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# Laboratory Test System for Small Wind Energy Generators

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**Abstract.** This research work is devoted to the development of a set-up facility for testing Permanet-Magnet Synchronous-Machines (PMSM) used in small wind energy generators. The developed test system can be used not only for PMSM parameters characterization but also for the study of the performance of the power electronic associated to the electrical machine.

## 1. Introduction

Small Wind energy is a hot topic. A study of the American Wind Energy Association (AWEA) [1] shows that even considering the economic downturn, the U.S. market for small wind generators grew a 15% in 2009 with an added capacity of 20.3 MW. Fig. 1 summarizes the 2009 global sales considering both off-grid and on-grid applications. The aggregated data shows over 10,000 new generators and pushes the total installed capacity in the U.S. to more than 100 MW. AWEA defines Small wind turbines (SWT) as having a generating capacity up to 100 kilowatts (kW) ( 18 m or 60 ft rotor diameter).

Spain can be considered a reference model regarding wind energy generation. However, the total installed power of small wind generator is below 7 MW. It is expected that the installed power will increase in the nearest future with the development of the smart grids and the distributed generation paradigm. At the moment there are more than 526 small wind turbines from 190 different manufacturers around the world [2]. The turbines can be included in two different sets:

- 426 Horizontal Axis Wind Turbines (HAWT)
- 100 Vertical Axis Wind Turbines (VAWT)

Acording to Fig. 1 it is expected that set-up facilities like the system it is presented in this paper will be necessary in the next future in order to test the performance of the electrical machine and the power converter.

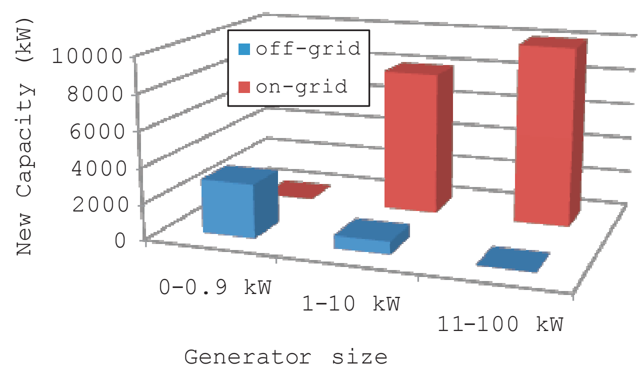


**Figure 1**. 2009 global sales of the U.S. small wind generator market [1].

## 2. Set-up Architecture

The architecture of the set-up facility is summarized in Fig. 3 and 2. The generator is a three-phase PMSM whose output is rectified by a full-wave rectifier. The dc component is adapted to a suitable value which can be inverted in order to inject the power to the grid.

Fig. 4 shows the set-up with all the components. An electronically regulated dc motor is used as a primary motor. In [3] the rotor blade performance can be evaluated by means of an axial flow fan which provides the wind source. Both torque and speed are measured in order to compute the mechanical power converted by the generator. The electrical magnitudes voltage, current and power are measured at all the stages of the conversion

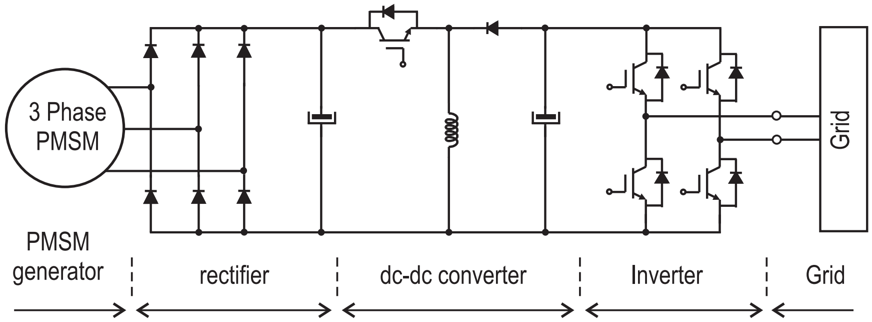


**Figure 2**. Basic equivalent circuit of the conversion system.

chain (rectifier and inverter). The PMSM under test has 20 poles, 3.5 kW and 250 rpm.

