Cosimulation of a wind turbine with doubly fed induction generator with PSCAD and SIMULINK.

Aitor MILO, Ana Isabel MARTINEZ - Ikerlan.

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IKERLAN is divided into different units which are, in turn, subdivided into various knowledge areas: one of these areas is the Control Engineering area.

Nowadays, the Engineering Control area works in two main research lines:

- Virtual prototyping for complex systems control.
- Distributed Generation (Micro-grids and Wind Farms)

This article describes one of the works developed in the frameworks of the latter research line, i.e., Distributed Generation.

1. Introduction

The decisive role played by the simulation in the power systems planning and operation phases is well known.

Likewise, the increasing trend towards the liberalization of electric power markets in the world has led to a quantum leap in the number of agents', the increase of the transactions not planned in a centralized way and, consequently, an intensive use of the existing networks. All this implies an evident increasing need for the use of this type of simulation tool to guarantee the reliability of the electrical system.

This article is part of a global project for the study of the impact of integrating wind farms in the grid.

The study has been developed on the PSCAD electromagnetic transient simulation software.

This work describes the development of a model of wind turbine equipped with a doubly fed induction generator (DFIG) using the **co-simulation** of the simulation software's PSCAD and MATLAB-SIMULINK.

The model incorporates an active crowbar protection to avoid immediate disconnection of the generator when a disturbance occurs in the grid.

The control also incorporates the blocking and re-start sequences of the rotor converter.

The aim of this work is to analyze the impact of grid voltage fluctuations over the wind turbine and to validate the PSCAD software for this type of study.

To achieve this aim, simplified models of the different components of a wind turbine have been made to adapt them to the needs of the study.

2. Co-Simulation PSCAD & MATLAB-SIMULINK

To achieve the aim of the project, we use one of the main advantages of PSCAD: co-simulation with MATLAB-SIMULINK. The simplified model used, shown in figure 1, is the one implemented for the individual wind turbine.

The simplified model includes the turbine shaft model, the DFIG, the simplified models of converters, the protection system, the wind farm+substation transformer model and the equivalent grid model. All these elements are implemented in PSCAD and the generator converters control is developed in MATLAB/SIMULINK.

This partition of the system allows us to validate the algorithms of generator converters controls developed in MATLAB/SIMULINK prior to implementing them in a real-world application.

3. Mechanical model

To achieve precise analysis of the dynamic behaviour of the wind turbine during grid disturbances, it is recommended to use the two masses model to represent the generator – turbine shaft system.

Figure 3 shows the used physical model of the generator - turbine mechanical system.

The PSCAD software library provides a dedicated model of this system: the "Torsional Shaft Model". This component can simulate the dynamics of up to 6 masses connected to a single rotating shaft.

Figure 1: Wind Farm.

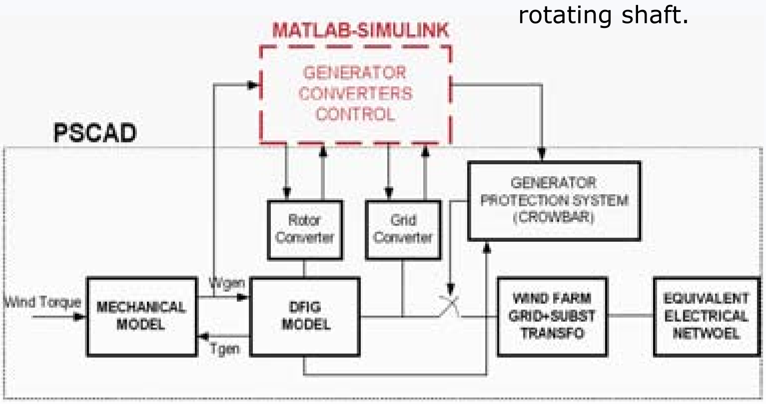

Figure 2: Simplified wind turbine model with interface to grid model.

