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 in a 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 such systems, working grid-connected, or disconnected from 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-AC converters, rechargeable batteries and supercapacitors. The monitoring and control is ensured by digital programmable equipment, both for the components and the entire microgrid.**

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

I. INTRODUCTION

The microgrid 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]-[5].

Compared with the conventional power systems, the main advantages of this concept are related to environmental issues, cost savings, power quality, power management and reliability. Presence of multiple sources in microgrid systems reduces the chance of all-out failure [6].

For proper integration and operation of microgrid, control and energy management strategies are necessary [7]-[9]. A comprehensive review regarding the integration of renewable energy sources to microgrids, the control systems, the communication and data monitoring aspects is given in [10].

A review of microgrid technologies, distributed generation and storage, interconnection and control strategies is given in [11]. In [12] some relevant standards that are intended to regulate the implementation of microgrids are presented.

As is mentioned in [13], it is essential to test the proposed concepts at laboratory level before it can be fully implemented to the real system and some relevant papers are focused on the microgrid laboratory facilities [14]-[17].

This paper presents a microgrid laboratory setup designed and implemented for testing different configuration and control strategies in various conditions. Sections II and III present the components, structure and operating modes of microgrid. The monitoring and control system together with some experimentally results are presented in section IV.

II. MICROGRID COMPONENTS DESCRIPTIONS

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

The entire system is fully configurable, in terms of hardware and software implementation, and affords different microgrid structures which may include one, two or all sources. This is possible because each system component has own automation structure, MPPT strategies and SOC of the storage elements.

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 PV panels (Fig. 3) and a programmable DC power supply, which can simulate (emulate) various I-V characteristics.

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). This controller can charge the battery bank from PV array, 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, by using the maximum power point tracking (MPPT) method.

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During on-grid operating mode, the solar sources are 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.

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

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 the turbine model is implemented. The emulator drives a PM synchronous generator (Fig. 5) [18]-[19].

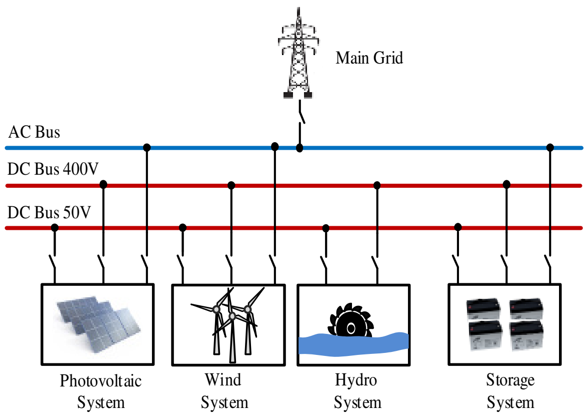

Fig. 1. Microgrid Topology

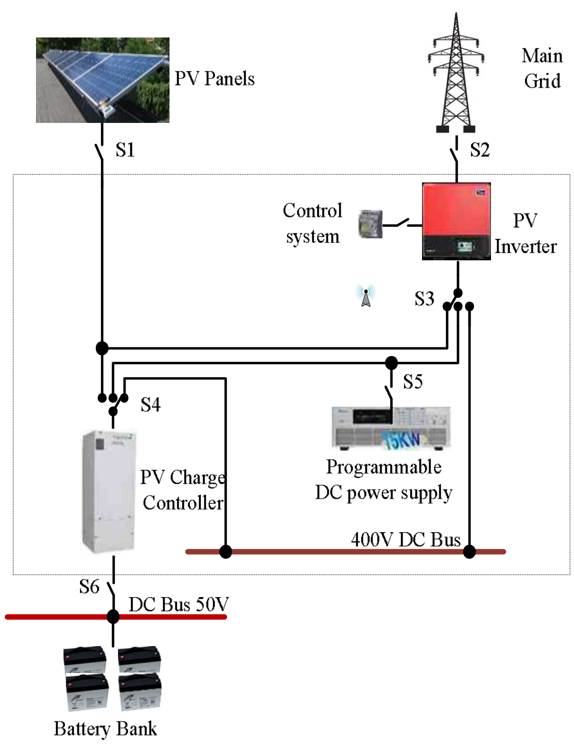

Fig. 2. PV system

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=230-550 (V), Output DC voltage=48(V), Output current =80(A), Power = 3.8 (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

