Document Title	WECC Wind Power Plant Dynamic Modeling Guide
File Name	WECCWindPlantDynamicModelingGuide.pdf
Category	( ) Regional reliability standard ( ) Regional criteria ( ) Policy (X) Guideline ( ) Report or other ( ) Charter
Document date	November 19, 2010
Adopted/approved by	M&VWG/TSS
Date adopted/approved	January 2011
Custodian (entity responsible for maintenance and upkeep)	M&VWG
Stored/filed	Physical location: Web URL:
Previous name/number	Wind Generator Dynamic Modeling Guide .pdf
Status	(X) in effect ( ) usable, minor formatting/editing required ( ) modification needed ( ) superceded by _______________________ ( ) other ________________________________ ( ) obsolete/archived)

WECC Guideline:

WECC Wind Power Plant Dynamic Modeling Guide

Date: 11/2010

Introduction

This guideline provides guidance for using generic dynamic models for wind power plants.

Approved By:

Approving Committee, Entity or Person	Date
WECC Modeling and Validation Work Group	November 19, 2010
WECC Technical Studies Subcommittee	January 2011

Western Electricity Coordinating Council
Modeling and Validation Work Group

WECC Wind Power Plant Dynamic Modeling Guide

Prepared by
WECC Renewable Energy Modeling Task Force

November 2010

1 Introduction

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[1] states that suitable wind turbine generators (WTG) power flow and dynamics data should be submitted to WECC. In response to this need, the 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 generic models.

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. Application of model verification requirements to WPPs remains a challenge due to insufficient industry experience[2]. The WECC generic models are useful for general bulk system planning studies, more work remains to be done[3].

2 Brief Technical Background

Wind power plants are different than conventional power plants in several important respects. Some of the key differences are explained in the chart below.

Conventional Power Plant	**Wind Power Plant**
▪ One or a few large generating units (40MW to 1000MW+)	▪ Many (typically hundreds) of small generators (1MW - 5MW), deployed over a large area
▪ Prime mover: Steam, Gas, Hydro turbines or combustion engine	▪ Prime mover: Wind turbine
▪ Dispatchable, maneuverable between maximum and minimum limits.	▪ Non-dispatchable, limited maneuverability (curtailment, ramp rate limit, output limit)
▪ Units have speed governors and are typically AGC-capable	▪ Real power follows the wind speed variation.
▪ Unit are equipped with an automatic voltage regulator, typically set for voltage control	▪ Reactive power is managed at the plant level, through coordinated control of wind turbine control and/or plant level reactive compensation.
▪ Located where convenient for fuel and transmission access.	▪ Located where the wind resource is good, may be far from load centers or strong transmission.
▪ Synchronous Generator	▪ Four different types (fixed speed, variable slip, variable speed, full converter)

[1] "*WECC Data Preparation Procedural Manual for Power Flow Base Cases and Dynamic Stability Data*", Rev. 7.1, WECC System Review Work Group, July 2010. (hyperlink)

[2] "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.

[3] "*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.

Figure 1 shows the topology of a wind power plant. Large WPPs can contain hundreds of individual WTGs connected together through an extensive collector system network.

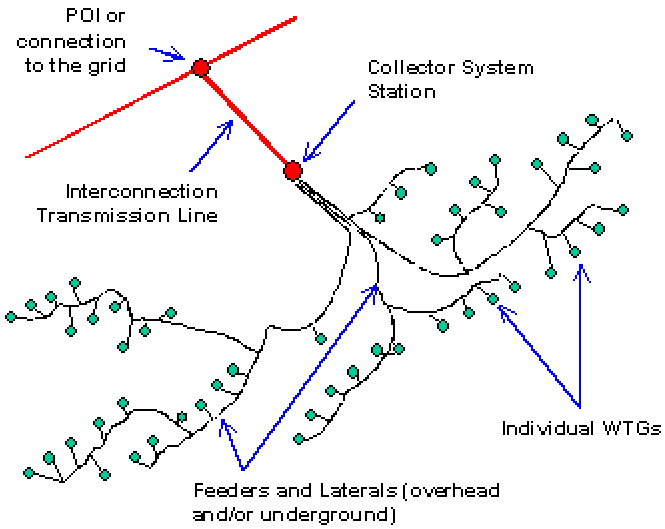


Figure 1 – Typical WPP Topology

2.1 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. 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 plant, or when the plant contains feeders with very dissimilar impedance, representing the plant with two equivalent generators. This representation has been shown to be sufficient for bulk-level dynamic simulations.

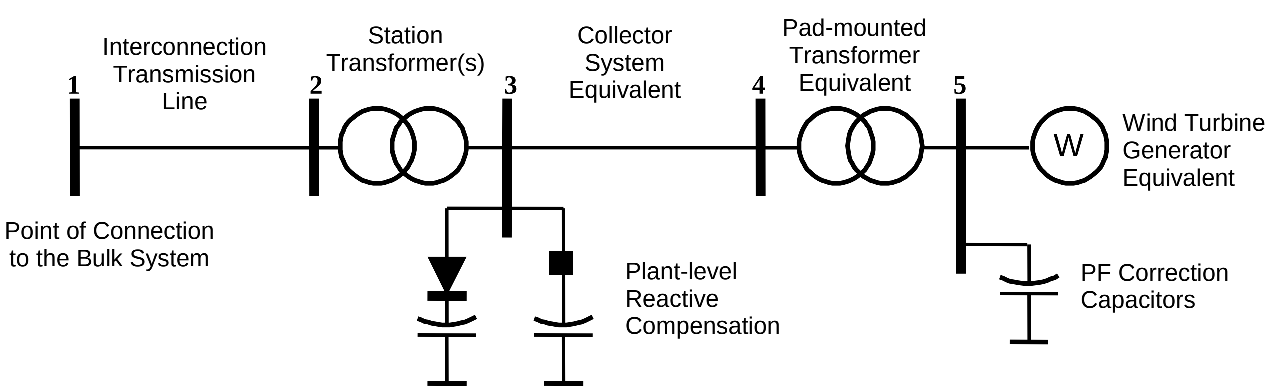


Figure 2 – Single-Machine Equivalent Power Flow Representation for a WPP

The WECC Wind Generation Power Flow Modeling Guide[4] describes a methodology to develop the parameters for the single-machine representation, including a way to derive the collector system equivalent analytically.

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

- 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

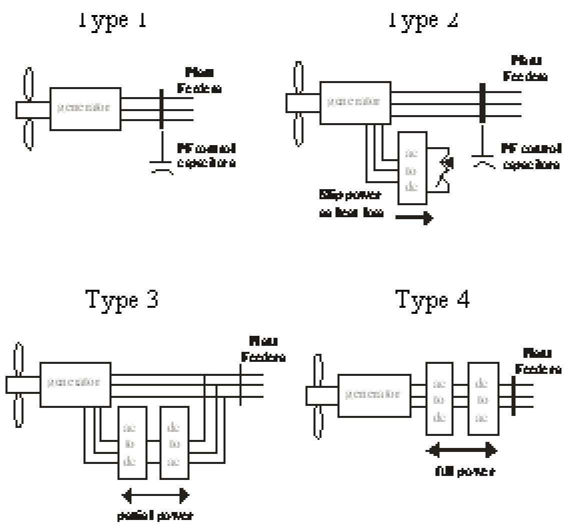


Figure 3 – Classification of WTGs Based on Generator Topology and Grid Interface

Each WTG type requires a different model structure because the dynamic characteristics of each type are fundamentally different.

2.2.1 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

[4] "*WECC Wind Generator Power Flow Modeling Guide*", WECC Wind Generator Modeling Group, May 2008 (hyperlink)

changes in wind speed or grid conditions. Type-1 WTGs pitch the blades to allow the generator to operate at constant mechanical speed even as wind varies.

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; 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.

2.2.2 Type-3 and Type-4 WTGs

The steady-state and dynamic characteristics of Type-3 and Type-4 WTGs are dominated by the 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 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 in 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. It is not possible to accurately simulate fault tolerance of these machines in a positive-sequence simulation environment. 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.

3 General Considerations for Dynamic Simulation of WPPs

3.1 Appropriate Models for Bulk System Simulations

The WECC generic models are reduced-order, positive-sequence models suitable for transmission planning studies involving a large network, and thousands of generators, loads and other dynamic components. The objective of dynamic simulation is to assess dynamic stability following large-signal disturbances such as transmission-level faults with integration time steps in the order of 1 to 5 milliseconds. The WECC generic models are intended to address NERC and WECC modeling requirements. As the generic models continue to be refined over time, they will eventually be used for generator interconnection studies as well, consistent with power system industry practice. At the discretion of the Transmission Planner, manufacturer-specific models may be used in the context of interconnection studies; however, such practice has a number of technical and process drawbacks.

3.2 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[5], or cause electromechanical oscillations of different amplitude. It is not practical 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. Figure 4 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[6]. In this example, a different wind speed was assumed for a portion of the WPP.

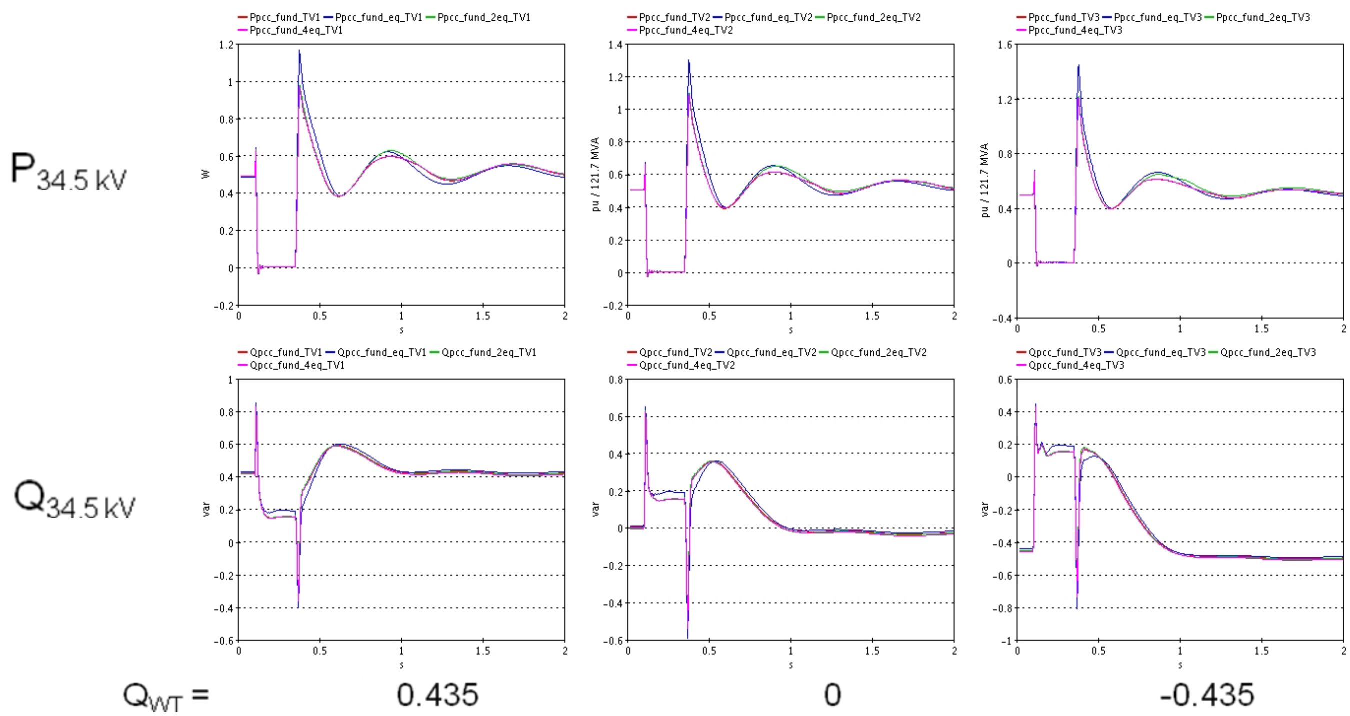


Figure 4 – Comparison of dynamic response obtained with single machine equivalent and with a four-machine, for different initial power factor conditions

Figure 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.

---

[5] E. Muljadi, Z. Mills, R. Foster, J. Conto, A. Ellis, "Fault Analysis at a Wind Power Plant for a One Year of Observation", presented at the IEEE Power Engineering Society, General Meeting, Pittsburgh, PA, July 20-24, 2008, http://www.nrel.gov/docs/fy08osti/42885.pdf

[6] Reference: 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.

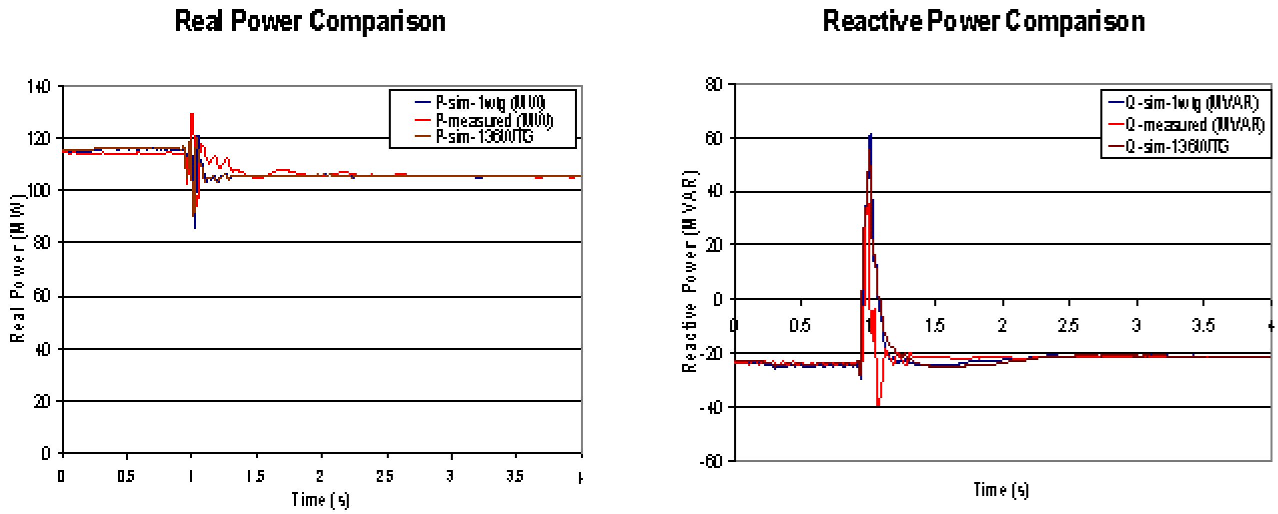


Figure 5 – Comparison of simulated dynamic response from a single machine model and a detailed WPP model (136 WTGs), against measured data.

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[7].

3.3 Voltage Control and Reactive Power Management

In steady-state, 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

[7] 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, http://www.nrel.gov/docs/fy08osti/42886.pdf

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.

In dynamic simulations, Type-1 and Type-2 WTGs are modeled as induction generators with special mechanical and electrical controls. 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.

3.4 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[8]. 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, some manufacturers offer a "synthetic inertia" feature, which is achieved by allowing the machine to slow down or speed up as a function of grid frequency. 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 this WECC guide 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 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

[8] When the sustained wind speed is above rated, the mechanical power input is reduced by pitching the blades.

with the generic models with suitable choice of generator MVA and turbine rating with respect to generator output (P_{gen}).

3.5 Dynamic Behavior during a Fault

The type of WTG and its controls determines 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") 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 in control during faults 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 fault recovery characteristics are of more interest in bulk system dynamic studies, it should be recognized that the specific control actions during the fault affects the behavior after the fault. The existing WECC generic models approximate the effect of controls during a fault, not the controls. 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.

4 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.

4.1 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: [9]

- 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.

[9] Working Group Joint Report – WECC Working Group on Dynamic Performance of Wind Power Generation & IEEE Working Group on Dynamic Performance of Wind Power Generation of the IEEE PES Power Stability Controls Subcommittee of the IEEE PES Power System Dynamic Performance Committee, "Description and Technical Specifications for Generic WTG Models – A Status Report," to be submitted to the 2011 IEEE Power System Conference and Exposition, March 2011

- 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.

The first generation of WECC wind plant generic models largely conform to these guidelines. The remainder of Section 4 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.

4.2 Generic Model Block Diagrams

The block diagram shown in Figure 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.

