ENERGY STORAGE FOR A STAND-ALONE WIND ENERGY CONVERSION SYSTEM

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Key words: Wind turbine, Permanent magnet synchronous generator, Variable – speed, Stand-alone system, Energy storage.

This paper deals with a wind-based stand-alone generating unit with Permanent Magnet Synchronous Generator (PMSG) and a Lead Acid Battery (LAB) for energy storage, during wind speed variation as well as transient performance under variable load. The main purpose is to supply 230 V/50 Hz domestic appliances through a single-phase inverter. Simulations and experimental results validate the stability of the supply.

1. INTRODUCTION

The requirements for clean and Renewable Energy Sources (RES) have resulted in the introduction of rather small power sources, supplying autonomous electrical systems. Among these, wind based generating units are of real interest. For powers under 10 kW, permanent magnet synchronous generators (PMSG) are used to obtain an efficient configuration [1, 2].

For stand-alone systems, energy storage devices are essential to store electricity for use when the wind speed is under a certain level. Wind energy systems have a fluctuating power output due to the wind speed variations, with power output varying by the cube of the wind speed. Integrating an appropriate energy storage system in conjunction with a wind generator removes the fluctuations and maximizes the reliability of loads power supply. In addition, both system voltage and frequency must be controlled. The reason of using Lead Acid Battery (LAB) is the proven reliability of their technology for stand-alone wind energy systems [3, 4].

2. SYSTEM CONFIGURATION

The proposed wind stand-alone system, designed for a residential location, is a 2 kW wind turbine system with a PMSG, diode-rectifier bridge, boost converter, LAB storage device, inverter, transformer and resistive loads.

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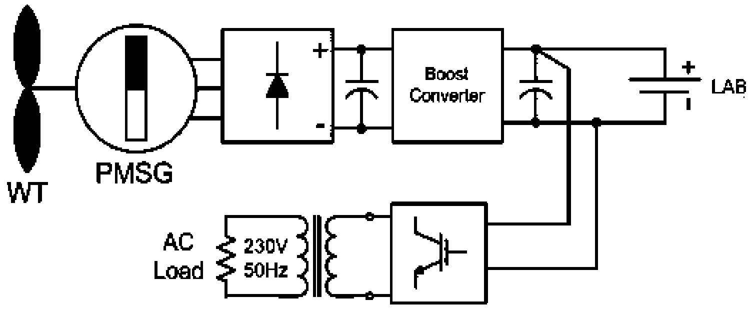


Fig. 1 – System configuration.

3. SIMULATION AND EXPERIMENTAL RESULTS

The proposed system has been modeled and simulated using the Matlab/Simulink/SimPowerSystems environment [5]. Fig. 2 shows the block diagram. Measurement blocks are also included.

The power of the wind is converted into the mechanical-rotational energy of the wind turbine rotor. A wind turbine cannot extract the power in the wind completely, theoretical only 59 % of the wind power could be utilized by a wind turbine [6], but for analyzed 2 kW wind turbine system the real power coefficient is 0.39.

The PMSG mathematical model is in the synchronous *dq* reference frame [7], with a sinusoidal flux distribution and surface mounted permanent magnets. Its parameters are listed below:

– rated power: $P = 2$ kW;
– rated voltage / frequency: 120 V / 50 Hz;
– rated current: 17 A;
– rated speed: 400 RPM;
– per-phase stator resistance: $R_s = 2\ \Omega$;
– the d-axis and q-axis stator inductances: $L_d = L_q = 0.001$ H;
– flux induced by magnets in the stator windings: $\psi = 0.46$ Wb.

The boost converter controls the electromagnetic torque by means of wind speed, in order to extract optimum power from the available wind resource. The control method for obtaining maximum power characteristic of wind turbine (MPPT), the voltage and battery state of charge (SOC) monitoring system, to ensure optimum charging conditions for LAB, are presented in [8, 9].

Energy storage system is composed of an inverter and storage element, in this case a bank of lead-acid batteries. The storage system is composed of a full bridge single-phase inverter that converts the DC voltage of the battery in AC voltage. Further, this voltage is applied to a single-phase transformer, which boosts-up the voltage to 230 V. The inverter controls the power transfer, changing the amplitude and phase of the voltage on the primary side of the transformer.

The battery bank consists of ten 12 V LABs connected in series. The LAB is able to supplement the power provided to the load by the wind turbine when the wind speed is too low.

