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Real time simulation applied to the implementation of generic wind turbine models

A. Lorenzo-Bonache, R. Villena-Ruiz, A. Honrubia-Escribano and E. Gómez-Lázaro

Department of Wind Energy and Power Systems
Renewable Energy Research Institute and DIEEAC/EDII-AB
Universidad de Castilla-La Mancha, 02071 Albacete, Spain
Phone/Fax number: +34 926 599200; ext=96259, e-mail: **Alberto.Lorenzo@uclm.es**

Abstract. This paper presents the use of real time simulation applied to the development of generic wind turbine models, defined by IEC 61400-27-1, which are used in order to obtain an accurate behaviour under power system stability concerns without the need of many computation resources.

These models have been implemented to be simulated in a real-time simulator. In contrast with conventional simulation tools, real time simulation allows dynamic interaction with the model, and hence the adjustment of models is faster and easier. It is also presented how physical devices can be implemented within the model aiming at an improved interaction approach.

Key words

IEC 61400-27-1, Real Time Simulation, Standard models, Wind turbines.

1. Introduction

According to the Global Wind Energy Council, in 2015, there were installed around 433 GW of wind energy around the world [1]. This means that wind power is a mature technology.

However, as a renewable energy resource, wind energy is difficult to manage, due to the unpredictable behaviour of its primary energy. Renewable energy control centers (such as CECRE in Spain) and research institutes, need new tools and resources to make possible the integration of wind energy into the electric system [2]. One of the most usual tools is the simulation of wind turbines and wind farms, in order to study the influence of these renewable energy sources into power system and grid stability [3].

Simulation is widely use to anticipate the behaviour of wind farms around the world. Problems such as voltage sags, power ramps, storms… must be simulated in order to prepare the electric system facing those issues [4].

Since some models may be extremely complex, traditional simulation methods are not powerful enough to cover current power system needs. In this sense, new tools, such as real time simulators, are more and more used nowadays.

In this paper, it is shown how generic wind turbine models, which are based on the guidelines imposed by the recently published IEC 61400-27-1, have been implemented [5]. Simulations will be conducted by a real time simulator, and the addition of physical devices is also included.

2. Generic wind turbine models

Four types of generic wind turbine (WT) models, which represent the most installed WT technologies, are defined by IEC 61400-27-1 [6]–[8]:

- Type 1: WT with directly grid connected asynchronous generator with fixed rotor resistance (typically squirrel cage).
- Type 2: WT with directly grid connected asynchronous generator with variable rotor resistance.
- Type 3: WT with doubly-fed asynchronous generator (directly connected stator and rotor connected through power converter).
- Type 4: WT connected to the grid through a full size power converter.

Generic models are designed to be used in power system stability analysis. Its main purpose is to obtain an enough accurate response of the WT, without the complexity of more detailed models.

Generic WT model parameters can be specified in order to adjust its response to a specific model of WT. Parameters can be obtained from manufacturers or adjusted manually to fit a desired response [9], [10].

In the present work, generic WT models have been modelled into MATLAB/Simulink [11], as the real time simulator uses this program as its basis. Later, these models must be adapted to the characteristics of real time simulation.

3. Real time simulation

A. Introduction to real time simulation

Real time simulation (RTS) responds to the need to improve conventional simulation methods. The flexibility which offers modelling in Simulink turns RTS in a tool which can fit with almost any engineering application. RTS can be applied to multiple areas, such as power generation, automotive, ships, trains, aerospace, mechatronics…

While a computer is conducting a simulation, it is usually running a lot of processes, which can interfere with simulation, making it slower. A real time simulator is a machine which is specifically working in the simulation of a model. It allows not only to simulate faster than a conventional computer, but also to establish a link between simulation time and real time [12].

Real time simulation allows fast prototyping. Parameters can be changed while simulation is running, and hence, the response of the model can be analysed in real time, without stopping and restarting the simulation.

The interaction with real world devices makes possible the simulation of the controller of a plant into the real time simulator, while it is connected to the physical plant. This is known as rapid control prototyping (RCP) and it is shown in Figure 1.

