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Published in:
Proceedings of the International Conference on Wind Energy Grid-Adaptive Technologies 2014

Publication date:
2014

Wind Turbine and Wind Power Plant Modelling Aspects for Power System Stability Studies

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Abstract –Large amount of wind power installations introduce modeling challenges for power system operators at both the planning and operational stages of power systems. Depending on the scope of the study, the modeling details of the wind turbine or the wind power plant are required to be different. A wind turbine model which is developed for the short-term voltage stability studies can be inaccurate and sufficient for the frequency stability studies. Accordingly, a complete and detailed wind power plant model for every kind of study is not feasible in terms of the computational time and also is not reasonable regarding the focus of the study. Therefore the power system operators should be aware of the modelling aspects of the wind power considering the related stability study and implement the required model in the appropriate power system toolbox. In this paper, the modelling aspects of wind turbines and wind power plants are reviewed for power system stability studies. Important remarks of the models are presented by means of simulations to emphasize the impact of these modelling details on the power system.

Keywords: wind turbine models, wind power plant models, power system stability, wind power impact studies

1. Introduction

Wind power installation capacity in most of the developed countries has been reached 10% to 30% of the total generation capacity [1]. Further installations have been planned to integrate especially large offshore wind power into power systems [2]. On one hand, these installations have been brought different generation technology compared to the conventional power plants with various integration challenges. On the other hand, wind power plants have flexible and different levels of control capability with large amount of turbines also voltage control devices (FACTs, STATCOMs, capacitor banks) and energy storage if applicable. These control capabilities will be enhanced further in the future to overcome the challenges due to the challenges of the fluctuating nature of the wind power and the different electrical characteristics compared to the synchronous generators. Accordingly, recent grid codes proposed by transmission system operators (TSOs) require the control capabilities from wind power plants in terms of active power, reactive power, voltage, and frequency control under steady-state and fault conditions [3]. However, the control capabilities are still under discussion in case of the wind power increase and replace the conventional power plants. In these scenarios, the approach is to emulate the synchronous generators behavior in order to sustain the power system stability as it was maintained before. Many of the studies by wind power plant developers and academia have shown that the wind power plants have flexible, fast, and configurable control structures like the conventional power plants [4]-[6]. Therefore, during the change of the power systems with the new wind power installations, the enhanced control functionalities should be investigated for the stable power system operation. In order to specify the new control functionalities and demonstrate the impact on power systems, accurate and reliable wind turbine and wind power plants are required.

Wind turbine and wind power plant models have been developed and implemented in several power system toolboxes for power system stability studies [4]-[8]. In these studies the models have different types of representative block diagrams due to the focus of the study and the power system stability phenomena. For instance, block diagrams representing aerodynamic characteristics of the wind turbine play very important role for the active power and frequency control studies [4], [5], [7]. Additionally, grid-side converter model of full-scale type

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wind turbine with its control blocks are essential for the fault-ride-through and voltage/reactive power control studies [6], [8].

The aforementioned models have been developed both by manufacturers [9], system operators and researchers [10]-[12]. Manufacturer models can be in some cases confidential and the details of the models are hidden like a black-box (i.e. only the inputs and the outputs are visible). Although these models are detailed and verified with the real wind turbines, they have limitations due to the confidentiality agreements and the tuning of the parameters. These challenges can be overcome by generic models which are not dependent on a specific wind turbine type and easy to exchange their parameters between different power system toolboxes.

The generic models have been developed by IEC [11], WECC, and IEEE [12] working groups. IEC working group is going to publish the first part of the IEC 61400-27 series which specify standard dynamic electrical simulation models for wind power generation. The first part specifies wind turbine models and model validation procedure of these models. In addition to the aforementioned advantages, the modular structure of the IEC 61400-27 standard models supports the WECC and IEEE working group models.

In this paper, the modeling and implementation aspects of the IEC 61400-27 standard models are presented considering the power system stability studies such as fault-ride-through (FRT) capability, overloading capability of wind turbines for inertial response control or frequency control of wind power plants [7], [11]. The aggregation of wind turbines is also described briefly when the wind turbines experienced different wind speeds [14]. In the conclusion, the modeling aspects are overviewed and an outlook on future work for the wind turbine and wind power plant modeling is given.