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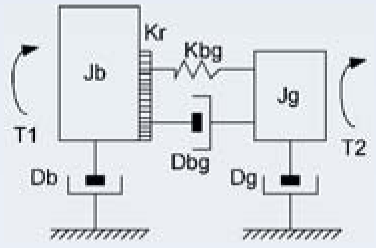

Figure 3: Two masses model.

Jb: Wind turbine rotor Inertia.
Jg: Generator rotor Inertia.
Kr: Gearbox.
Kbg: Shaft stiffness.
Dbg: Mutual Damping turbine-generator coefficient.
Db: Turbine rotor Damping coefficient.
Dg: Generator rotor Damping coefficient.

In our system we have used the "Torsional Shaft Model" component of PSCAD and we have developed, in blocks, the physical model of figure 3 (figure 4). The results obtained were identical in both cases.

4. Electric model

For the DFIG component, we use the "Wound rotor Induction Machine" component of the PSCAD library. The rest of the components, resistors and inductors, wind turbine transformer and wind park transformer, simplified model of the grid, power meters, current meters and volt meters for measuring the electrical magnitudes for controlling, and breakers for the performances of the protections, are also configured using PSCAD's library.

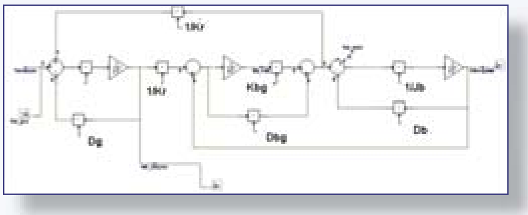

Figure 4: Two masses model.

PSCAD allows the development of personalized controls, in FORTRAN, which can interact with the rest of the components in the simulation. Taking advantage of this possibility, personalized controls have been developed to integrate the protections of the wind turbine. This protection system is developed in the block "Crowbar protection". This block integrates a function in FORTRAN that manages the activation sequences of generator protection.

The main goal of this protection is to avoid the immediate disconnection of the wind turbine when a disturbance appears in the grid.

5. Simulation results

Figure 5 shows the developed wind turbine model.

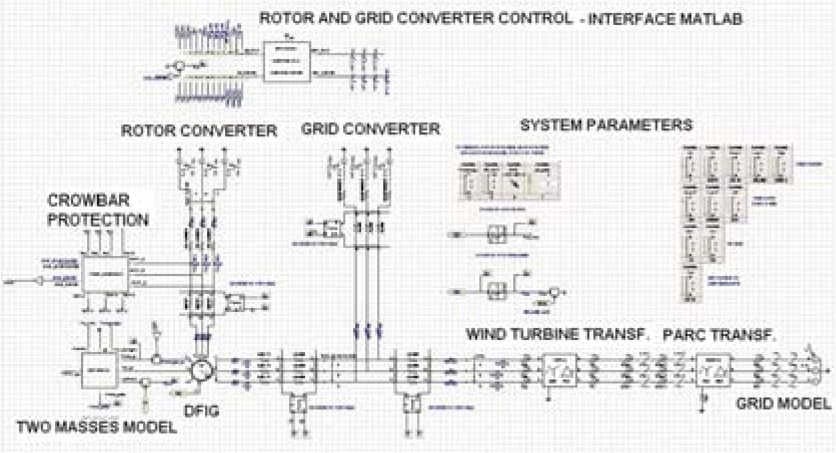

Figure 5: Wind turbine model.

When the wind turbine is at rated operation, a voltage drop (figure 6) is applied at the access of the wind park.

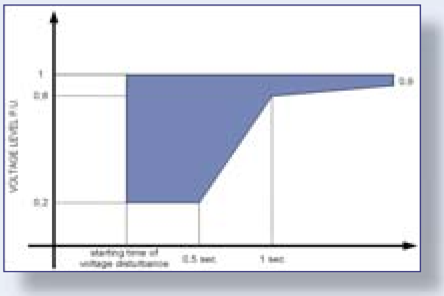

Figure 6: Voltage drop.