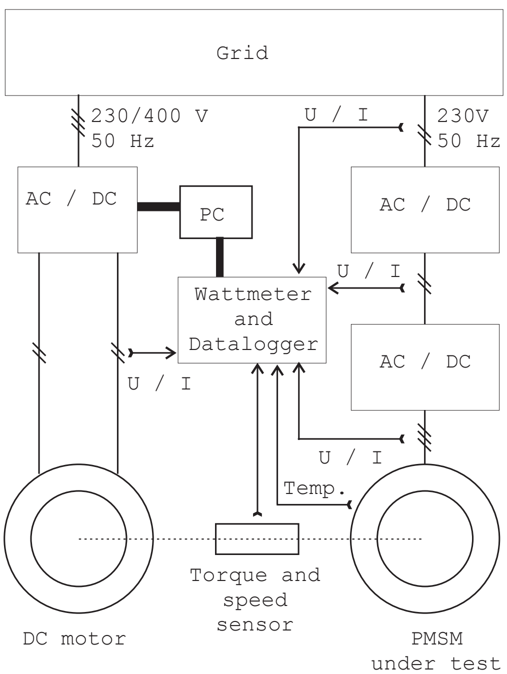


**Figure 3**. Architecture of the set-up facility.

The implemented test system is able to register not only the electrical magnitudes at all stages of the energy conversion process but also mechanical parameters (torque and speed) and temperature [4]. The system is controlled by a PC in a similar way to other approaches [5–7]. Other research teams have proposed a similar approach based on LabView [3].

The equivalent model showed in Fig. 2 can be used for simulation purposes using software like Matlab [8] or PSCAD [9]. The electrical machine can be simulated using a finite elements simulation software. In [10] a 2D and 3D model has been implemented using Flux [11].

The power injected into the grid can be modulated by defining a $P$ vs $V_{dc}$ curve. Fig. 5 shows the software form used for this configuration.

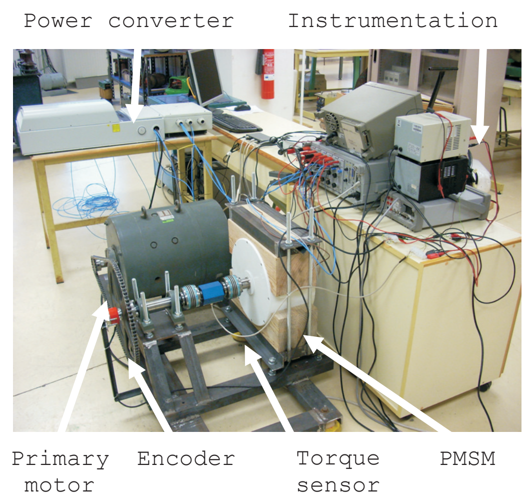


**Figure 4**. Set-up with all the components.

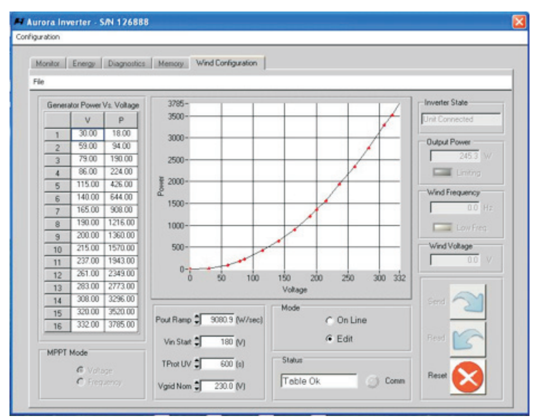


**Figure 5**. Software form used for $P$ vs $V_{dc}$ configuration [12].

## 3. Results

The test systems can provide different results related with both the electrical and mechanical performance. As an example, Fig. 6 shows the active power $P$ produced by the PMSM vs mechanical speed considering a constant electric load.

The test system can also be used for registering the

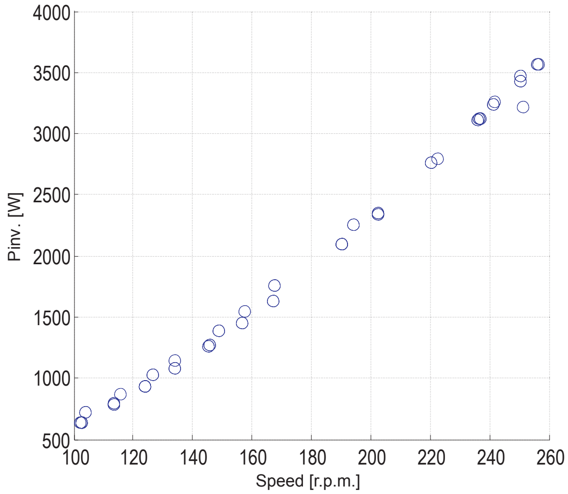


**Figure 6**. PMSM power curve.

evolution of the stator temperature during the test. Fig. 7 shows the evolution of the temperature measured in the stator of the electrical machine during a test under nominal conditions.