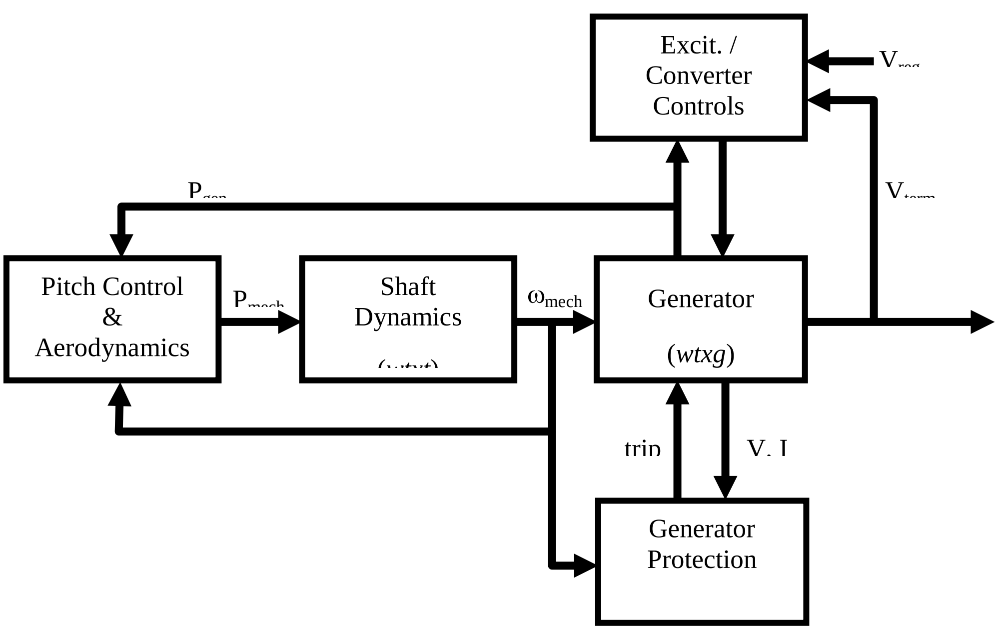


Figure 6 – Block Diagram Showing Different Modules of the WECC Generic Models

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		

4.3 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 MVAbase defined in load flow will be used as default. The following PSLF examples show how to set the parameter for a WPP rated at 100 MW:

wt3g 5 "BUS5" 0.6 "1 ": #9 mva=110 …

For proper initialization, the value of *mwcap* should be equal or larger than P_{gen} 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. 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 following examples are for a 100 MW WPP:

wt3e 5 "BUS5" 0.6 "1 " : #9 mwcap=100 …

The wind turbine is not modeled in the Type-4 generic model, so there is no *mwcap* value to set.

4.4 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[10], 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 the WPP 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. Some examples of voltage control reach are provided below.

Example 1: *wt3e 5 "BUS5" .575 "1 " : #9 …*

Example 2: *wt3e 5 "BUS5" .575 "1 " 3 "BUS3" 34.5 "1 " 1 : #9 …*

Example 3: *wt3e 5 "BUS5" 0.6 "1 " 3 "BUS3" 34.5 "1 " 2 "BUS2" 230 "1 " 1 : #9 …*

Assuming that *varflg = 1*, example 1 simulates voltage control at bus 5 (terminals of the equivalent generator), the example 2 simulates voltage control at bus 3, and example 3 simulates voltage control at a point that is an impedance *Xc* between bus 3 and bus 2. These are shown pictorially in Figure 5.
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.

[10] The WECC SVC Task Force recently developed definitions for improved SVC and STATCOM models.

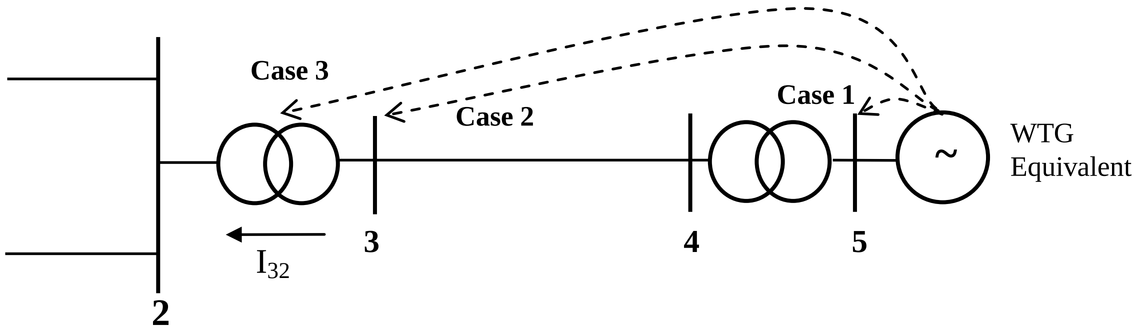


Figure 5 – Three examples of voltage control reach that can be simulated.

Table 4 – Selecting the WPP 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 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.

4.5 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 describes voltage and frequency protection modules available in PSLF and PSSE, which can be used with the WECC generic models. It should be noted that the voltage and frequency protection modules simulate single protection setting. Thus, to simulate a voltage ride through with multiple relay, multiple protection modules need to be included in the dynamic file.

4.6 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 and Type-2 and Type-3 WTGs (*wt1t*, *wt2t*, and *wt3t*) allow for a single-mass of 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[11].

5 Summary

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 and new models as new technologies evolve. Representation of WPPs is an area of active research area. Models will continue to evolve as new technology options become available. This guide is not intended to be comprehensive. The most recent model documentation should always be consulted.

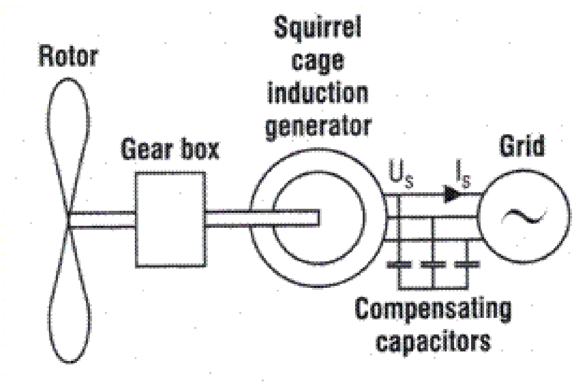
[11] Price, W.W., Sanchez-Gasca, J.J., “Simplified wind turbine generator aerodynamic models for transient stability studies” Power Systems Conference and Exposition, 2006. PSCE '06. 2006 IEEE PES, Oct. 29 2006 - Nov. 1, 2006.

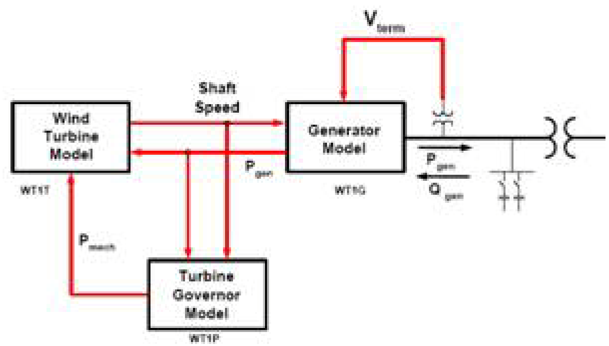
APPENDIX A
DYNAMIC DATA FOR FOUR DIFFERENT TYPES OF WIND TURBINES

Some manufacturers provide the data sheet corresponding to their turbines and some of them may release their data to be posted at the WECC site.

1. Type-1 - Fixed-speed, induction generators (Available in PSSE and PSLF)

The physical diagram and control block diagram of the wind turbine Type-1 is shown below:





The WT1 modeling package includes 3 main models as follows:

- Generator model WT1G
- Wind turbine model WT1T
- Pseudo turbine-governor model WT1A.

Control input parameters:

- Most of the parameters are given and unique for a specific turbine.
- This data will be made available from WECC or turbine manufacturers.
- Available in PSSE and PSLF
- The compensating capacitor is not dynamically modeled but it should be provided and initialized from load flow data.
- *WIND PLANT SPECIFIC ADJUSTMENT:*
  - Plant Size (MVA and MWCAP)
  - Dual mass versus single mass

WT1G1U and WT1G
Induction Generator for the WT1 Generic Wind Model

The generator model WT1G1U is based on the standard PSSE model of the induction generator CIMTR3. This model takes into account the rotor flux dynamics and can be used for single cage or double cage machines. At initialization this model calculates the reactive power consumption of the machine Qact at given terminal voltage and MW-dispatch. It places on the machine terminal bus a "hidden" shunt with the size equal to a difference between Qgen from the load flow and Qact.

Input data for PSSE:
Bus # 'USRMDL' ID ''WT1G1U' 1 1 1 10 5 3 0 CONs(J) to (J+9)/

W1G1U-PSSE Data

CONs	#	Value	Description
J		0.846	T open circuit transient time constant, sec, (>0)
J+1		0	T", open circuit subtransient time constant,sec, (≥ 0); if T" = 0, single cage
J+2		3.927	X, synchronous reactance, pu
J+3		0.1773	X', transient reactance, pu
J+4		0.0	X", subtransient reactance, pu (≥ 0); if X" = 0, single cage
J+5		0.1	Xl, leakage reactance, pu
J+6		1	E1
J+7		0.03	S(E1)
J+8		1.2	E2
J+9		0.179	S(E2)

The generator model WT1G is based on the standard PSLF model for an induction generator (genind), but without the mechanical components, i.e., the generator inertia which is included in the turbine model (WT1T). The model is initialized to match the power generation specified in the power flow. The reactive requirements of the generator are met by the addition of a fictitious shunt at the machine terminals.

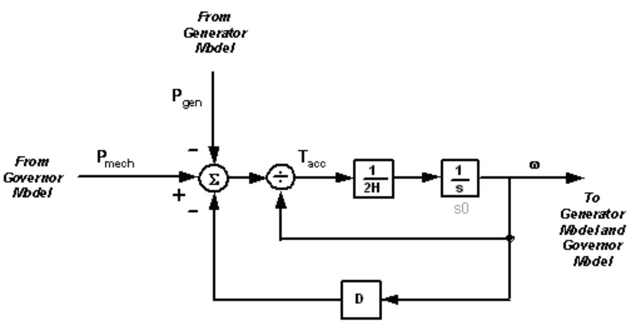
Input data for PSLF:

WT1G-PSLF Data

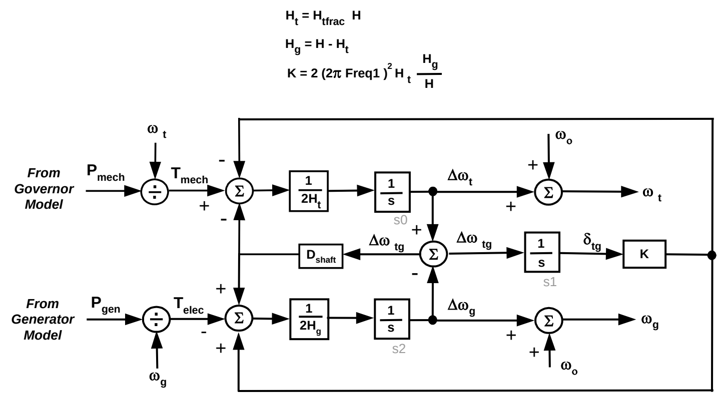
```
wt1g    5 "WTG TERM" 0.60 "1" : #9 mva=110 /
"Ls"      3.93      /
"Lp"      0.1773    /
"Ra"      0.0       /
"Tpo"     0.846     /
"Se1"     0.030     /
"Se2"     0.179     /
"Acc"     0.5       /
"Lpp"     0.0       /
"Ll"      0.10      /
"Tppo"    0.0       /
"ndelt"   10        /
"wdelt"   0.80
```

WT12T1U and WT1T
Two mass turbine model for the WT1 Generic Wind Model

The turbine WT1T1 model uses the two-mass representation of the wind turbine shaft drive train. It calculates the speed deviations of the rotor on the machine and on the blade sides. By setting the turbine inertia fraction Htfrac = 0 the model can be switched to a conventional single mass representation. The datasheet of the WT1T1U model is shown below. The block diagrams for the single and two mass representations are as follows:



Single Mass Model



Dual Mass Model

Input data for PSSE:
Bus # 'USRMDL' ID 'WT1T12U' 5 0 1 5 4 3 0 CONs(J) to (J+4)/

WT12T1U-PSSE Data

CONs	#	Value	Description
J		5.30	H, Total inertia constant, sec
J+1		0.0	DAMP, Machine damping factor, pu P/pu speed
J+2		0.925	H_{tfrac}, Turbine inertia fraction (Hturb/H)[1]
J+3		5.0	Freq1, First shaft torsional resonant frequency, Hz
J+4		1.0	D_{shaft}, Shaft damping factor (pu)

[1] To simulate one-mass mechanical system, set $H_{tfrac} = 0$.
To simulate two-mass mechanical system, set H_{tfrac} as $0 < H_{tfrac} < 1$

Input data for PSLF:

WT1T-PSLF Data

```
WT1T   5   "WTG TERM" 0.60 "1" : #9  /
"H"         5.30     /
"D"         0.0      /
"Htfrac"    0.925    /    # Optional
"Freq1"     5.0      /    two-mass
"Dshaft"    1.0      /    model:
```

WT1A1 and WT1P
Pseudo-governor model for the WT1 Generic Wind Model

The pseudo governor model WT1A1 is an attempt to simplify and generalize calculation of the aero-torque. This model was designed and developed after thorough investigation of aero-dynamic characteristics and pitch control of several vendor specific wind turbines. Finally the arrangement shown below was suggested.

The model uses two inputs, one in terms of the blade rotor speed deviation and another in terms of the real power at the machine terminals. These two inputs combined together are processed by a PI controller with non-wind-up limits. The filtered output is the mechanical power on the rotor blade side which is used by the WT1T1 model.

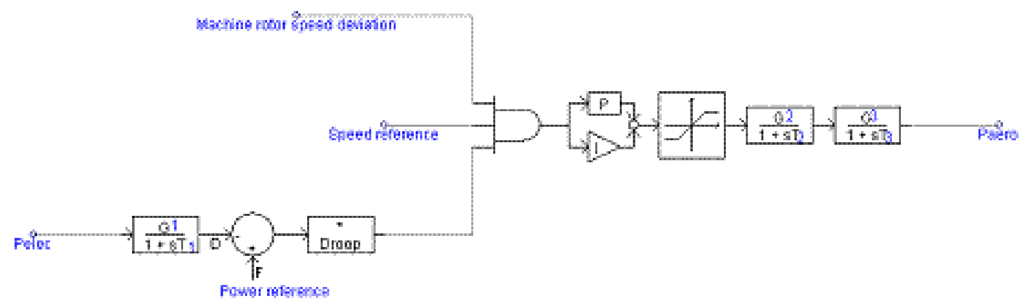
Input data for PSSE:

0 'USRMDL' 0 'WT1A1' 8 0 2 8 4 1

Bus # 'ID ' CONs(J) to (J+7)/

WT2A1U-PSSE Data

CONs	#	Value	Description
J		0.015	Droop
J+1		0.1	K_p, proportional gain, pu
J+2		0.015	T_i, integrator time constant, sec.
J+3		0.1	T_1, output filter 1 time constant, sec.
J+4		0.1	T_2, output filter 2 time constant, sec.
J+5		0.1	T_p, power filter time constant, sec.
J+6		1.0	Lim_{max}, maximum output limit
J+7		0.25	Lim_{min}, minimum output limit

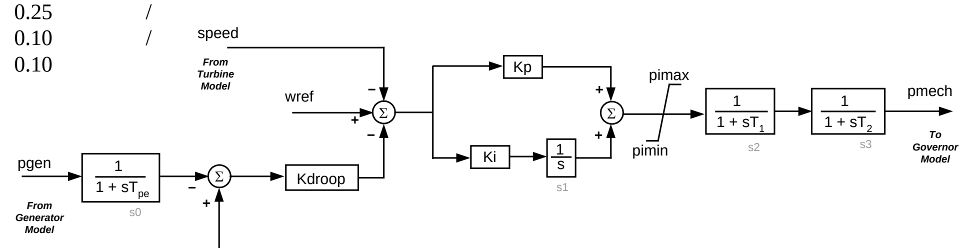


Input data for PSLF

WT1P-PSLF Data

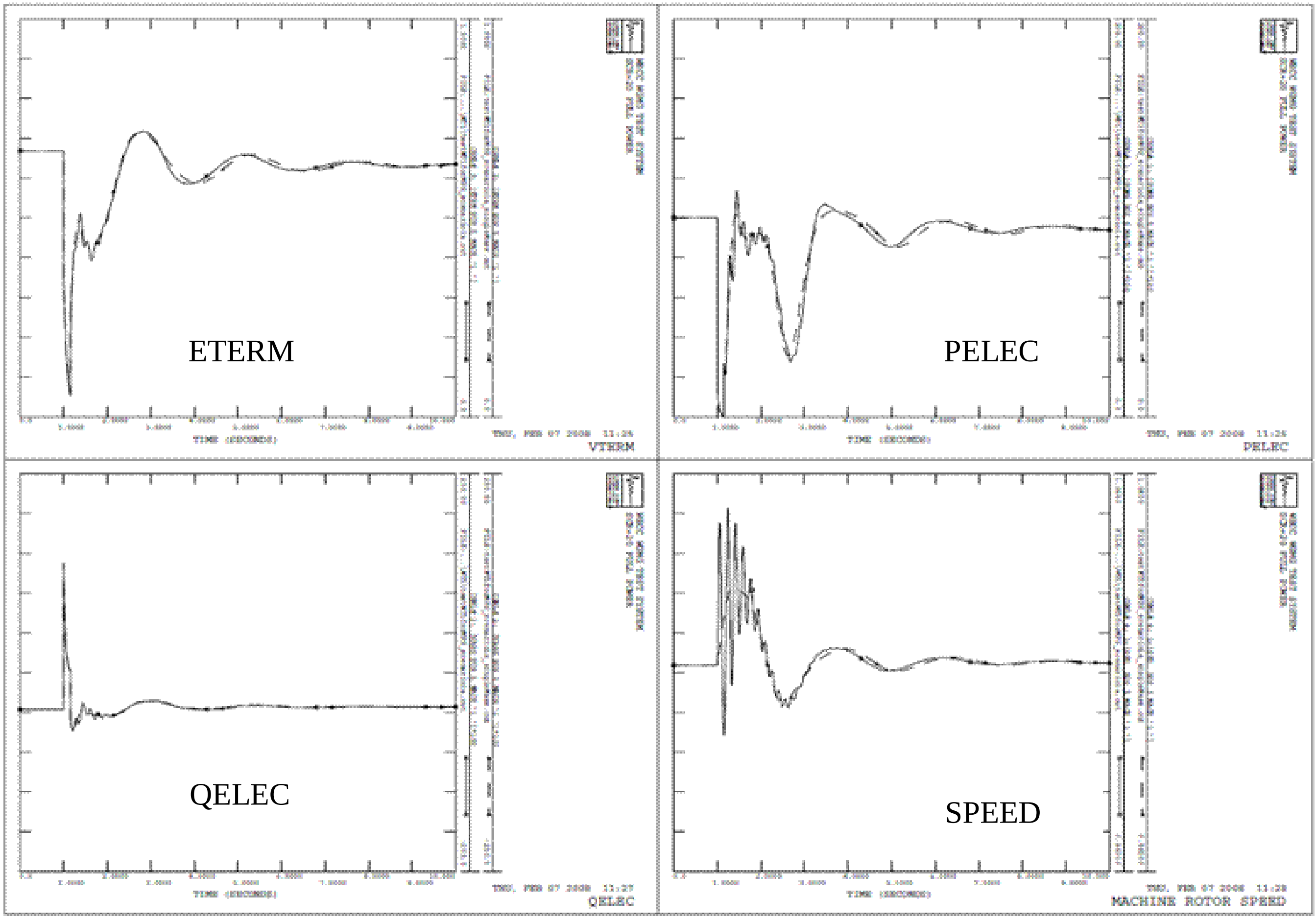
wt1p 5 "WTG TERM" 0.60 "1" : #9 /

"Tpe"	0.10	/
"Kdroop"	0.015	/
"Kp"	0.10	/
"Ki"	66.667	/
"Pimax"	1.00	/
"Pimin"	0.25	/
"T1"	0.10	/
"T2"	0.10	



