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Generic Models for Simulation of Wind Power Plants in Bulk System Planning Studies

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***Abstract*—The need for generic, standard, non-proprietary models for wind power plants continues to be the subject of much discussion and debate. From a technical point of view, the representation of the often complex dynamic behavior of modern wind power plants is not trivial. However, system planners and compliance organizations continue to struggle with the process deficiencies associated with the black-box and proprietary nature of manufacturer-specific models. For several years, the Western Electricity Coordinating Council (WECC) has championed the development of generic models for wind power plant models, and the progress to date is reported in this document. Recently, other organizations including the International Electromechanical Commission (IEC), manufacturers, software developers, and even utilities have been pursuing similar technical goals. It is anticipated that, through the collective efforts of these stakeholders, generic models will fulfill a much needed gap. This paper reports on the progress made to-date within the Western Electricity Coordinating Council (WECC) regarding the development of generic models suitable for representing wind power plants in typical transmission planning studies. The manuscript address technical issues associated with the representation of wind turbine generators for load flow and transient stability analyses. Current capabilities and envisioned enhancements to existing models are also discussed.**

***Index Terms*—Generic Models, Dynamic Modeling, Power System Simulation, Wind Power Plant Representation.**

I. Introduction

The need for generic, standard, non-proprietary models for wind power plants continues to be the subject of much discussion and debate. Despite the large existing and planned wind generation deployment, industry-standard models for wind generation have not been formally adopted. Models commonly provided for interconnection studies are not adequate for use in general transmission planning studies, where public, non-proprietary, documented and validated models are needed. NERC MOD reliability standards require that power flow and dynamics models be provided, in accordance with regional requirements and procedures. The WECC modeling procedures state that suitable wind turbine generators (WTG) power flow and dynamics data should be submitted to WECC. In response to this need, the WECC has championed the development of generic models for wind power plants. Over the course of several years, WECC's Renewable Energy Modeling Task Force (REMTF) has developed a set of generic models for wind generation that are now implemented in the simulation platforms most commonly used in the Western Interconnection. This document discusses the use and limitations of WECC WTG generic models. Control diagrams for the WECC models are discussed in [1] and [2]. It should be noted that representation of WPPs is an area of active research. Models will continue to evolve as new technology options become available. Model validation and hence application of existing model verification standards to wind power plants remains a challenge due to insufficient data industry experience. Recent progress in the area of wind plant model validation is reported in [3].

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II. Technical Background

A. *Wind Power Plants*

Fig. 1 shows a typical configuration for a wind power plant (WPP). WPPs are different than conventional power plants in several important respects. They consist of many (typically hundreds) of small wind turbine-generators deployed over a large area. The rating of each WTG ranges from 1MW to 5MW. There are several types of wind turbine generators with various combinations of grid interface as well as electrical and mechanical controls. The characteristics of the four major wind turbine-generator types are discussed in Section II. Unlike most conventional power plants, the energy source for wind power plants is variable. For this reason, only limited dispatchability and controllability of active power is possible. Reactive power is managed at the plant level, through coordinated control of wind turbine control and/or plant level reactive compensation. At the point of connection, reactive power performance similar to synchronous generators can be achieved.

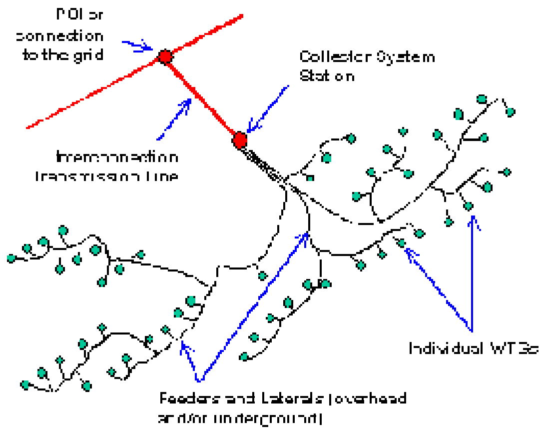

Fig. 1 – Typical WPP Topology

B. Load Flow Representation

For bulk system studies, it is impractical and unnecessary to model the collector system network inside the plant to the level of detail shown in Figure 1. The single-machine equivalent model shown in Figure 2 is the recommended approach to represent WPPs in WECC base cases [4]. For the vast majority of WPPs, regardless of size or configuration, a single generator equivalent is sufficient for planning studies. In some situations where there are two or more types of WTGs in the same plant, or when the plant contains feeders with very dissimilar impedance, representing the plant with two equivalent generators is needed. This representation has been shown to be sufficient for bulk-level dynamic simulations [5].

