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Published in:
Complexity in Engineering

Link to article, DOI:
10.1109/COMPENG.2010.27

Publication date:
2010

Document Version
Publisher's PDF, also known as Version of record

2010 Complexity in Engineering

Modeling of DFIG Wind Turbine and Lithium Ion Energy Storage System

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***Abstract*- The paper is aimed at describing the dynamic models of DFIG equipped wind turbine and Lithium Ion Energy System. The purpose of the energy storage system is to be coupled to the wind generation system in order to smooth its power output. Depending on the size of the storage system different task can be performed, starting from short term fluctuation leveling and power quality, getting to primary frequency-power regulation and, in case on large sizing, granting day-ahead turbines dispatching.**

***Index Terms* – Renewable Generation, Embedded Generation, Wind Power, DFIG, Lithium Ion, Storage.**

I. INTRODUCTION

Significant changes introduced by the deregulation of electricity markets, driven by sustainable development and therefore the use of cleaner fuels, development of technology generation for small and medium-size and investment in renewable energy sector are increasingly significantly. The power system is facing an evolution from traditional concept of few localized power plants through a meshed system with an increase of the embedded generators. So, the medium voltage networks, designed to distribute power from transmission network to local loads, are evolving from a passive system, where power flows are mono-directional, to an active concept, where the presence of numerous generators can cause reverse power flows to the main grid.

Moreover some typologies of this embedded generators are fed by renewable sources like wind and sunlight. Their main drawback, a part the low energy density that implies large space requirement, is their unscheduled behaviour. That means to have for example maximum production during minimum demand, causing bottlenecks and overvoltage situations in most critical section of the grid [1].

Hence the presence of energy storage system could give some effort to the system. Of course the cost per Wh stored is quite high and so it is not economical feasible install huge amount of batteries. Depending on the duty it is asked to fulfill, the storage system size can vary considerably. For example, considering wind energy issues related to power fluctuation could be mitigated by coupling the wind farm to a system storage. Another topic, getting more and more important with the growth of the percentage of wind power in power system, is ancillary service provision: a non-wasting energy primary frequency/power regulation could be realized, the size of the battery is related to the band power (% of the plant power) devoted to this task [2].

At the present the dynamic models of both stand alone wind turbine and battery have been detailed and analyzed in a reference test grid. Their brief description is proposed in the next two paragraphs. The main aim is to describe the benefits that the storage system can have on a wind turbines plant. The dynamic behaviour of a system composed by a wind power plant coupled with the storage system will be so analyzed in DIgSILENT simulation environment [3].

II. DFIG WIND TURBINE

A. Description of the Model

The analyzed turbine is a 850 kW @ 13 m/s equipped DFIG. The plant considered is composed by three turbines located about 300 meters each other and sited in an hilly terrain. The electric diagram of the wind turbine is shown in Fig. 1.

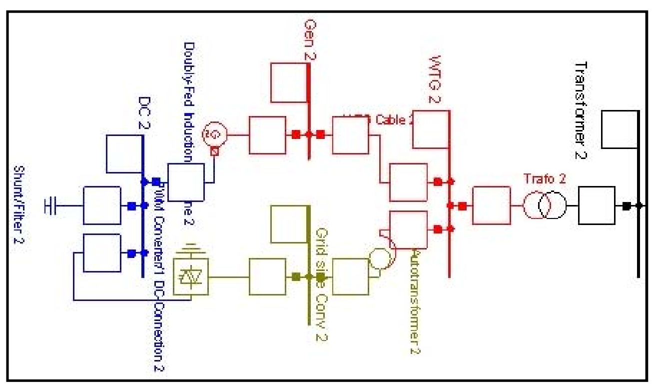

Fig. 1. Wind turbine electric diagram

The stator windings of the asynchronous generator are connected to the bus WTG (in red), the rotor windings instead are connected to the rotor side converter. The DC side of the converters (both rotor and grid one) are connected via a DC link (in blue). The AC connection of the

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DOI 10.1109/COMPENG.2010.27

grid side converter is wired, via an autotransformer, to the bus WTG. At last there is the machine transformer.
Fig. 2 shows the blocks diagram that describes the prime mover dynamics and the control system of the DFIG&Rotor Side Converter.