WT1 Model Comparison

Against Mitsubishi MWT1000A Manufacturer Model

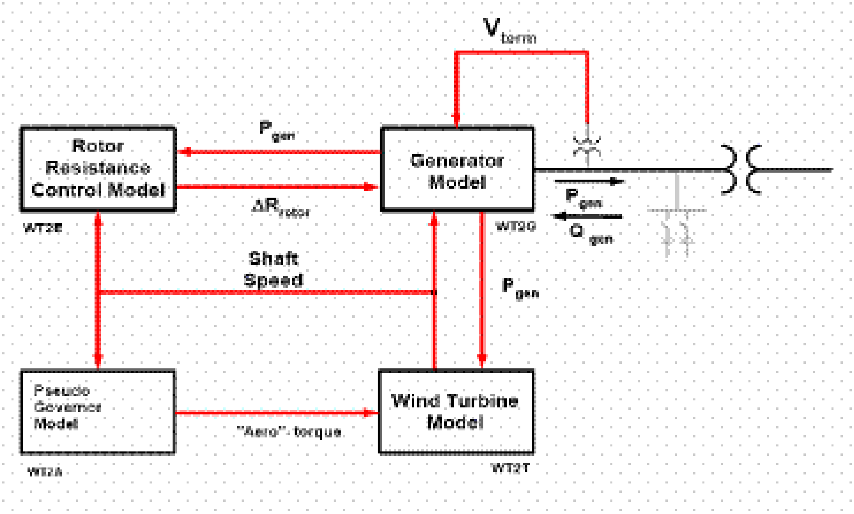


Type-2 - Induction generators with variable rotor resistance

The WT2 modeling package includes 4 main models as follows:

- Generator model WT2G1
- Rotor resistance control model for the WT2 Generic Wind Model WT2E1
- Two mass turbine model for the WT2 Generic Wind Model WT2T1
- Pseudo-governor model for the WT2 Generic Wind Model WT2A1

The control block diagram for Type-2 WTG is presented below:



Type 2 WTG Dynamic Model Connectivity

Control input parameters:

- Most of the parameters are given and unique for a specific turbine.
- This data will be made available from WECC or turbine manufacturers.
- Available in PSSE and PSLF (being developed)
- The compensating capacitor is not dynamically modeled but it should be provided and initialized from load flow data.
- WIND PLANT SPECIFIC ADJUSTMENT:
  - Plant Size
  - Dual mass versus single mass

WT2G1U and WT2G
Induction Generator with the controlled external rotor resistor
for the WT2 Generic Wind Model

The Generator model WT2G is a modified standard model of the induction machine with the logic for calculating the external rotor resistance at initialization and some other provisions included. Actually, this is the slightly modified model of the wound rotor induction machine.

Input data for PSSE:
IBUS, 'USRMDL' ID ‘WT2G1U’ 1 1 1 19 3 3 0 List of CONs/

W2G1U-PSSE Data

CONs	#	Value	Description
J		0.126	XA, stator reactance, pu
J+1		6.84	XM, magnetizing reactance, pu
J+2		0.18	X1, rotor reactance, pu
J+3		0.0044	R_ROT_MACH, rotor resistance, pu
J+4		0.1099	R_ROT_MAX, a sum of R_ROT_MACH and total external resistance, pu
J+5		1.0	E1, first saturation coordinate
J+6		0.0	SE1, first saturation factor
J+7		1.20	E2, second saturation coordinate
J+8		0.0	SE2, second saturation factor
J+9		0.0	POWER_REF_1, first of 5 coordinate pairs of the power-slip curve
J+10		0.0217	POWER_REF_2
J+11		0.8988	POWER_REF_3
J+12		0.9	POWER_REF_4
J+13		0.905	POWER_REF_5
J+14		0.0	SLIP_1
J+15		0.0054	SLIP_2
J+16		0.02	SLIP_3
J+17		0.04	SLIP_4
J+18		0.1	SLIP_5

In PSLF, this data is supplied through Module WT2E

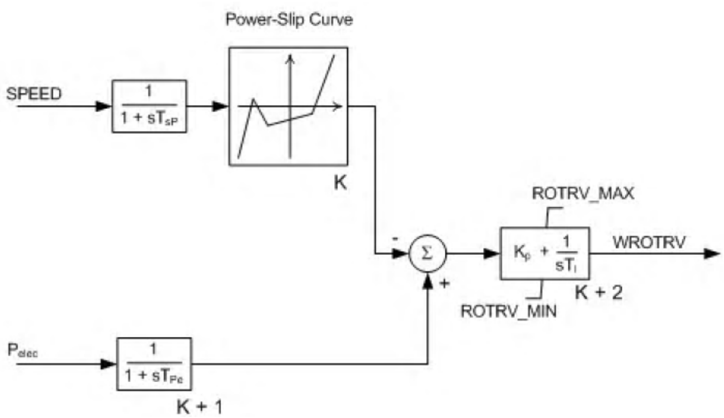
WT2G-PSLF Data

	wt2g 5 "WTG TERM" .575 "1 " : #9 mva=100 /			
"	Ls"	6.84		/
"	Lp"	0.126		/
"	Ll "	0.18		/
"	Ra"	0.004		/
"	Tpo"	4.23		/
"	Se1 "	0		/
"	Se2"	0		/
"	Spdrot"	1.04		/
"	Acc"	0		

WT2E1U and WT2E
Rotor resistance control model for the WT2 Generic Wind Model

The Rotor Resistance Control WT2E model was developed based on pre-computed resistance-slip table.

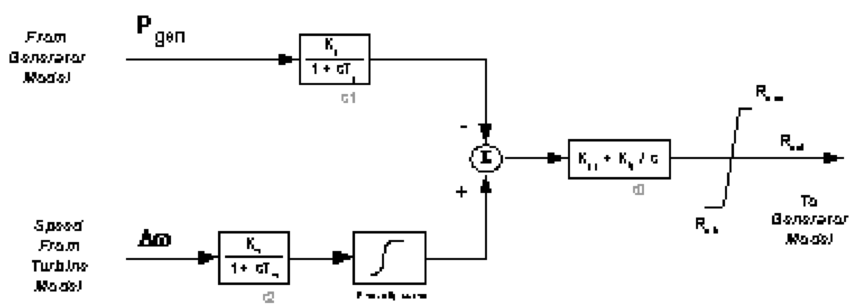
Input data for PSSE:
IBUS, 'USRMDL' ID ‘WT2E1U’ 4 0 1 16 3 1 0 List of CONs/



W2E1U-PSSE Data

CONs	#	Value	Description
J		0	T_{sp}, rotor speed filter time constant, sec.
J+1		0.05	T_{pe}, power filter time constant, sec.
J+2		1	T_i, PI-controller integrator time constant, sec.
J+3		1	K_p, PI-controller proportional gain, pu
J+4		0.99	ROTRV_MAX, Output MAX limit
J+5		0.05	ROTRV_MIN, Output MIN limit

Input data for PSLF



wt2e 5 "WTG TERM" .575 "1 " : #9 /			
" "Tw"	0.05		/
" "Kw"	1		/
" "Tp"	0.05		/
" "Kp"	1		/
" "Kpp"	0.01		/
" "Kip"	0.01		/
" "Rmax"	0.1099		/
" "Rmin"	0.0044		/
" "Slip1"	0		/
" "Slip2"	0.0054		/
" "Slip3"	0.02		/
" "Slip4"	0.04		/
" "Slip5"	0.1		/
" "Powr1"	0		/
" "Powr2"	0.0217		/
" "Powr3"	0.8988		/
" "Powr4"	0.9		/
" "Powr5"	0.905		

In PSSE this data is supplied via Module W2G1U

WT2T1U and WT2T

Single or dual mass turbine model for the WT2 Generic Wind Model

The turbine WT2T1 model uses the two-mass representation of the wind turbine shaft drive train. It calculates the speed deviations of the rotor on the machine and on the blade sides. By setting the turbine inertia fraction Htfrac = 0 the model can be switched to a conventional single mass representation.

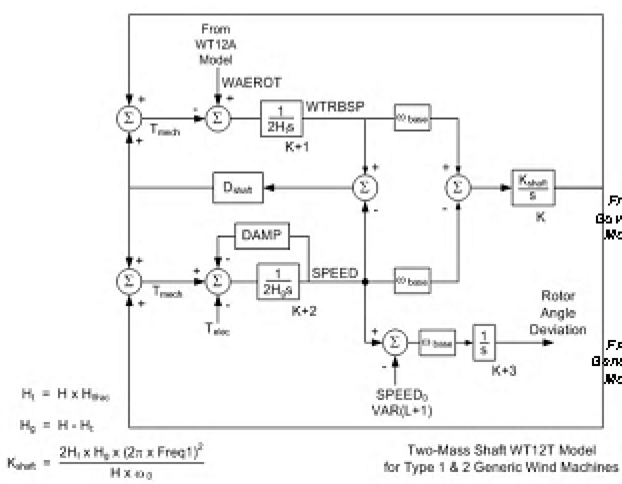
Input data in the dynamic file:

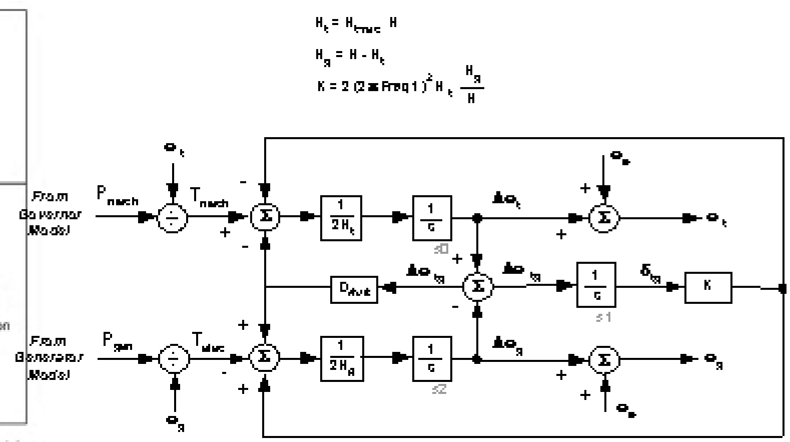
Bus # 'USRMDL' ID 'WT2T1U' 5 0 1 5 4 3 0 CONs(J) to (J+4)/

WT2T1U-PSSE Data

CONs	#	Value	Description
J		3.46	H, Total inertia constant, sec
J+1		0.00	DAMP, Machine damping factor, pu P/pu speed
J+2		0.81	H_{tfrac}, Turbine inertia fraction (Hturb/H)[1]
J+3		1.50	Freq1, First shaft torsional resonant frequency, Hz
J+4		0.30	D_{shaft}, Shaft damping factor (pu)

[1] To simulate one-mass mechanical system, set $H_{tfrac} = 0$.
To simulate two-mass mechanical system, set H_{tfrac} as $0 < H_{tfrac} < 1$





Input data for PSLF

WT2T-PSLF Data

wt2t 5 "WTG TERM" .575 "1 " : #9			/
"h"	3.46		/
"d"	0		/
"htfrac"	0.81		/
"freq1"	1.5		/
"dshaft"	0.3		

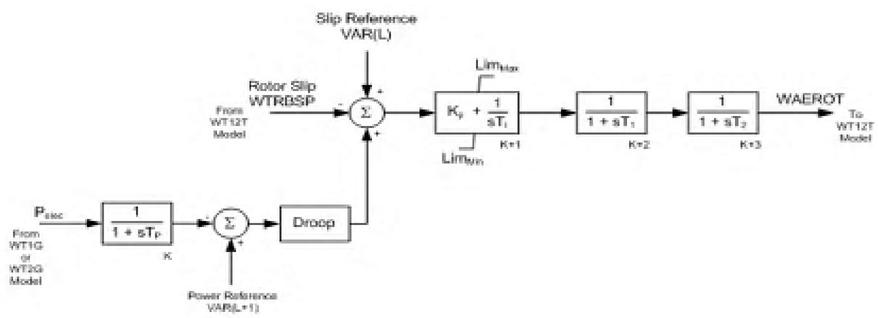
WT2A1U and WT2P
Pseudo-governor model for the WT2 Generic Wind Model

The Pseudo Governor WT2A model is the same as was suggested and tested for the WT1 generic model. WECC’s REMTF has recommended that the parameter Pimax

Input data for PSSE:
0 'USRMDL' 0 'WT2A1U' 8 0 2 8 4 2 Bus # 'ID ' CONs(J) to (J+7)/

WT2A1U-PSSE Data

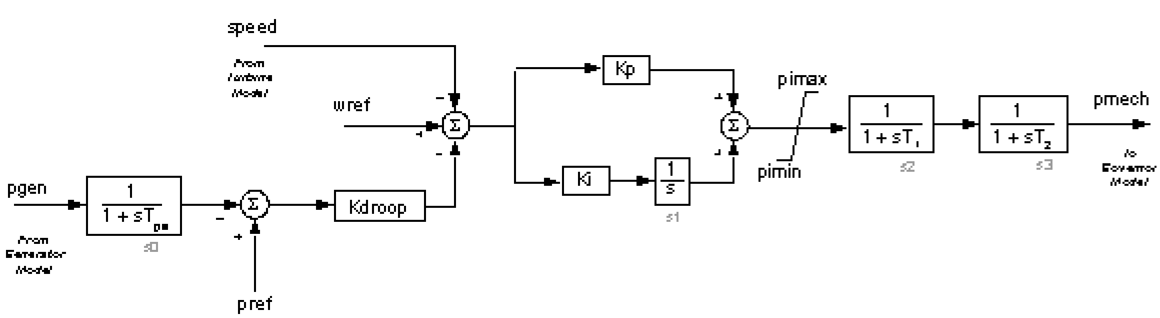
CONs	#	Value	Description
J		0.015	Droop
J+1		20.0	K_p, proportional gain, pu
J+2		1.0	T_i, integrator time constant, sec.
J+3		0.1	T_1, output filter 1 time constant, sec.
J+4		0.1	T_2, output filter 2 time constant, sec.
J+5		0.1	T_p, power filter time constant, sec.
J+6		1.0	Lim_{max}, maximum output limit
J+7		0.25	Lim_{min}, minimum output limit