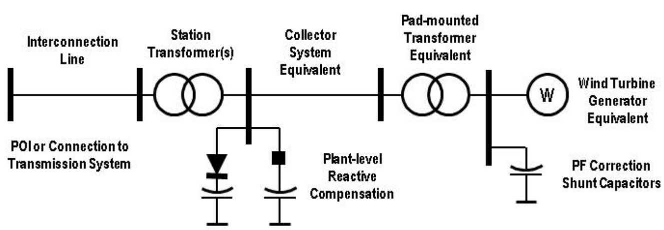

Fig. 2 – Single-Machine Equivalent Representation for a WPP

A methodology to develop the parameters for the single-machine representation, including a way to derive the collector system equivalent analytically has been described in previous work [6].

C. Type of WTGs

Despite the seemingly large variety of utility-scale WTGs in the market, each can be classified in one of four basic types described below.

- Type-1 – Fixed-speed, induction generator
- Type-2 – Variable slip, induction generators with variable rotor resistance
- Type-3 – Variable speed, doubly-fed asynchronous generators with rotor-side converter
- Type-4 – Variable speed generators with full converter interface.

The classification is based on the type of generator and grid interface, as show in Fig. 3.

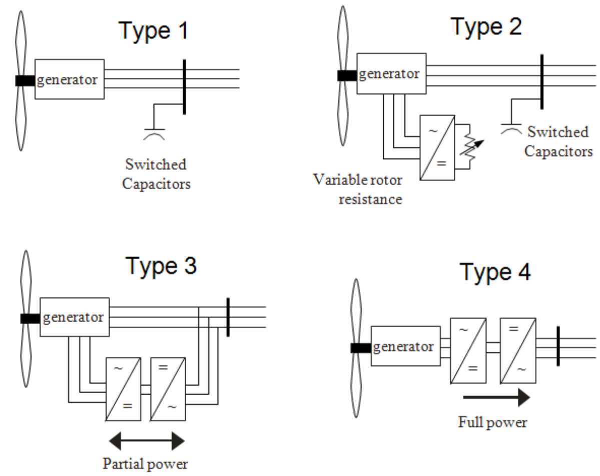

Fig. 3 – Classification of WTGs Based on Grid Interface

The following sections describe the characteristics of each type of WTGs.

Type-1 and Type-2 WTGs

The Type-1 WTG is an induction generator with relatively simple controls. The torque speed characteristic is very steep (about 1% slip at rated torque), which means that these generators operate at nearly constant speed. As with any induction generator, the Type-1 WTGs absorb reactive power. Most commercial Type-1 WTGs use several mechanically switched capacitors (MSCs) to correct the steady-state power factor at the WTG terminals to unity, over the range of power output. With a slow varying wind speed, the individual MSCs switch in and out to follow the varying reactive power demand. A significant reactive power imbalance may occur due to changes in wind speed or grid conditions. Type 1 and Type 2 WTGs pitch the blades to limit the aerodynamic power above rated wind speed, thus mechanical loads are imposed on the gearbox and shaft are within design limits.

Type-2 WTGs, similar to Type-1, are induction generators with power factor correction capacitors, and have a similar steady-state behavior. Type-2 WTGs have the capability to rapidly adjust the effective rotor resistance in order to be able to operate at variable slip levels above rated slip; therefore, the dynamic behavior is very different compared to Type-1 WTGs. The rotor resistance control (fast) and the pitch control (slower) work in harmony to control speed and reduce mechanical stress. WPPs with Type-1 and Type-2 WTGs typically have plant-level reactive compensation equipment to meet steady-state and dynamic reactive power requirements. External reactive support also helps the plant meet voltage ride-through requirements.

Type-3 and Type-4 WTGs

The steady-state and dynamic characteristics of Type-3 and Type-4 WTGs are dominated by a power converter. The converters allow the machine to operate over a wider range of speed, and control active and reactive power independently. This means that Type-3 and Type-4 WTGs have the capability to participate in steady-state and dynamic volt/var control. In some Type-3 WTG designs, a crow-bar or DC chopper circuit may be used to short the rotor-side converter during a close-in transmission fault to avoid excessively high DC link voltage and keep the machine running. If the rotor-side converter is shorted, the dynamic behavior is similar to an induction generator. In contrast, the converter in the Type-4 WTG completely isolates the generator from the grid. Only the converter and its controls come into play during grid disturbances. During a low voltage event, the converter tries to retain full control of active and reactive currents. Both Type-3 and Type-4 WTGs can be designed to meet low voltage ride-through requirements without external reactive power support. Converters are current-limited devices, and this plays a major role in the dynamic response of Type-3 and Type-4 WTGs to grid disturbances. Type-3 and Type-4 WTGs also have a pitch control to optimize energy capture and to control the rotor speed in high wind speeds regimes.

Based on these fundamental differences, it has been postulated that each WTG type requires a different generic dynamic model structure. The WECC REMTF has followed this general approach.

