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Preprint

A. Honrubia-Escribano,[1] F. Jiménez-Buendía,[2]
A. Molina-García,[3] J.A. Fuentes-Moreno,[3]
E. Muljadi,[4] and E. Gómez-Lázaro[1]

[1] *University of Castilla-La Mancha*
[2] *Gamesa Innovation & Technology*
[3] *Polytechnic University of Cartagena*
[4] *National Renewable Energy Laboratory*

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ANALYSIS OF WIND TURBINE SIMULATION MODELS: ASSESSMENT OF SIMPLIFIED VERSUS COMPLETE METHODOLOGIES

A. Honrubia-Escribano,[1] F. Jiménez-Buendía,[2] A. Molina-García,[3] J.A. Fuentes-Moreno,[3] E. Muljadi,[4] E. Gómez-Lázaro[1]

[1] Renewable Energy Research Institute and DIEEAC/EDII-AB, Universidad de Castilla-La Mancha, 02071 Albacete, Spain, andres.honrubia@uclm.es, emilio.gomez@uclm.es
[2] Gamesa Innovation & Technology, Pamplona, Navarra, Spain, fjimenez@gamesacorp.com
[3] Department of Electrical Engineering, Universidad Politécnica de Cartagena, Cartagena, Murcia, Spain, angel.molina@upct.es, juanalvaro.fuentes@upct.es
[4] National Renewable Energy Laboratory, Golden, CO, USA, Eduard.Muljadi@nrel.gov

Abstract ***– This paper presents the current status of simplified wind turbine models used for power system stability analysis. This work is based on the ongoing work being developed in IEC 61400-27. This international standard, for which a technical committee was convened in October 2009, is focused on defining generic (also known as simplified) simulation models for both wind turbines and wind power plants. The results of the paper provide an improved understanding of the usability of generic models to conduct power system simulations.***

1. Introduction

Renewable energy sources have experienced rapid development in the last few years. Among the different types of renewable energy sources, wind energy can be considered the most promising technology to produce the largest share of renewable electricity needed to meet the European Union's 2020 targets. In Spain, approximately 21% of the electricity demand was met by wind energy during 2013 and 2014; in 2013, wind represented the first largest contribution to demand coverage in Spain. Similar figures are found in Portugal, where wind energy covered 24% of electricity consumption in 2014. (This is in line with the value observed in 2013 as well.) On one day in 2014, wind energy reached 89% of instantaneous penetration in Portugal. From a global point of view, 51.477 MW of new wind generating capacity was added in 2014, leading to a total cumulative wind capacity quite close to 370 GW at the end of 2014, Fig. 1, [1].

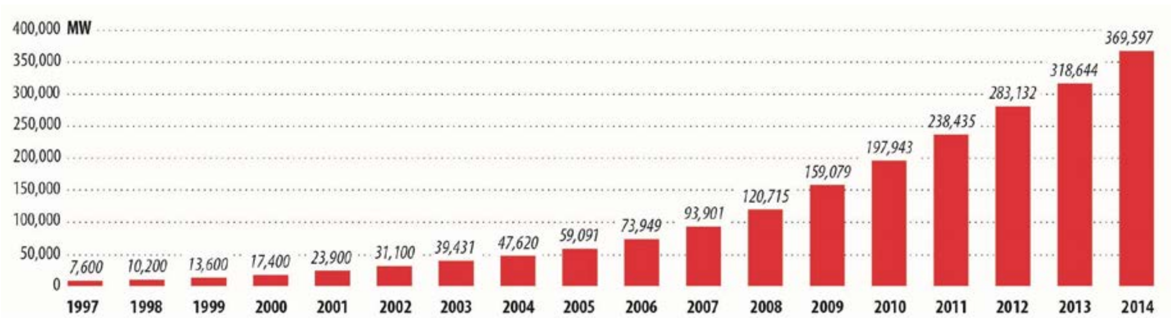


Fig. 1. Global cummulative installed wind capacity, [1].