Input data for PSLF

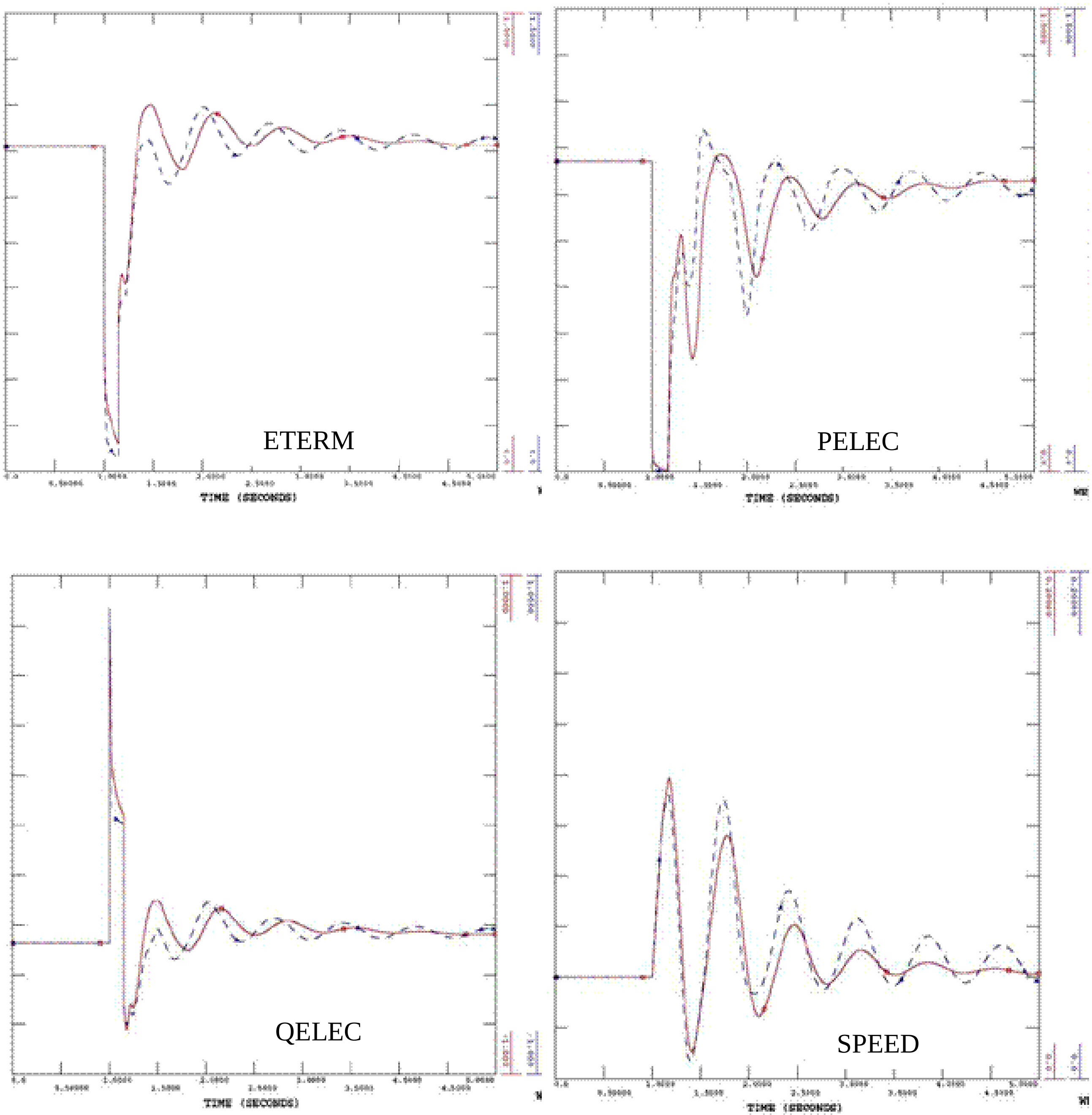
WT2P-PSLF Data

wt2p 5 "WTG TERM" .575 "1 " : #9 /			
"tpe"	0.1		/
"kpdroop"	0.015		/
"kp"	20		/
"ki"	1		/
"pimax"	1		/
"pimin"	0.25		/
"t1"	0.1		/
"t2"	0.1		



WT2 Model Comparison

Against Vestas V80 Manufacturer Model

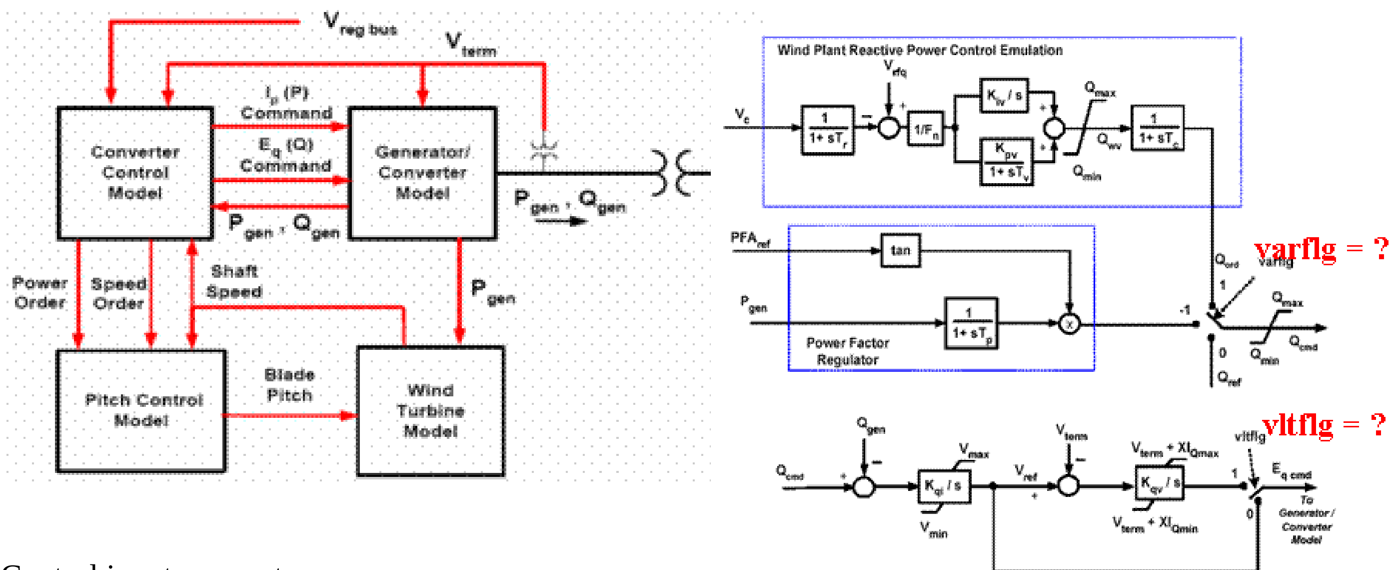


2. **Type-3 - Doubly-fed asynchronous generators with rotor-side converter (Available in PSSE and PSLF)**

The WT3 modeling package includes 3 main models as follows:

- Generator/Converter Model WT3G
- Converter Control Model for the Generic Wind Model WT3E
- Two mass turbine model for the WT2 Generic Wind Model WT2T1
- Pseudo-governor model for the WT2 Generic Wind Model WT2A1

The overall control block diagram and the reactive power control block diagram for the Type-3 WTG are presented below:



Control input parameters:

- Most of the parameters are given and unique for a specific turbine.
- This data will be made available from WECC or turbine manufacturers.

WIND PLANT SPECIFIC ADJUSTMENTS:

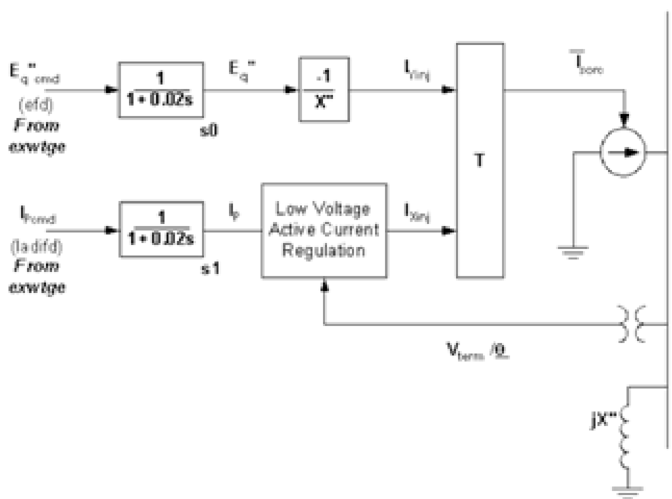
- varflg and vltflg are flags that must be set by the user based on the setting defined for each WPP to be included in the case study.
- F_n = fraction of WTG on the wind plant that are on-line. Used only for VAR control gain adjustment
- PFAref = initialized from load flow data
- V_c is the controlled bus specified within the module wt3e. It can be terminal voltage or remote bus voltage or fictitious remote bus voltage.
- X_c is a fictitious reactance used to compute the voltage drop to offset the reference voltage of a known bus voltage V_{rfq} and a known branch current I_{reg}. ($V_c=|V_{rfq} - jX_c I_{reg}|$)
- V_w > 1.0 p.u. will be used to initialize pitch angle.

WT3G1U and WT3G
Generator/Converter Model for the WT3 Generic Wind Model

This model (WT3G) is an equivalent of the generator and the field converter and provides the interface between the WTG and the network. Unlike a conventional generator model, it contains no mechanical state variables for the machine rotor – these are included in the turbine model (WT3T). Further, unlike conventional generator models, all of the flux dynamics have been eliminated to reflect the rapid response to the higher level commands from the electrical controls through the converter. The net result is an algebraic, controlled-current source that computes the required injected current into the network in response to the flux and active current commands from the electrical control model.

For modeling an aggregation of several (N) WTGs, MVAb must equal N times the MVA rating of a single WTG.

Input data in the dynamic file:
wt3g [<n>] {<name> <kv>} <id>} : #<rl> {mva=<value>}



Type 3 WTG Generator/Converter Model

WT3G1-PSSE Data

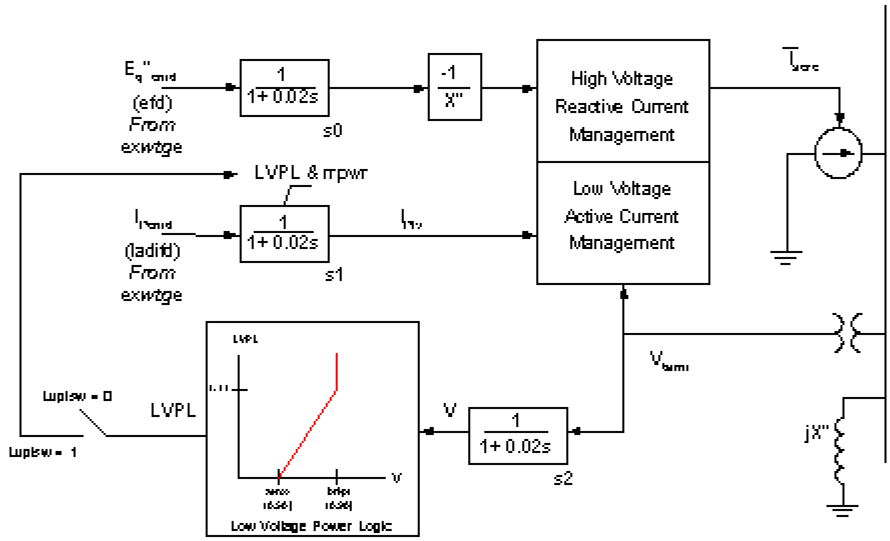
CONs	#	Value	Description
J		0.8	X_{eq}, Equivalent reactance for current injection (pu)
J+1		30.0	K_{pll}, PLL first integrator gain
J+2		0.0	K_{ipll}, PLL second integrator gain
J+3		0.1	P_{llmax}, PLL maximum limit
J+4		1.5	Prated, Turbine MW rating

IBUS, 'WT3G1', ID, ICON(M), CON(J) to CON(J+4) /

ICON	#	Description
M	67	Number of lumped wind turbines

WT3G-PSLF Data **(refer to W3G2U for PSSE Equivalent)**

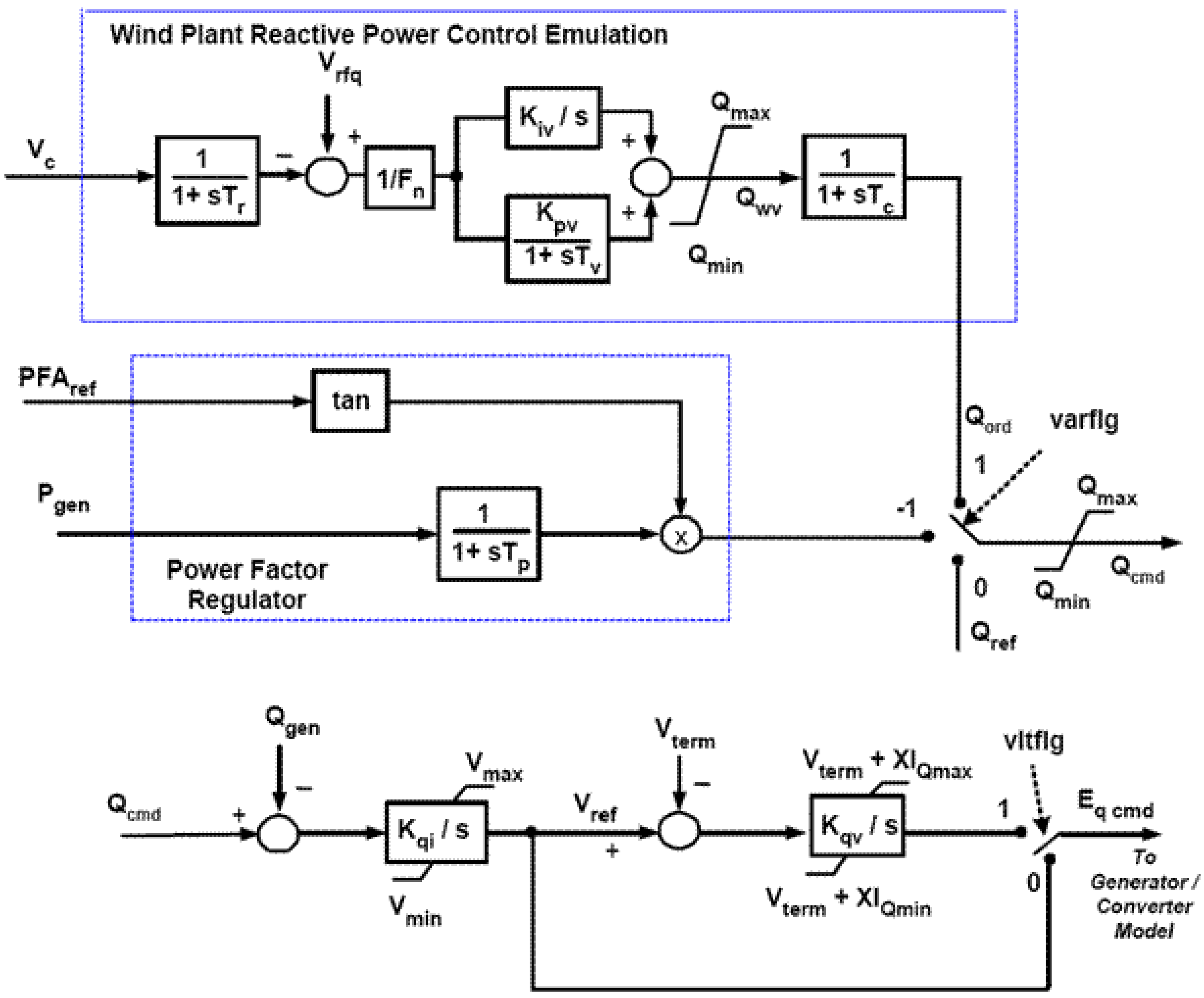
wt3g 5 "WTG TERM" .575 "1 " : #9 mva=111 /			
lpp	0.8	/	Generator effective reactance, p.u. on gen. MVA base
lvplsw	1	/	Connect (1) / disconnect (0) Low Volt. Power Logic switch
rrpwr	5	/	LVPL ramp rate limit, p.u.
brkpt	0.9	/	LVPL characteristic breakpoint, p.u.
zerox	0.5		LVPL characteristic zero crossing, p.u.



WT3E1 and WT3E
Converter Control Model

This model (WT3E) dictates the active and reactive power to be delivered to the system. The reactive controls including the emulation of the centralized Wind Plant reactive power controller is shown below. The switch, VARFLG, provides for 3 modes of control: constant reactive power, constant power factor angle, or voltage regulation by a wind plant reactive power controller.

The switch, VLTFLG, provides for bypassing the closed loop terminal voltage regulator, which is not used in all implementations and currently is always set to 1.



Type-3 WTG Reactive Power Control Model.