III. General Considerations for Simulation of WPPs

This section describes several important considerations for simulation of wind power plants in bulk system simulations. To a large extent, the WECC generic modeling effort is consistent with these technical principles.

A. *Appropriate Models for Bulk System Simulations*

From the system planners' point of view, simulation of WPPs should adhere to well established power system simulation methodologies, using models that are similar in character to models for other major system components. In the case of wind generation, however, there is significant disagreement and some misconception about what type of dynamic models are appropriate for bulk system planning studies. In general, the industry has settled on using manufacturer-specific models for interconnection studies. Manufacturers advocate for this approach to increase confidence in simulation results upon which interconnection requirements are based. However, the use of manufacturer models can be very cumbersome when multiple projects are being evaluated. Furthermore, manufacturer-specific models are impractical for regional planning studies if they are proprietary and not fully supported by simulation software as standard library models. The generic models developed by WECC are intended to be used for regional planning studies, where reduced-order, positive-sequence models are used for various practical reasons. In this application, uniformity, standardization, computational cross-platform compatibility, and computational efficiency are very important considerations. It should be noted that generic models for conventional generators and other power system components are routinely used for interconnection studies as well as regional planning. This reflects a level of maturity that has not yet been achieved by generic wind models. As the generic models continue to be refined over time, their use in interconnection studies should become standard industry practice.

B. *Effect of Collector System Impedance*

To simulate the plant behavior at the point of connection, it is very important that the equivalent impedance of the collector system be represented. Since WPPs typically extend over a large geographical area, the electrical impedance between the terminals of each WTG and the point of interconnection is different. System disturbances may challenge protection settings or terminal voltage limits for some WTGs in the plant, but not others, or cause electromechanical oscillations of different amplitude. It is not possible to capture this level of detail with a single-machine equivalent. However, the net effect of this electrical diversity is relatively small, as long as the correct equivalent collector system impedance is represented. Fig. 4 documented in [5] compares simulated responses to a 3-phase fault, as measured at the collector system station, obtained with a single machine equivalent and with a multiple-machine equivalent. In this example, a different wind speed was assumed for a portion of the WPP.

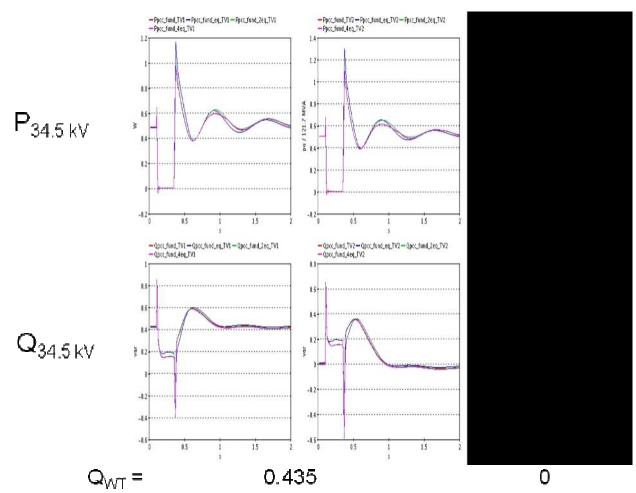

Fig. 4 – Comparison of dynamic response obtained with single machine equivalent and with a four-machine, for different initial power factor conditions [5].

Fig. 5 shows a similar comparison for an actual Type-3 WPP in New Mexico. In this case, the simulated response with a single machine representation (blue traces) and a detailed full representation (thick red traces) are almost identical. The thin red traces represent measured data [2].

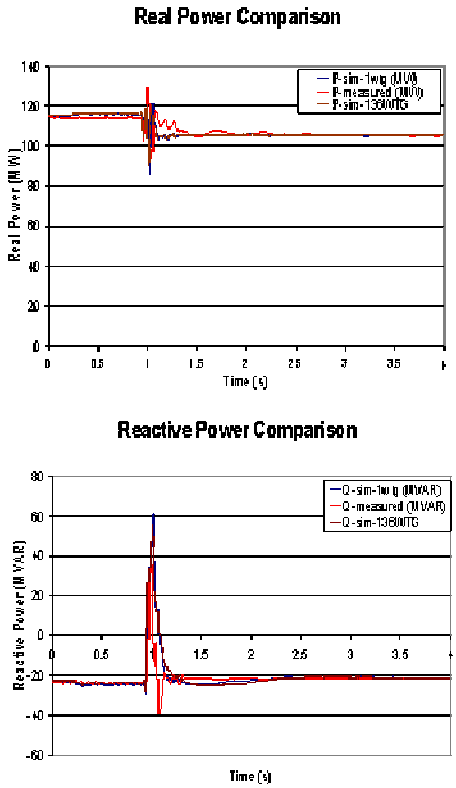

Fig. 5 – Comparison of simulated dynamic response from a single machine model and a detailed WPP model (136 WTGs), against measured data.