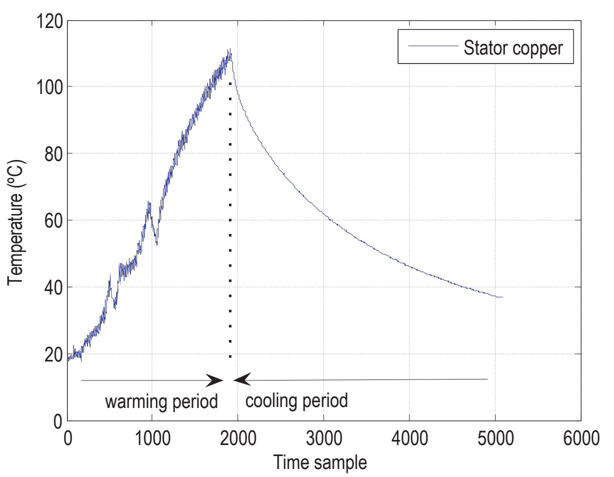


**Figure 7**. Temperature evolution in the stator of the 3.5 kW PMSM wind generation system during a full load test (1 sample every 5 seconds).

Fig. 8 shows the voltages and currents at the generator terminals.

## *A. Performance analysis*

The set-up facility can be used for obtaining not only the performance of the overall system but also the individual value of each element. Considering the basis architecture of a small-wind generation system showed in fig. 4. The table I summarizes the performance of each component as a percentage of the total losses for a 3.5 kW generator.

The results summarized in table I shows that the electrical machine is the element with the worst performance

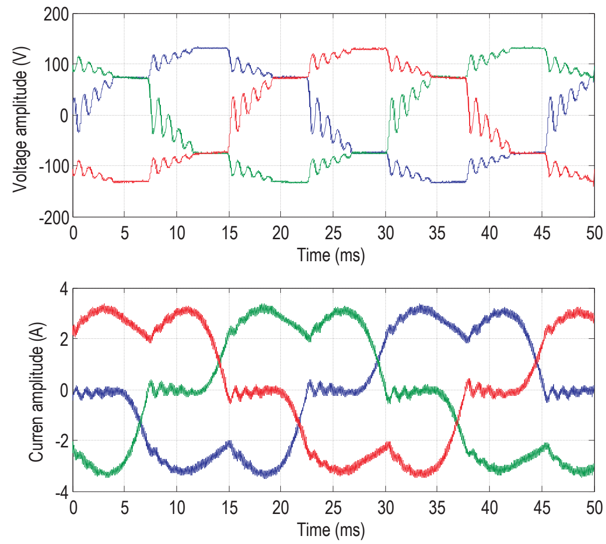


**Figure 8**. Voltage and current at generator terminals.

TABLE I

PERCENTAGE OF POWER LOSSES IN A 3.5 KW SMALL-WIND GENERATOR GRID CONNECTED.

| | electrical machine | rectifier | inverter |
|---|---|---|---|
| min | 2.40 | 1.25 | 2.10 |
| mean | 11.20 | 1.94 | 2.84 |
| max | 18.98 | 2.75 | 4.02 |
| std | 3.145 | 0.487 | 0.607 |

in terms of efficiency. On the opposite side, the rectifier is the element with the best performance. From this point of view, the most important effort has to be focused on the improvement of the electrical machine.

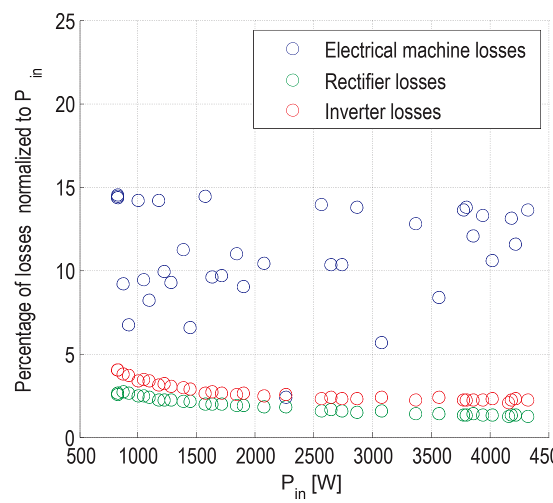


**Figure 9**. Losses vs $P_{in}$ in a 3.5 kW generator.

## 4. CONCLUSIONS

The proposed set-up for PMSM testing meets the features needed for parameter extraction in small wind generators and enable the research of both the machine and the power electronic behaviour in different operational conditions. An improvement of this system can be obtained by including an axial flow fan and accelerometers able to measure the vibrations levels. The test system and methodology have been tested with a commercial grade 3.5 kW small wind generator.


## ACKNOWLEDGEMENT

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