.

In off-grid mode, presented in Fig. 10, the energy produced by renewable energy sources is stored or used by local loads.

The energy from wind system is rectified and a hybrid DC-DC converter gives the energy to the supercapacitor. The stored energy in the supercapacitor is used then to charges the batteries.

After being injected to 400V DC Bus, through an AC-DC converter, the energy form hydro system is transferred to the batteries through a bidirectional DC-DC converter. Also this converter can transfer energy from batteries to 400V DC Bus, according to microgrid needs.

The PV charge controller charges the batteries from 400V DC Bus, PV panels or programmable DC power supply, depending on position of the switch S3.

In this operating mode, the energy from renewable sources and storage system is transformed to AC by a hybrid inverter which provides energy to the loads.

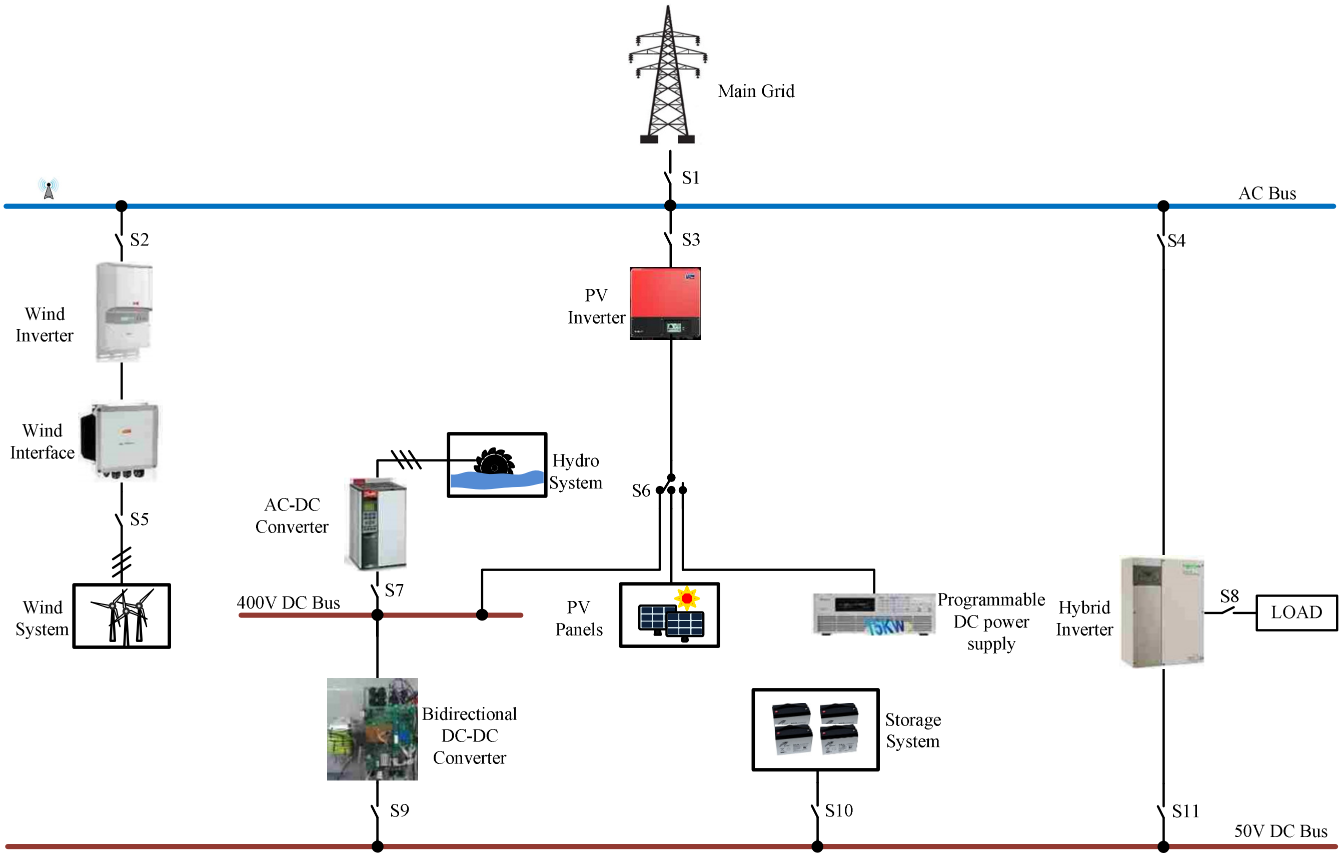

Fig. 9. On Grid Operation Mode

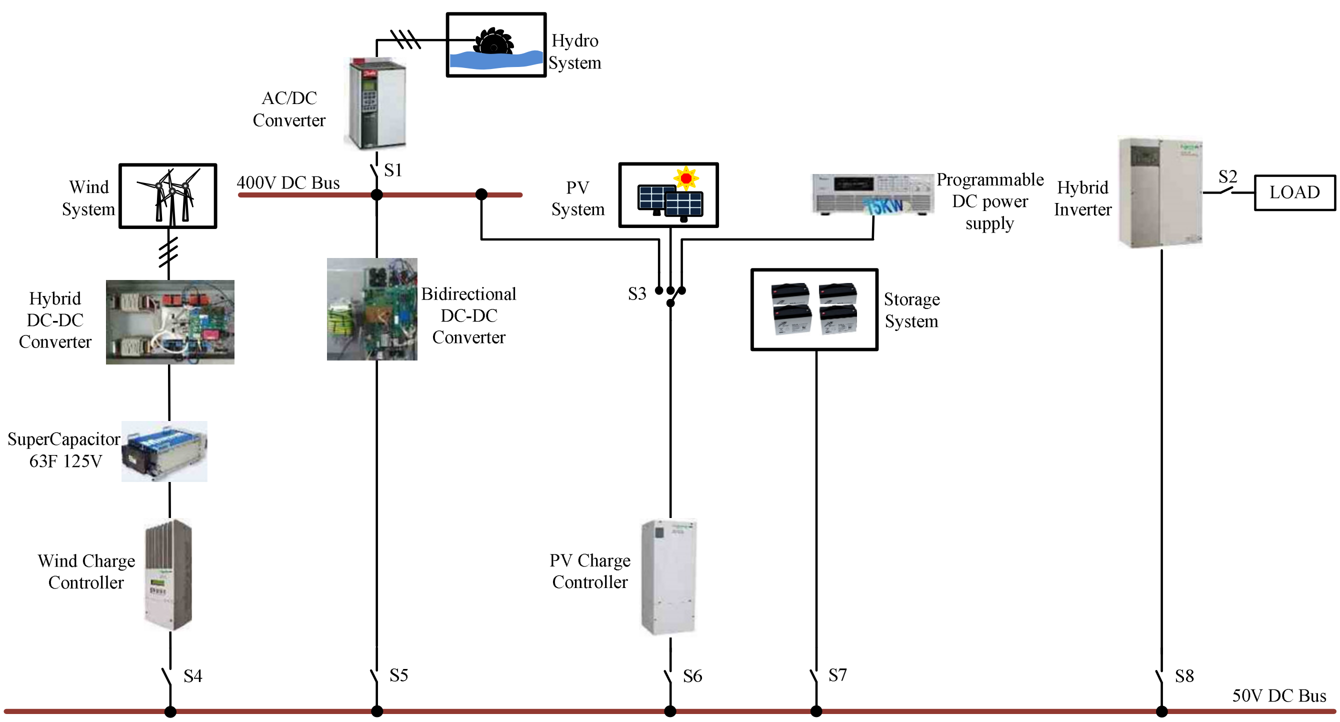

Fig. 10. Off Grid Operation Mode

IV. Conclusion

The smart grid is more complex than traditional power systems and needs more study and experiments before be implemented.

Since microgrid projects are often built in different areas with different renewable energy sources, the structure of the microgrid laboratory is flexible and allows various possibilities to connect the modules, according to the required studies and tests.

Even though the microgrid laboratory uses emulators instead of real renewable energy sources, most of components are real and the system can serve as a verification platform for such projects. Also, using simulators, it allows testing the behavior of microgrid with sources in different environment conditions.

This microgrid laboratory is ideal for study of renewable energy sources behavior, control methods and different operating modes. Also, the laboratory allows testing various types of power converters used in microgrid to connect energy sources with loads.

The microgrid laboratory will be further improved and detailed information about experimentally results will be presented in the future.

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