When the difference in connection impedance for a group of WTGs in the WPP is considerably different, or when different types of WTGs are present in the WPP, it may be prudent to represent the plant with a two- (or more) machine equivalent circuit.

C. Voltage Control and Reactive Power Management

Type-1 and Type-2 WTGs are induction generators, and as such, the steady-state power factor is approximately 0.9 leading (absorbing VARs). Capacitors are added at the generator terminals to correct the power factor. Several capacitor stages are used to maintain steady-state power factor close to unity over the range of output of the WTG. However, these WTGs do not have the ability to control reactive power dynamically. STATCOMS or SVCs are usually needed for Type-1 and Type-2 WPPs to compensate for reactive power losses in the collector system lines and transformers, and meet reactive control requirements at the point of connection. Type-3 and Type-4 WTGs, on the other hand, have the capability of absorbing or sourcing reactive power. In actual implementation, each Type-3 or Type-4 WTGs follow a power factor reference that can be adjusted by a plant-level supervisory controller, possibly dynamically, to help achieve a control objective at the point of connection (voltage control or reactive power control). Faster-acting controls local to the WTG can override the power factor reference to avoid exceeding converter current and terminal voltage limits. Depending on the plant design, additional reactive power support equipment may be added to meet connection reactive control and voltage ride-through requirements. This is especially true in weak interconnections.

Obviously, the reactive control objective and how it is achieved should be taken into account in the power flow and dynamic representation. For example, if WTGs do not participate in dynamic voltage control (even though they may be technically capable of doing so), then the dynamic model should reflect a constant power factor. The WECC generic models for the Type-3 and Type-4 WTGs include a volt/var emulator that can be used to simulate the contribution of the WTGs. For Type-1 and Type-2 WTGs, the generator part of the WTG is modeled as a conventional induction machine. Capacitor compensation should be modeled externally at the equivalent generator terminal bus.

It is important to assign a reasonable power factor to the equivalent Type-1 and Type-2 generator in power flow to ensure a clean initialization before a dynamic run. A power factor of approximately 0.9 leading for the generator corrected to unity with a shunt capacitor (assuming nominal voltage) would a reasonable assumption. This ensures that capacitance added during initialization is kept to a minimum. The WECC power flow guide also discusses this detail [4].

WTGs in the wind plant may be subjected to steady-state voltages near or at their design limits. Under these conditions, reactive power capability may be limited. In traditional power system studies, reactive power capability for machines is not considered as voltage dependent. System planners should determine, in consultation with the WTG manufacturer or plant owner, whether voltage dependence should be taken into account and how.

D. Frequency Response and Active Power Management

Wind plants have limited ability to control active power. Under normal conditions, the goal is to capture as much energy from the wind as the equipment can handle. Electrical output power is not normally curtailed. For rapid changes in wind, the rate of increase of electrical power could be controlled with little energy loss. However, this might not be the case for the rate of decrease of electrical power for rapid decrease in wind. Similarly, WPPs are capable of reducing power output during high frequency events by turning off some WTGs, or by allowing the WTGs to temporarily operate below their optimal level. A positive frequency droop is also possible, but this entails a higher energy loss since “spilling” wind over a long period time would be required. Electrical disturbances create a temporary imbalance between electrical and mechanical power, and how this imbalance is handled depends on the Type of WTG and how they are controlled. Because generators of Type-1 and Type-2 WTGs are directly coupled to the grid, they provide a small amount of inertial response. Type-3 and Type-4 WTGs do not inherently have inertial response because their generators are effectively isolated from the grid by the converter dynamics. However, it is possible to implement various types of active power control features including synthetic or programmed inertia characteristics [7]. Following transmission disturbance, the electrical output power of Type-1 and Type-2 WTGs tends to oscillate since shaft speed is coupled with the grid. For Type-3 and Type-4 WTGs, the converter effectively isolates the shaft from the grid, therefore electromechanical interaction is much less significant. In most situations, the addition of WT3 and WT4 WTGs tends to improve damping in the local system.

The first version of the WECC generic models discussed in the WECC guide [2] captures the basic effects of shaft coupling and inertia characteristics of WTGs, as discussed above. The Type-3 and Type-4 generic models allow for active power ramp limits. However, other active power management functions such as frequency droop and synthetic inertia are not represented in the existing version of the generic models. REMTF is working to include these power management functions in subsequence versions of the models. The existing WECC generic dynamic model implementation assumes that the wind speed is constant during the typical dynamic simulation run (10 to 30 seconds); therefore, dynamics associated with changes in wind power do not come into play. This is a reasonable assumption for WPPs. Partial power output can also be simulated with the generic models with suitable choice of generator MVA and turbine rating with respect to generator output (*Pgen*).