When the fault occurs, the rotor control disconnects since this disconnection causes the rotor to accelerate. When the rotor current or the DC-link voltage exceed the limits, the protection is activated. The crowbar protection and the generator control are able to reduce the rotor current and to maintain the DC-link inside the security limits. Once the fault is cleared, the rotor control restores the wind turbine's normal operation. The corresponding simulation results are shown in figure 7.

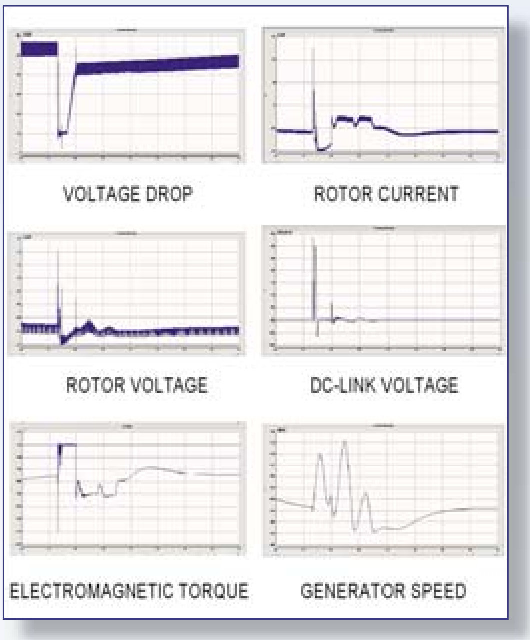

Figure 7: Simulations results.

6. Conclusion

The results obtained with the model developed in PSCAD-MATLAB shows the validity of this tool for the study of transient phenomena in wind turbines.

Despite the disadvantage that the slowing down of the simulation entails by using cosimulation, it is interesting to observe the behaviour of the control algorithms that will later be incorporated into the wind turbine control hardware.

This step will allow not only the simulation acceleration but also the multiplicity of wind generator models. This multiplicity will contribute to study the impact of the integration of wind farms in the electrical grid and vice versa.

Axial Flux Permanent Magnet Generator for Wind Power Applications.

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Small-scale wind power plants are an attractive choice to generate electrical power on rural areas where the installation of the distribution network is not economically reasonable. In such locations, e.g. on small islands, wind power plants or solar sells or both together can be used to charge batteries or in direct heating purposes. Concerning stand-alone windmill applications the rated power of which is below 10 kW, the use of permanent magnet machines as a generator has been studied intensively during the last decades. Recently, Lappeenranta University of Technology design and manufactured low-speed axial flux permanent magnet generator designed to use in a 1.6 kW windmill application. During the design of the generator, FLUX 3D finite element software was an essential tool to verify the performance of the design before building up the prototype generator. The prototype generator is installed to the pilot power plant, which has been on operation since November 2003. Figure 1 presents the experimental power plant and illustrates the used generator concept.

Figure 1. Experimental wind power plant and the used single sided axial flux permanent magnet generator.

Axial flux PMM with duple layer concentrated winding

The generator was realized with a duple layer concentrated winding. Concentrated stator windings are an effective solution to reduce Joule's losses in low-speed permanent magnet machines, thus to improve the overall efficiency of the machine. By combining the concentrated winding and axial flux permanent magnet machine, which offers a high torque to volume ratio, a high performance electrical machine is obtained. Short end-windings decrease also the overall external diameter of the axial flux machine. Thereby the overall space, required by the generator, is decreased which is a highly desired feature for the wind power generators.

Permanent magnets are Nd-Fe-B magnets and are installed directly on the surface of the solid iron rotor disk. As a drawback of the single sided construction, illustrated in figure 1, there appears quite a large uncompensated attractive force between the rotor and the stator, which has to take into account while design the mechanics. According to the performed 3D finite element analysis the attractive force between the stator and rotor is 6800 N for the generator under no-load condition with nominal air gap.