2. Wind Turbine Models

The modular structure of the IEC 61400-27 wind turbine models is shown in Figure 1. These models will be time domain positive sequence simulation models, intended to be used in power system and power system stability analyses. The horizontal aligned blocks starting from aerodynamic model block to electrical equipment block reflects the physical power flow (wind energy to electrical energy). The protection and control blocks, which represent physical protection, controller dynamics and limitations, are shown above and below respectively.

These simulation models specified in IEC 61400-27 are independent of any software simulation tool. Depending on the type of wind turbine, some of the blocks can be omitted, but all wind turbine types include generator system, electrical equipment and grid protection models. Over- and under- voltage- and frequency protection is included in the grid protection for grid code, which controls a circuit breaker in the electrical equipment. The wind turbine step-up transformer may also be included in the electrical equipment, depending on the manufacturer definition of wind turbines.

Wind turbines are generally divided into 4 types, which are currently significant in power systems [15]. These types have the following characteristics:

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

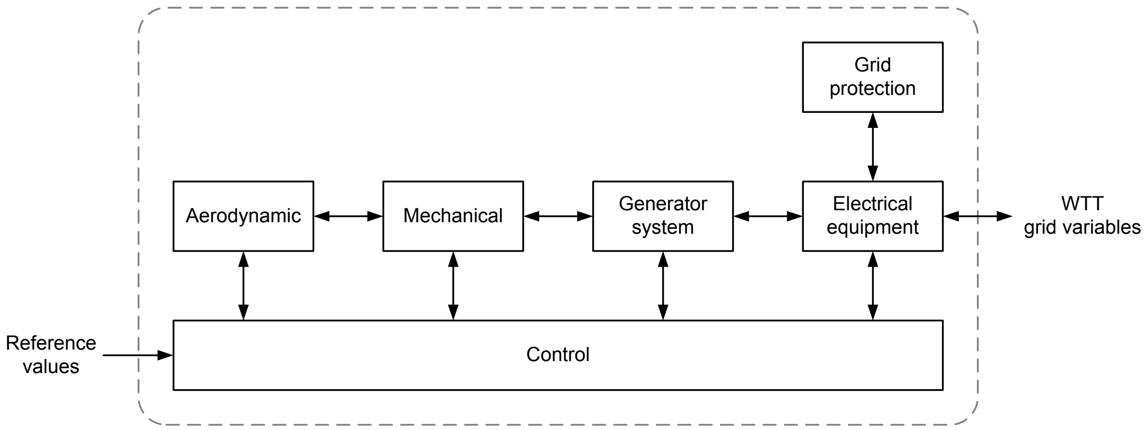

Fig. 1. The modular structure of IEC 61400-27 wind turbine models [11]

3. Phase Angle Measurement for Short Circuit Faults

Type 3 and Type 4 wind turbine models in IEC 61400-27, the generator system block represents the power electronic converters and the electrical generator as an interface. This interface includes the phase angle measurement to synchronize the grid at the connection terminal of the wind turbine. The phase angle of the terminal voltage is required to inject the active and reactive currents into the power system at the grid reference frame. Therefore, the output active and reactive currents of the control and generator system blocks should be transferred from the control reference frame to the grid reference frame. This transformation block diagram is shown in Figure 2.

