Emulation of a hybrid PV-Wind-Battery system*

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Abstract— **This paper is focused on the design and the implementation of a hybrid PV-wind power system with batteries. It aims to emulate the behavior of a hybrid power system in order to face load consumption variations. Final system includes relevant contributions such as quality of emulator (a large number of parameters are considered); capacity to study various impacts simultaneously, a fast dynamic and a set of experimental tests that have been achieved and validated with a test bench.**

I. INTRODUCTION

Real time simulation test beds for renewable energy sources investigations are fully recommended for industrial development [1]. In case of photovoltaic generators, tests are conducted to ensure and guarantee quality and performances of the final product. However, it is costly, consumes time and is strongly dependent on climatic conditions. In addition, a few risks must be controlled since direct employment of PV modules for prototype testing can damage the source. A solution for developing experimentations without real PV panels is so recommended. Also, tools' development in laboratory is very useful for carrying out measurements and analyses, independently of climatic conditions. A wide range of photovoltaic array emulators with power converters has been investigated, proposed and developed during those last years. Some of them are without galvanic isolation, and are based on structures with low frequency transformer or on HF transformers and use Pulse Width Modulation (PWM) principle or linear converters to avoid Electro-Magnetic Compatibility (EMC) interferences. Trying to emulate PV power (I-V curve), converters amplify advantageously the solar cell reference or modify the I-V curve with convenience: a discrete table of value is stored in a memory and points can be interpolated, but most of them are using mathematical models for I-V curve and calculations are done with array's parameters, making possible modifications and simulation of PV curve under different conditions more easily [2].

In wind generators applications, real time simulators [3] [4] [5] are carried out to control wind velocity in laboratory, that in fact, in real conditions, it is particularly difficult to perform such objective.

So, this paper is focusing on real time simulation and supervision for a hybrid renewable power system with storage capabilities. A test bed reproducing with accuracy the behavior of a hybrid system is implemented with a relevant supervision technique based on current mode control and State of Charge (SOC) estimation for batteries. It is mainly composed of photovoltaic and wind turbine conversion systems combined with batteries. The real-time emulator for photovoltaic arrays is based on a closed-loop reference model structure whereas wind turbine simulator is based on two DC machines controlled by speed and torque. Both permit to analyze, Maximum Power Point Tracking (MPPT) techniques and complete system's behavior under specific conditions.

In the first part of this paper, development and implementation of a photovoltaic solar simulator are described. Then, in the second part, wind turbine simulator is presented. Finally, the two simulators are integrated and connected together for the hybridization of the two sources with batteries combination. Tests are conducted and hybrid system performances have been assessed.

II. PHOTOVOLTAIC GENERATOR EMULATION

The proposed photovoltaic generator simulator consists of a programmable power supply controlled in real time by dSPACE card (DS1104) through Matlab/SimulinkTM surroundings as shown in Figure 1. Control part uses the return (by measurement) of voltage and current (Figure 2). So, from reference model, the operating point is connected to load and follows characteristic of photovoltaic panel using a PI controller [2]. PVmodule block is used to generate Ipv current from equations presented on [6]. To overcome problem of implementation with algebraic loop in dSPACE, Newton - Raphson method [7] is employed for solving the current equation:

$$I_{pv} = I_{in} - I_0 \left[\exp\left(\frac{Vpv+R_S\, I_{pv}}{V_t\, a}\right) - 1\right] - \frac{Vpv+R_S\, I_{pv}}{R_p} \qquad (1)$$

With:

I_{in} : photovoltaic current due to irradiation. If the panel is composed of *Np* cells connected in parallel, then

$I_{in} = \mathrm{I_{in\,cell}} \times \mathrm{N_p}$ where $\mathrm{I_{in\,cell}}$ is the saturation current for a single cell,

$\mathrm{I_0}$: saturation current of the diode. $\mathrm{I_0} = \mathrm{I_{0\,cell}} \times \mathrm{N_p}$ where $\mathrm{I_{0\,cell}}$ is the current of a single cell and $\mathrm{N_p}$ the number of cells in parallel,

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V_t : thermal potential of the panel. $V_t = \frac{N_s \times K \times T}{q}$, N_s is number of cells in series, K: Boltzmann constant $[1.3806503 \times 10^{-23}\,J/K]$, q charge of an electron $[1.60217646 \times 10^{-19}\,C]$ and T temperature of p-n junction in Kelvin degree [°K]. T is assumed equal to ambient temperature.
a: ideal constant of the diode, assumed equal to 1 in our case.
Vpv: voltage across the panel.