FE-model of the machine

For the point of the modeling, the geometry of the axial flux machine is an actual 3D problem, which cannot be reduced to the 2D plane if an accurate electromagnetic analysis is required. Thereby, the machine is modeled as a 3D problem by using FLUX 3D FE-software. The used FE-model is illustrated in figure 2 as well as the air gap side view of actual prototype machine. Due to the used consternated 3-phase winding, one cannot model only one pole since one rotor pole does not represent the symmetry on a stator side as it does with conventional integral slot 3-phase windings. In this case the whole geometry was described even though the size of the FE-problem comes very large. The total amount of second order volume elements used in a FE-model was 116878. Computations were performed with mechanical sets in order to model the rotation and with circuit coupling. 3D FEA was performed both under load and no-load conditions giving

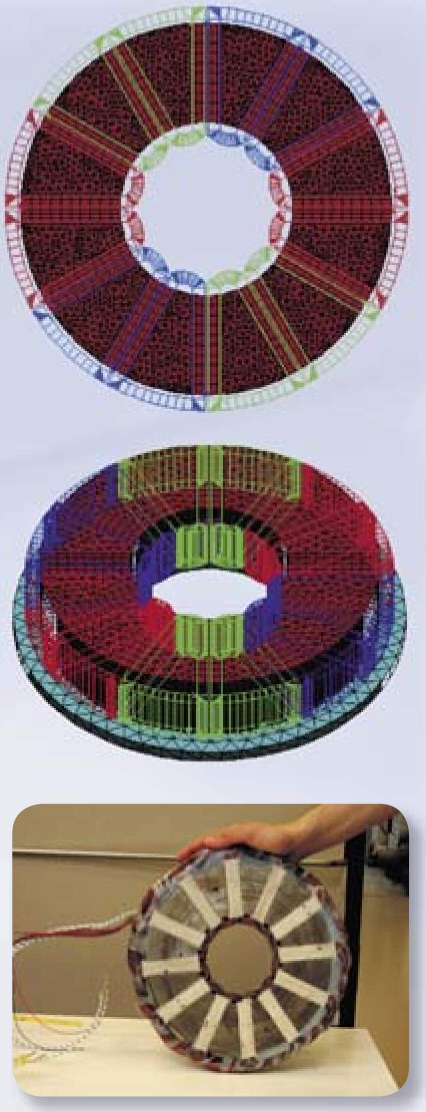

Figure 2. The used 3D FE-model and an actual generator stator presented from the air gap side. The used generator structure includes 12 slots in a stator and 14 poles in a rotor.

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Axial Flux Permanent Magnet Generator for Wind Power Applications. (continued)

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information, for example, from phase voltages, torque ripple and torque production capability of the generator.

