

Development of a grid connected micro wind generator. A practical activity for the course on electric generation with wind energy

José M. Sánchez, María E. Díaz, M. Lafoz, C. Veganzones
Polytechnic University of Madrid
c/ José Gutiérrez Abascal, 2.
Madrid, 28002. Spain
Tel.: +34 / (91) – 335.71.94.
Fax: +34 / (91) – 335.71.97.
E-Mail: chemasanchezgarcia@gmail.com
URL: <http://www.etsii.upm.es>

Keywords

«Windgenerator systems», «Permanent magnet motor», «Generation of electrical energy», «Education methodology».

Abstract

This paper describes a practical activity, part of the renewable energy course where the students have to build their own complete wind generation system, including blades, PM-generator, power electronics and control. After connecting the system to the electric grid the system has been tested during real wind scenarios. The paper will describe the electric part of the work surface-mounted permanent magnet machine design criteria as well as the power electronics part for the power control and the grid connection. A Kalman filter is used for the voltage phase estimation and current commands obtained in order to control active and reactive power. The connection to the grid has been done and active and reactive power has been measured in the system.

Introduction

The course of Electric Energy Generation based on Wind Energy belonging to the Degree on Electric Engineering by the Polytechnic University of Madrid has been recently completed with a practical activity for the students, consisting in the complete development of a micro wind energy generator connected to the grid. This paper describes the activity remarking the educational points derived from it as well as the technical issues. As a result of this work the students have passed through every discipline related to the wind energy generation in terms of the electrical drive. Although the number of hours is very limited, the activity is organized in the way of going directly to the critical design and control aspects, obtaining practical experience from the laboratory mounting and testing stages. The students are grouped in teams of 4 or 5 people and they organize themselves for the different project tasks: blades, generator design and construction, integration of the mechanical parts, power electronics mounting, control programming and finally grid connection.

The wind energy generator construction

Firstly, the blade design has been simplified and it is used a commercial model for not to complicate this part. A dimensional analysis has been done to validate the scaled model together with the generator.

Although there are many options for selecting the electrical generator, a surface mounted permanent magnet synchronous machine has been chosen because of the simplicity for mounting and high power density. The Electrical Machines Laboratory will provide the students with different models for the rotor and stator sheets that take into account the different configurations for the electrical machine

[1][3]. The student has to wind the conductor considering their own design of poles, coils distribution and number of turns.

Rotor can be built following different possibilities based on the magnets distribution over the rotor magnetic sheets. Fig. 1 presents a detail of the stator stack and the final machine prototype

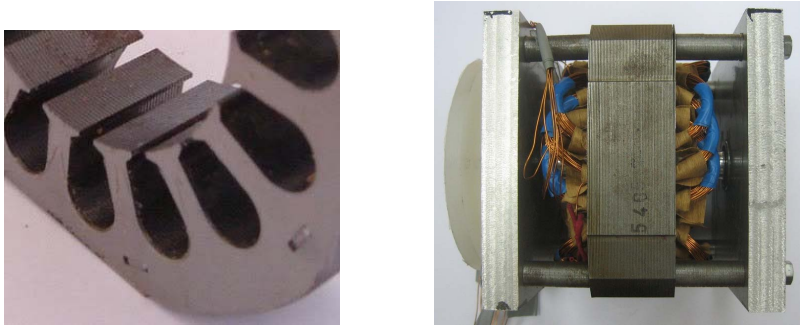


Fig. 1. Magnetic plate models, winding copper and magnets for electrical generator construction.

Considering rotor speed and frequency considerations, a 3-pair of poles machine has proposed. The shape of the rotor will be a polygon of 18-sided base. 2 of each 3 sides will contain a magnet with the scheme that shows Fig. 2.

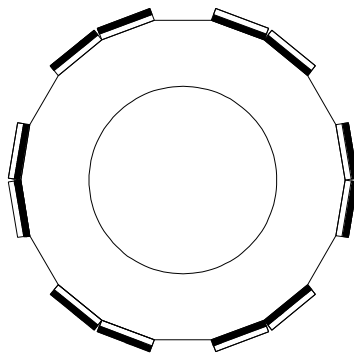


Fig. 2. Rotor configuration with 3 pairs of poles and polygon shape to use conventional magnets

The configuration bellow is chosen for several reasons. For a correct use of the magnets, leaving a small gap between 2 of the poles respect to the air-gap, a magnetic field may flow from one pole to the consecutive one without trespassing the stator and the winding, having no contribution to the generated voltage and torque. Moreover, this underuse of the magnets implies economic losses. As long as the air-gap increases this disperse field also grows.