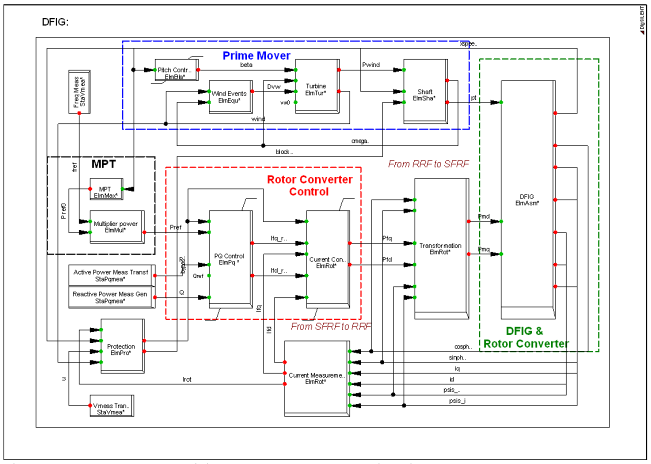

Fig. 2. DFIG&Rotor Side Converter Control Scheme

The blocks can be regrouped into four macro-blocks that describe, in order from left to right, the dynamics of the:

a) Maximum Power Tracking (black rectangle)
b) Prime Mover (blue one)
c) Rotor Converter Control (red one)
d) Generator&Rotor Converter (green one)

Next figure, Fig. 3, shows the blocks diagram that describes the control system of the Grid Side Converter.

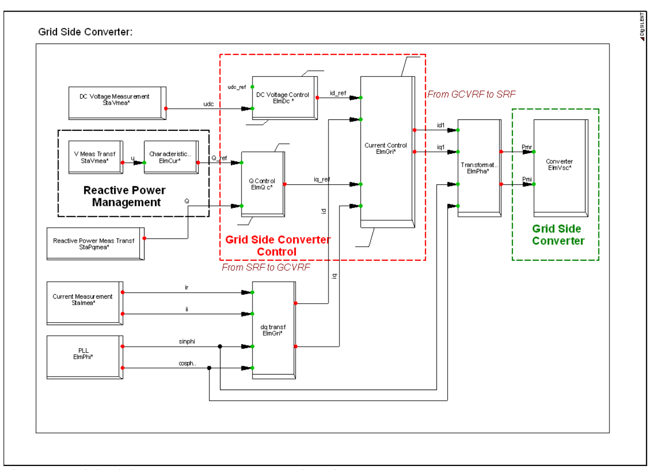

Fig. 3. Grid Side Converter Control Scheme

Here the blocks can be regrouped into three macro-blocks that simulate, in order from left to right, the dynamics of the:

a) Reactive Power Management (black rectangle)
b) Grid Side Converter Control (red one)
c) Grid Side Converter (green one)

Other blocks contain measurement points, matrix reference transformation and the protection system.

B. Simulations

The results hereafter show the behaviour of the simulated turbine in condition of an hypothetical wind with low turbulence. Fig. 4 shows the power output of 3 wind turbine in function of the three wind speeds shown in the first following diagram. To take into account the distance between the turbines and hence the fact that the three hubs will not see the same wind, it is assumed that the same wind is delayed of 20 seconds between each turbine. As it can be seen the total plant power production benefits from these delays, its course in fact is more smoothed than the course of the single turbine power production. Further improvements can be obtained by the coupling of storage system.

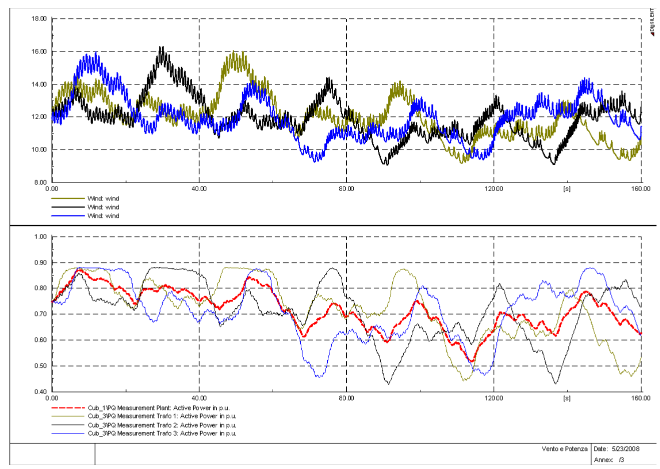

Fig. 4. Wind speeds (in m/s); Active power production of the single turbine and mean power output (bolder line)

III. LITHIUM ION BATTERY

A. Description of the Model

The storage system is modeled with the following assumption:

1. The typology analyzed is based on lithium ion.
2. Battery parameters do not depend on temperature.
3. The initialization is done by setting the value of the state of charge (SOC), the value of voltage follows.
4. No auto-discharge considered.
5. Resistances of the equivalent circuit are not function of current direction.

Equivalent circuit is shown in Fig. 5. This circuit has a dc source that is function of the SOC as described by the following expression [5]:

$$V_{oc}(SOC) = -1{,}031 * e^{35*SOC} + 3{,}685 + 0{,}2156 * SOC - 0{,}1178 * SOC^2 + 0{,}3201 * SOC^3$$

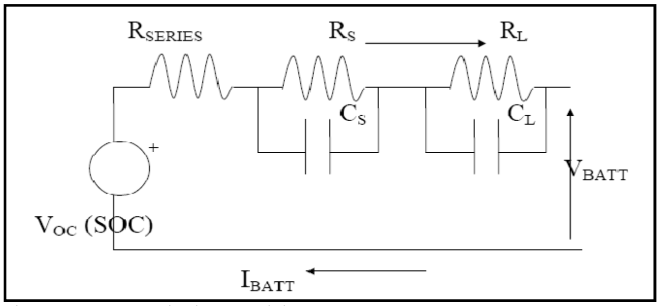

Fig. 5. Battery Equivalent Model

Also the parameter R_{series} R_s e C_s, R_L e C_L that take in account the electric dynamics are function of the SOC. Fig. 6 reports the electric scheme of the storage system.