Thereafter, reference current Ipvref provides the reference signal of the programmable power supply with PI controller.

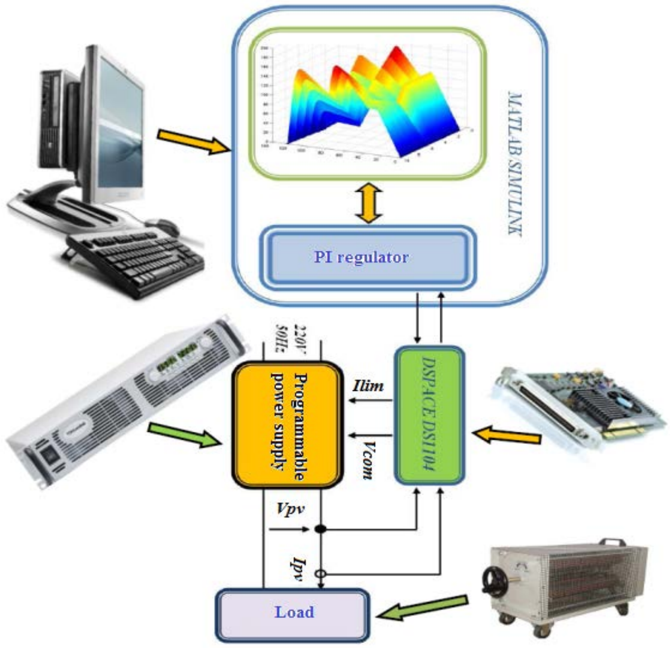

Figure 1: Synoptic scheme of photovoltaic system emulator [2]

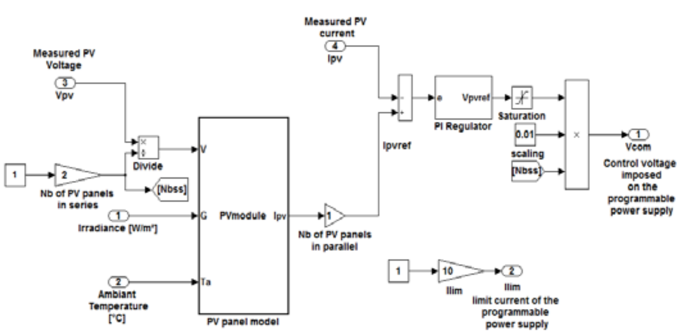

Figure 2: Matlab/Simulink implementation for developed emulator regulation

A complete photovoltaic conversion chain is then set up according to the following wiring diagram:

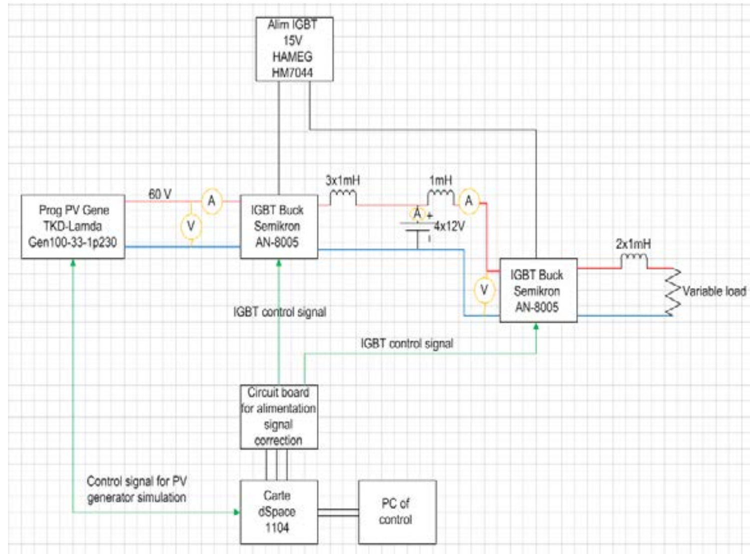

Figure 3: Wiring diagram of the developed solar photovoltaic simulator

III. Development of a wind turbine system physical

This simulator permits to reproduce in laboratory the behavior of Lacota SC (900 W) wind turbine with a one third reduced scale (for safety reasons: reducing wires current and protecting converters). Development of such a tool is interesting for reproducing various research investigations and ensures a good flexibility for wind turbines characteristics and also a fully control of wind speed. It combines several elements: wind profiles, wind turbine model (Lacota SC (750W at 12m / s)), two DC electrical machines: MCC1 for wind turbine torque production and MCC2 for simulating generator, energy storage system (batteries bank and/or accumulators), a first step-down chopper to control MCC1 and another one for MPPT control of the generator [8-9]. Both are commanded via a PI regulator, and finally a continuous variable load.
Block and wiring diagrams of the simulator are given figure 4 and 5.