Moreover, assuming that the air-gap field generated by the magnet follows a trapezoidal distribution, being α_m the fraction of the polar-step covered by the magnet, the first spatial harmonic of this field will have an amplitude presented in eq. 1

$$\frac{4}{\pi} \sin\left(\alpha_m \cdot \frac{\pi}{2}\right) \quad (1)$$

If $\alpha_m = 0.66$ (the implemented case) this harmonic component will have an amplitude 0.86 times the one that would have in the case of filling the pole with the magnet. Increasing the pole surface covered by the magnet, the generation of the first harmonic for mass unit of the magnet is lower.

Last but not least, as long as it is going to be constructed by hand by the students, this separation of the poles will allow an easy placement of the magnets

Fig. 3 presents the difference in the disperse field when the gap between the magnets varies. The left graph shows that the disperse flux increases when the magnets are closer, so a certain amount of distance has been left to reduce it.

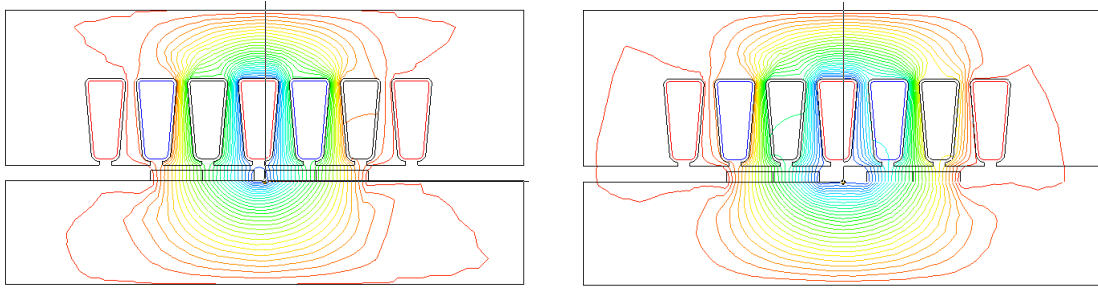


Fig. 3. Influence of the magnets separation in the rotor configuration.

This configuration is chosen to get a uniform air gap and to minimize the disperse flux. A finite elements analysis is done with Maxwell to check the saturation level along the different parts of the machine and presented in Fig. 4.

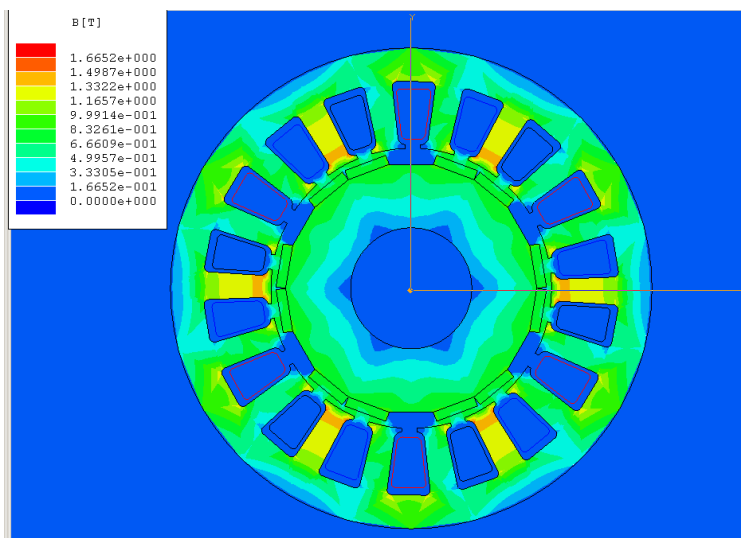


Fig. 4. FEM study of the machine configuration.

With this configuration, the machine can develop a power of around 100W, and it is designed to obtain a line to line voltage of 20V.

The results of this test are the different waveforms of the output voltage shown in Fig. 5. Fig. 66 shows the output machine line voltage after being processed (no real scale in this case).