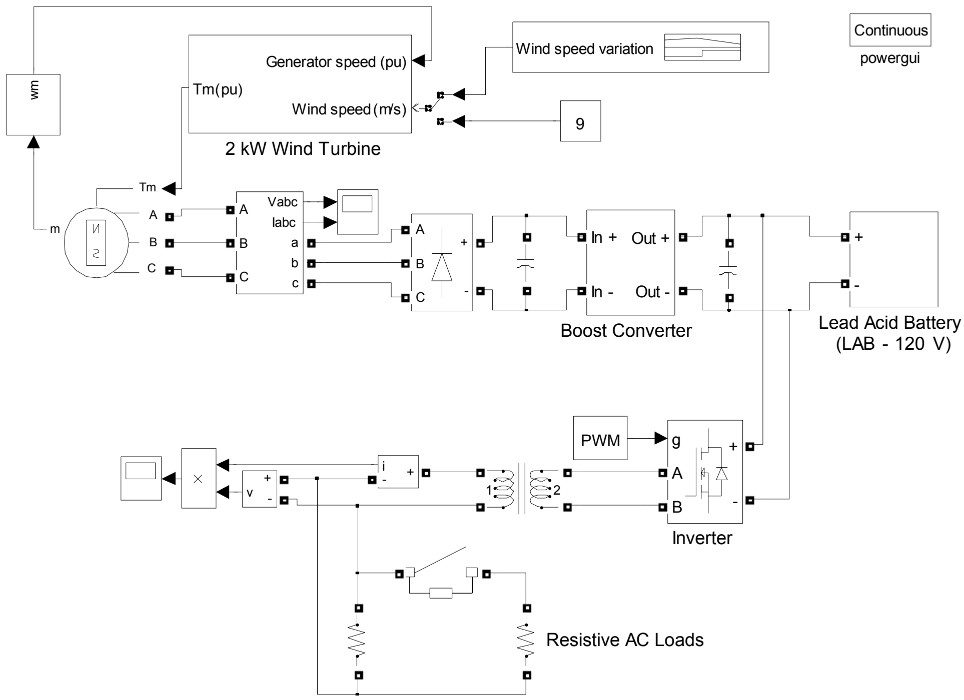


Fig. 2 – Simulink block diagram.

The experimental results are obtained on a laboratory test bench, including the described system with a wind turbine emulator that drives the PMSG. The control system is implemented in a dSPACE™ DS1103 real-time board. This emulator is able to reproduce the steady and dynamic behavior of a real wind turbine. The hardware scheme is based on a frequency converter, Danfoss VLT – FC302 (5 kW) with vector control and open loop torque control, and real-time control system dSPACE™ DS1103.

The operating principle is based on a control loop, where the input signal is the electromagnetic torque of the asynchronous motor (AM), and the output signal is the motor speed. The wind speed can be modified through one independent input of the emulator [10, 11]. The block diagram of the wind turbine emulator is presented in Fig. 3.

In order to investigate the system's operation, the following simulations and experiments were carried out:

– variation of the wind speed, while the load is constant;

– load switching, with fixed wind speed.

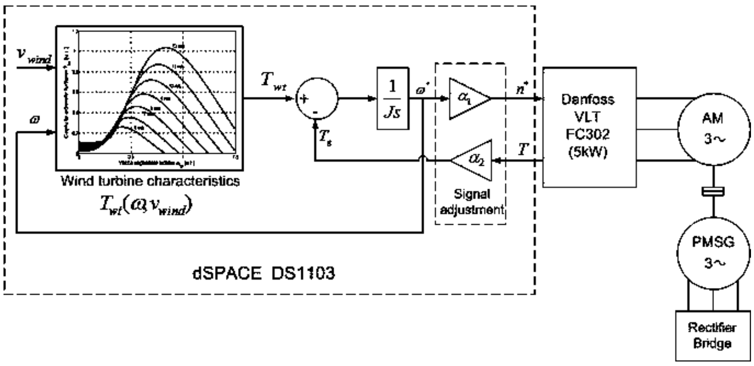


Fig. 3 – Wind turbine emulator.

3.1. VARIATION IN THE WIND SPEED, WHILE THE LOAD IS CONSTANT

In the following example, wind speed drops from 9 m/s (at t = 3s) to 5 m/s (at t = 7s). The output voltage and current for the LAB are shown in Figs. 4 and 5. The considered initial battery SOC is 80 %. When the LAB is discharging, the battery SOC decreases in order to ensure the stable supply for the loads.