Input data in the dynamic file:

wt3e [<n>] {<name> <kv>} <id> ! ! ! ! ! [<mon_i>] {<namei> <kvi>} [<mon_j>] {<namej> <kvj>} <ck> <sec> : [mwcap=<value>]

Example:

WT3E1-PSSE Data

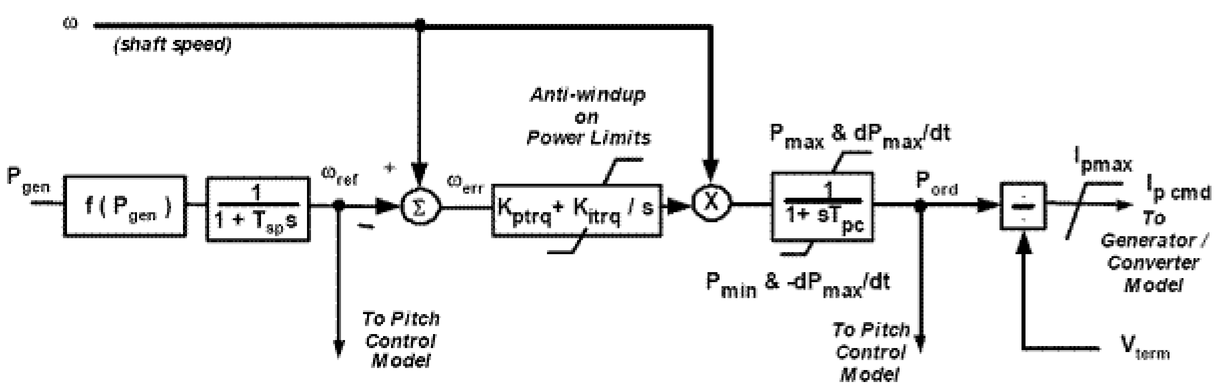
CONs	#	Value	Description
J		0.15	T_{fv}, Filter time constant in voltage regulator (sec)
J+1		18.0	K_{pv}, Proportional gain in voltage regulator (pu)
J+2		5.0	K_{IV}, Integrator gain in voltage regulator (pu)
J+3		0.0	X_c, Line drop compensation reactance (pu)
J+4		0.05	T_{FP}, Filter time constant in torque regulator
J+5		3.0	K_{pp}, Proportional gain in torque regulator (pu)
J+6		0.6	K_{IP}, Integrator gain in torque regulator (pu)
J+7		1.12	P_{MX}, Max limit in torque regulator (pu)
J+8		0.1	P_{MN}, Min limit in torque regulator (pu)
J+9		0.296	Q_{MX}, Max limit in voltage regulator (pu)
J+10		-0.436	Q_{MN}, Min limit in voltage regulator (pu)
J+11		1.1	IP_{MAX}, Max reactive current limit
J+12		0.05	T_{RV}, Voltage sensor time constant
J+13		0.45	RP_{MX}, Max power order derivative
J+14		0.45	RP_{MN}, Min power order derivative
J+15		5.0	$T_{\_Power}$, Power filter time constant
J+16		0.05	K_{qi}, MVAR/Voltage gain
J+17		0.9	V_{MINCL}, Min voltage limit
J+18		1.2	V_{MAXCL}, Max voltage limit
J+19		40.0	K_{qv}, Voltage/MVAR gain
J+20		-0.5	XIQ_{min}
J+21		0.4	XIQmax
J+22		0.05	T_v, Lag time constant in WindVar controller
J+23		0.05	T_p, P_{elec} filter in fast PF controller
J+24		1.0	Fn, A portion of online wind turbines

CONs	#	Value	Description
J+25		0.69	ωP_{min}, Shaft speed at P_{min} (pu)
J+26		0.78	ωP_{20}, Shaft speed at 20% rated power (pu)
J+27		0.98	ωP_{40}, Shaft speed at 40% rated power (pu)
J+28		1.12	ωP_{60}, Shaft speed at 60% rated power (pu)
J+29		0.74	P_{min}, Minimum power for operating at ωP_{100} speed (pu)
J+30		1.2	ωP_{100}, Shaft speed at 100% rated power (pu)

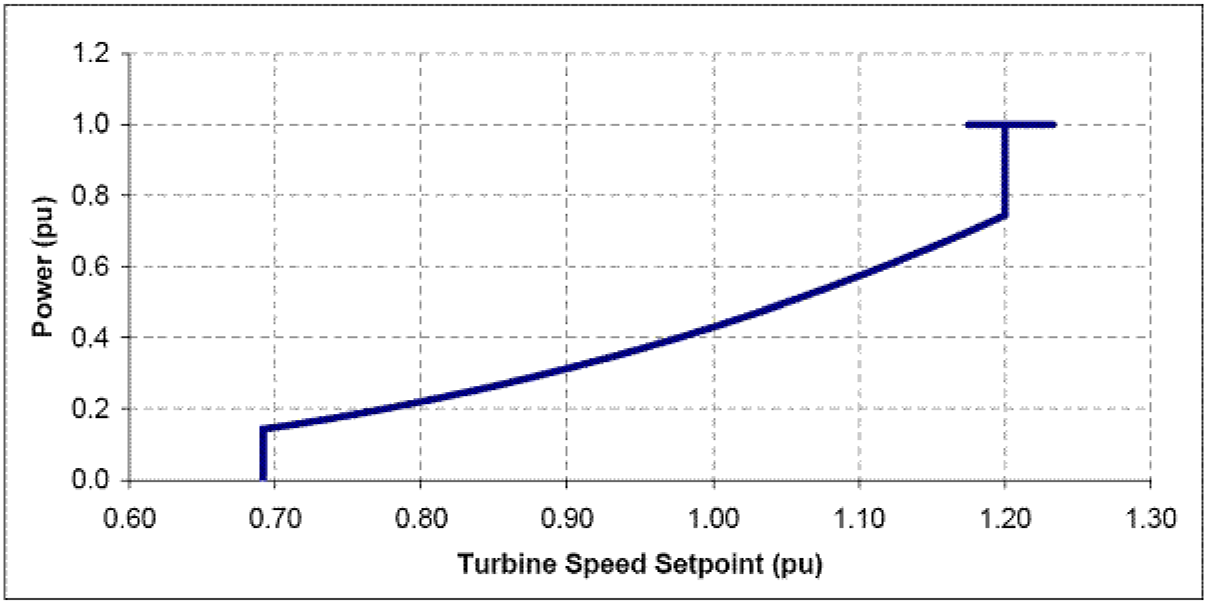
W3E - PSLF Data

wt3e 5 "WTG TERM" .575 "1 " 4 "WTG 34 " 34.5 "1 " 1 : #9 mwcap=100 /			
"varflg"	-1	/	0 = Constant Q cntl; 1 = Use Wind Plant reactive p
"vltflg"	1	/	1 = Use closed loop terminal voltage control
			0 = Bypass closed loop terminal voltage control
"tsp"	5	/	Speed reference lag (sec)
"kptrq"	3	/	Torque control proportional gain (p.u. P)
"kitrq"	0.6	/	Torque control integral gain (p.u. P / sec)
"tpc"	0.05	/	Power control lag (sec)
"pmax"	1.12	/	Maximum power order (p.u.)
"pmin"	0.1	/	Minimum power order (p.u.)
"pwrat"	0.45	/	Power order rate limit (p.u./sec)
"ipmax"	1.1	/	Maximum reactive current order, (p.u. of rated curre
"wpmin"	0.69	/	Shaft speed at Pmin (p.u.)
"wp20"	0.78	/	Shaft speed at 20% rated power (p.u.)
"wp40"	0.98	/	Shaft speed at 40% rated power (p.u.)
"wp60"	1.12	/	Shaft speed at 60% rated power (p.u.)
"pwp100"	0.74	/	Minimum power for operating at wp100 speed (p.u.)
"wp100"	1.2	/	Shaft speed at rated power (p.u.)
"kqi"	0.1	/	Reactive control gain (p.u. V/p.u. Q sec)
"kqv"	120	/	Terminal voltage control gain, (p.u. V/p.u. V)
"qmax"	0.436	/	Maximum reactive power limit (p.u.)
"qmin"	-0.436	/	Minimum reactive power limit (p.u.)
"vmax"	1.1	/	Maximum voltage limit (p.u.)
"vmin"	0.9	/	Minimum voltage limit (p.u.)
"xiqmax"	1.55	/	Terminal voltage regulator maximum limit (p.u.)
"xiqmin"	0.55	/	Terminal voltage regulator minimum limit (p.u.)
"tp"	0.05	/	Power factor control filter time constant (sec)
"xc"	0	/	Compensating reactance for voltage control (p.u.)
"tr"	0.05	/	Voltage transducer time constant (sec)
"fn"	1	/	Fraction of WTG in Wind Plant that are on-line
"kiv"	5	/	Integral gain (p.u. Q/p.u. V sec)
"kpv"	18	/	Proportional gain (p.u. Q/p.u. V)
"tv"	0.05	/	Proportional path time constant (sec)
"tc"	0.15		Communication lag (sec)

Figure below shows the active power (torque control) system. The non-linear function, f(Pelec), is used to model the desired WTG speed as a function the power level. The input data for this function are values of the desired speed at several levels of power output, with linear interpolation to be used between specified values.



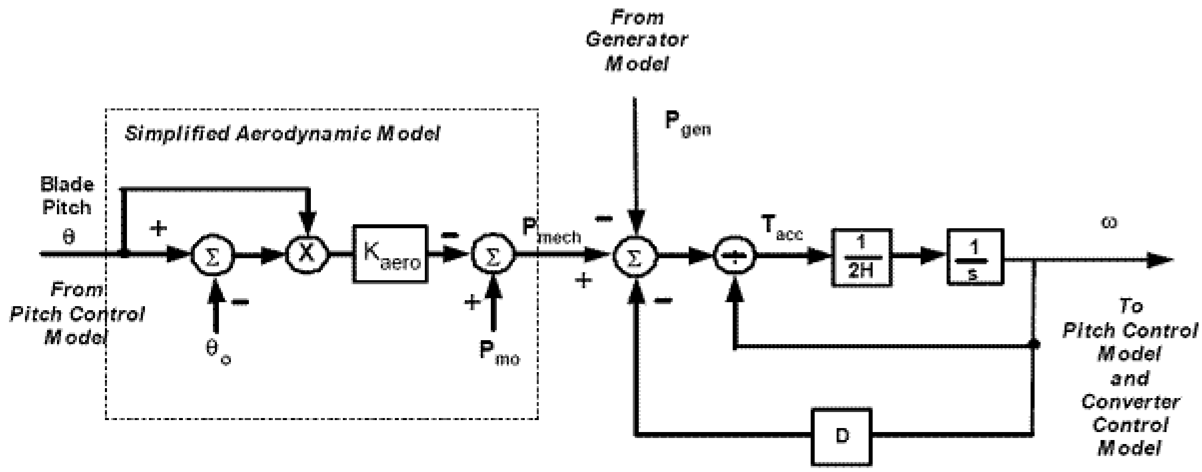
Type-3 WTG Active Power (Torque) Control Model



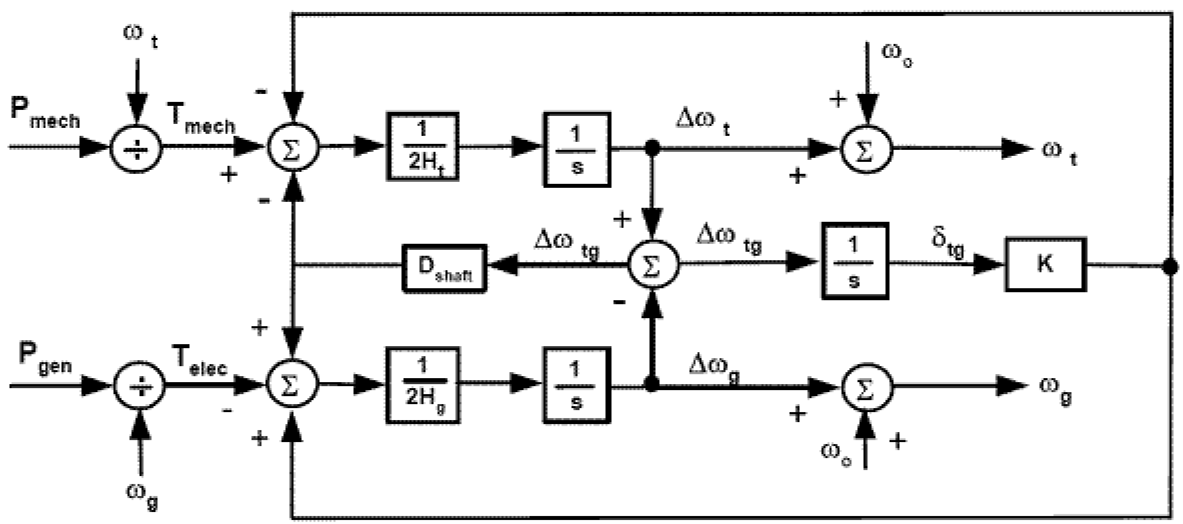
Wpmin	**0.69**	Shaft Speed at Pmin, pu
Wp20	**0.78**	Shaft speed at 20 % rated power, pu
Wp40	**0.98**	Shaft speed at 40 % rated power, pu
Wp60	**1.12**	Shaft speed at 60 % rated power, pu
Pwp100	**0.74**	Minimum power for operating at Wp100 speed, pu
Wp100	**1.2**	Shaft speed at rated power, pu

WT3T1 and WT3T
Wind Turbine Model

The wind turbine model (WT3T) is shown in Figures below. The first Figure shows the complete single mass model; the next Figure shows the torsional system for the two-mass model. The parameters for this model are shown in Table below.



Type-3 WTG Turbine Model (One-mass model).



Type-3 WTG Turbine Torsional Model (Two-mass model).

Input data in the dynamic file:
wt3t [<n>] {<name> <kv>} <id> :

For a single shaft model: Htfrac = Freq1 = Dshaft = 0

Calculation used internally by the model:

$$H_t = H_{tfrac} * H$$

$$H_g = H - H_t$$

$$K = 2 * (2\pi\ Freq1)^2 * H_t * H_g / H$$

WT3T1-PSSE Data

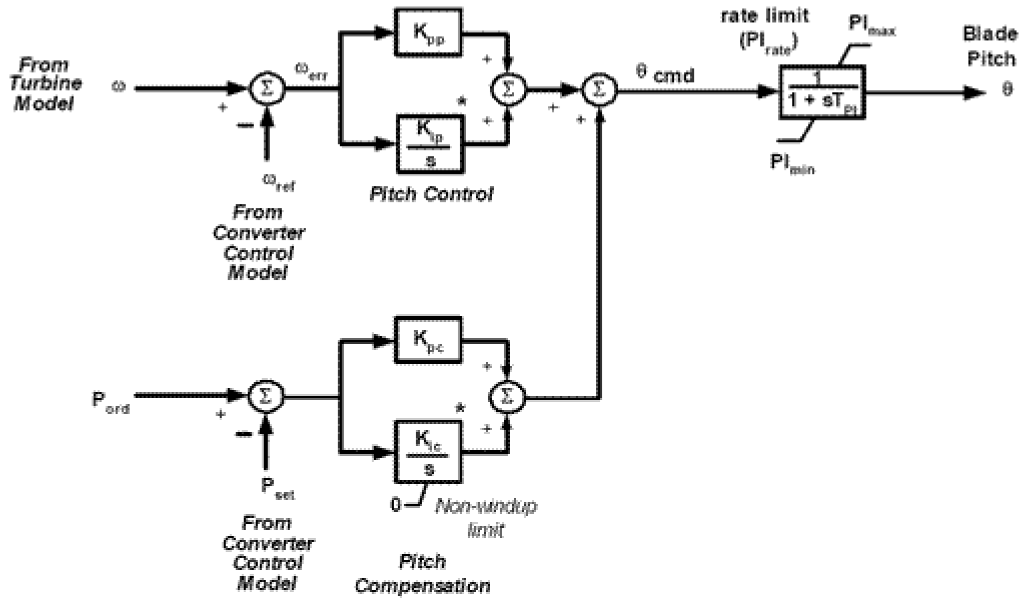
CONs	#	Value	Description
J		0.44	VW, Initial wind, pu of rated wind speed
J+1		4.95	H, Total inertia constant, MW*sec/MVA
J+2		0	DAMP, Machine damping factor, pu P/pu speed
J+3		0.007	Kaero, Aerodynamic gain factor
J+4		21.98	Theta2, Blade pitch at twice rated wind speed, deg.
J+5		0.8747	Htfrac, Turbine inertia fraction (Hturb/H)
J+6		1.8	Freq1, First shaft torsional resonant frequency, Hz
J+7		1.5	DSHAFT, Shaft damping factor (pu)

WT3T-PSLF Data

wt3t 5 "WTG TERM" .575 "1 " : #9 /				
"	vw"	0.44	/	Initial wind speed, p.u. of rated wind speed
"	h"	4.95	/	Total inertia constant, MW-sec/MVA
"	d"	0	/	Damping factor, p.u. P / p.u. speed
"	kaero"	0.007	/	Aerodynamic gain factor
"	theta2"	21.98	/	Blade pitch at twice rated wind speed, deg.
"	htfrac"	0.8747	/	Turbine inertia fraction (Ht / H)
"	freq1"	1.8	/	First shaft torsional resonant frequency, Hz
"	dshaft"	1.5		Shaft damping factor, p.u. P / p.u. speed

WT3P1 and WT3P
Pitch Control Model

The pitch control model (WT3P) is shown in Figure below. The parameters for this model are shown in Table below.