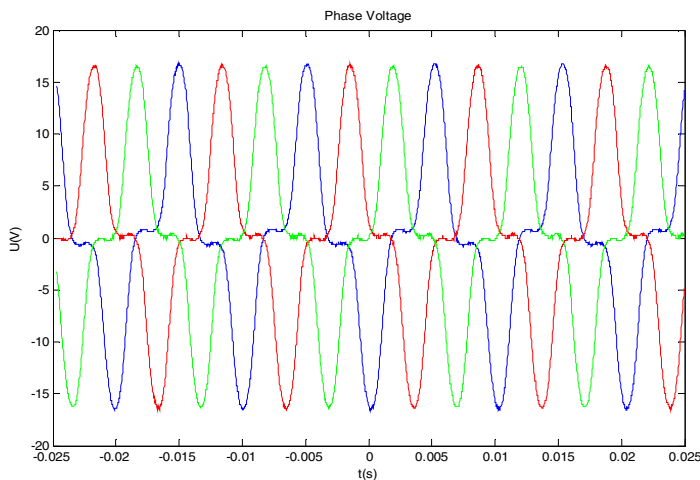


Fig. 5. Phase voltage obtained from the electrical generator.

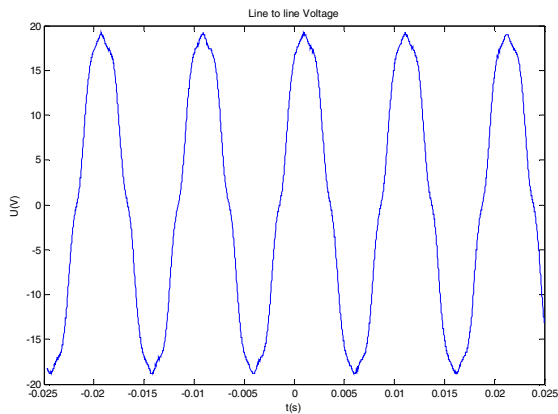


Fig. 6. Line to Line voltage from the electrical generator.

This analysis is not proposed to the students during this course activity. Nevertheless the different options that they can cover during the configuration have been analyzed to check the electromagnetic behaviour ensuring feasible designs.

Power Electronics for grid connection and control platform

The power level is very low and therefore a very low cost topology composed by a step-up converter has been selected [4][6]. The power electronics part consists on a diode rectifier, a DC-boost converter and a full-bridge PWM converter. The generator will be controlled by means of the DC-boost converter following the maximum power working point means while the grid-converter keeps constant the DC-link and maintain the power factor. Fig. 7 presents the power electronics topology and a picture of the first converter prototype used for the experimental tests.

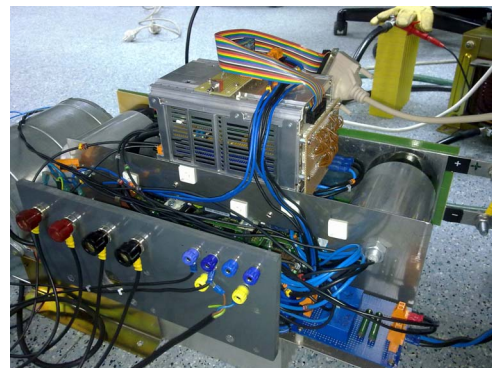
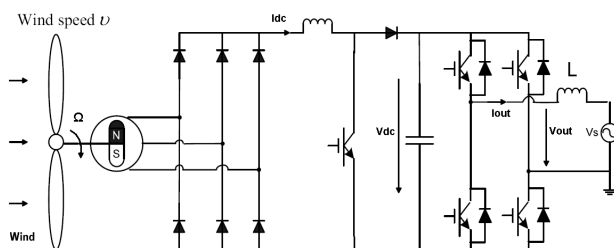


Fig. 7. Power electronics converter

A compact and robust power electronics module (58,5mm, 60gr) based on press pack technology (MiniSkiiP) is being used for this application. The idea is to have a robust and compact module not to be developed by the students. Student will mount the DC-link capacitance, the boost inductance, pre-charge and discharge resistances and grid connection filter in a power PCB presented in Fig 1. The power modules support 600V and 30A, much more that they will use in the practical. However, it has been selected for future increase of power level. The average switching frequency is 5kHz and a first harmonic current of 20kHz will be obtained. Fig. 8 shows the power electronics modules and the power PCB to be mounted.