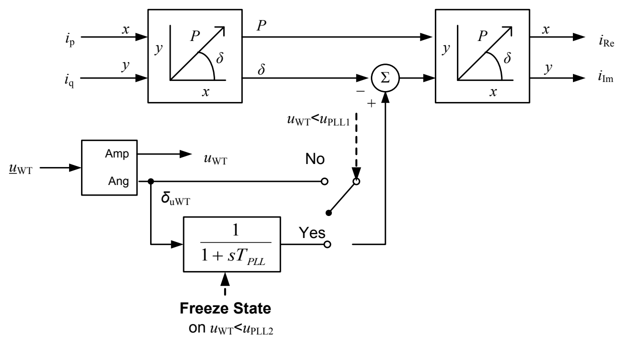

Fig. 2. Block diagram for the reference frame rotation [11]

Since the fundamental frequency positive sequence (i.e. rms) models are targeted to realize large scale power system analyses, they are simplified in terms of complexity and number of modelling components, while yielding sufficient representation of related dynamics. As a common practice in rms models, the dynamics of the above mentioned grid synchronization is omitted, such that the converter is modeled as an ideal current injection source. However, the assumptions and neglecting the phase angle measurement dynamics can cause problems at low voltage during short circuit faults. When the injected currents lead to loss of synchronism, the active and reactive current references cannot be realized for FRT and the simulation results in no convergence error since there is no valid operating point for these references. This situation is exemplified in Figure 3. As a result, during FRT the phase angle measurement dynamics should be implemented for wind turbine models and carefully considered for FRT capability of wind turbines.

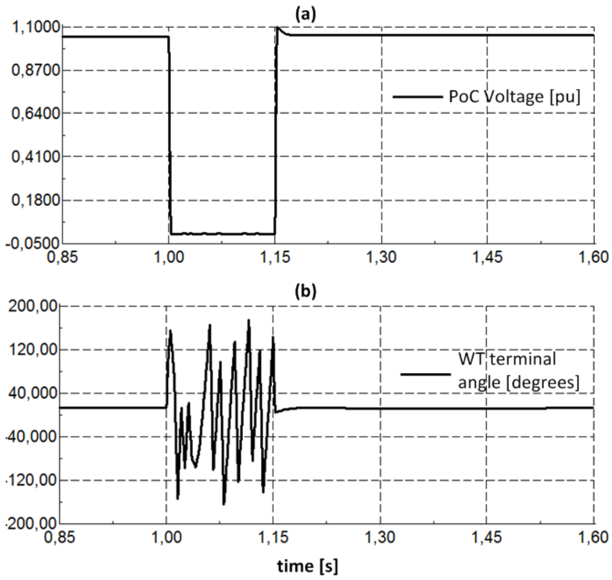

Fig. 3. Loss of synchronism and convergence problems during short circuit faults

4. Overloading Capability of Wind Turbine Models

The IEC 61400-27 wind turbine models are applicable for dynamic simulations of short term stability in power systems. However, these models can be extended to simulate active power and frequency control studies. The extended modular structure implementation for the Type 4 wind turbine is given in Figure 3 [7].

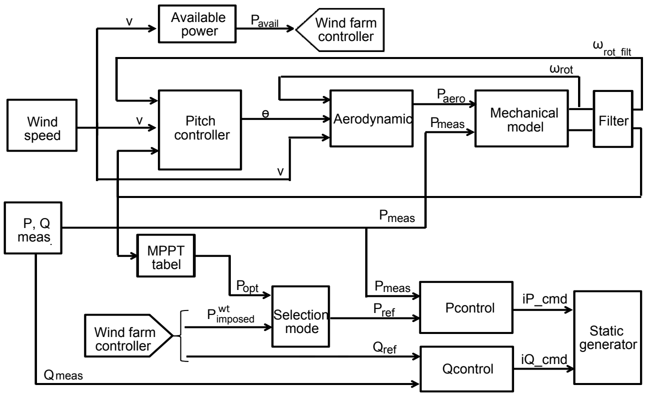

Fig. 4. Loss of synchronism and convergence problems during short circuit faults [7]

Due to modular structure, this implementation is suitable to reflect the dynamic frequency control features of variable speed wind turbines (Type 3 and 4), i.e. the dynamics caused by changing the active power references in the active power control loop. The extension of the model includes the aerodynamic behavior of the rotor, the pitch control, the maximum power point tracking (MPPT) control and the available power calculation for wind speed variability, as it might be of high relevance whenever the implementation and study of new control functionalities, like short-term active power overproduction, inertial response and primary frequency control.