Input data in the dynamic file:
wt3p [<n>] {<name> <kv>} <id>

WT3P1-PSSE Data

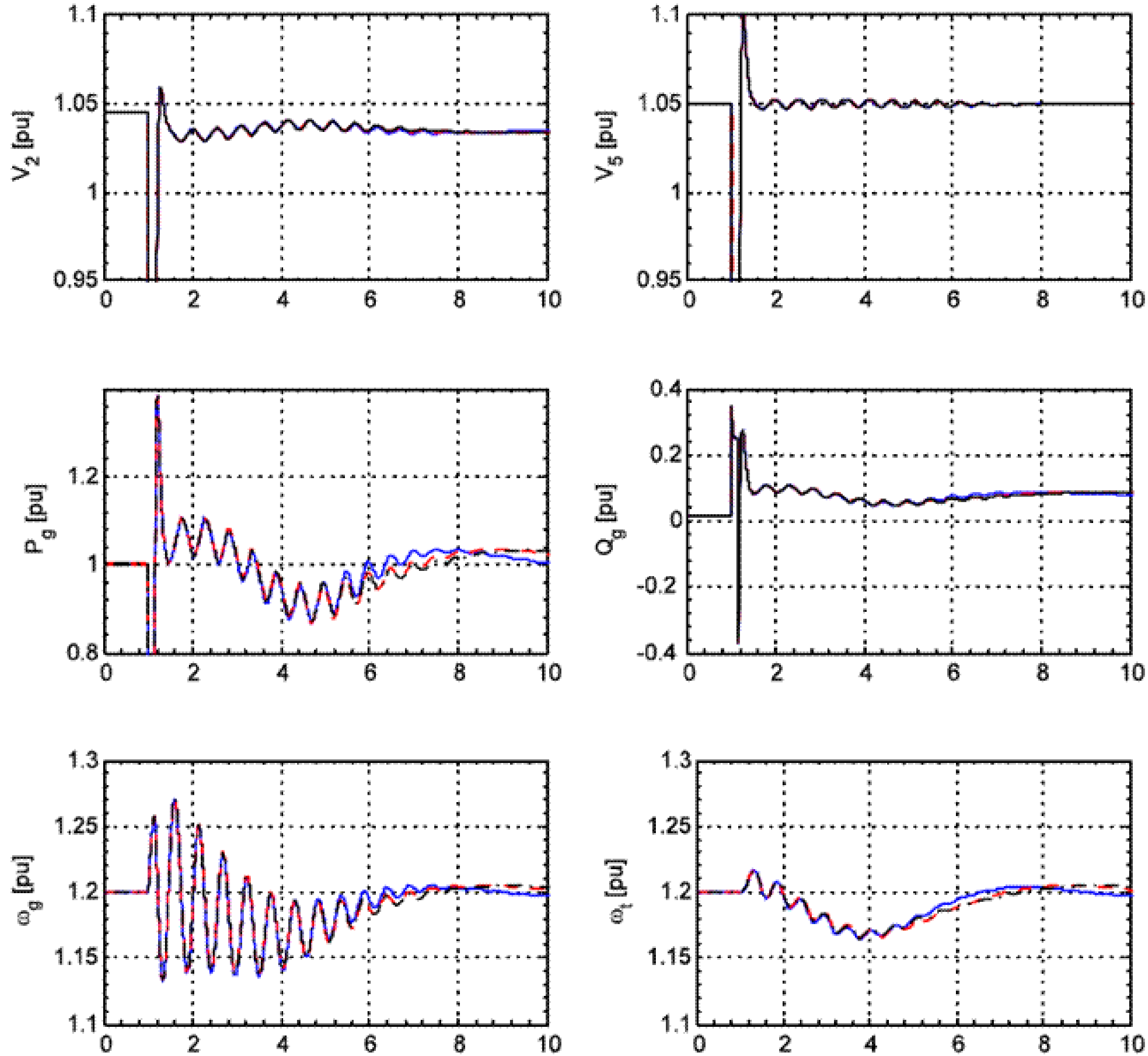
CONs	#	Value	Description
J		0.3	Tp, Blade response time constant
J+1		150	Kpp, Proportional gain of PI regulator (pu)
J+2		25	Kip, Integrator gain of PI regulator (pu)
J+3		3	Kpc, Proportional gain of the compensator (pu)
J+4		30	Kic, Integrator gain of the compensator (pu)
J+5		27	TetaMin, Lower pitch angle limit (degrees)
J+6		0	TetaMax, Upper pitch angle limit (degrees)
J+7		10	RTetaMax, Upper pitch angle rate limit (degrees/sec)
J+8		1	PMX, Power reference, pu on MBASE

WT3P-PSLF Data

wt3p 5 "WTG TERM" .575 "1 " : #9 /					
"	kpp""	150.00		/	Pitch control proportional gain, deg./ p.u. speed
"	kip"	25.00		/	Pitch control integral gain, deg./ (p.u. speed-sec.)
"	kpc"	3.00		/	Pitch compensator proportional gain, deg./ p.u. P
"	kic"	30.00		/	Pitch compensator integral gain, deg./ (p.u. P-sec.)
"	pimax"	27.00		/	Maximum pitch angle, deg.
"	pimin"	0.00		/	Minimum pitch angle, deg.
"	pirat"	10.00		/	Pitch rate limit, deg./sec.
"	tpi"	0.30		/	Blade response time constant, sec.
"	pset"	1.00			Power set point, p.u.

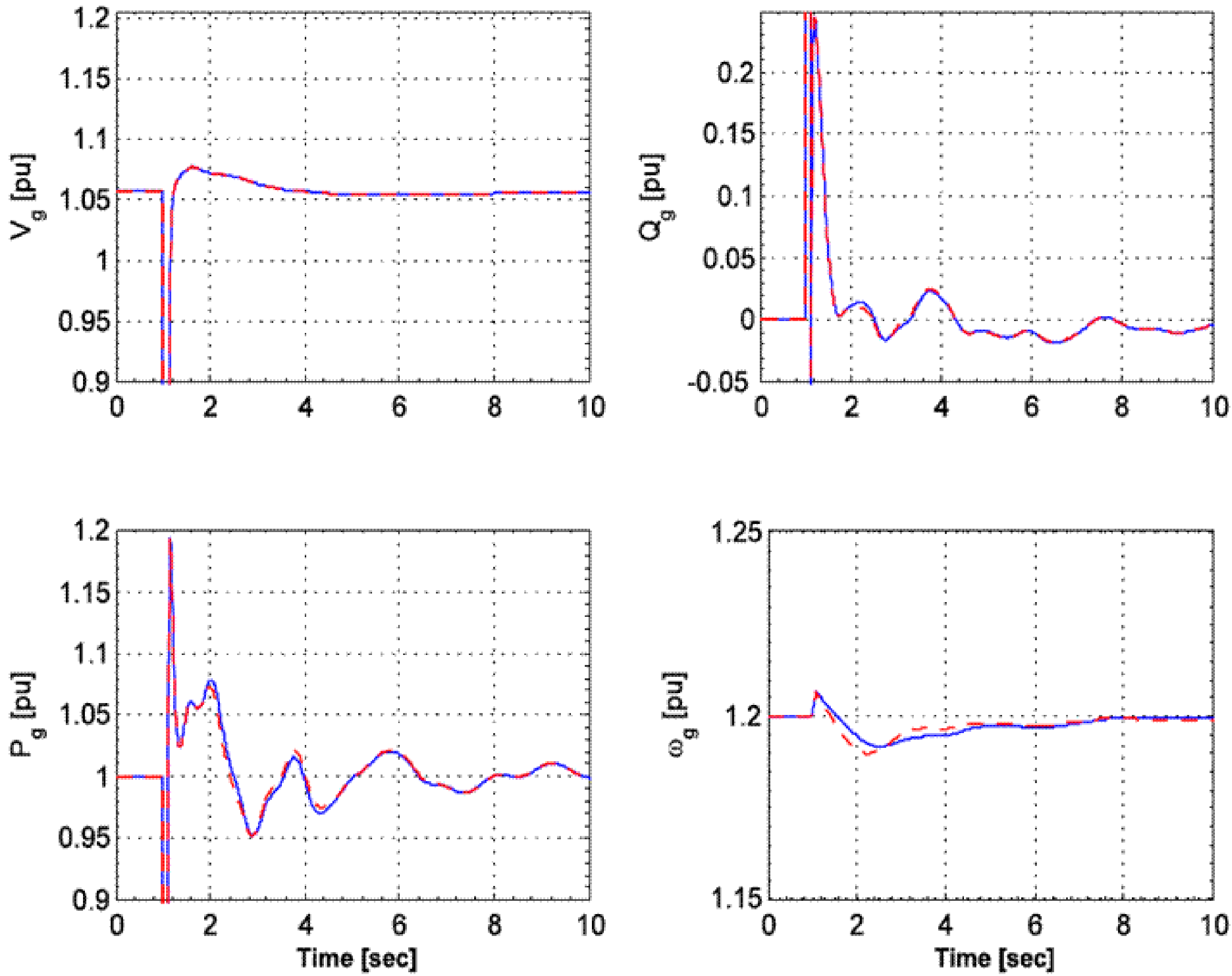
WT3 Model Comparison
Against GE 1.5 MW Manufacturer Model

Small System



WT3 Model Comparison
Against GE 1.5 MW Manufacturer Model

Large System

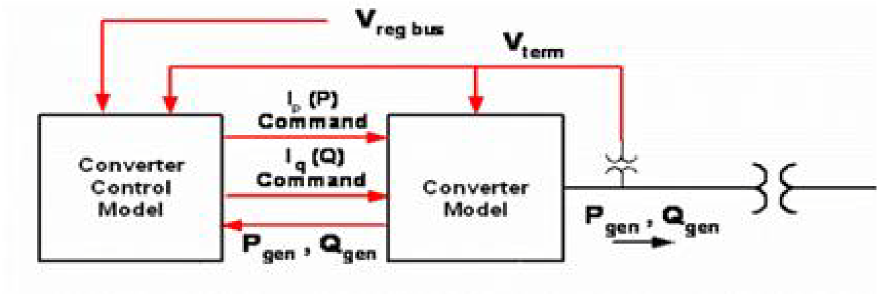


Type-4 - Variable speed generators with full converter interface.

The WT4 modeling package includes 3 main models as follows:

- Generator/Converter Model WT4G
- Converter Control Model for the Generic Wind Model WT4E

The overall control block diagram and the reactive power control block diagram for the Type-4 WTG are presented below:



Control input parameters:

- Most of the parameters are given and unique for a specific turbine.
- This data will be made available from WECC or turbine manufacturers.

<u>WIND PLANT SPECIFIC ADJUSTMENTS:</u>

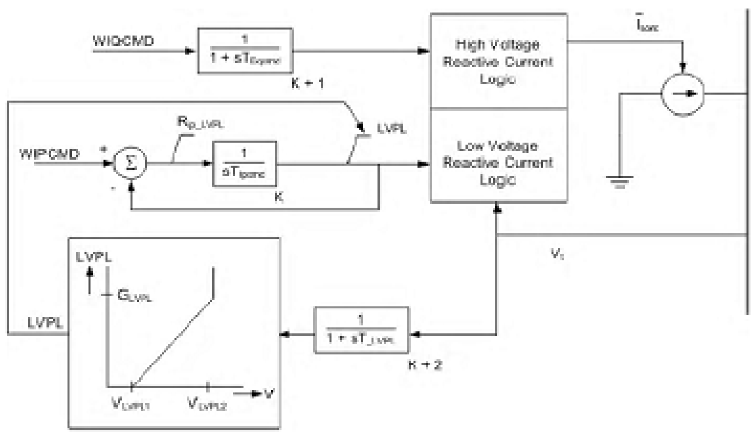
- varflg and vltflg are flags that must be set by the user based on the setting defined for each WPP to be included in the case study.
- F_n = fraction of WTG on the wind plant that are on-line. Used only for VAR control gain adjustment
- PFAref = initialized from load flow data
- Refer to Type-3 description of Remote Control Voltage V_c and V_{rfq}
- Turbine model is ignored.

WT4G1U and WT4G
Generator/Converter Model for the WT4 Generic Wind Model

This model (WT4G) is an equivalent of the generator and the field converter and provides the interface between the WTG and the network. Unlike a conventional generator model, it contains no mechanical state variables.

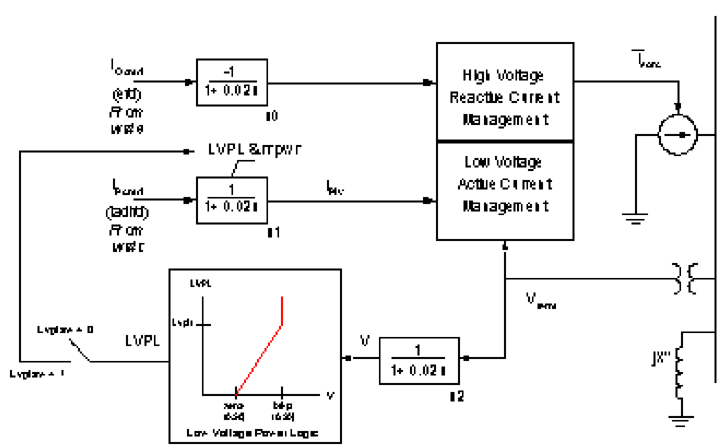
W4G1U-PSSE Data

	CONs	#	Value	Description
0.02	J			T_{IQCmd}, Converter time constant for IQcmd
0.02	J+1			T_{IPCmd}, Converter time constant for IPcmd
0.4	J+2			V_{LVPL1}, LVPL voltage 1 Low voltage power logic
0.9	J+3			V_{LVPL2}, LVPL voltage 2
1.11	J+4			G_{LVPL}, LVPL gain
1.2	J+5			V_{HVRCR}, HVRCR voltage (High voltage reactive current limiter
2.0	J+6			CUR_{HVRCR}, HVRCR current (Max. reactive current at VHVRCR)
2.0	J+7			R_{Ip_LVPL}, Rate of LVACR active current change
0.02	J+8			$T_{\_LVPL}$, Voltage sensor for LVACR time constant



WT4G-PSLF Data

wt4g 5 "WTG TERM" .575 "1 " : #9 mva=111 /			
" Lvplsw"	1.00	/	Connect (1) / disconnect (0) Low Volt. Power Logic switch
" Rrpwr"	5.00	/	LVPL ramp rate limit, p.u.
" Brkpt"	0.70	/	LVPL breakpoint, p.u.
" Zerox"	0.00	/	LVPL zero crossing, p.u.
" Lvpl1"	1.11		LVPL breakpoint, p.u.

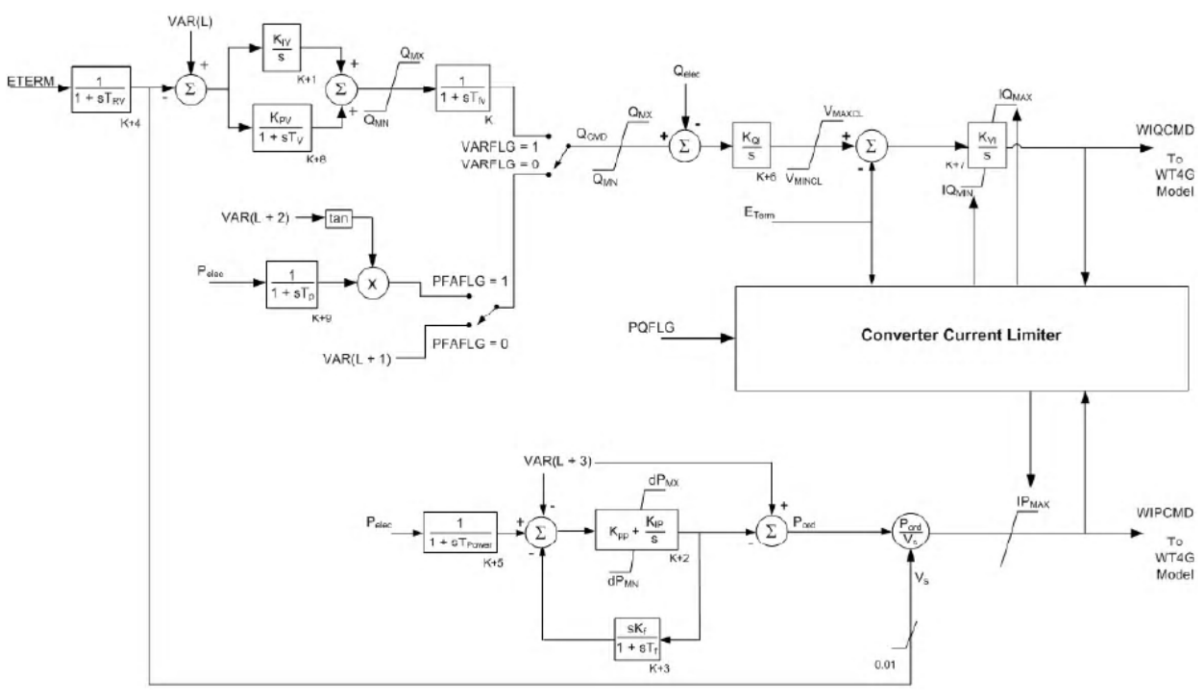


WT4E1U and WT4E
Electrical Control Model for the WT4E Generic Wind Model

This model (WT4E) is an equivalent of the controller for the power converter.