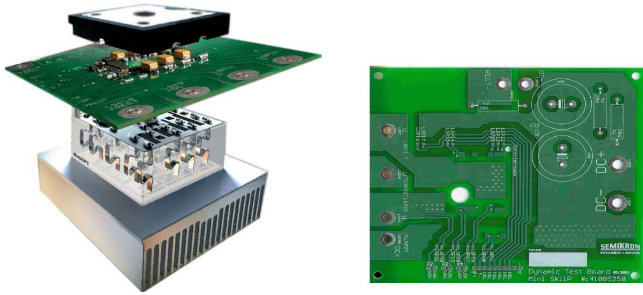


Fig. 8. Power electronics converter

The digital signal processor which controls the power electronics is the DSP Texas TMS320F2812. This DSP is included in the evaluation board eZdsp™ F2812 that is used as a platform to develop, evaluate and run DSP's software. This board has 32 digital input/output pins (12 of which can be used as PWM outputs), 16 analog inputs, a 150 MHz crystal oscillator, 256 kB of program memory, 36 kB of RAM memory and RS232 connection. The TMS320F2812 Texas DSP has an important characteristic, it's the RTDX communication (Real Time Data Exchange). RTDX set communication between DSP and PC to show variables of the algorithm and change some parameters real-time, allowing the user to tune up the system during the performance. The user can create a GUI (Graphical User Interface) using Matlab toolbox GUIDE to monitor the variable and generate dials to modify parameters.

Finally, several voltages can be selected for the power transformer to connect to the grid, since the generated voltage will be lower than the 230V of the single-phase connection point.

Operation and control strategy

The system operation will begin when the wind turbine gets a minimum speed due to the wind. Then, the system will be connected to the grid after a previous DC-link pre-charge operation that will be programmed at the control device.

Fig. 9 presents the complete system topology as well as the global control schema.

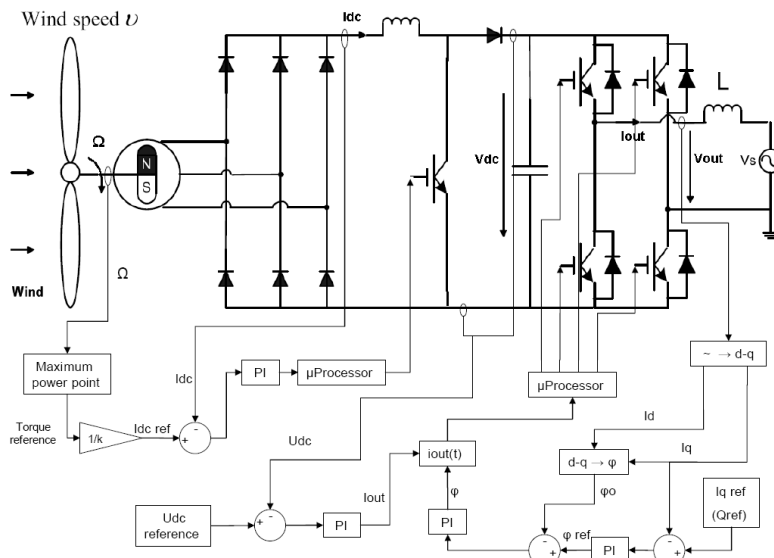


Fig. 9. Control strategy for both DC-boost converter and grid-connection PWM converter.

The control strategy has essentially two parts: the first part controls the rectifier output current (I_{dc}). It allows to manage the generator torque depending on the wind conditions, controlling the wind turbine torque and rotation speed [2]. The DC/DC converter is controlled by means of a hysteresis-band strategy, setting a reference current and two boundaries, depending on the wind turbine torque-speed curve, stored in a look-up table. By this way we can choose the optimum operation point, trying to get the maximum power from the wind turbine. This control is not optimum from the point of view of the generator (in this case a permanent magnet synchronous machine is used) since the current is not controlled to be with a certain phase respect to the back e.m.f. No control criteria for maximum torque per ampere [5] or similar can be achieved with a rectifier connected to the generator. Nevertheless, the operation point is close enough to the optimum for a low power generator.

The second part controls the output AC current of grid-connected PWM converter (I_{out}) generating a PWM output voltage (V_{out}). This voltage is defined whit the d-q components, where d component represents the active power and q component the reactive power that the inverter gives to the grid. The control algorithm keeps constant the voltage on the output of the DC-boost converter (V_{dc}), by modifying the d component of V_{out} . Reactive power is controlled setting a reference for the q component of I_{out} (I_q), then the control takes I_q to the reference changing the q component of V_{out} . For this control the grid's angle and output current's d-q components are needed, each one will be calculated using Kalman filter. The Kalman filter takes a sinusoidal wave and eliminates the wave's noise, then it generates a second wave similar to the filtered one but delayed $\pi/2$ rad.

Kalman filters achieve a better dynamic behaviour with a minimum calculation time consumption at the DSP.

Fig. 10 shows how from the voltage measurement a pair of references I_x, I_y are determined for the control.