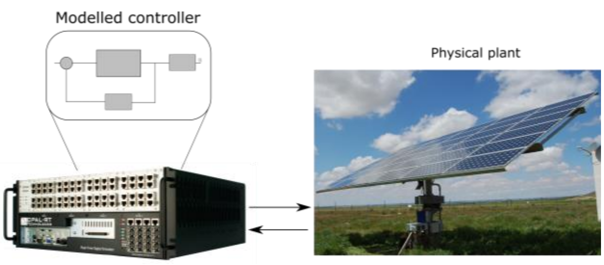

Figure 1: Rapid Control Prototyping

Hardware-in-the-Loop simulation (HIL), happens if a physical controller is connected to a plant modelled into the real time simulator [13]. This is shown in Figure 2. This kind of simulation is very useful in order to make a fine adjustment of the physical controller without stopping the plant.

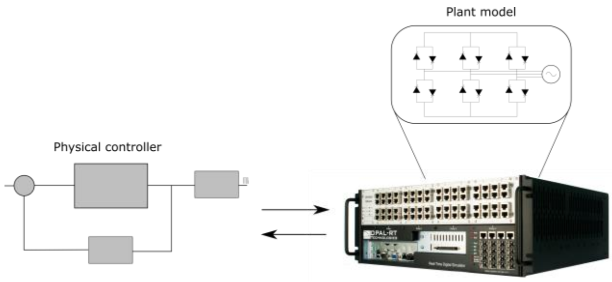

Figure 2: Hardware-in-the-Loop

Finally, if the controller and the plant are both simulated into an enough powerful simulator, it is known as Software-in-the-Loop (SIL). Since the full WT models have been simulated into the real time simulator, this is the type of application which has been used in this paper. A scheme for SIL is shown in Figure 3.

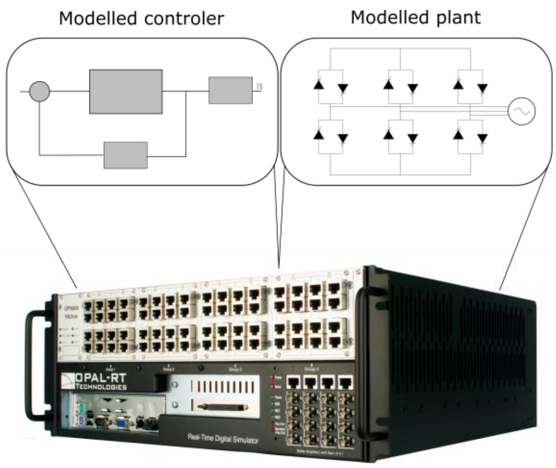

Figure 3: Software-in-the-Loop

In SIL simulation, if physical signals are not needed, the simulation can run as fast as the simulator allows. The model does notneed to be coordinated with real time, as the full system is simulated by the device.

The model of real time simulator that has been used in this work is OP5600, from the trademark OPAL-RT Technologies. The structure of this equipment is modular. Each particular device can be adapted for each application. For example, the CPU has six cores available, but the model used in this paper only has one of them activated. Up to 4 FPGAs can be installed, however, one is activated in our device. Even software can be chosen in agreement with the specific application. This model allows a minimum time step of 16μs.

The real time simulator must be connected to a host PC, by an Ethernet cable, which runs the software RT-Lab. RT-Lab is the software developed by OPAL-RT. This tool allows to edit, build and load the model into the simulator. It is also possible to change parameters on-the-fly while simulation is running, initialize the model from an external script, visualize results through virtual scopes…

For RTS, fixed-step solvers must be used in order to know the exact duration of each step. Within this time, all the operations of the model must be solved. These operations include the lecture of physical inputs, the calculation of the equations of the model and the generation of physical outputs. If all these operations can't be done within a step, an overrun happens, and the simulation is considered erroneous.

For fixed-step solvers, time step must be carefully selected. If it is too big, the precision of the response may be insufficient. Nevertheless, if it is too small, overruns can occur.

Algebraic loops, which are extremely usual in control systems, can not be directly solved by fixed-step solvers. A detailed study of the solutions which can be adopted to solve them must be done, in order to avoid stability or misbehaviour problems.

B. Interaction with real world

The relationship between simulation time and real world time allows the utilization of physical signals to interact with the model.

Through RJ45 or DB37 connectors, voltage signals of physical devices, such as sensors, can be used as inputs to the model (±16V). In addition, the real time simulator can generate voltage signals which can be used as outputs. These signals can be applied to actuators or be visualized into scopes, showing the results in real time. Inputs and outputs can be either analogical or digital.