This remarkable amount of installed wind capacity must be integrated into the electric power systems in a proper way to enable power systems to operate safely, reliably, and cost-efficiently, [2]. In this sense, grid operators—both transmission system operators and distribution system operators—need dynamic models of wind power generation to conduct power system stability studies [3]–[5]. Wind turbine manufacturers have developed models to estimate the electrical and mechanical behavior of their generators with the highest level of accuracy, [6], [7]; however, such detail is not suitable for stability studies of large power systems for several reasons, such as the considerable input data required, high computational cost and excessive complexity, and limited use of the models due to confidentiality issues, [8], [9]. With the aim of providing a solution to these concerns, the International Electrotechnical Commission (IEC) is focused on the development of an international standard, IEC 61400-27, related to the definition of generic (i.e., simplified or standard) dynamic models for wind power systems. These generic models are intended to be applicable to transient and dynamic events, such as faults, loss of generation or loads, and switching of lines.

Under this framework, the aim of this paper is to present the current status of simplified wind turbine models used for power system stability analysis based on the ongoing work in IEC 61400-27. After this introduction, the paper is structured as follows: Section 2 provides the basis of generic wind turbine dynamic models together with a general overview of the current status of the standardization work carried out in this field. Section 3 presents the four types of wind turbine generator models developed and some specific results from simulations. Finally, Section 4 concludes the paper.

2. The need for simplified wind turbine simulation models

One of the key challenges with renewable generation technologies has been the development and maintenance of standard public computer simulation models for power system studies. In this line, generic models composed of a model structure that is publicly available have been required in the United States by many utilities [3], [10]–[12]. The term *generic* refers to a model that is standard, public, and not specific to any vendor so that it can be parameterized to reasonably emulate the dynamic behavior of a wide range of equipment while not directly representing any actual wind turbine controls, [13].

Based on these assumptions, the Renewable Energy Modeling Task Force (formerly known as the Wind Generator Modeling Group) of the Western Electricity Coordinating Council (WECC, established in 2005, [14]) and the Institute of Electrical and Electronics Engineers (IEEE) Working Group on Dynamic Performance of Wind Power Generation have developed generic wind turbine generator models. Specifically, the first generation of WECC generic models was released around 2009. These WECC generic models were developed by simplifying a detailed transient stability model, [15]. Instead of addressing electromagnetic transients, the generic positive sequence models are of main concern. It is worth mentioning that in the scientific literature many models are proposed for the simulation of a wind turbine, but only a little work is found for generic modeling that considers practical requirements for stability analysis, [16].

Other initiatives, such as JWG C4/C6.35/CIRED, titled "Modelling and dynamic performance of inverter based generation in power system transmission and distribution studies," are studying dynamic electrical simulation models together with the specific modeling methodologies. Although the models study inverter-based sources, this initiative is focused primarily on photovoltaics and the relevant parameters for both distribution and transmission system studies. However, it is also relevant to the development of a set of recommendations and step-by-step procedures for the dynamic electrical simulation and validation of renewable energy sources for different types of large system dynamic studies, including the aggregation equivalents when dynamic electrical simulation models of clusters are taken into account.

With regard to IEC 61400-27, the first meeting of the technical committee was convened in October 2009. It focused on the definition of standard (i.e., simplified or generic) public dynamic simulation models for wind turbines and wind power plants, including a complete model validation procedure. In this sense, the goal of model validation is to verify that the model and its chosen parameters adequately represent the dynamic performance of the real physical device being modeled for power system studies, [17]. These IEC models aim to be applicable to dynamic simulations of power system events, such as short circuits (e.g., low-voltage ride-through), loss of generation or loads, and typical switching events.