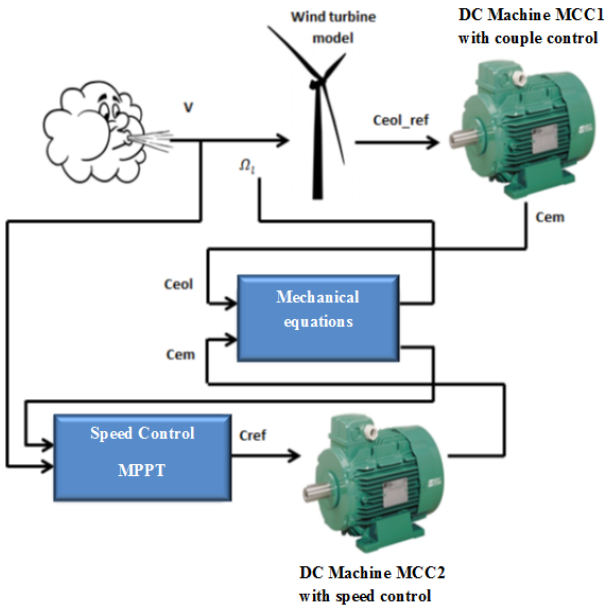

Figure 4: Schematic representation of wind energy simulator in laboratory

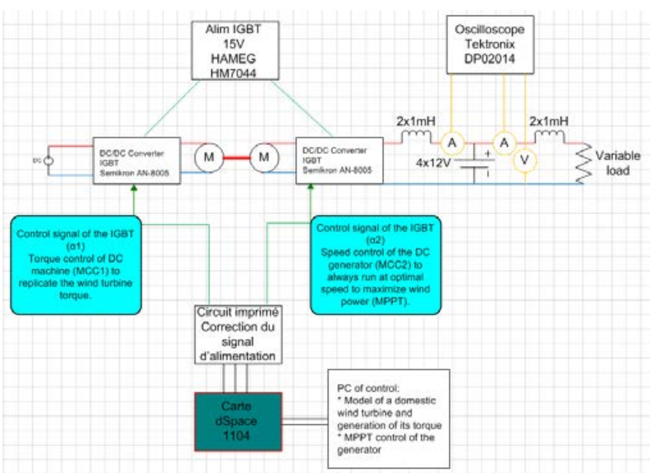

Figure 5: Connection diagram of the developed wind energy simulator

All parameters were set precisely to get an electrical power of about 250 W for a wind speed of 12 m/s. Thus, we ensure the scaling of 1/3 for the Lacota SC Engineering wind turbine (750W at 12m / s).

Figure shows the implementation of wind turbine model for torque reproduction and the current mode control of DC machine (MCC1).