The FPGA is the responsible of acquiring or stablishing the voltage signals of the model. Communication between the FPGA and the model is automatically done by RT-Lab.

Voltage level is acquired, or stablished, at each time step. This operation must be done within the time step interval, in order to avoid overruns.

The following physical devices have been used in the present work for developing and testing the response of the WT models while simulation is running in real time:

- Cup anemometer: Used to obtain the wind speed signal input to the model.
- Button: Connected to a voltage source, it is used to create voltage dips in a dynamic way.
- ScopeCorder *Yokogawa DL750*: To show the results of the model in real time.
- Signal generator *Tektronix AFG3102*: That provides a pulse voltage signal.

To use the signals acquired by the FPGA, some special blocks from RT-Lab must be inserted into the model. The most important block is shown in Figure 4. This block is the responsible for the communication with the FPGA.

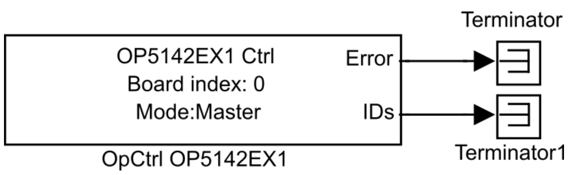

Figure 4: OpCtrl block

Board index indicates which FPGA is controlling the block (up to 4 can be installed in the device), the control mode (master/slave) is also indicated by each FPGA. Into its internal options, the files provided by the manufacturer which allow the communication with the FPGA, must be indicated.

For using analogical input signals, a specific block, shown in Figure 5, must be inserted. The output signal must be demuxed. Each signal from the mux block is the voltage level adquired from a pair of wires of the RJ45/DB37 connector.

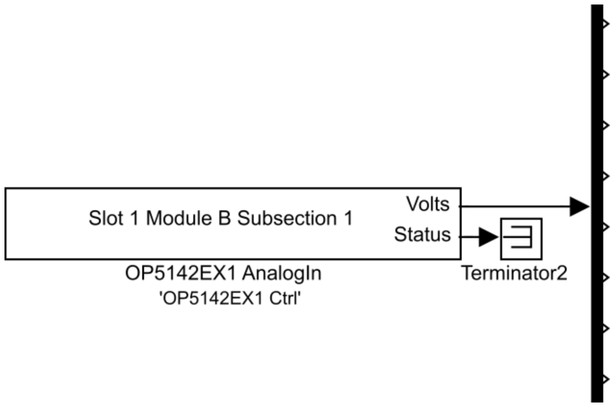

Figure 5: Analogical input block

The parameters which are used to identify the desired group of connectors are shown in Figure 6.

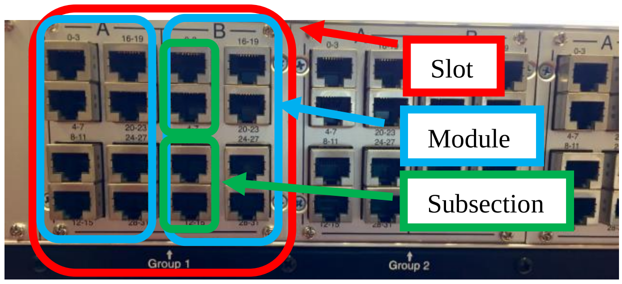

Figure 6: Configuration of IO ports

Each group has different functions (analogical/digital or input/output). The user manual provides the configuration of the activated modules.

For analogical outputs, a similar block to the shown in Figure 5 is used. This block is shown in Figure 7.

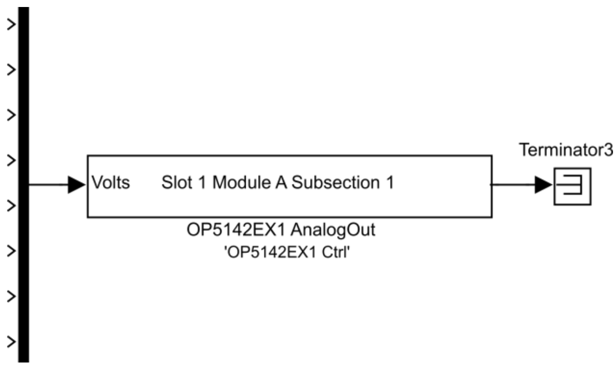

Figure 7: Analogical output block

The desired signals which want to be used as outputs are muxed, and the output of this mux block is the input of the output block.