E. Dynamic Behavior during a Fault

The type of WTG and its controls determine the behavior during a system fault. Except in the case of Type-1 WTGs, fast-acting electronic controls are active during and shortly after fault condition. This is especially true for faults that result in significant voltage drop across the WTG terminals. In some Type-3 WTG designs, the rotor-side converter may be short-circuited ("crow-bar") or dynamic breaking resistance may be activated to avoid an overvoltage condition across the DC link capacitor. In this case, the machine temporarily behaves as an induction generator. Modern Type-3 and Type-4 WTGs are able to remain on line during faults in accordance with their low- or zero-voltage ride-through specifications and continue to regulate the magnitude and angle of the current injection. For more severe voltage dips, mechanical and electrical limits may come into play. While the bulk system dynamic studies focus more on voltage recovery characteristics, it should be recognized that the specific control actions during the fault affects the dynamic behavior after the fault, but not all relevant control details are represented in the generic models. It is difficult to capture the complex behavior of actual hardware in detail using positive-sequence models. However, REMTF is evaluating the feasibility of making improvements in this area, taking into account the intended use of the models. The challenge is to maintain balance between model complexity and functionality, and maintain the generic, non-proprietary character of the models.

IV. WECC Generic Models

This section contains a general description of the WECC generic models as currently implemented in the General Electric PSLF, Siemens-PTI PSSE and other simulation programs used in WECC. Several important aspects of WPP dynamic simulation using the generic models are also described, including scaling to simulate a WPP of any size, simulation of reactive control options, and protection settings.

A. Technical Specifications for the WECC Generic Models

The WECC REMTF developed a set of general specifications to guide the development of the first generation of generic WTG models, and to define the intended use and limitations of the models: The key specifications are [1]:

- The models must be non-proprietary and accessible to transmission planners and grid operators and for inclusion and distribution in WECC dynamic models without the need for non-disclosure agreements.
- The models need to provide a reasonably good representation of dynamic electrical performance of wind power plant at the point of interconnection with the utility grid, not inside the wind power plant.
- Studies of interest to be performed using the generic models are electrical disturbances, not wind disturbances. Electrical disturbances of interest are primarily balanced transmission grid faults, not internal to the wind power plant, typically of 3 - 6 cycles duration. Other transient events such as capacitor switching and loss of generation can also be simulated.
- The accuracy of generic models during unbalanced events needs further research and development. At the present time, there is no standard guideline.
- Model users (with guidance from the manufacturers) should have the ability to represent differences among generators of the same type by selecting appropriate model parameters for the Generic model of the WTG type.
- Simulations performed using these models typically cover a 20-30 second time frame, with a ¼ cycle integration time step. Wind speed is assumed to be constant.
- The generic models are functional models suitable for the analysis and simulation of large-scale power systems. Their frequency range of validity is from dc to approximately 10 Hz.
- A generic model should include the means for external modules to be connected to the model, e.g., protection functions.
- The models will be initialized based on the power-flow power dispatch. For power less than rated, blade pitch will be set at minimum and wind speed at an appropriate (constant) value. For rated power, a user-specified wind speed (greater than or equal to rated speed) will be held constant and used to determine initial conditions.
- For Type-2 WTG, a look-up table of power versus slip should be provided.
- For converter-based WTG (Type-3 and Type-4) appropriate limits for the converter power and current should be modeled.
- Power level of interest is primarily 100% of rated

power, with wind speed in the range of 100% to 130% of rated wind speed. However, performance should be correct, within a reasonable tolerance, for the variables of interest (current, active power, reactive power and power factor), within a range of 25% to 100% of rated power.

- In addition to the overall machine inertia, the first shaft torsional mode characteristics should be user-specified in terms of frequency, turbine inertia, and damping factor, with calculations performed internally to determine appropriate torsional model parameters to match the modal frequency. The model should be able to represent one or two masses.
- The models should be applicable to strong and weak systems with a short circuit ratio of 2 and higher at the point of interconnection. The models should not behave erratically when the SCR is low.
- Aerodynamic characteristics will be represented with an approximate performance model that can simulate blade pitching, assuming constant wind speed, without the need for traditional CP curves.
- Shunt capacitors and any other reactive support equipment will be modeled separately with existing standard models.

B. Description of WECC Generic Models

The first generation of WECC wind plant generic models largely conform to these guidelines. This section describes the WECC generic dynamic models and their application. Appendix A contains additional details, including default parameters for each module. Since the generic models will continue to evolve, the user should always refer to the most current model documentation for additional details.

The block diagram shown in Fig. 6 depicts the major components of the WECC generic dynamic models. In the Type-1 and Type-2 generic models, the generator is represented as a conventional "one-cage" or "two-cage" induction generator model. For Type-3 and Type-4, a simplified model is used. The power converter/excitation block represents external rotor resistance control in Type-2 WTGs, or active/reactive controls in Type-3 and Type-4 WTGs. The pitch control and aerodynamics block represents the aerodynamic-to-mechanical power conversion and rotor speed controls. The mechanical drive train block represents the mechanical link between the generator and the turbines i.e. shaft stiffness, gearbox, etc. Finally, a protection model is added to simulate generator tripping based on voltage or speed.