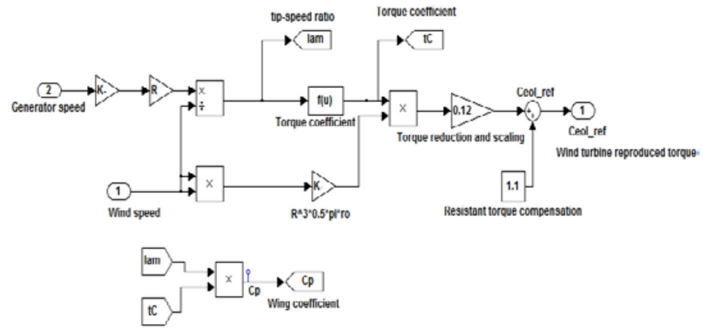

Figure 6.a Wind turbine model under Matlab/Simulink

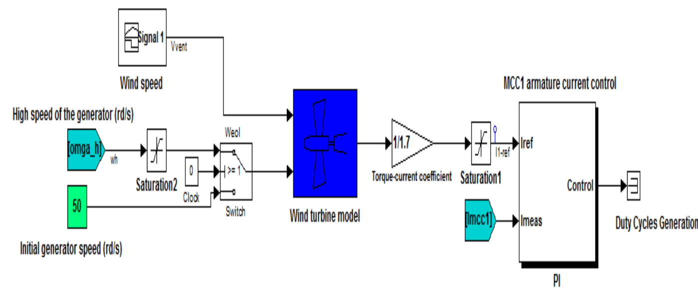

Figure 6.b Matlab/Simulink implementation of wind turbine torque (MCC1 armature current) regulation

Figure 6: Matlab/simulink implementation of wind turbine model and DC machine (MCC1) current mode control for torque reproduction

IV. Experimental Implementation of the Hybrid Wind Photovoltaic Batteries System

Photovoltaic and wind turbine generator previous simulators are integrated for carrying out hybrid power system test bed (Figure 7).

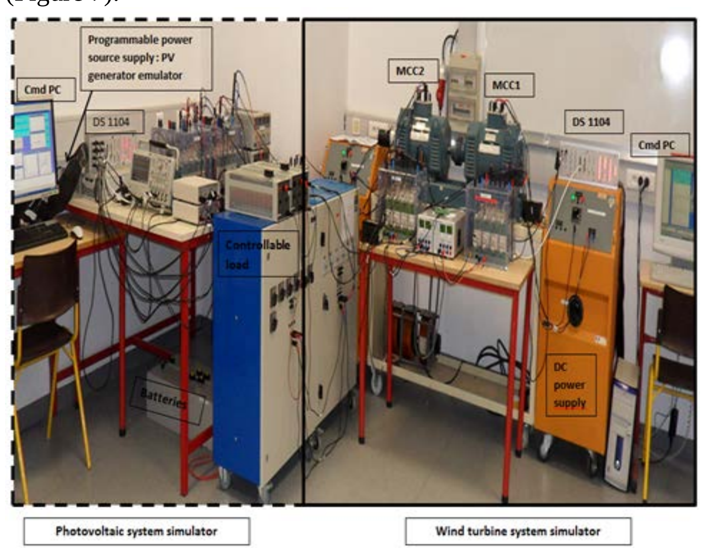

Figure 7: Hybrid power system test bed with PV, wind turbine and batteries sources

In autonomous hybrid power system operation, batteries can be exposed to overcharges (SOC ≥ SOCmax) or deep discharges (SOC ≤ SOCmin). In addition, load can be not satisfied in case of renewable energy absence or insufficient capabilities of energy storage. Considering that, a new technique has been designed for motorizing hybrid power system with different current converters and taking into consideration batteries State Of Charge (SOC) estimation.

Supervision algorithm implemented on Dspace environment is represented by following chart:

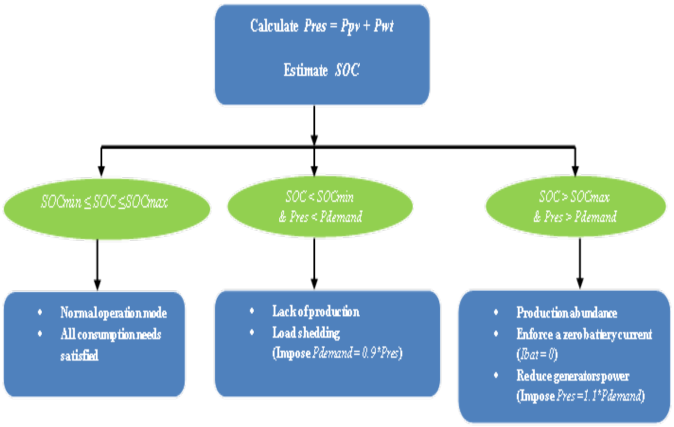

Figure 8: Proposed supervision method flowchart

V. Results and Discussions

In order to test the bench, under real conditions, data from weather station (figure 9) have been acquired [10]. Obviously, it is not a real size reproduction of the hybrid power system but for demonstration of its behavior. For the load, same consumption profile for one day is considered third scaled. A step simulation 30s is employed. Batteries SOC is managed between *SOCmin* = 49.8% and *SOCmax* = 50.2% (thresholds are chosen deliberately closed in order to test rapidly the functioning of energy management system). All results are published in figures 10-12:

- While t ∈ [0; 4.2 hrs.[, a low energy consumption is beginning but there is not enough energy produced to satisfy the electric demand. Batteries are discharging as depicted in figure 12. Nevertheless, it remains in the normal functioning mode.
- During t ∈ [4.2; 8.3 hrs. [, batteries' SOC reaches its lowest value due to lack of production. Consequently, batteries current is set to zero, as displayed in figure 11 and only 90% of power demand is satisfied (figure 11).
- Throughout t ∈ [8.3; 16.1 hrs. [, sun brings a significant amount of energy to the system. Demand is fulfilling and batteries are charging. System operates now in a normal functioning phase again.
- During t ∈ [16.1; 17.3 hrs. [, maximum SOC is achieved. So, batteries current is forced to zero. Wind turbine power output is reduced. As still excess production remains, photovoltaic power output is also degraded. This is clearly visible when comparing figures 9 and 10. There is a drop in photovoltaic power output not due to reduction of solar irradiance: working point of the photovoltaic generator has been adapted.
- While t ∈ [17.2; 20.6 hrs. [, consumption increases intensely. It has to be noted that Pload (demand) is already scaled down with a three factor to prevent damage caused by excessive currents (maximum allowed load for simulation is 400W). Since batteries are fully charged, the system is returning to a normal functioning state.
- When t ∈ [20.6; 24 hrs. [, no energy is produced, and SOC achieves its minimal allowed value. Thus, the system has to put batteries current at zero. No power practically is delivered for electrical loads.