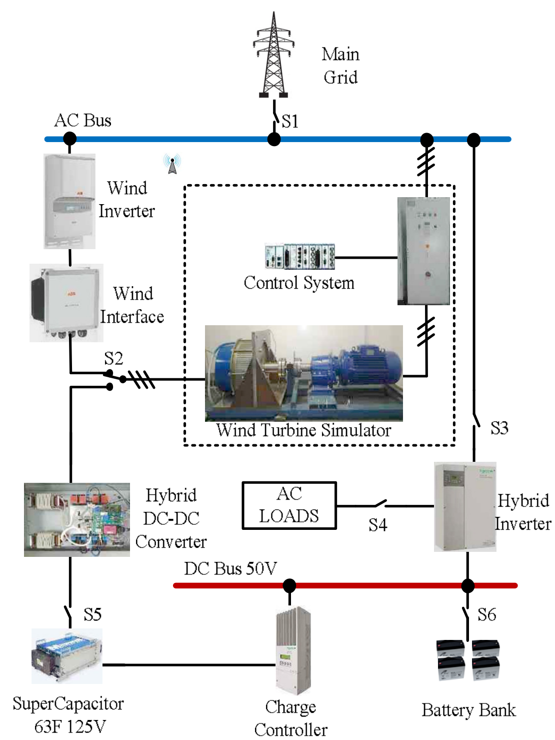

Fig. 4. Wind System

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. 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. In on-grid mode, the inverter can charge the battery bank, provide energy to AC loads or send power to the grid. In off-grid mode, the inverter produces power to the AC loads from the battery bank. The main data of wind turbine system components are shown in Table II.

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= 5 kW/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=18 (A), output power=4.5 (kW)
Charge Controller	Xantrex XW MPPT 60/150 Charge Controller Input voltage=140 (V), input current=48 (A), output voltage=48 (V), output current=60 (A), output power=3.5(kW)
Supercapacitor	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=5 (kW)

Fig. 5. The Wind Turbine Simulator

C. Hydro System

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

A bidirectional DC-DC converter connects the 400V DC bus with the 50V DC Bus, creating the opportunity to transfer power in both directions [20]. 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.

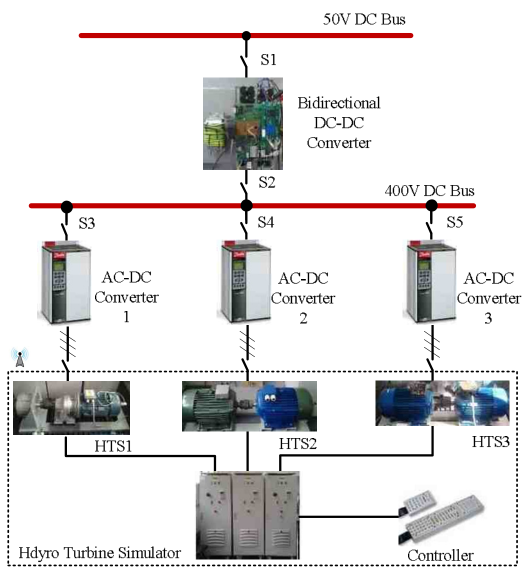

Fig. 6. Hydro System

Fig. 7. Photo of the Hydro Turbine Simulators

TABLE III. 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)

III. OPERATING MODES

A possible microgrid structure is shown in Fig. 8. It can operate in on-grid or off-grid mode by opening and closing switches; the microgrid can have as inputs one or multiple renewable energy sources. In grid-connected mode, the power can be transferred in both directions.

A hybrid inverter is used to send/receive power to/from the grid, to feed the AC loads and to charge/discharge the batteries. Also, the PV inverter can sell the excess power from 400V DC Bus or from PV panels.

In off-grid mode, the PV inverter and Hybrid Inverter are disconnected from the main grid, by opening the S1 switch and the energy produced by renewable energy sources is stored or used by local loads.

Regardless of operating modes, a bidirectional DC-DC converter links the 400V and the 50V DC Busses and transfer energy to/from batteries according to microgrid needs.

The energy from wind system is rectified and a hybrid DC-DC converter gives the energy to the supercapacitor which acts as a buffer. The stored energy in the supercapacitor is used then to charge the batteries. The energy produced by hydro systems is injected to 400V DC Bus, through an AC-DC converter.

Depending on S5 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.

The storage system is permanently supplied with energy by all sources and discharging occurs only when the system demands.