In the work developed by IEC 61400-27, there is a substantial overlap with similar efforts previously undertaken by WECC; however, with the aim of covering a reasonable amount of wind turbines included in the study , the IEC standard considers inputs from additional sources, such as publications from European researchers and vendors. One of the common decisions from both WECC and IEC is to move toward a modular approach. This implies that the models are made up of smaller modules that are truly generic and usable for any appropriate renewable generation system, [18], [19]. This allows additional versions to be developed for each module as changes are deemed necessary in the future. In addition, this methodology makes it easier to identify the differences between the WECC and IEC approaches through the development of separate modules.

3. Generic wind turbine modeling

The general structure of the IEC generic wind turbine models for all wind turbine types is given in Fig. 2, [20]. The first submodel (i.e., module) used to generate the global wind turbine dynamic model is composed of the aerodynamic model, which calculates the wind turbine mechanical power from the energy contained in the wind. Authors in [3] present a simplified aerodynamic model. Then the mechanical system of a wind turbine (also called a drivetrain) considers the rotating masses and the connecting shafts, including the gearbox, in case it is considered. The generator module contains all the parameters needed to emulate the electric generator of the wind turbine, whereas the electrical equipment refers to devices such as circuit breakers or capacitor banks. Finally, protection and control is shown at the top and bottom, respectively; however, the protection module includes only grid protection instead of other types, such as overspeed protection, because these are normally not activated by grid disturbances, [21].

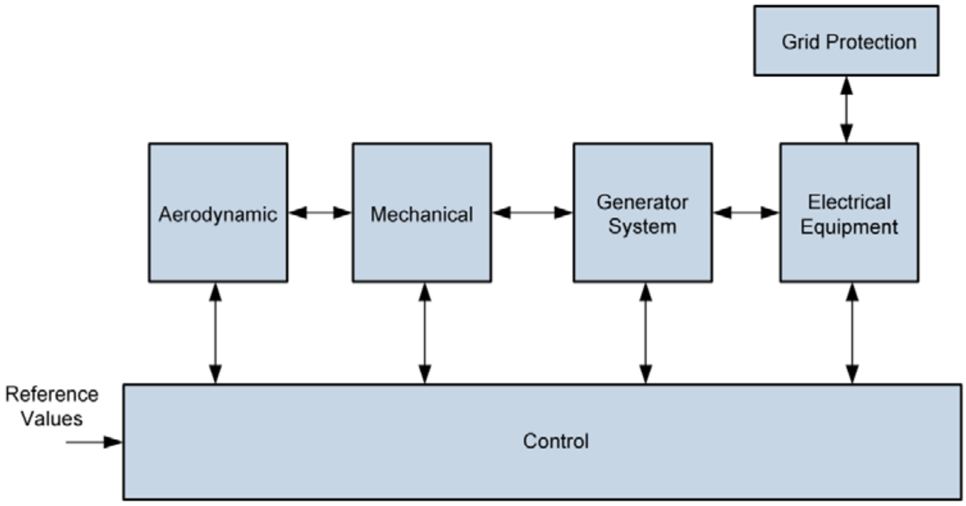


Fig. 2. General model structure according to IEC 61400-27.

IEEE has defined four generic wind turbine model types that are commercially available, Fig. 3: conventional asynchronous generator (Type 1), variable rotor-resistance asynchronous generator (Type 2), doubly-fed asynchronous generator (Type 3), and full-converter topology (Type 4).