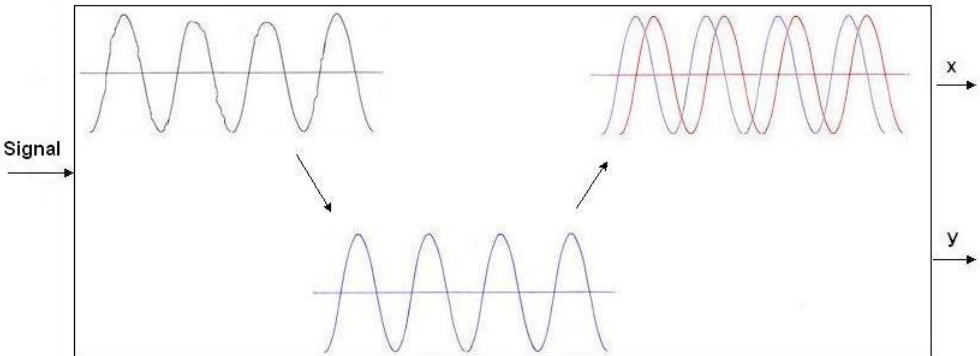


Fig. 10. Kalman filter implementation scheme

Kalman filter generates two similar waves delayed $\pi/2$ rad, the first one can be considered as the x component of the original wave and the second one as the y component. Now the angle can be obtained calculating the arctangent of x/y and the d-q components of the original wave can be obtained using Clark-Park transformation. So now the grid voltage's angle and the output current's d-q components can be calculated.

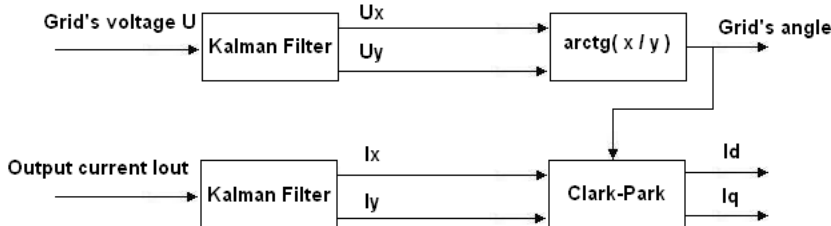


Fig. 11. From output voltage and current, I_d and I_q are obtained.

Experimental tests for the complete system and energy validation

Once the system has been assembled and the control tested by simulation, each student team will connect their wind generator to the electrical grid, validating it in a laboratory workbench. A fan will be used to create a certain wind speed, given as preliminary specification, and that the student will have to use as parameter for selection of blades dimensions and the generator design, related to the rotational speed and voltage. The workbench for testing the system also includes the necessary devices for measuring wind speed, rotational speed, output voltage and current and power and reactive power. The system will be operated considering that when the speed achieves a minimum speed, the system has to have programmed a protocol for the grid connection.

Fig. 12 includes a picture of the testing workbench used for the experiments. A power analyser will be used to measure the output power, current, energy and harmonic distortion to evaluate the operation parameters for every device.



Fig. 12. Experimental workbench for testing system at the Lab.

Experimental results

The converter has been connected to the grid to check the correct performance of the system to sudden torque changes. Fig. 13 contains the evolution of the different variables (I_{dc} , U_{dc} and I_{ac}), to obtain and to show the parameter revolution. The pictures have been recorded from the GUI interface that controls the system from a PC.

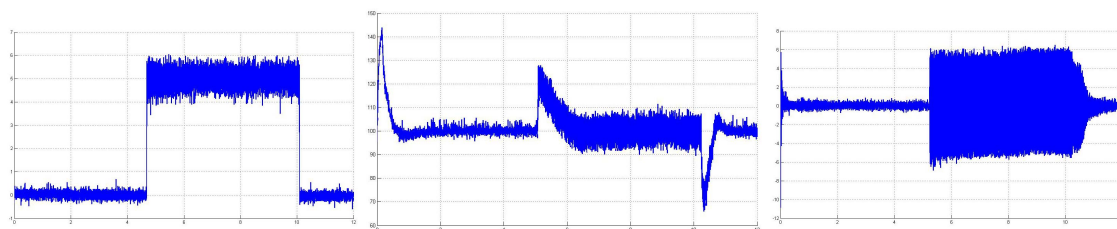


Fig. 14. I_{dc} , U_{dc} and I_{ac} for twelve seconds of operation

One connected to the grid, voltage and power have been presented in figure 15 for a very few power situation around 100W.