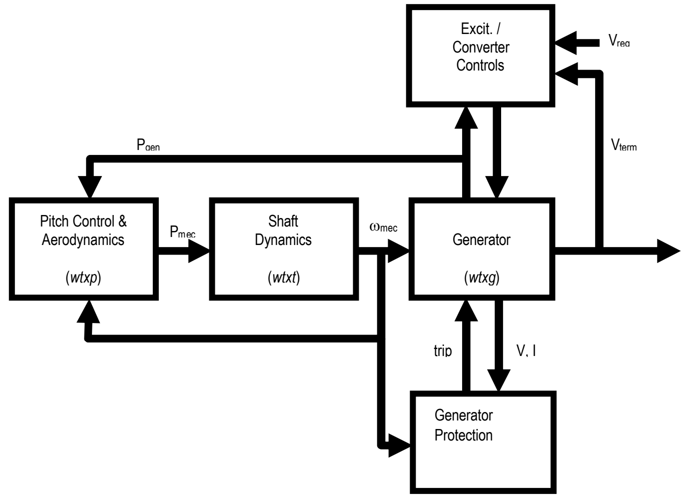

Fig. 6 – Block Diagram Showing Different Modules of the WECC Generic Models

A first version of the WECC generic models has been implemented in several simulation platforms being used in WECC, including the General Electric PSLF and Siemens PTI PSSE simulation platforms. A list of available simulation modules for both PSSE and PSLF is shown in Table 1 and Table 2. Although there are differences in the program implementation, the models are functionally equivalent and have the same set of parameters. Note that the models for certain WTG types only require two modules (e.g., Type-4); while others require four modules (e.g., WT3).

Table 1: Completed generic models implemented as standard-library models in PSLF 17

Model Type	Type 1	Type 2	Type 3	Type 4
Generator	wt1g	wt2g	wt3g	wt4g
Excitation / Controller		wt2e	wt3e	wt4e
Turbine	wt1t	wt2t	wt3t	wt4t
Pitch Controller	wt1p	wt2p	wt3p	

Table 2: Completed generic models implemented as standard-library models in PSSE 32

Generic model	WT1	WT2	WT3	WT4
Generator	WT1G	WT2G	WT3G	WT4G
El. Controller		WT2E	WT3E	WT4E
Turbine/shaft	WT12T	WT12T	WT3T	
Pitch control			WT3P	
Pseudo Gov/: aerodynamics	WT12A	WT12A		

C. Scaling of Generic WTG Models for Simulation of WPP

All model parameters are represented in per unit of the generator MVA base (*mvabase*) and turbine MW capacity (*mwcap*). By scaling the generator and turbine base capacity to the total generator MVA and total MW rating, respectively, WPPs of any size can be represented. The generator MVA base is a parameter in the *wt1g*, *wt2g*, *wt3g* or *wt4g* module. Nominally, the value of *mvabase* can be assumed to be 110% of the *mwcap* value. If the *mvabase* is not set in the dynamic model call, the generator MVA base defined in load flow will be used as default. For proper initialization, the value of *mwcap* should be equal or larger than *Pgen* in load flow. In the current implementation of the Type-1 and Type-2 generic models, all parameters are on the generator *mvabase*, and the turbine limit (corresponding to *mwcap*) can be simulated by setting the parameter *pimax* in the *wt1p* or *wt2p* module. For example, to make the Type-1 or Type-2 generator rating 110% of the turbine rating, *pimax* should be set to 0.909. In the Type-3 model, the value of *mwcap* is specified in the *wt3e* module. The wind turbine is not modeled in the Type-4 generic model, so there is no *mwcap* value to set. As stated before, the generic WTG models are evolving; therefore, users must consult manufacturers and simulation program documentation for specific guidance on parameter settings.

Simulation of Plant-Level Volt/Var Controls

For Type-1 and Type-2 WPPs, the equivalent generator representation in load flow should have a constant power factor set to 0.9 in the power flow model, and external shunt compensation should be added to correct the net power factor to unity (see Power Flow guide for detail). This allows for proper initialization of the *wtxg* models in dynamics. External reactive compensation devices such as STATCOMS are typically installed at the collector system station. Appropriate dynamic models for those devices should be used , reflecting the actual control objective implemented in the field.

As stated earlier, Type-3 and Type-4 WTGs could participate in dynamic volt/var control through a plant-level supervisory control. The excitation/converter control module (*wt3e* or *wt4e*) can emulate WTG participation in voltage control, power factor or reactive power at a remote bus. In the Type-3 model, the control mode is specified by setting a flag (*varflg*) parameter, as described in Table 3 below.