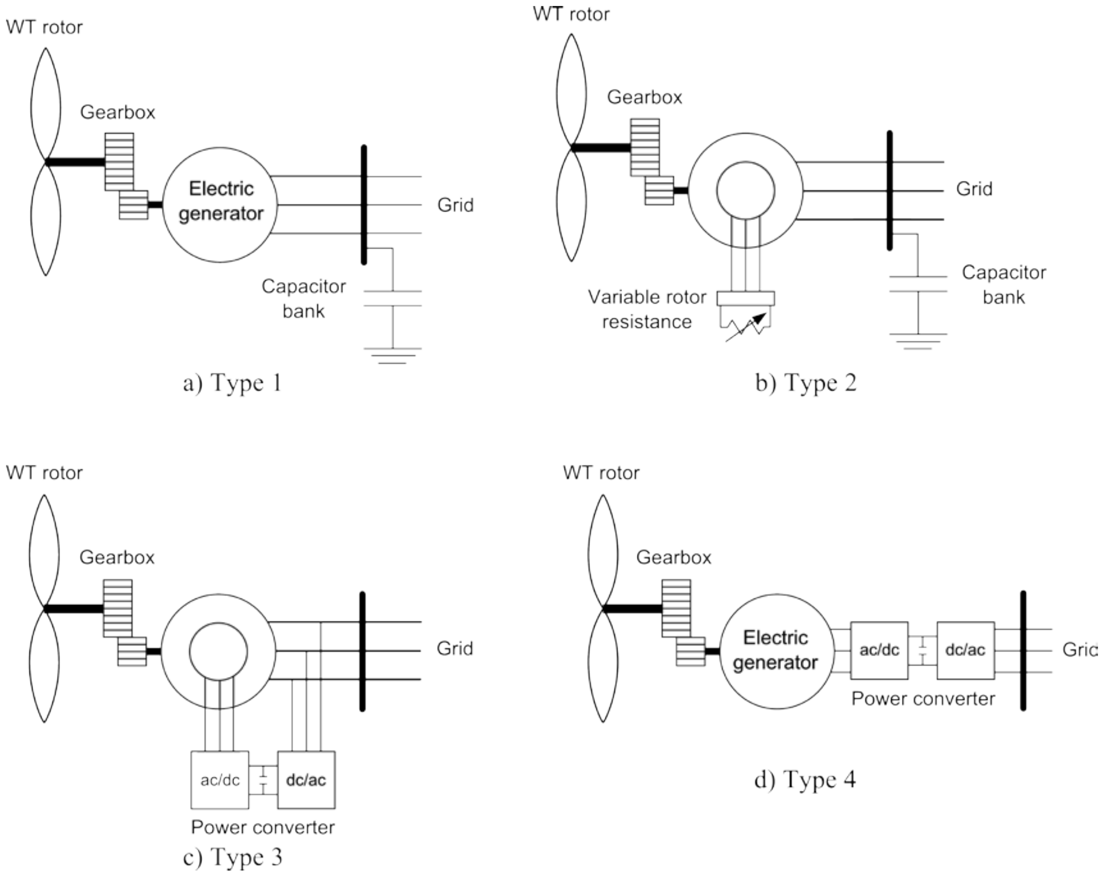
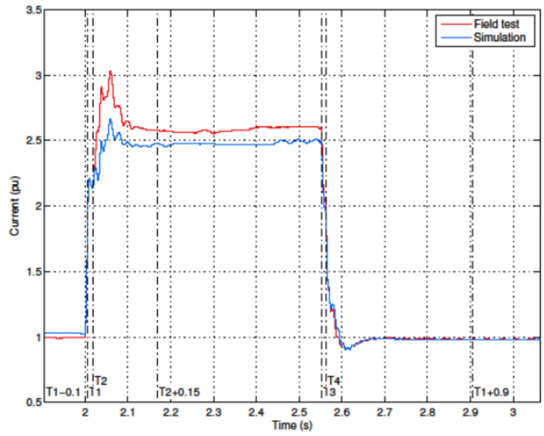


Fig. 3. IEC generic wind turbine model types.