Figure 16 shows a sudden step of I_{dc} current that would come from the turbine control to get the maximum power operation point (MPP). At the right picture commutation of the current at 5kHz is presented, controlled by means of hysteresis-band as explained before.

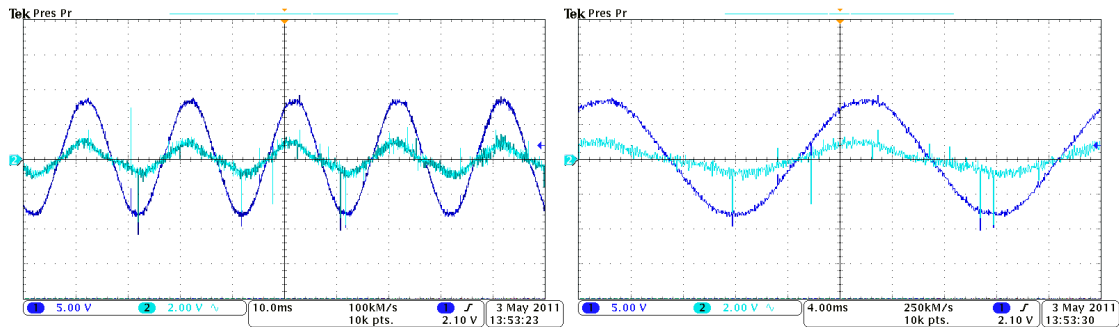


Fig. 15. I_{out} (light blue) and U_{ac} (dark blue)

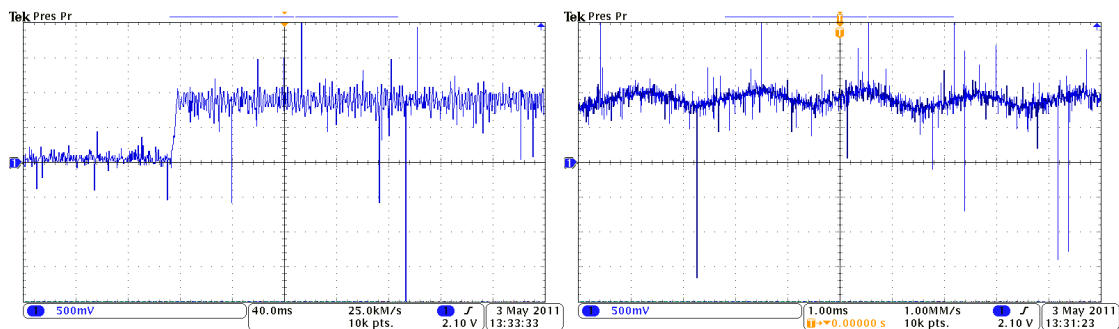


Fig. 16. Step of I_{dc} current and detail of I_{dc} shape

Conclusion

The paper describes the complete process that the students will develop from defining the type of generator they want to build, building it, mounting the power electronics converter, programming the complete control strategy, testing the generator and connecting it to the electric grid to measure the power delivered to it.

It results very pleasing for the student to realize that the system that they have built by their own is able to transform wind energy into electrical energy and although they are not achieving a great efficiency they know perfectly how is working every stage of the energy transformation process.

References

- [1] Chen, J.T.; Zhu, Z.Q. "Winding Configurations and Optimal Stator and Rotor Pole Combination of Flux-Switching PM Brushless AC Machines"; IEEE Transactions on Energy Conversion, Volume: 25, Issue: 2, 2010, Page(s): 293 – 302.
- [2] Haraguchi, H. Morimoto, S. Sanada, M. "Suitable design of a PMSG for a small-scale wind power generator"., 2009. International Conference on Electrical Machines and Systems (ICEM'09) Tokyo. 15-18 Nov. 2009. Pages:1 – 6.
- [3] Binder, A.; Schneider, T "Permanent magnet synchronous generators for regenerative energy conversion - a survey". European Conference on Power Electronics and Applications, 2005 (EPE.2005)
- [4] Muhammad H. Rashid. Power Electronics Handbook.. Elsevier Editions 2007.
- [5] S. Heier, "Grid Integration of Wind Energy Conversion Systems". Chichester, Sussex (UK): John Wiley & sons, 1998.
- [6] Jansen, Helle, Blaabjerg, Ritchie, Munk-Nielsen, Bindner, Sorensen and Bak-Jensen. "Conceptual survey of generators and power electronics for wind turbines". Riso National Laboratory, Roskilde, Denmark. December 2001.