The voltage range of the output can be selected (±5V, ±10V, ±16V), and hence, it can be addapted to the device that is connected with the simulator. If any input or output exceeds its voltage range, it is saturated.

C. *Real Time Simulation example*

The model shown in Figure 8 has been designed in order to show some capabilitiesof RTS. A pulse voltage signal has been applied as an analogical input to the model. This signal goes through a first-order (low-pass) filter, which transfer function (H(s)) is defined by (1).

$$H(s) = K\frac{1}{\tau s+1} \qquad (1)$$

Simulink has implemented a Transfer Function block, nevertheless, the inner parameters of this block can not be modified during the simulation by RT-Lab. The purpose of this example is varying on-the-fly the time constant of the filter (τ) in order to show how this variation modifies the output signal. Hence, the transfer function of the filter has been transformed into the differential equation form as (2-5).

$$\frac{Y(s)}{X(s)} = K\frac{1}{\tau s+1} \qquad (2)$$

$$Y(s) = X(s)\cdot K\frac{1}{\tau s+1} \qquad (3)$$

$$Y(s)\cdot(\tau s+1) = X(s)\cdot K \qquad (4)$$

$$\tau\cdot Y(s) = K\cdot\frac{X(s)}{s} - \frac{Y(s)}{s} \qquad (5)$$

Thus, the variation of the gain parameter, which is allowed by RT-Lab, modifies the time constant of the filter. Finally, the output signal goes through the analogical output block in order to show it in any device.

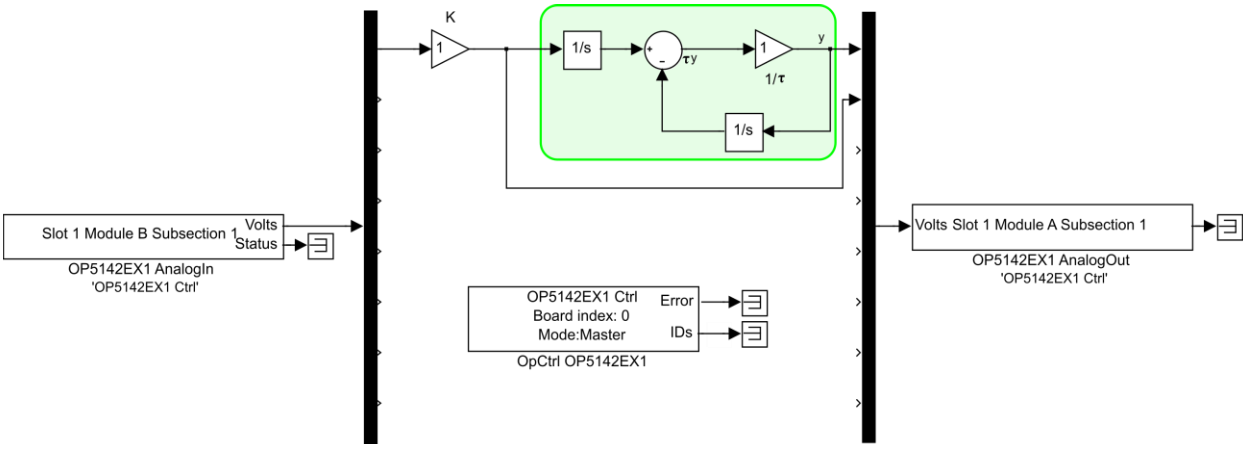

Figure 8: Scheme of the example of RTS

The results of the simulation that was conducted are shown in Figure 9. The input to the filter is a pulse signal, with a period of 2 seconds and a duty cycle equals 25%. Initially, the gain parameter (1/τ) value is equal to 1. At, approximately, 7 seconds, this value is changed to 10 on-the-fly with RT-Lab, and as it can be seen, higher armonic components of the pulse signal can pass the filter, and the output signal resembles more to the input signal. Finally, when the gain parameter is changed to 100, both signals are almost the same, as most of the armonic components of the input signals goes through the filter.

In this example of application of RTS, its behavior and advantages are shown. The parameters of the model are changed while the simulation is being conducted, and a fine adjustment of the filter can be done without resetting the simulation for each value. However, it is also shown one of its main disadvantages: the models that are used for conventional simulation may not work for RTS. A careful study must be done in order to avoid problems and to get a full functional model that deservers the economical and extra-work effort that RTS implies.