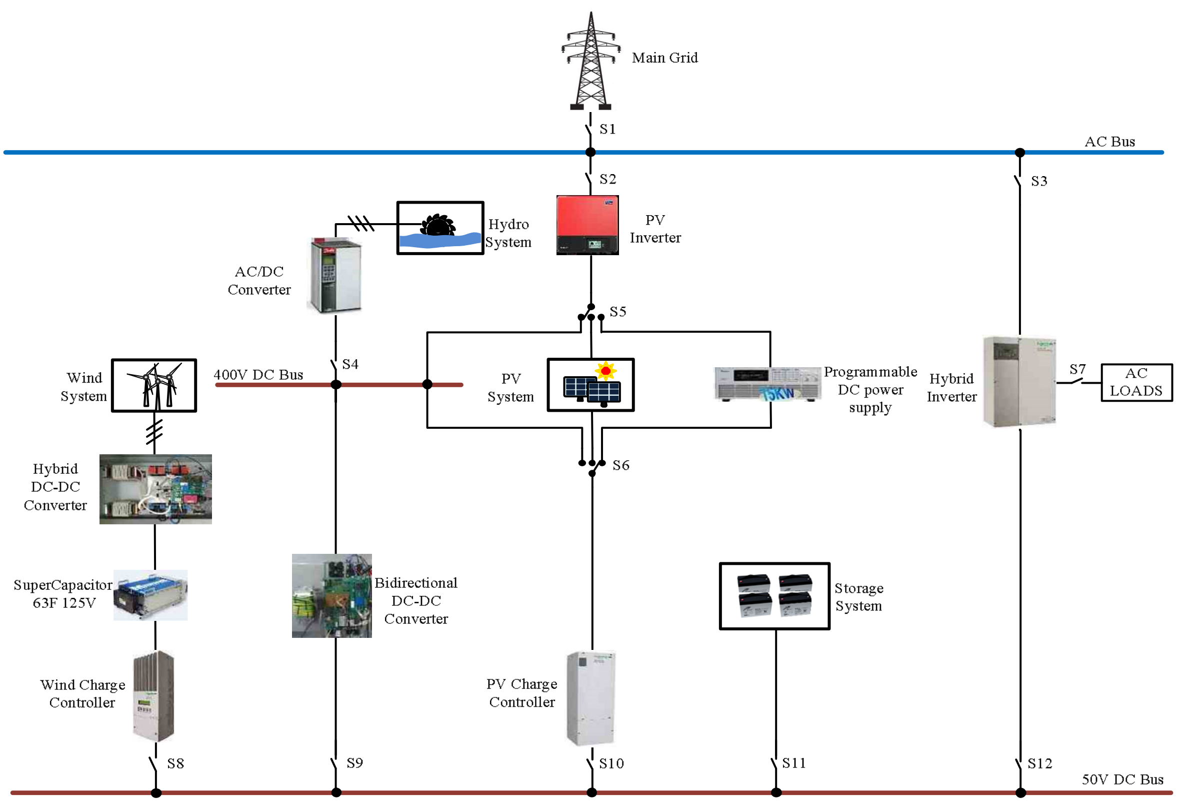

Fig. 8. Microgrid Structure

IV. MONITORING AND CONTROL SYSTEM

The monitoring and control of microgrid is made with a SCADA (Supervisory Control and Data Acquisition) system implemented in LabVIEW environments (Fig. 9). For the structure presented in Fig. 8, the user interface provides measurements from battery, PV, wind and hydro turbine inverters (voltage, current and power) in real time and provides a historical data base of voltages, currents and power produced by every source.

The communication between PLC, analog input module and LabVIEW is based on Modbus TCP/IP and the measurements and commands are transmitted over the network infrastructure

In order to highlight the monitoring system and operating mode of wind and PV systems, some waveforms were acquired through SCADA. Fig. 10 presents the waveforms of PV arrays output power and the battery voltage for 24 hours. In PV output power waveform can be observed that the maximum obtained power was at middle of the day, when solar irradiance was higher.

The wind turbine emulated speed as a function of the wind speed and the corresponding electrical delivered power are presented in Fig. 11. The wind speed waveform was obtain by real data acquired from outside. In order to obtain the wind turbine power, the wind speed waveform was implemented in the wind emulator system described in section II.