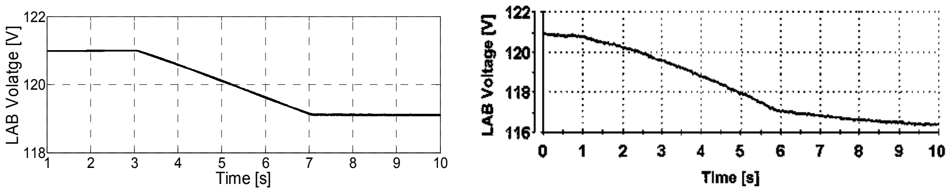
The results can be seen in Fig. 6. The wind turbine cannot supply the entire energy load demand (0.5 kW) in the transient regime, therefore the battery will supply the difference. Fig. 7 shows that the active power balance of the system is maintained with the LAB, which will pass from charging to discharging mode.

It can be observed in the experimental results, small changes are reflected in the waveform of voltage and current through the battery.

The explanation for these differences is that the real system is more complex than the model used in simulation and its performance can be affected by many parameters that are not considered in the simulation (the neglected/unknown resistances).

These differences are more significant in the results presented in Fig. 8, due to the real inverter used for laboratory test bench, which has a low dynamic during the transient regime (Fig. 8b), compared with the simulation case where an ideal inverter is modeled (Fig. 8a).

In addition, the mismatch of the time axis between simulation and experimental results occurs because of the difficulty of controlling the real system as in the simulation case.



a) b)

Fig. 4 – The LAB voltage variation: a) simulation results; b) experimental results.

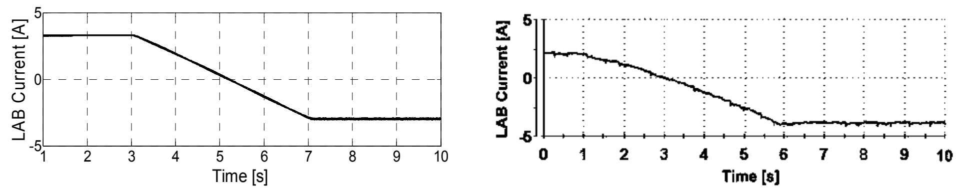


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Fig. 5 – The LAB current variation: a) simulation results; (b) experimental results.

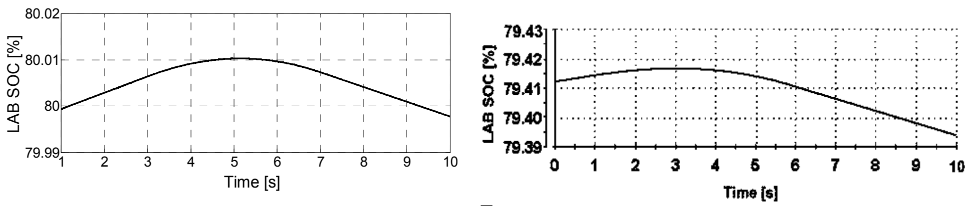

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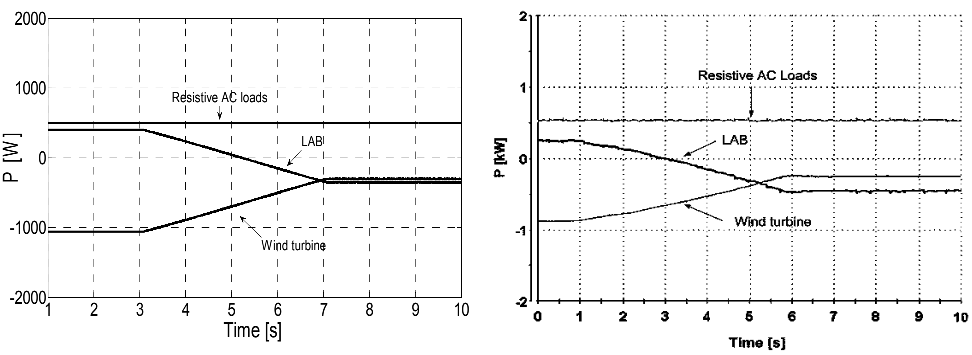
Fig. 6 – The LAB SOC variation: a) simulation results; b) experimental results.



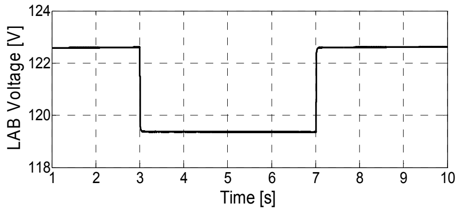
a) b)

Fig. 7 – The active power balance of the system: a) simulation results; b) experimental results.