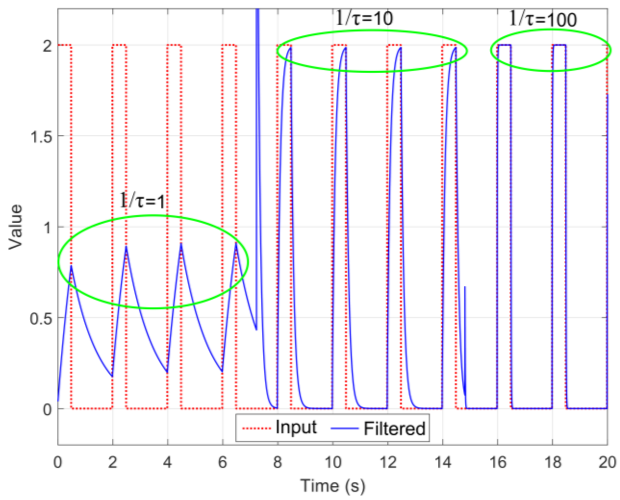

Figure 9: Results of the RTS example

D. RTS applied to generic WT models

The development of generic WT models which can be simulated in real time is important, due to the needs of electrical system operators, that perform real time analysis of the national power system to assure the correct operation of the grid [14].

The utilization of physical devices, such as the cup anemometer or the button that is used to create voltage dips in a fast way, has allowed a faster development of the models.

The assembly that was made to simulate voltage dips with the generic models, using these devices, is shown in Figure 10.

The input of the anemometer can be disabled if a constant wind speed signal is needed [15], [16]. While simulation is running, a voltage dip can be made in any time with the use of the button. The response of the WT is shown in the physical scope, and also can be observed in a virtual console of RT-Lab.

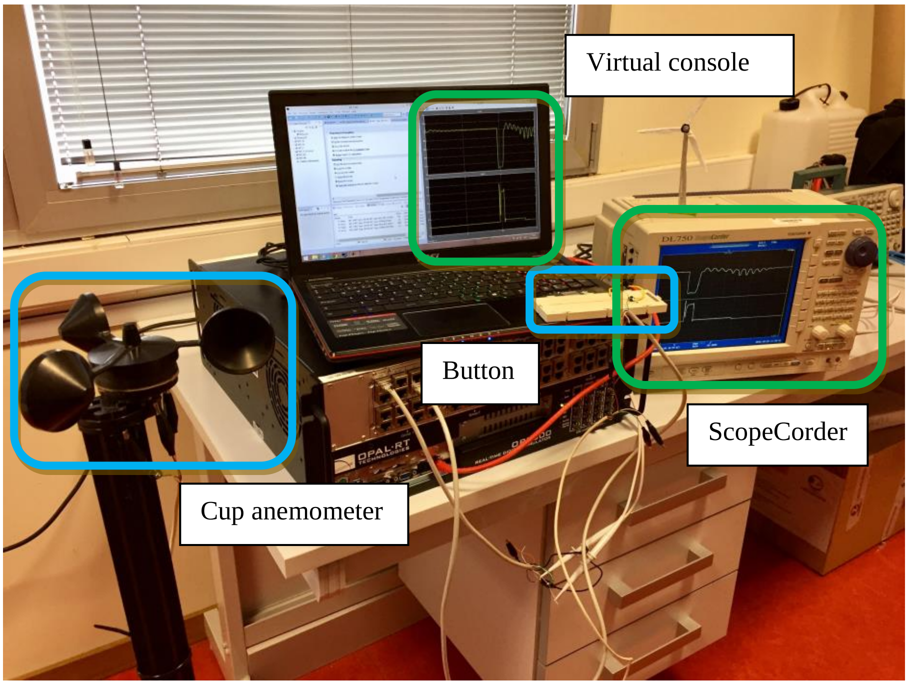

Figure 10: Assembly with OP5600 and physical devices

4. Conclusion

Real time simulation involves a new way to understand simulation. The development of models can be done in a dynamic method, adjusting its parameters while its behaviour can be observed without stopping the simulation. Furthermore, the link that can be stablished with the physical world allows a deeper interaction with the models.

The applications of RTS are almost unlimited, but one of the most important is its application to renewable energies, for example, with the development of the models defined by the recently published IEC 61400-27-1.

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References

[1] GWEC, “GLOBAL WIND REPORT 2015 | GWEC,” 2016.