Table 3 – Specifying volt/var control mode in the *wt3e* module

Type of Control	*varflg*	Note
Voltage Control	*1*	The controlled voltage can be the generator terminal or a remote bus as specified by the *wt3e* call.
Reactive Power Control	*0*	The reactive power reference is set to the initial output of the generator (Q_{gen}) in load flow.
Power Factor Control	*-1*	The power factor reference is set by the initial load flow conditions: $PF_{ref} = cos\ (arctan\ (Q_{gen\ init}/\ P_{gen\ init})$.

For proper initialization, the controlled bus should be consistent with the load flow set-up. A compensating reactance parameter, *Xc*, can be set to a nonzero value to allow a user to simulate voltage control at a point along a branch. For example, voltage control half way across the station transformer could be simulated by setting *Xc* to 50% of the transformer impedance. The default value for *Xc* is 0. Assuming that *varflg* = *1*, the *wt3e* module can be used to simulate any of the voltage control scenarios shown in Fig 7.

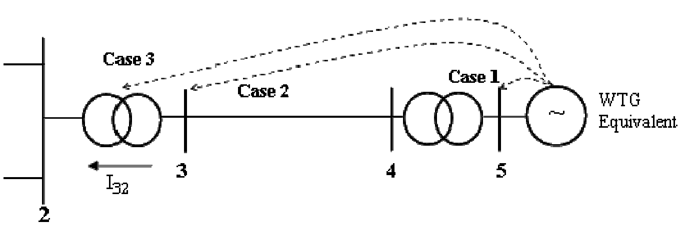

Fig. 7 – Examples of voltage control that can be simulated with *wt3e* module.

The volt/var implementation of the wt4e module is similar to the wt3e, except that an additional control option (an external regulator) is allowed. Table 4 below shows the settings for the various control options. Note that in some cases the settings do not select the same control options, and that an additional parameter, *pfaflg*, is needed.

Table 4 – Selecting the volt/var control mode in the *wt4e* module

Type of control	*varflg*	*pfaflg*	Note
Voltage Control	1	n/a	The controlled voltage can be the generator terminal or a remote bus as specified by the *wt3e* call. For proper initialization, the controlled bus should be consistent with the load flow solution.
Reactive Control via separate model	-1	n/a	Can be used to control Q_{cmd} from a separate, external model.
Reactive Power Control	0	0	The reactive power reference is set to the initial output of the generator (Q_{gen}) in load flow.
Power Factor Control	0	1	The power factor reference is set by the initial load flow conditions: $PF_{ref} = cos\ (arctan\ (Q_{gen\ init}/\ P_{gen\ init})$.

The Type-3 and Type-4 generic models also implement variety of voltage and current limits that simulate the operation of the converter and affect reactive power dynamic behavior. Table 5 lists some of those parameters and their significance. For additional information, refer to the full model documentation included in the software manual.

Table 5 – Other important parameters for Type-3 and Type-4 generic models

Parameter	Note
pqflag	Used to prioritize the allocation of active and reactive current when the vector sum exceeds the converter current limits. The default value is 0 (Q priority)
Q_{max} Q_{min}	Maximum and minimum reactive command, in pu of MVA base. Generally, these values should correspond to the Q_{max} and Q_{min} values used in power flow.
I_{phl} I_{qhl}	Maximum active and reactive currents for the converter.
K_{pv} K_{iv}	Plant-level control proportional and integral gains. The default values (18 and 5, respectively) should be reduced when the ratio of system short-circuit MVA and plant MVA is lower than 5. See documentation for details.

Representation of Voltage and Frequency Protection

WPPs are required to comply with voltage ride-through requirements. However, the WECC generic models (or any other positive-sequence model) are not suitable to fully assess compliance with this requirement. Voltage ride-trough is engineered as part of the plant design, and requires far more sophisticated modeling detail than is possible to capture in a positive-sequence simulation environment. As stated before, severe system disturbance may challenge protection settings or terminal voltage limits for some WTGs in the plant, but not others, and it is not possible to capture this level of detail using a single-machine equivalent model. However, an external protection model can be used with the WECC generic models to provide an indication of plant sensitivity to voltage. Appendix A of ref [2] describes voltage and frequency protection modules available in PSLF and PSSE, which can be used with the WECC generic models.

Shaft Dynamics

Shaft dynamics can have a significant effect on dynamic stability, particularly for Type-1 and Type-2 WPPs connected to a weak part of the network. The turbine models for the Type-1, Type-2, and Type-3 WTGs (wt1t, wt2t, and wt3t) allow for a single-mass or a two-mass model. For the single mass model, only the inertia and damping needs to be specified. For the two-mass model, the ratio of turbine to generator inertia, first shaft torsional resonant frequency and shaft damping factor need to be specified. Type-3 and Type-4 WTGs effectively isolate the generator and turbine shaft dynamics from the grid. The turbine model for the Type-3 WTG (wt3t) is included primarily to emulate the effect of aerodynamics on the dynamic performance.