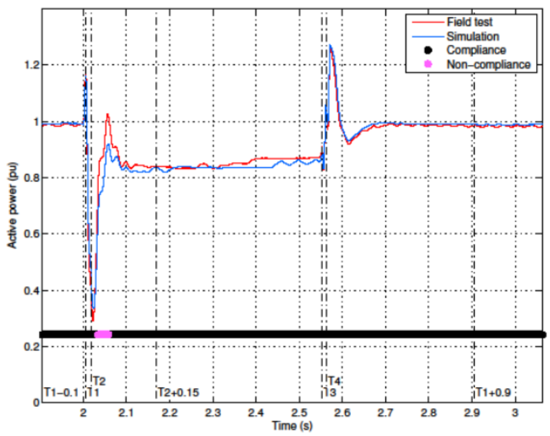
Detailed models offer better precision because of their more complex characteristics. For example, a real wind turbine, Gamesa G52, is modeled with the PSCAD/EMTDC software package, [2], using a time step of 10.024 µs and taking into account the real mechanical, electrical, and electronic subsystems—design, parameters, and algorithms—such as the power converter (IGBT control) and later submitted to the validation process. Previously, the mechanical model subsystem was compared to a detailed model using the BLADED software package and the electrical subsystem was compared to the test bench results, [6]. The wind turbine is submitted to a two-phase voltage dip with a retained voltage of 60%–62.08%, 64.62%, and 95.07% for the R, S, and T phases, respectively, for a duration of 0.5705 s. Fig. 4 shows the results. For example, in the RMS currents in the R phase, shown in figure 4a, both currents show good agreement, with some differences between the T2 and T3 marks because of the effect of the waveform amplitudes. The evolutions of the active and reactive power are shown in figures 4b and 4c, which are obtained from the positive sequence component of the voltages and currents in accordance with the Spanish grid code (PVVC). Active power, shown in figure 4b, presents an almost perfect fit between the field test and simulation results, showing some differences around the second peak after T2. In that figure, the intervals marked in black are those that have differences between the simulated and field test results that do not exceed 10% of the rated wind turbine. Those that exceed the 10% limit are marked in pink. Previously, the tests under validation had to comply with the Spanish Grid Code PO 12.3. According to PO 12.3, in terms of active power during the intervals [T1+150 ms,T2] and [T3+150 ms,TEND], active power consumption was not allowed or restricted, where TEND is the time when voltage is recovered. In these intervals, however, consumption of active power must comply with some requirements in terms of active energy or the value of the active power itself. The reactive power evolution, in fig. 4c, shows a good fit between the field test and simulation results. There is one interval, between T2 and T2+150 ms, in which the threshold value is exceeded. The constraints of the reactive power are imposed by the grid codes to avoid the absorption of a large amount of reactive power when the generator is admitted to remain connected to the grid during faults and post-fault periods. This absorption of a large amount of reactive power may induce instability on the line, especially for large-scale wind power plants.

With detailed models, as shown in the previous figures, the unbalanced voltage dips produce current and voltage fluctuations in the rotor that are difficult to limit. The limits to power consumption during unbalanced voltage dips were imposed by the Spanish transmission system operator in the grid code and are based on transient realistic simulations provided by wind turbine manufacturers in the presence of the Spanish market. The voltage dip influence on the doubly-fed induction generator (DFIG) rotor speed is presented in figure 4d, which shows that the field test and the simulated results are quite similar. Obviously, rotor speed excursions during phase-to-phase voltage dips are much more limited than they are during three-phase faults, [7], according to retained voltages imposed by the PVVC.

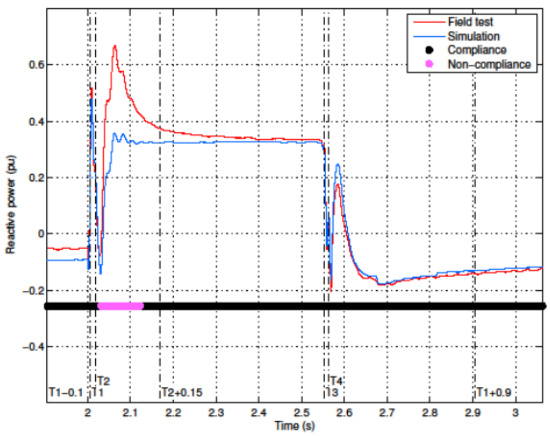
On the contrary, simplified models are designed to represent steady and dynamic characteristics in large-scale, positive-sequence simulations.