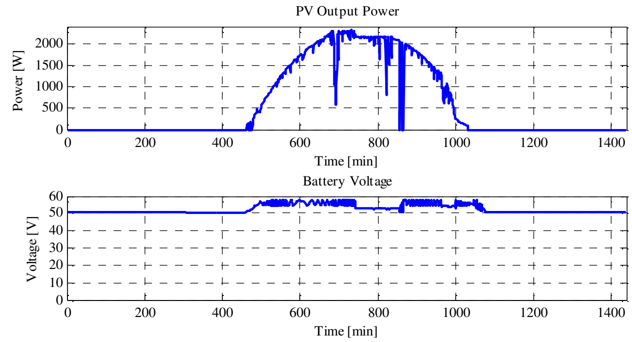

Fig. 10. PV output power and battery voltage waveforms

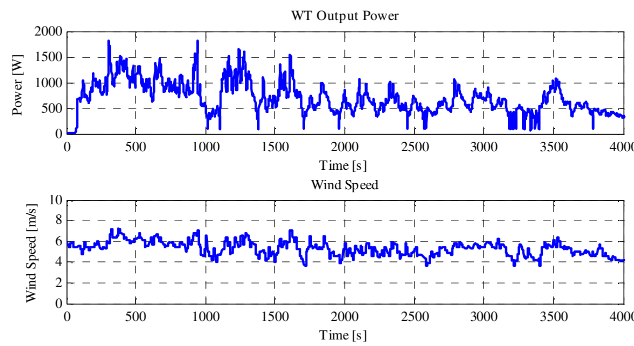

Fig. 11. Wind turbine output power and wind speed waveforms

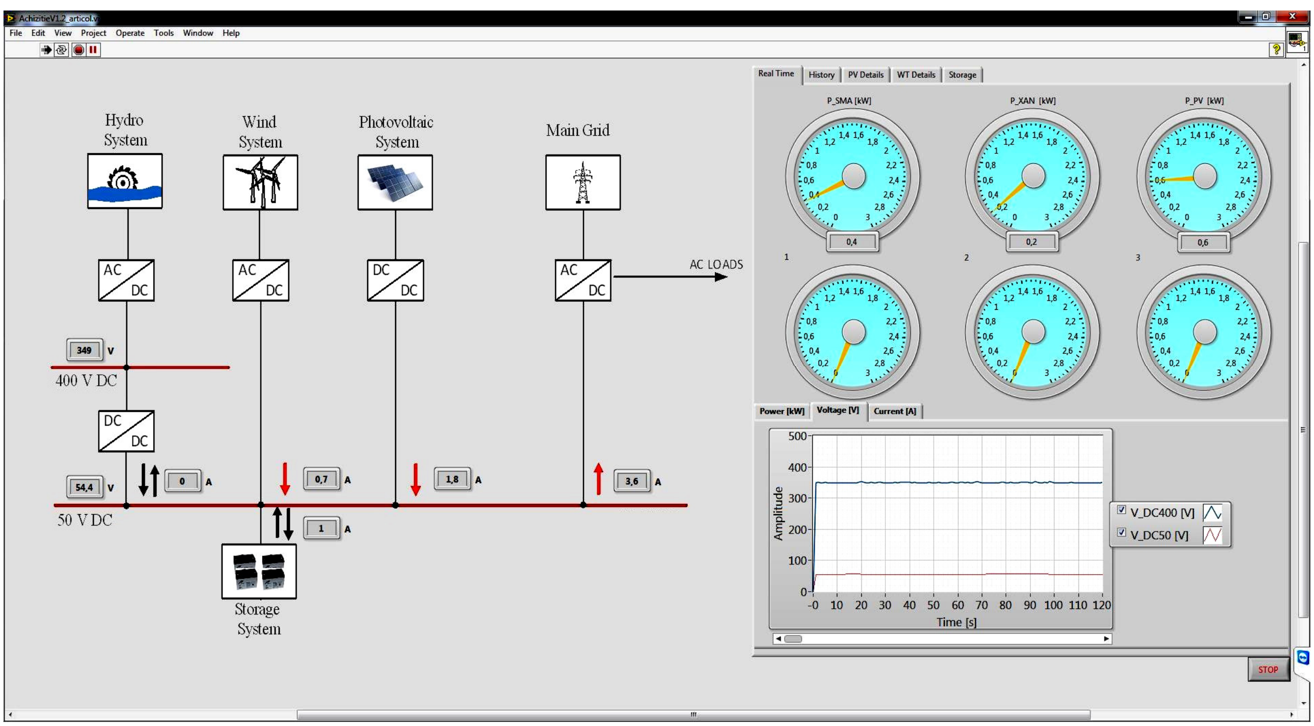

Fig. 9. SCADA User Interface

V. Conclusion

The microgrid is more complex than traditional power systems and needs more study and experiments before being 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 presented in this paper uses emulators instead of real renewable energy sources, most of components are real and the system can serve as a testing platform for such projects for 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, or to connect the internal DC bus with the storage elements.

The microgrid laboratory will be further improved and detailed information about more experimental results, for different configurations and energy management control strategies, will be presented in the future.

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References

[1] S. Chowdhury, S.P. Chowdhury and P. Crossley, “Microgrids and Active Distribution Networks,” IET renewable energy series 6, London: IET, 2009.