5. Aggregated Wind Power Plant Model

With the aforementioned adjustments and extension of the IEC wind turbine models, wind power plant models can be implemented for the power system stability studies. In order to implement a wind power plant model, a wind power plant controller and each individual wind turbine model are required. The details of the wind power plant controller can be varied in terms of the power control loop, dispatcher, and the control functionalities and services required for the grid requirements [14]. All these considerations are shown in Figure 5.

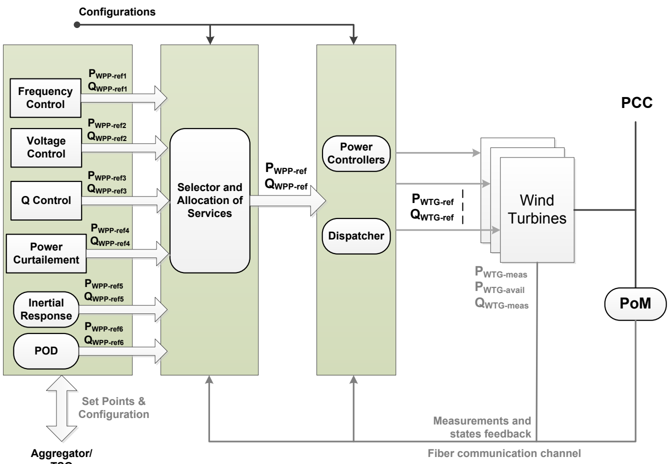

Fig. 5. Loss of synchronism and convergence problems during short circuit faults

The detailed wind power plant model in Figure 5 has the advantage to simulate and show the signals and behavior of each individual wind turbine during power system events. However, for large power systems with large wind power plant penetration, it is not feasible to implement each wind turbine model in detail in terms of the simulation time and the focus of the study. An aggregated wind power plant model is required to represent the generic behavior of the wind power plant with the stability phenomena and the needed amount of detail. Accordingly, the wind power plant is assumed as a single unit, thus the internal dynamics in the collector system of the wind power plant is omitted.

An aggregation method, proposed in [14] and illustrated in Figure 6, is verified by comparing the active power performance of the aggregated WPP model with the active power performance of the detailed WPP model for different relevant wind speed conditions and WPP control service.

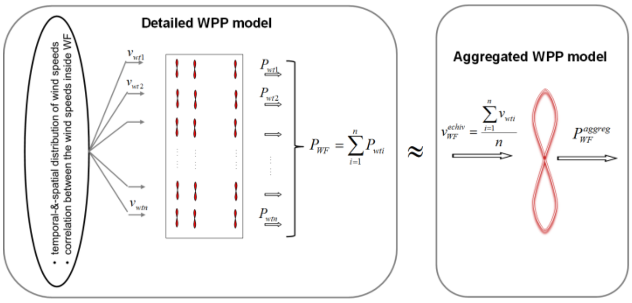

Fig. 6. Wind power plant aggregation method [14]

As shown above the aggregation is performed in two parts; the wind speed aggregation and the electrical system aggregation. The aggregated WPP model uses as the input of an "equivalent wind speed", created as an average of the individual wind speed time series at the wind turbine level, generated by an algorithm or real-time measurements. The aggregation of the electrical system (i.e. the generators and the transformers) is implemented by upscaling the wind turbine model to the overall size of the wind power plant. Furthermore, the collector system is also aggregated by changing the transformer and the cable sizes and parameters to include the losses and voltage variation.

6. Conclusion

Wind turbine technology has been advanced in the last decade which leads to install larger power plants in power systems. Accordingly, the control capabilities are also enhanced to perform better than conventional power plant for some cases. Even with the wind speed variability, the studies have shown that wind power plants can improve the power system stability. In order to present and conduct these power system studies with wind power, wind turbine and wind power plant models are the key factors for wind power plant developers and power system operators.