3.2. LOAD SWITCHING, WITH FIXED WIND SPEED

For the following simulation, the wind speed is maintained constant at 9 m/s. The LAB voltage, current, and LAB SOC variation, are provided in Figs. 8, 9 and 10, respectively. At $t = 3$ s, a 1 kW load is connected and disconnected at $t = 7$ s.

In Figs 8 and 9, it can be seen that the LAB operating mode changes from charge to discharge during the transient event. Because initially no load is connected, the power difference supplied by the wind turbine is stored in the battery. The LAB stored energy is released when the 1 kW load is connected, in this way the supply of the load is ensured. The SOC slope changes when the load is switched on and off , as shown in Fig. 10, which means that the battery passes from charging to discharging mode. Consequently, Fig. 11 shows that the active power balance of the system is maintained regardless the load change.



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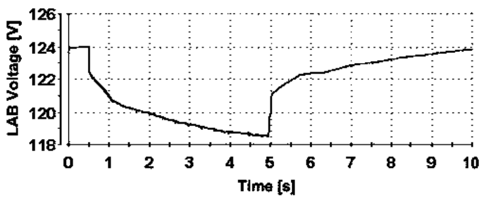

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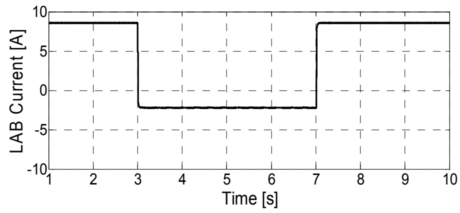
Fig. 8 – The LAB voltage variation: a) simulation results; b) experimental results.



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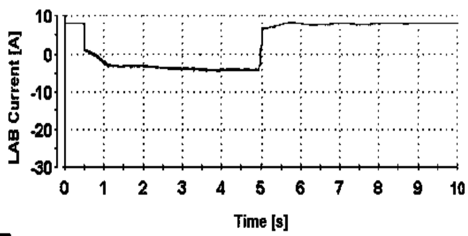

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Fig. 9 – The LAB current variation: a) simulation results; b) experimental results.

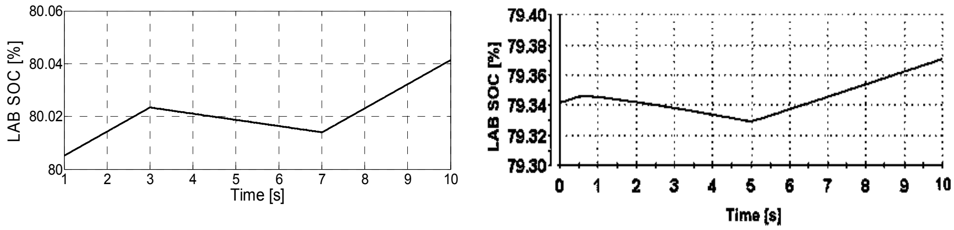

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Fig. 10 – The LAB SOC variation: a) simulation results; b) experimental results.

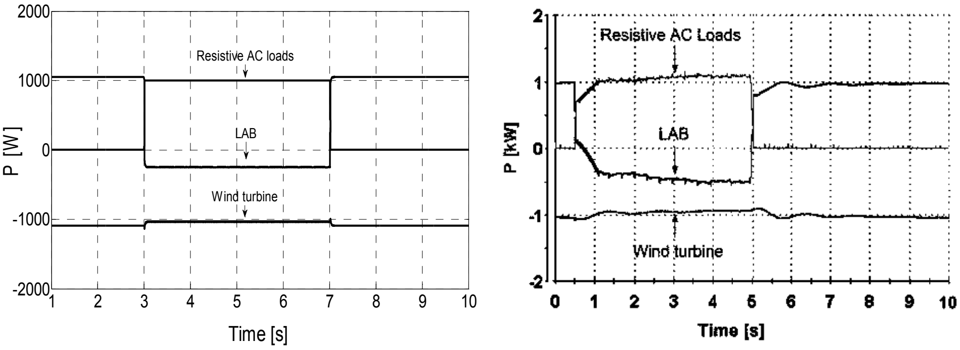

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Fig. 11 – The active power balance of the system: a) simulation results; b) experimental results.

4. CONCLUSIONS

In this paper, a LAB model and its integration in a typical stand-alone wind energy conversion system is analyzed. Simulation and experimental case studies show that the active power balance of the system proves to be satisfying during transient loads and variable wind speed conditions.

LAB always ensures the safe supply of the loads (households) regardless of the problems caused by wind speed and loads variations.

In conclusion, the power system's stability can be ensured by using the proposed configuration.

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