[2] R. H. Lasseter, “Microgrids,” IEEE Power Engineering Society Winter Meeting, vol. 1, pp. 305-308, 2002.

[3] E. Hayden, “Introduction to microgrids,” Nov. 2013, available at: www.securicon.com.

[4] L. Mariam, M. Basu, M.F. Conlon, “A Review of Existing Microgrid Architectures,” HINDAWI Journal of Engineering, Article ID 937614, pp. 1-8, 2013.

[5] A. Banerji, D. Sen, A.K. Bera, D. Ray, D. Paul, A. Bhakat and S.K. Biswas, “Microgrid: A review,” IEEE Global Humanitarian Technology Conference: South Asia Satellite, GHTC-SAS 2013, pp. 27-35, Aug. 2013.

[6] R. H. Lasseter, “Microgrids and Distributed Generation,” J. Energy Eng, Vol. 113, nr.3, pp.144-149, 2007

[7] Y. Li, F. Nejabatkhah, “Overview of control, integration and energy management of microgrids,” J Mod. Power Syst. Clean Energy, Volume 2, Issue 3, pp. 212-222, Sept. 2014.

[8] Nanfang Yang, Paire, D., Fei Gao, Miraoui, A., “Power Management Strategies for Microgrid-A short review,” IEEE Industry Applications Society Annual Meeting, pp. 1-9, 6-11 Oct. 2013.

[9] J. Oyarzabal, J. Jimeno, J. Ruela, A. Engler, C. Hardt, “Agent based Micro Grid Management System,” IEEE Int. Conf. on Future Power Systems, pp. 6, 18 Nov. 2005.

[10] K.S. Reddy, M. Kumar, T.K. Mallick, H. Sharon, S. Lokeswaran, “A review of Integration, Control, Communication and Metering (ICCM) of renewable energy based smart grid,” Renewable and Sustainable Energy Reviews, no. 38, pp. 180-182, 2014.

[11] B. Kroposki, R.H. Lasseter, T. Ise, S. Morozumi, S. Papatlianassiou, N. Hatziargyriou, “Making Microgrid Works”, *IEEE Power & Energy Magazine*, pp. 41-53, May/June 2008.

[12] B. Kroposki, T. Basso, R. DeBlasio, “Microgrid Standars and Technologies”, in *Proc. 2008 IEEE Power and Energy Society General Meeting – Conversion and Delivery of Electrical Energy in the 21st Century*, pp. 1-4.

[13] B. Zhao, X. Zhang, J. Chen, “Integrated Microgrid Laboratoty System,” IEEE Trans. on Power Systems, vol. 27, issue 4, pp. 2175-2185, Nov. 2012.

[14] M. Barnes, A. Dimeas, A. Engler, C. Fitzer, N. Hatziargyriou, C. Jones, S. Papathanassiou, M. Vandenbergh, “MicroGrid Laboratory Facilities,” IEEE Int. Conf. on Future Power Systems, pp. 6, 18 Nov. 2005.

[15] Z. Yang, Y. Che, C. Wang, “Construction, Operation and Control of a Laboratory-Scale Microgrid,” 3rd Int. Conf. on Power Electronics Systems and Applications, Nanjing, pp. 5, 6-7Apr. 2009.

[16] M. Kezunovic, “Teaching the smart grid fundamentals using modeling, simulation, and hands-on laboratory experiments,” IEEE Power and Energy Society General Meeting, pp.1-6, 25-29 Jul. 2013.

[17] M. Shamshiri, C.K. Gan, C.W. Tan, “A Review of Recent Development in Smart Grid and Micro-Grid Laboratories,” IEEE Int. Conf. PEDCO, Melaka, Malaya, pp. 367-372, 6-7 June 2012.

[18] N. Muntean, L. Tutelea, D. Petrila, O Pelan “Hardware in the Loop Wind Turbine Emulator,” ACEMP 2011- International Aegean Conference on Electric and Power Electronics & Electromotion Joint Conference, pp. 53-58, pp. 53-58, 8-10 Sept. 2011.

[19] O. Pelan, N. Muntean, O. Cornea, “Comparative evaluation of buck and switched-capacitor hybrid buck DC-DC converters,” Int. Symp. Power Electron., Electr. Drives, Autom. Motion (SPEEDAM), pp.1330-1335, 20-22 June 2012.

[20] D. Hulea, N. Muntean, O. Cornea, “Valley Current Mode Control of a Bi-Directional Hybrid DC-DC Converter,” ACEMP OPTIM ELECTROMOTION Joint Conference, pp. 274-279, 2-4 Sept. 2015.