In this paper, the modeling and implementation aspects of the IEC 61400-27 standard models are presented briefly considering the fault-ride-through (FRT) capability, overloading capability of wind turbines for inertial response control or frequency control of wind power plants, the aggregation of wind turbines to represent the wind power plant as a single unit. All above considerations are not just for the IEC models but also other models developed by the industry and the academia. The models of the wind turbine and the wind power plant can be different depending on the stability study and the power system size. The assumptions of the implemented models should be considered carefully and can be changed for the relevant study and also the power system characteristics. Additionally, the advantages of the IEC models are their modular structures, the easiness extension for the relevant study, the generic representation of the dynamics, and the easiness for exchanging the parameters between different power system tools.

For the future work, the wind power plant model in the second part of the IEC 61400-27 should be tested by means of simulations for different stability studies and different grid conditions. By conducting these simulations, the assumptions and the capability of the generic models are going to be verified. The aggregation of the wind turbines as a single power plant should be also specified with the parameter tuning methodology in the IEC standard and also in the other studies.

Acknowledgements

This work was supported by the European Commission through the European FP7 project iTesla under the grant agreement no283012. The authors support the development of IEC 61400-27 standard with IEC Technical Committee 88 – Working Group 27 (IEC TC88 WG27).

References

[1] BTM Consult ApS, "International Wind Energy Development, World Market Update 2013," Mar. 2013.

[2] E. G. Ochieng, Y. Melaine, S. J. Potts, T. Zuofa, C. O. Egbu, A. D. F. Price, X. Ruan, "Future for offshore wind energy in the United Kingdom: The way forward, " *Renewable and Sustainable Energy Reviews*, vol. 39, Nov. 2014, pp. 655-666.

[3] M. Altin, Ö. Göksu, R. Teodorescu, P. Rodriguez, B. B. Jensen, and L. Helle, "Overview of recent grid codes for wind power integration, " in *Proc. 2010 International Conference on Optimization of Electrical and Electronic Equipments*, pp. 1152-1160.

[4] A. D. Hansen, P. Sørensen, F. Iov, F. Blaabjerg. "Centralised power control of wind farm with doubly fed induction generators." *Renewable Energy* (2006) 31, pp. 935-951.

[5] N. R. Ullah and T. Thiringer, "Temporary primary frequency control support by variable speed wind turbines-potential and applications," *IEEE Transactions on Power Systems,* vol.23, no.2, pp.601-612, May 2008.

[6] O. Anaya-Lara, F. Hughes, N. Jenkins, and G. Strbac, "Contribution of DFIG-based wind farms to power system short-term frequency regulation," in *Generation, Transmission and Distribution, IEE Proceedings*, 2006, vol. 153, no. 2, pp. 164-170.

[7] A. D. Hansen, M. Altin, I. D. Margaris, F. Iov, and G. C. Tarnowski, "Analysis of the short-term overproduction capability of variable speed wind turbines, " *Renewable Energy* 68, 2014, pp. 326-336.

[8] J. Fortmann, "Reactive Power Control of Wind Plants." *Modeling of Wind Turbines with Doubly Fed Generator System*. Springer 2015, pp. 113-158.

[9] N. W. Miller, W. W. Price, and J. J. Sanchez-Gasca, "Dynamic modeling of GE 1.5 and 3.6 wind turbine-generators," *GE-Power systems,* 2003.

[10] NERC Special Report, Standard Models for Variable Generation, NERC 2010.

[11] IEC 61400-27-1 Ed.1. Wind Turbines - Part 27-1: Electrical simulation models for wind power generation – Wind turbines. Committee Draft (CD) 2012-01-13.

[12] A. Ellis, Y. Kazachkov, E. Muljadi, P. Pourbeik, and J. Sanchez-Gasca, "Description and Technical Specifications for Generic WTG Models – a status report, " in Proc. 2011 IEEE PES PSCE.

[13] A. D. Hansen, , N. A. Cutululis, and M. Altin, "Methods for Representations of Wind Power Plants for Active Power Studies, " 12th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power, 2013.

[14] A. D. Hansen, F. Iov, F. Blaabjerg, L. H. Hansen. "Review of Contemporary Wind Turbine Concepts and their Market Penetration," *Wind Engineering* vol. 28, Issue 3, pp 247–263 (2004).