[2] F. Jimenez, E. Gómez-Lázaro, J. A. Fuentes, A. Molina-García, and A. Vigueras-Rodríguez, “Validation of a DFIG wind turbine model and wind farm verification following the Spanish Grid Code,” *Wind Energy*, vol. 15, no. 4, pp. 645–659, May 2012.

[3] A. Honrubia-Escribano, S. Martín-Martínez, A. Estanqueiro, F. Jiménez Buendía, and E. Gómez Lázaro, “Simplified wind turbine models for wind energy integration into power systems,” *Eur. Wind Energy Conf.*, p. 6pp, 2015.

[4] F. Jiménez, E. Gómez-Lázaro, J. A. Fuentes, A. Molina-García, and A. Vigueras-Rodríguez, “Validation of a DFIG wind turbine model submitted to two-phase voltage dips following the Spanish Grid Code,” *Renew. Energy*, vol. 57, pp. 27–34, 2013.

[5] A. Honrubia-Escribano, F. Jiménez Buendía, A. Molina-Garcia, J. A. Fuentes-Moreno, E. Muljadi, and E. Gómez Lázaro, “Analysis of Wind Turbine Simulation Models : Assessment of Simplified Versus Complete Methodologies,” *XVII Int. Symp. Electromagn. Fields Mechatronics, Electr. Electron. Eng*, p. 8, 2015.

[6] P. Sørensen, B. Andresen, J. Fortmann, K. Johansen, and P. Pourbeik, “Overview , status and outline of the new IEC 61400 -27 – Electrical simulation models for wind power generation,” *10th Int. Work. Large-Scale Integr. Wind Power into Power Syst.*, 2011.

[7] H. Zhao, “Coordinated control of wind power and energy storage,” DTU, 2014.

[8] P. Sørensen, J. Fortmann, F. J. Buendia, J. Bech, A.

Morales, and C. Ivanov, “Final Draft International Standard IEC 61400-27-1 Electrical simulation models of wind turbines,” in *13th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Plants*, 2014.

[9] H. Zhao, Q. Wu, I. Margaris, J. Bech, P. E. Sørensen, and B. Andresen, “Implementation and validation of IEC generic type 1A wind turbine generator model,” *Int. Trans. Electr. Energy Syst.*, vol. 25, no. 9, pp. 1804–1813, 2015.

[10] A. Honrubia-Escribano, E. Gomez-Lazaro, A. Vigueras-Rodriguez, A. Molina-Garcia, J. a. Fuentes, and E. Muljadi, “Assessment of DFIG simplified model parameters using field test data,” *2012 IEEE Power Electron. Mach. Wind Appl.*, pp. 1–7, 2012.

[11] P. Sorensen, B. Andresen, J. Fortmann, and P. Pourbeik, “Modular structure of wind turbine models in IEC 61400-27-1,” in *IEEE Power and Energy Society General Meeting*, 2013.

[12] J. Belanger, P. Venne, and J.-N. Paquin, “The What, Where and Why of Real-Time Simulation,” *PES IEEE Gen. Meet.*, pp. 37–49, 2010.

[13] C. Dufour, S. Abourida, and J. Belanger, “Hardware-In-the-Loop Simulation of Power Drives with RT-LAB,” *Power Electron. Drives Syst. 2005. PEDS 2005. Int. Conf.*, vol. 2, pp. 1646–1651, 2005.

[14] F. Jiménez, A. Vigueras-Rodríguez, E. Gómez-Lázaro, J. A. Fuentes, and A. Molina-García, “Validation of a Mechanical Model for Fault Ride--Through: Application to a Gamesa G52 Commercial Wind Turbine,” *IEEE Trans. Energy Convers.*, vol. 28, no. 3, pp. 707–715, 2013.

[15] A. J. Pujante, J. A. Fuentes, E. Gómez-Lázaro, A. V. Rodriguez, and A. Molina-García, “Performance comparison of a 2 MW DFIG wind turbine model under wind speed variations,” in *European Wind Energy Conference and Exhibition*, 2009, pp. 121–124.

[16] A. Honrubia-Escribano, F. Jiménez-Buendía, E. Gómez-Lázaro, and J. Fortmann, “Validation of Generic Models for Variable Speed Operation Wind Turbines Following the Recent Guidelines Issued by IEC 61400-27,” *Energies*, vol. 9, no. 12, 2016.