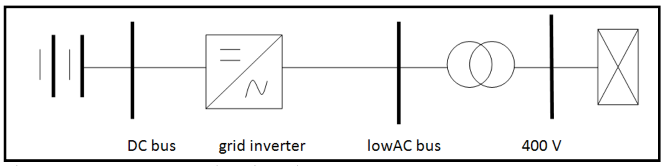

Fig. 6. Battery System Electric Scheme

Fig. 7 shows instead part of the control scheme realized in DIgSILENT environment to characterize the battery equivalent model.

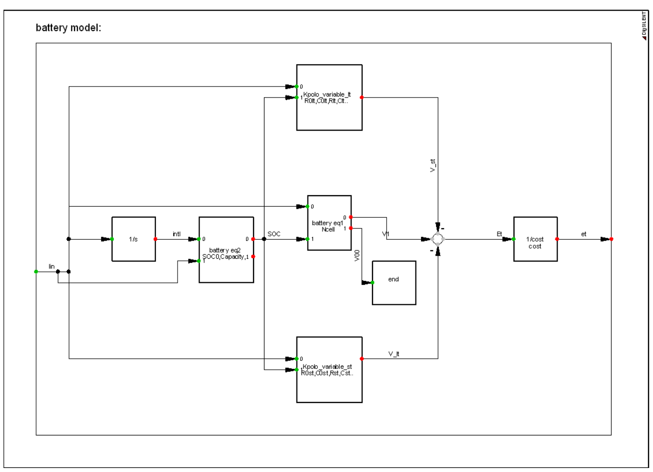

Fig. 7. FEM Battery modeling

B. Simulations

The behaviour of the battery charging and discharging is tested subsequently. Fig. 8 report the simulation results regarding the power output (positive if produced – negative if adsorbed) during a charging and discharging task.

The second diagram reports the behaviour of the cell voltage (3,6 V nominal), needed to have information concerning the state of charge.

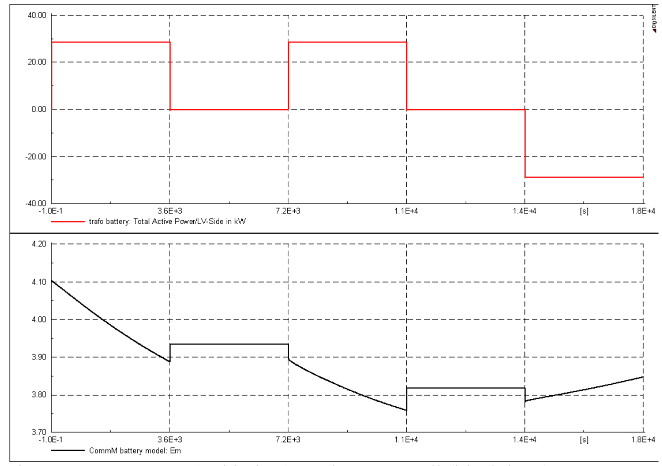

Fig. 8. Power Output (red in kW); Voltage per cell (black in V)

IV. CONCLUSIONS

The dynamic models of wind turbine DFIG equipped and Lithium Ion Battery have been described and characterized in DIgSILENT environment. Further studies will be focused on the coupling of the two systems in order to improve wind turbine outputs quality and eventually have the wind turbine to provide ancillary services.

The economic issues of course have not to be forgotten and the sizing of the storage has to keep in account the reward for the task it has been designed for.

REFERENCES

[1] S. Grillo, M. Marinelli, E. Pasca, G. Petretto, F. Silvestro, "Characterization of Wind and Solar generation and their influence on distribution network performances", 44th UPEC, 2009

[2] R. J. Thomas, "Putting an Action Plan in Place", IEEE power&energy magazine, July/August 2009

[3] DIgSILENT, Technical Documentation, "DPL Manual", 2003

[4] A. D. Hansen, C. Jauch, P. Sørensen, F. Iov, F. Blaabjerg, "Dynamic wind turbine models in power system simulation tool DIgSILENT (v 12.0)", Risø National Laboratory, December 2003

[5] M. Chen, A. Rincon – Mora, "Accurate Electrical Battery Model Capable of Predicting Runtime and I–V Performance", IEEE Transactions on Energy Conversion, vol. 21, no. 2, June 2006