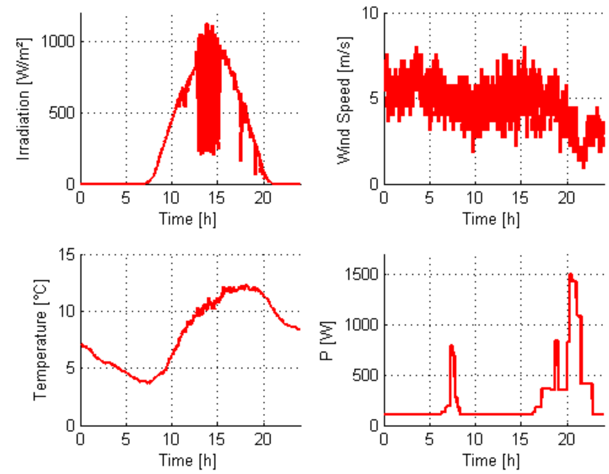

Figure 9: Input variables variations for one day simulation

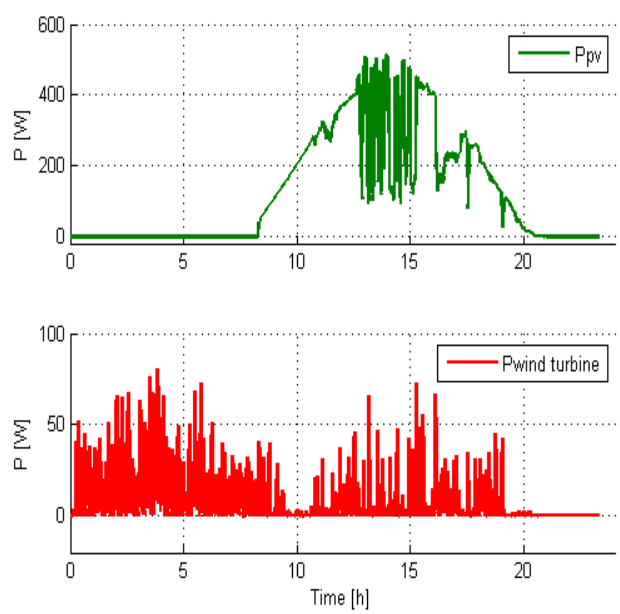

Figure 10: Photovoltaic generator and wind turbine power output for one day

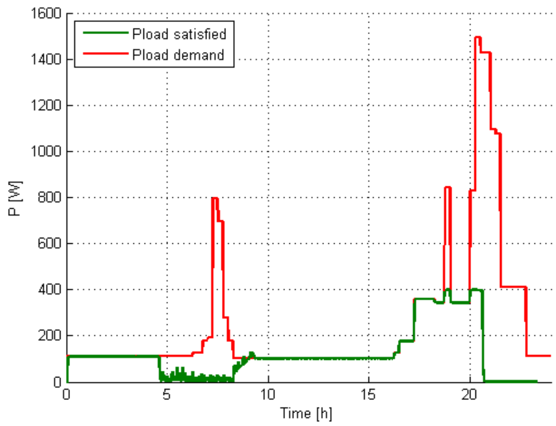

Figure 11: Satisfied and demanded power consumption for one day

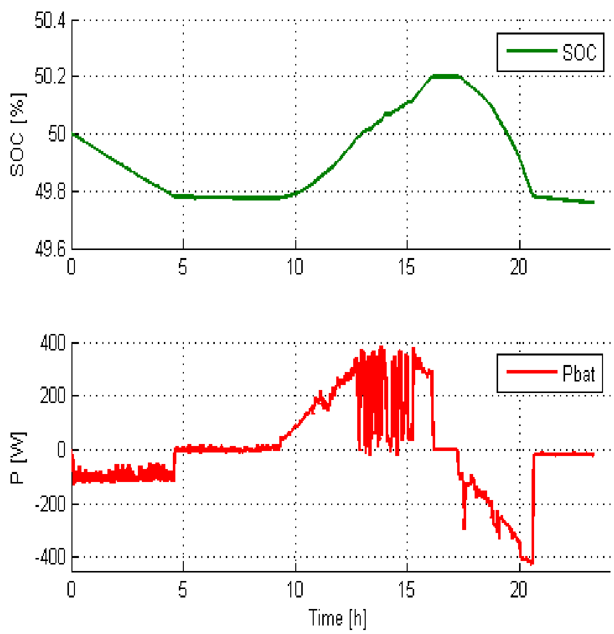

Figure 12: SOC and battery power output for one day

VI. Conclusions

In this paper, an experimental PV-wind-batteries power system has been successfully developed in a third scale test bench. It allows a realistic emulation for multiple energy sources system. A relevant control strategy based on current control and batteries State Of Charge estimation has been successfully implemented and validated for different configurations with many tests. This experimental bench is a useful tool for investigators to test and combine multiple sources power systems with various types of control.

Acknowledgment

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References

[1] R.Sanchez, X.Guillaud, G.Duaphin-Tanguy, Hybrid electrical power system modeling and management, Journal of Simulation Modelling Practice and Theory 25 (2012) 190-205.
[2] R. kadri, J.P. Gaubert, G. Champenois, M. Mostefaï , Real-time emulator of photovoltaic array in partial shadow conditions based on closed-loop reference model, Scientific Bulletin of the Electrical Engineering Faculty 3 (14) (2010) 71-77.
[3] I. Munteanu, A. I. Bratcu, S. Bacha, D. Roye, Real-time physical simulation of wind energy conversion systems, Wind Power , Book edited by : S.M. Muyeen (2010), pp.558.
[4] I. Munteanu, A. I. Bratcu, M. Andreica, S. Bacha, D. Roye, J. Guiraud, A new method of real-time physical simulation of prime movers used in energy conversion chains, Journal of Simulation Modelling Practice and Theory 18 (2010) 1342-1354.
[5] Gabriel O. Cimuca, Christophe Saudemont, Benoît Robyns, Mircea M. Radulescu, Control and Performance Evaluation of a Flywheel Energy-Storage System Associated to a Variable-Speed Wind Generator, IEEE Transactions on Industrial Electronics 53 (4) (2006) 1074-1085 .
[6] Dhaker Abbes, Gérard Champenois, André Martinez, Benoit Robyns, Modeling and simulation of a photovoltaic system: An advanced synthetic study, 3d International Conference on Systems and Control (ICSC13), 29 to October 31, 2013, in Algiers, Algeria.
[7] T. J. Ypma, Historical development of the Newton-Raphson method, SIAM Review, 37 (4) (1995) 531-551.
[8] Dhaker Abbes, André Martinez, Gérard Champenois, Benoit Robyns, Real time simulation and supervision for a renewable hybrid power system, Journal of Simulation Modelling Practice and Theory Journal, under review.
[9] I. Munteanu, A. I. Bratcu, N.-A. Cutululis, C. Emil, Optimal Control of Wind Energy Systems, Verlag London: Springer, 2008.
[10] Meteo Data website: http://lerpa.eigsi.fr/meteo.