W4E1U-PSSE Data

CONs	#	Value	Description
J		0.15	T_{fv}, Filter time constant in Voltage regulator (sec)
J+1		18.0	K_{PV}, Proportional gain in Voltage regulator(pu)
J+2		5.0	K_{IV}, Integrator gain in Voltage regulator (pu)
J+3		0.05	Kpp, Proportional gain in Active Power regulator(pu)
J+4		0.10	K_{IP}, Integrator gain in Active Power regulator (pu)
J+5		0.0	K_f, Rate feedback gain (pu)
J+6		0.08	T_f, Rate feedback time constant (sec.)
J+7		0.47	Q_{MX}, Max limit in Voltage regulator (pu)
J+8		-0.47	Q_{MN}, Min limit in Voltage regulator (pu)
J+9		1.1	IP_{max}, Max active current limit
J+10		0.0	T_{RV}, Voltage sensor time constant
J+11		0.5	dP_{MX}, Max limit in power PI controller (pu)
J+12		-0.5	dP_{MN}, Min limit in power PI controller (pu)
J+13		0.05	$T_{\_Power}$, Power filter time constant
J+14		0.1	K_{QI}, MVAR/Voltage gain
J+15		0.9	V_{MINCL}, Min. voltage limit
J+16		1.1	V_{MAXCL}, Max. voltage limit
J+17		120.0	K_{VI}, Voltage/MVAR Gain
J+18		0.05	T_v, Lag time constant in WindVar controller
J+19		0.05	T_p, Pelec filter in fast PF controller
J+20		1.7	ImaxTD, Converter current limit
J+21		1.11	Iphl, Hard active current limit
J+22		1.11	Iqhl, Hard reactive current limit



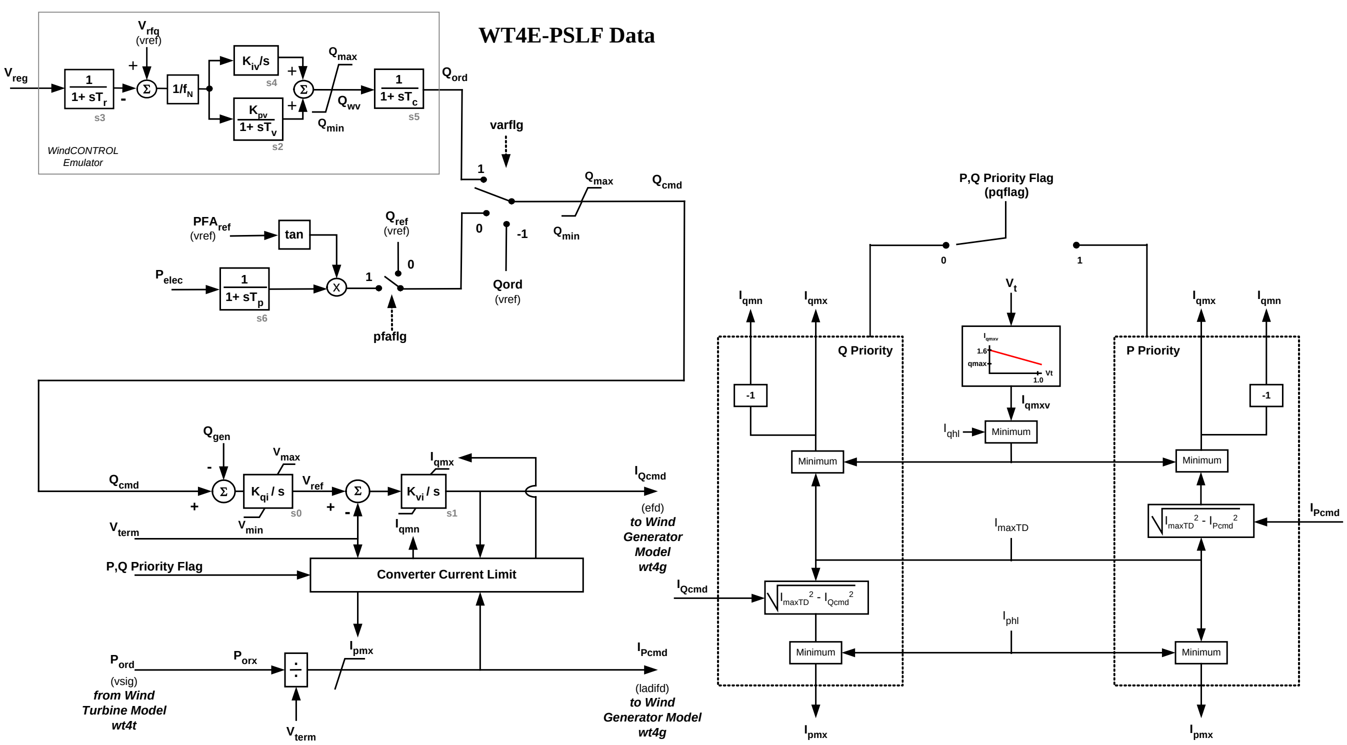
WT4E
Electrical Control Model for the WT4E Generic Wind Model

This model (WT4E) is an equivalent of the controller for the power converter.

WT4E-PSLF Data

wt4e 5 "WTG TERM" .575 "1 " 4 "WTG 34 " 34.5 "1 " 1 : #9 /				
"	varflg"	1.00	/	1 = Qord from WindCONTROL emulation; -1 = Qord from vref (i.e., s
"	Kqi"	0.10	/	Q control integral gain (see note f)
"	Kvi"	120.00	/	V control integral gain
"	Vmax"	1.10	/	Maximum V at regulated bus (p.u.)
"	Vmin"	0.90	/	Minimum V at regulated bus (p.u.)
"	Qmax"	0.40	/	Maximum Q command (p.u.)
"	Qmin"	-0.40	/	Minimum Q command (p.u.)
"	Tr"	0.02	/	WindCONTROL voltage measurement lag, sec.
"	Tc"	0.15	/	Lag between WindCONTROL output and wind turbine, sec.
"	Kpv"	18.00	/	WindCONTROL regulator proportional gain (see note g)
"	Kiv"	5.00	/	WindCONTROLregulator integral gain (see note g)
"	pfaflg"	0.00	/	1 = regulate power factor angle; 0 = regulate Q
"	fn"	1.00	/	fraction of WTGs in wind farm that are on-line
"	Tv"	0.05	/	Time constant in proportional path of WindCONTROL emulator, sec.
"	Tpwr"	0.05	/	Time constant in power measurement for PFA control (Tp), sec.
"	Iphl"	1.11	/	Hard limit on real current, p.u.
"	Iqhl"	1.25	/	Hard limit on reactive current, p.u.
"	Pqflag"	0.00		0 = Q priority ; 1 = P priority

WT4E-PSLF Data



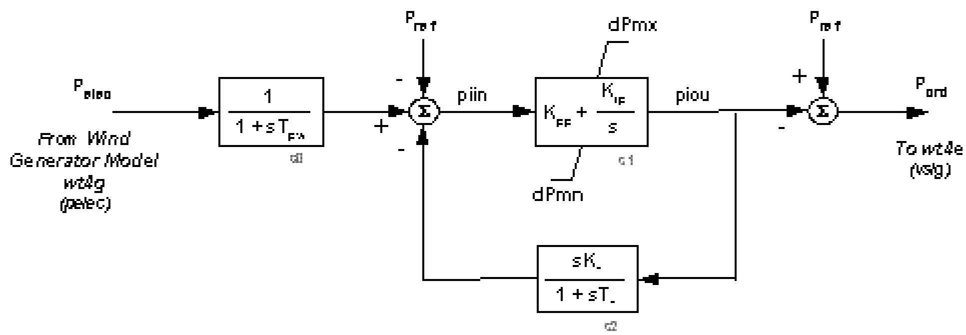
WT4T (PSLF)

Power converter controller for the WT4T Generic Wind Model

This model (WT4T) is an equivalent of the controller for the power converter.

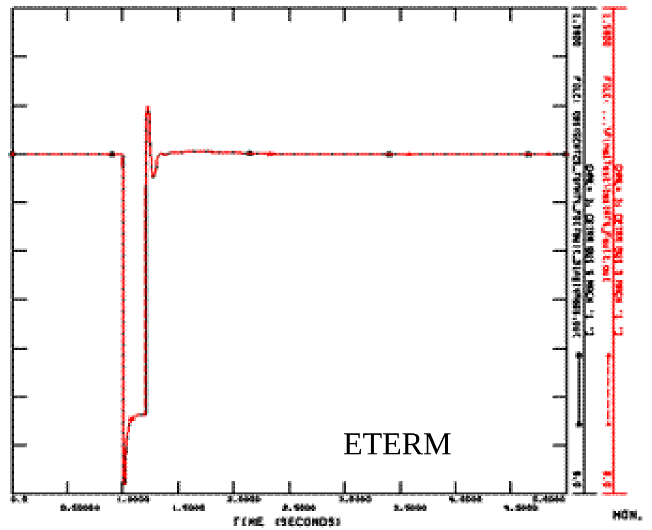
PSLF Data

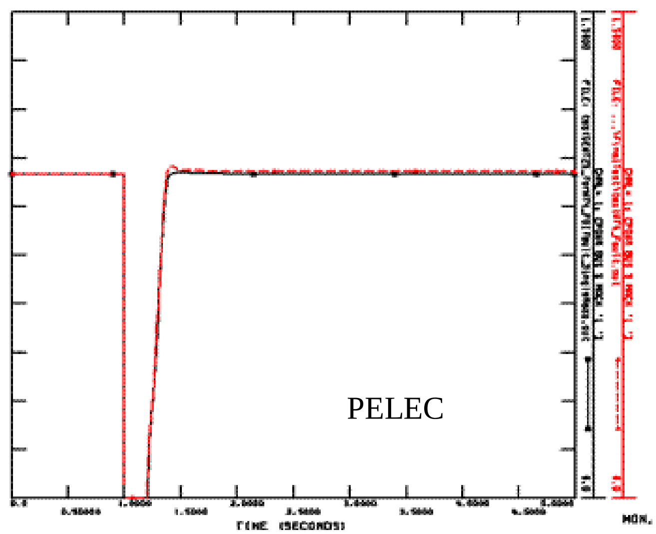
wt4t 5 "WTG TERM" .575 "1 " : #9 /				
"	Tpw"	0.05	/	Voltage transducer time constant, p.u.
"	Kpp"	0.08	/	PI controller proportional gain, p.u.
"	Kip"	0.10	/	PI controller integral gain, p.u.
"	Tf"	0.08	/	Rate feedback time constant, p.u.
"	Kf"	0	/	Rate feedback gain, p.u.
"	dPmx"	0.1	/	Maximum PI controller output, p.u.
"	dPmn"	-0.1		Minimum PI controller output, p.u.

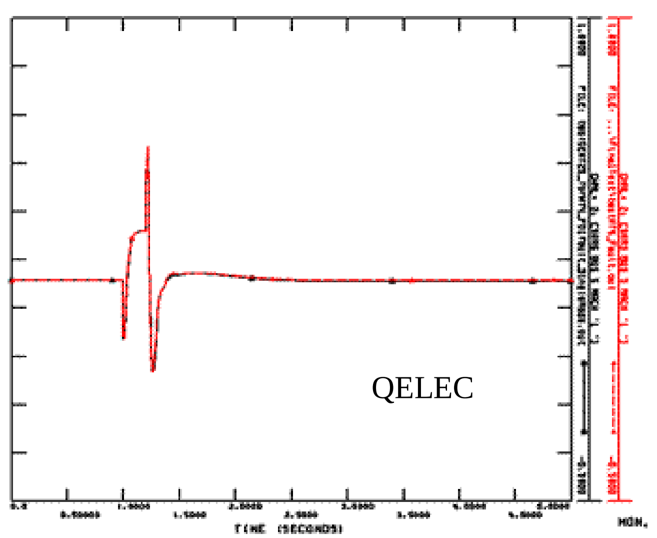


WT4 Model Comparison

Against GE 2.5 MW Manufacturer Model



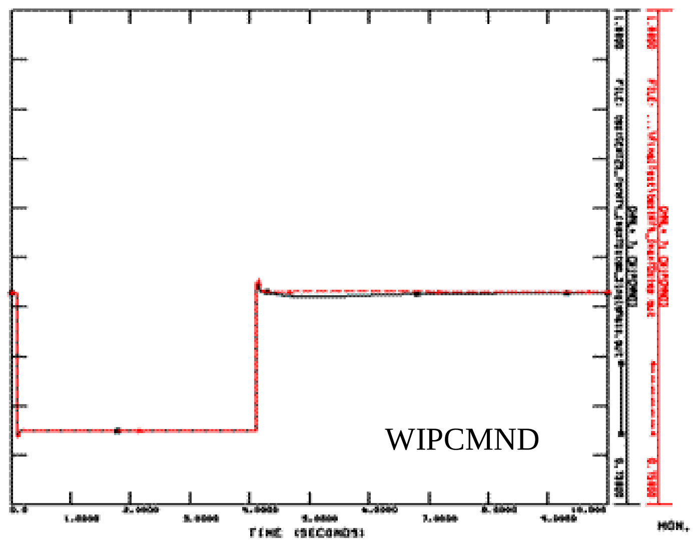


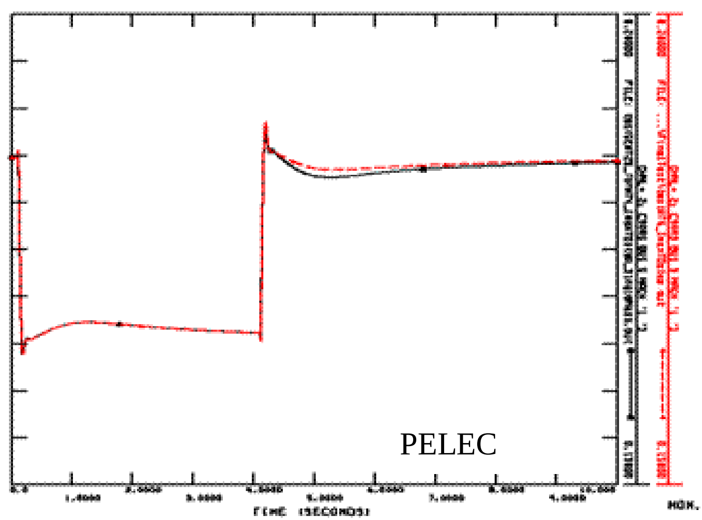


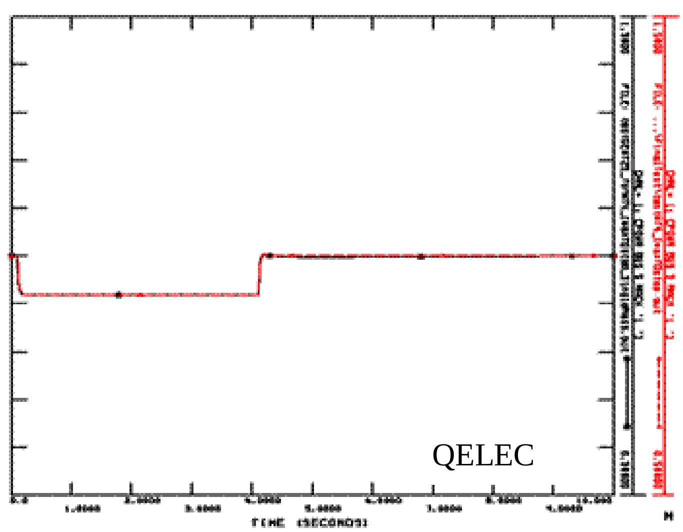
At T = 0.1 sec., place fault at POI, clear in 250 ms

WT4 Model Comparison

Against GE 2.5 MW Manufacturer Model





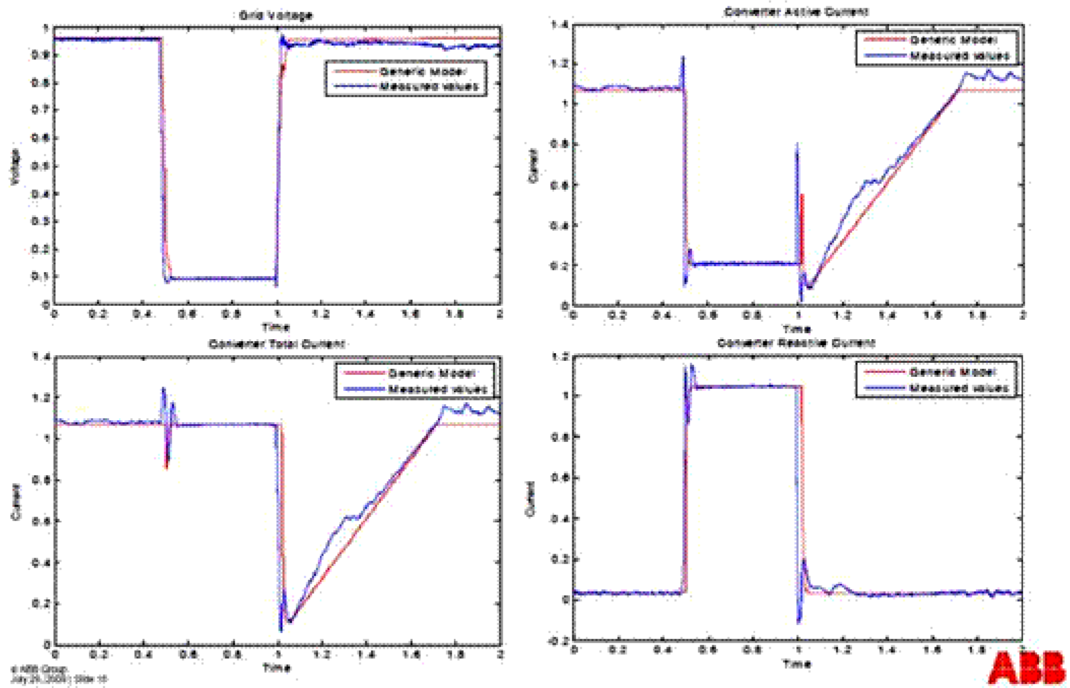


At T = 0.1 sec., converter current limit is reduced from 1.7 p.u. to 0.8 p.u. Restore back to 1.7 p.u. at T = 4.1 sec.