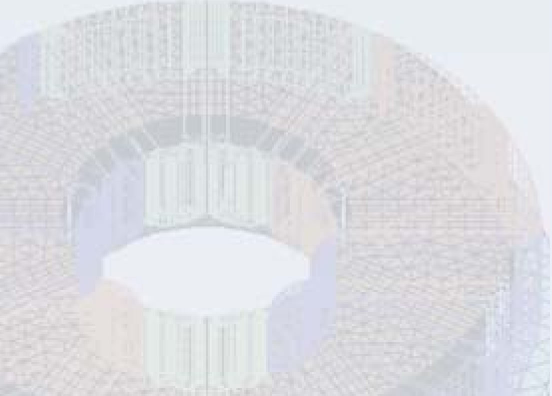
Results

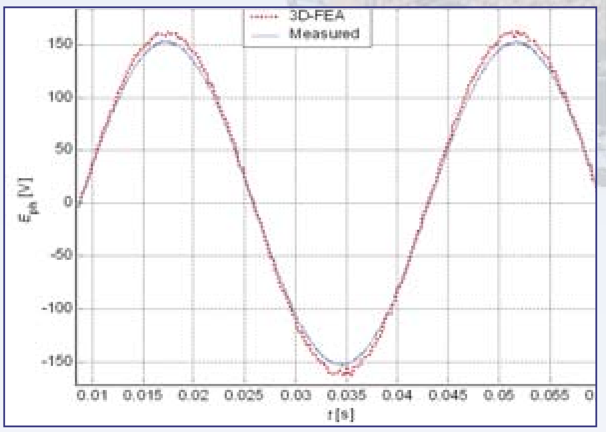
Since the 3D-FE problem was coupled to the circuit, it was possible to analyse the performance of the machine in actual operation conditions by introducing a time transient FE-model. Figure 3 compares the measured no-load phase voltage (for the hot machine) to the calculated one as well as measured and calculated phase currents under load condition. The similarity between the obtained curvatures is excellent, however the amplitudes of the measured ones are lower. This is mainly related to the permanent magnet operation temperature; it is slightly higher than the calculated one, giving actually lower B_r for the Nd-Fe-B magnet than the used one was in a FE-model.

One important property for the direct-driven wind power generator is a torque quality. Low cogging torque is required in order to allow the turbine start easily even with low wind speeds. Secondly, low amplitude for the torque pulsations is required also under load condition. Even though the presented design uses totally open slots, which were introduced due to the extreme simplicity of the manufacturing of the winding, a low torque ripple was achieved. Figure 4 presents the obtained electromagnetic torque from the computation under load condition. The peak-to-peak value of torque ripple is around 3 % from the rated torque, which can be considered as a good result for the structure used.

Conclusions

A direct drive axial flux PM generator designed to small-scale wind power application was described shortly. The 3D-finite element analysis, performed by using FLUX 3D, was an essential tool to verify the performance of the generator before manufacturing of the prototype machine. A comparison between the measurements and the results offered by the 3D-FEA shows good agreement. Even though the 3D-FE model for the fractionally wound PM machine is relatively large, it can be solved in a reasonable time and thus it offers very detail and useful information for the designer about the performance of the design.





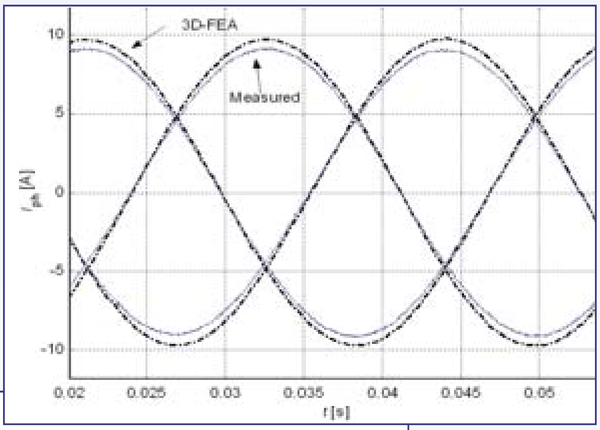


Figure 3. Measured and calculated phase voltage and measured and calculated phase currents with resistive load.

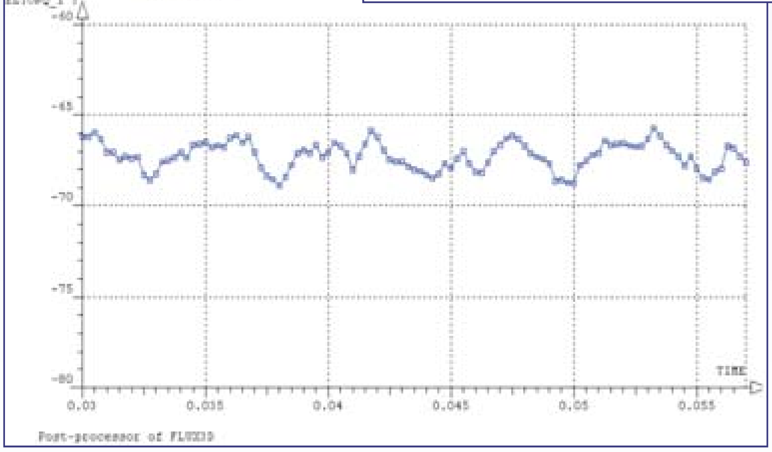


Figure 4. Electromagnetic torque of the generator with resistive load.