V. Future Plans to Upgrade the WECC Generic Models

The first generation of WECC wind plant generic models are currently available, but recent experience has shown that modification to the some of the models is needed to represent a wider range of control approaches. This is particularly true for the Type 3 generic model. REMTF is currently evaluating modifications to the Type 1 and Type 3 generic models based on recommendations by model users and manufacturers. For example, some key recommended changes to the Type 3 generic model are contained in [8].

VI. Summary and Conclusions

This document discusses the use and limitations of WECC generic models developed by REMTF. The models have been developed and are implemented and readily available as standard-library models in the simulation platforms most commonly used in the Western Interconnection. The WECC generic models are useful for general bulk system planning studies, however, the REMTF will continue to work and refine the generic models to enhance the performance of the current models or add new functionalities. Representation of WPPs is an area of active research. Models will continue to evolve as new technology options become available.

It should be noted that other organizations including the International Electromechanical Commission (IEC), manufacturers, software developers, and even utilities have been pursuing similar technical goals. It is anticipated that, through the collective efforts of these stakeholders, generic models will fulfill a much needed gap.

References

[1] "Description and Technical Specifications for Generic WTG Models – A Status Report", Joint Report of the WECC Renewable Energy Modeling Task Force & IEEE Working Group on Dynamic Performance of Wind Power Generation, Submitted to 2011 IEEE Power System Conference and Exposition, March 2011.

[2] WECC Wind Power Plant Dynamic Modeling Guide", WECC Wind Generator Modeling Group, November 2010.

[3] "Model Validation for Wind Turbine Generator Models", Ad hoc Task Force on Wind Generation Model Validation, IEEE PES Working Group on Dynamic Performance of Wind Power Generation, Submitted for publication in the IEEE Transactions on Power Systems, September 2010.

[4] "WECC Wind Power Plant Power Flow Modeling Guide", WECC Wind Generator Modeling Group, May 2008.

[5] J. Brochu, R. Gagnon, C. Larose, "Validation of the WECC Single-Machine Equivalent Power Plant", Presented at the IEEE PSCE DPWPG-WG Meeting, Seattle, Washington, March 2009.

[6] E. Muljadi, S. Pasupulati, A. Ellis, D. Kosterev, "Method of Equivalencing for a Large Wind Power Plant with Multiple Turbine Representation", presented at the IEEE Power Engineering Society, General Meeting, Pittsburgh, PA, July 20-24, 2008.

[7] N. Miller, K. Clark, M. Shao, "Impact of Frequency Responsive Wind Plant Controls on Grid Performance", presented at 9th International Workshop on Large-Scale Integration of Wind Power Into Power Systems, Quebec City, Canada, October 2010.

[8] J. Fortmann, S. Engelhardt, J. Kretschmann, C. Feltes, M. Janßen, T. Neumann and I. Erlich, "Generic Simulation Model for DFIG and Full Size Converter based Wind Turbines", presented at 9th International Workshop on Large-Scale Integration of Wind Power Into Power Systems, Quebec City, Canada, October 2010.

VII. Author Biographies

Abraham Ellis received his M.S. Ph.D. in EE from New Mexico State University in 1995 and 200, respectively. Until 2008, he worked at Public Service Company of New Mexico in the transmission planning and operations area. Since 2008, he is with Sandia National Laboratories, where he is technical lead for renewable integration. His area of responsibility includes wind and solar system model development, analysis of power system operations, and technology development. Mr. Ellis is a Senior Member of the IEEE Power and Energy Society, and a Professional Engineer in New Mexico.

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Juan Sanchez-Gasca is a Principal Engineer in GE Energy - Energy Consulting Department, he has worked extensively in the areas of dynamic simulation and control of power systems. Dr. Sanchez-Gasca has been involved in the development of generic wind turbine generator models suitable for transmission planning studies. He is an IEEE Fellow and currently chairs the IEEE Power System Dynamic Performance Committee.

Eduard Muljadi (M'82-SM'94-F'10) received his Ph. D. in EE from the University of Wisconsin, Madison. From 1988 to 1992, he taught at California State University, Fresno, CA. In June 1992, he joined the National Renewable Energy Laboratory in Golden, Colorado. His current research interests are in the fields of electric machines, power electronics, and power systems in general with emphasis on renewable energy applications. He is member of Eta Kappa Nu, Sigma Xi and a Fellow of the IEEE. He is involved in the activities of the IEEE Industry Application Society (IAS), Power Electronics Society, and Power and Energy Society (PES). He holds two patents in power conversion for renewable energy.