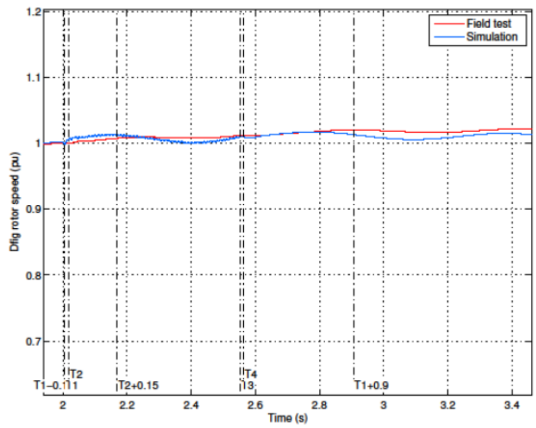
a) RMS current (R phase)



b) Active power



a) Reactive power



b) DFIG rotor speed

Fig. 4. Comparison of results from the detailed models and field data.

Generic models can be close to one of the vendor-specific models in their functionality and structure—for example, as shown in Fig. 5, in which the DFIG model was based on the GE model. In this case, the only difference is because of the aerodynamic conversion, in which the voltage, current, and the active and reactive power together with the generator speed show good agreement between the two models.

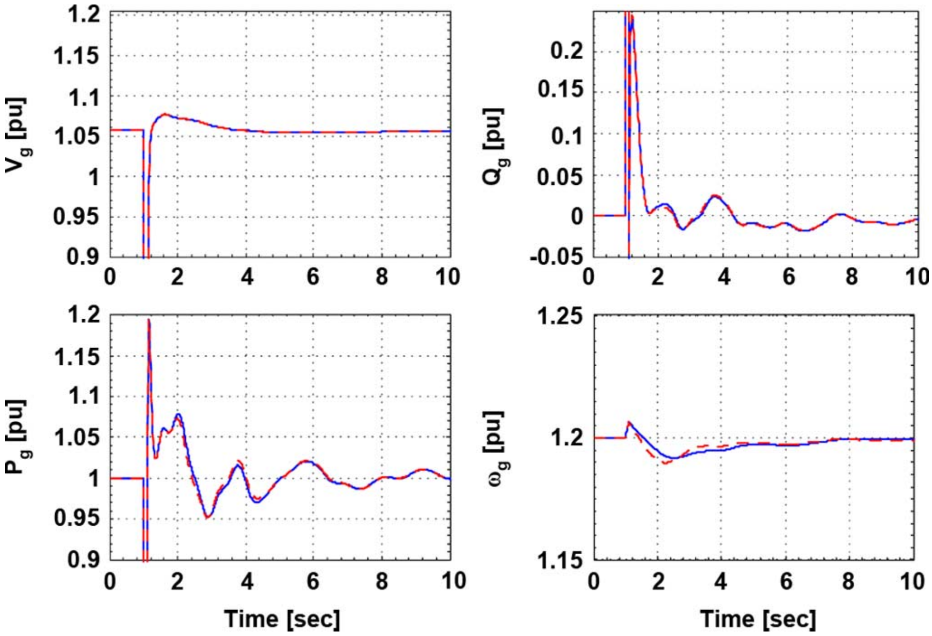


Fig. 5. Comparison of results from the simplified models and the detailed models, [23] .

4. Conclusions

Because of the need to integrate large amounts of installed wind power capacity into power systems around the world, wind turbine simulation models are required by grid operators. This paper has highlighted the relevance of generic wind simulation models for this purpose. The paper has defined the current status of the IEC and WECC working groups, which focus on the definition of dynamic models for wind power systems intended to be applicable for transient and dynamic events such as faults, loss of generation or loads, and switching of lines. The main characteristics of these generic models have been reviewed together with some exemplary commercial wind turbine versions. The results thus provide an improved understanding of the usability of generic models for conducting power system stability analysis.

Validation efforts have been found by some authors, but an increase of the validation work is expected to be conducted in the short term.

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