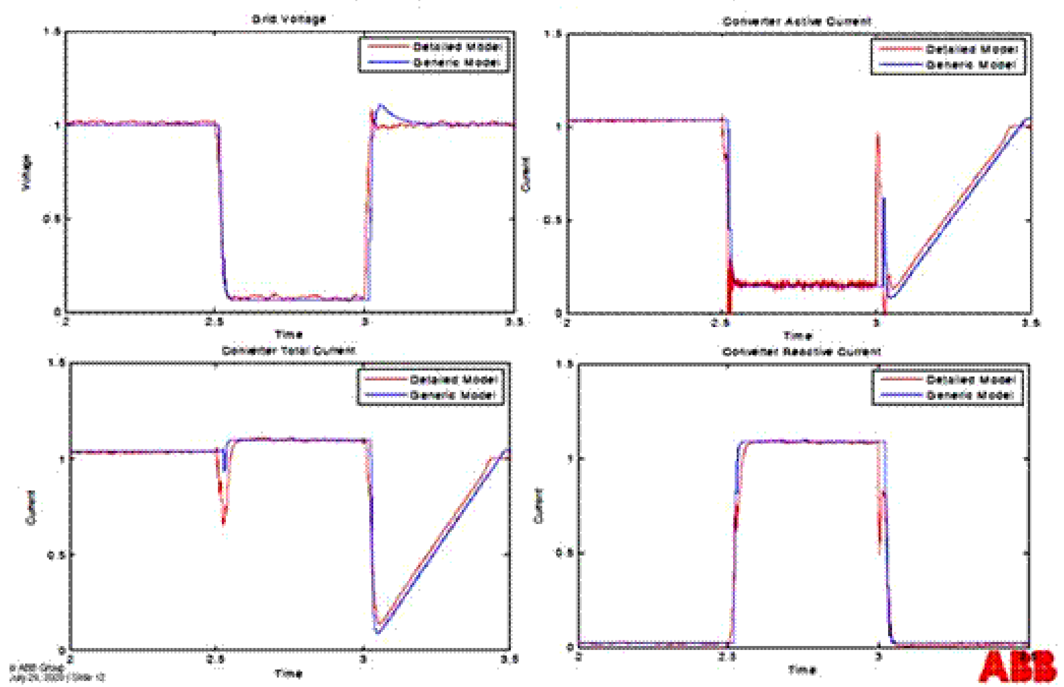
WT4 Model Verification

Against ABB Converter Full Power Test

Full converter WTD under 3-ph dip , Generic model Ts = 5 ms



Full-converter WTD under 3-ph dip, Detailed model Ts=0.5 μs, Generic model Ts=5 ms



From "WECC - Model Specifications, Validation", presentation by Slavomir Seman, 7/29/09 at the IEEE PES General Meeting, Calgary, Canada.

VOLTAGE AND FREQUENCY RELAYS

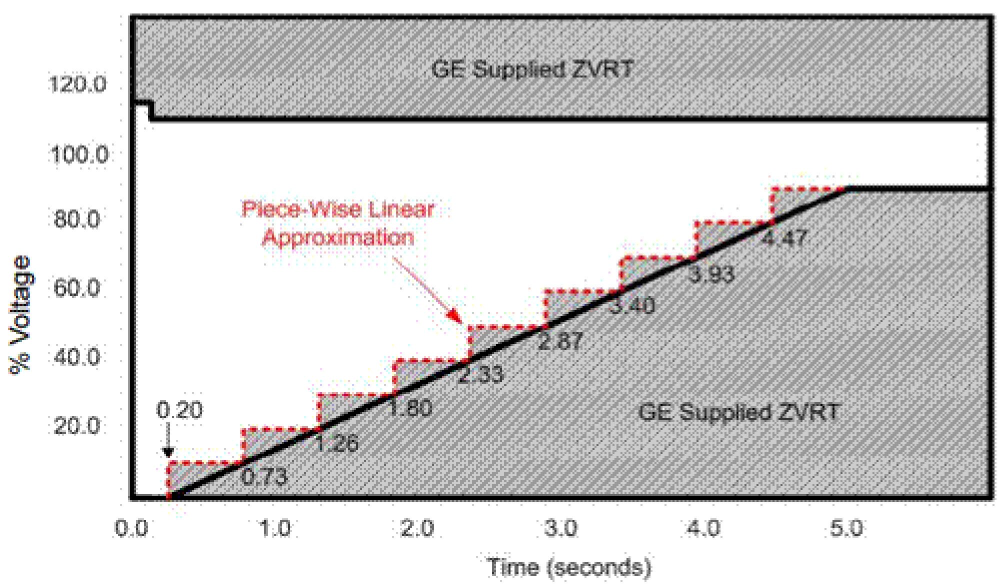
PSSE Modules:

The under/over frequency models (FRQDCA) and under/over voltage models (VTGDCA) are protection models that are located at the generator bus to which the WTG equivalent is connected. They continuously monitor the frequency/voltage on that bus or a remote bus specified by the user. They trip the WTG equivalent for under- and over-frequency/voltage conditions on the generator (or remote bus). FRQDCA and VTGDCA relays disconnect WTG bus, i.e., it disconnects all equipment attached to WTG bus.

A relay timer is started during under/over frequency/voltage conditions, i.e., when frequency/voltage is less/greater than or equal to the corresponding pickup threshold. The relay resets instantaneously if the frequency/voltage is restored between the two pickup thresholds. If the relay is not reset, a trip signal is sent to the circuit breaker if the timer reaches its setting; frequency/voltage must have remained in an under/over frequency/voltage condition for the entire time delay for generator tripping to occur. Generator tripping is delayed by the circuit breaker time.

The voltage and frequency protection setpoints set in the example DYRE files represent our best knowledge at the time of issuing this manual. Since this is a rapidly evolving technology, requirements to interconnection have been changed several times during last two years; and there is no guarantee they won't change in near future. This explains the Siemens PTI strong recommendation to contact the manufacturer regarding setpoints and monitored voltage and frequency (terminal bus or point of interconnection to the system) before doing the study. Manufacturer's requirements may be easily implemented by manually modifying respective data in the DYRE file.

The LVRT voltage versus time curve provided by a manufacturer can be step-wise interpolated, and every each step can be entered as a setpoint for the protection model.



Example:

The following example shows how to set up VTGDCA and FRQDCA.
The following set of voltage protection modules for simulating this interpolation should be added to the dyr-file:

0 'USRMDL' 0 'VTGDCA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.1 5.0 0.200 0.08 /
0 'USRMDL' 0 'VTGDCA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.2 5.0 0.733 0.08 /
0 'USRMDL' 0 'VTGDCA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.3 5.0 1.267 0.08 /
0 'USRMDL' 0 'VTGDCA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.4 5.0 1.800 0.08 /
0 'USRMDL' 0 'VTGDCA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.5 5.0 2.333 0.08 /
0 'USRMDL' 0 'VTGDCA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.6 5.0 2.867 0.08 /
0 'USRMDL' 0 'VTGDCA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.7 5.0 3.400 0.08 /
0 'USRMDL' 0 'VTGDCA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.8 5.0 3.933 0.08 /
0 'USRMDL' 0 'VTGDCA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.9 5.0 4.467 0.08 /
0 'USRMDL' 0 'VTGDCA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.0 1.1 0.100 0.08 /
0 'USRMDL' 0 'VTGDCA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.0 1.15 0.0 0.08 /

Here bus #7005 is an equivalent WTG machine terminal bus number, and bus #7002 is a bus in the point of interconnection. The first nine models will result in the desired gray tripping area under the red dashed line. Since a number of interpolation points is limited to 9, the defined VTGDCA points must lie above, not on, the sloping line to avoid under-tripping. The last two models will result in desired gray tripping area for overvoltage.

A similar approach can be used for simulation of frequency protection, for example:

0 'USRMDL' 0 'FRQDCA' 0 2 6 4 0 1 7005 7005 '1' 0 0 0 57.0 66.0 0.02 0.08 /
0 'USRMDL' 0 'FRQDCA' 0 2 6 4 0 1 7005 7005 '1' 0 0 0 57.5 66.0 10.0 0.08 /
0 'USRMDL' 0 'FRQDCA' 0 2 6 4 0 1 7005 7005 '1' 0 0 0 57.8 66.0 20.0 0.08 /
0 'USRMDL' 0 'FRQDCA' 0 2 6 4 0 1 7005 7005 '1' 0 0 0 54.0 61.5 30.0 0.08 /
0 'USRMDL' 0 'FRQDCA' 0 2 6 4 0 1 7005 7005 '1' 0 0 0 54.0 62.5 0.02 0.08 /

Actual protection characteristics depend on the project, on the protection option supplied by a manufacturer, on the transmission planning criteria, etc. That is why users are strongly recommended to contact the manufacturer to get the latest update of the protection characteristics and then to synthesize these characteristics using the suggested approach.

Input Data:

FRQDCA is an Under Frequency / Over Frequency Generator Bus Disconnection Relay

0 'USRMDL' 0 'FRQDCA' 0 2 6 4 0 1 ICON(I) ICON(I+1) 'ICON(I+2)' 0 0
0 CONs from (J) to (J+3) /

CONs	#	Value	Description
J			FL, lower frequency threshold (Hz)
J+1			FU, upper frequency threshold (Hz)
J+2			TP, relay pickup time (sec)
J+3			TB, breaker time (sec)

ICONs	#	Description
I		Bus number where frequency is monitored
I+1		Bus number of generator bus where relay is located
I+2		Generator ID
I+3*		Delay flag
I+4		Time-out flag
I+5		Timer status

* **Note**: ICONs (I+3) through (I+5) are control flags that are not to be changed by the user.

VTGDCA is an Under Voltage / Over Voltage Generator Bus Disconnection Relay

0 'USRMDL' 0 'VTGDCA' 0 2 6 4 0 1 ICON(I) ICON(I+1) 'ICON(I+2)' 0 0 0
CONs from (J) to (J+3) /

CONs	#	Value	Description
J			VL, lower voltage threshold (Hz)
J+1			VU, upper voltage threshold (Hz)
J+2			TP, relay pickup time (sec)
J+3			TB, breaker time (sec)

ICONs	#	Description
I		Bus number where voltage is monitored
I+1		Bus number of generator bus where relay is located
I+2		Generator ID
I+3*		Delay flag
I+4		Time-out flag
I+5		Timer status

* **Note**: ICONs (I+3) through (I+5) are control flags that are not to be changed by the user.

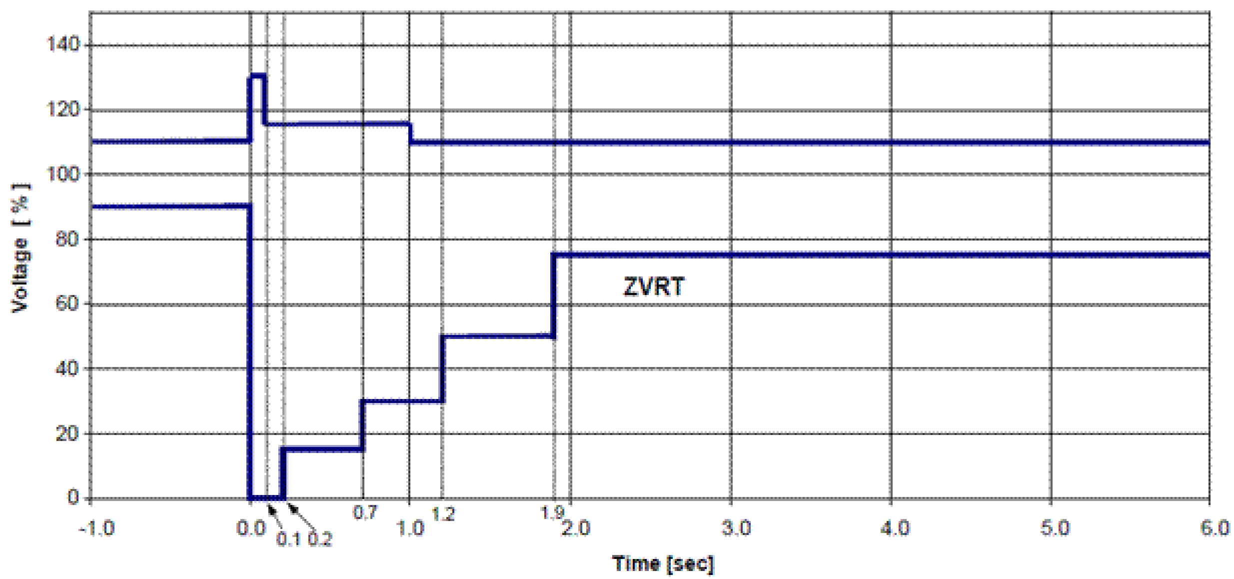
Note:
FRQDCA and VTGDCA relays disconnect WTG bus, i.e., it disconnects all equipment attached to WTG bus. Another version of the voltage and frequency for wind turbine application are FRQTPA and VRQTPA. FRQTPA and VTGTPA relays disconnect WTG only, i.e., it disconnects only the wind turbine generator attached to WTG bus. The input data format for FRQTPA and VTGTPA are the same as the input data format for the FRQDCA and VTGDCA.

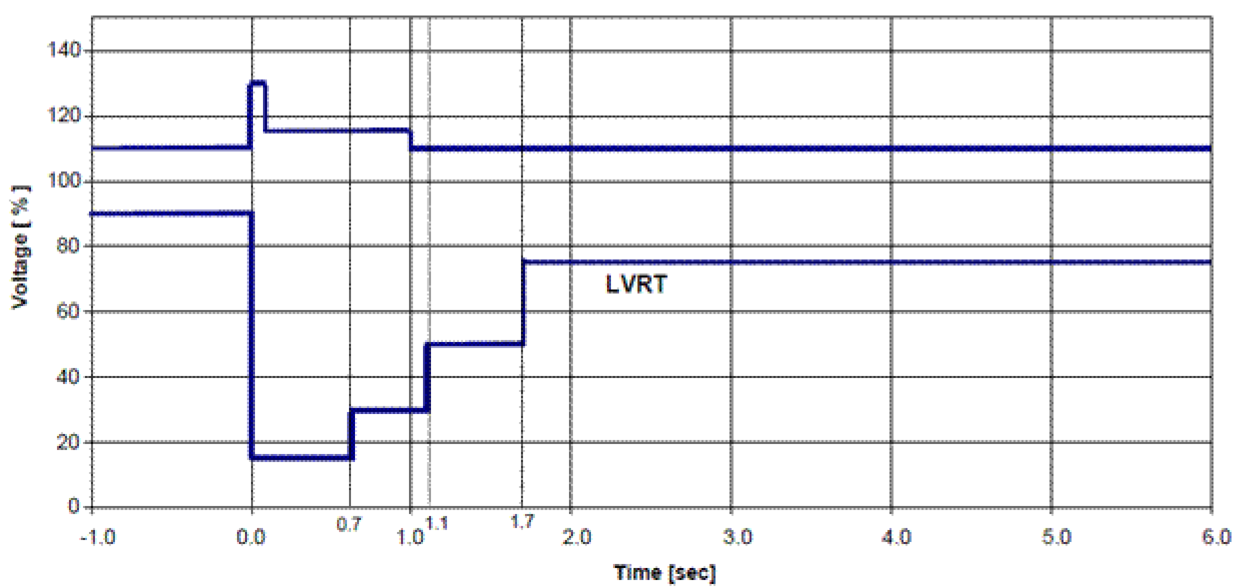
PSLF Modules:

The under/over voltage model in PSLF is the protection model located at the generator bus to which the WTG equivalent is connected. The input to this model is the set points indicating the deviations from the reference voltage and the duration allowed at the specific voltage deviation as described by the voltage ride through of the generation. This model should be placed after the wind turbine generator module.

Example:

As an example, this relay can be used to protect the wind turbine generator based on the Low Voltage Ride Through or Zero Voltage Ride Through as shown in the figures and table below:





		Time (sec)	
V (%)	ΔV (pu)	ZVRT	LVRT
75	-0.25	1.9	1.7
50	-0.50	1.2	1.1
30	-0.70	0.7	0.7
15	-0.85	0.2	0.02
110	0.10	1.0	1.0
115	0.15	0.1	0.1

The model invocation in the .dyd file for the LVRT case shown above is as follows:

lhvrt 5 "WTG TERM" .575 "1 " : #8 /
"vref" 1.00 /
"dvtrp1" -0.10 "dvtrp2" -0.50 "dvtrp3" -0.85 "dvtrp4" 0.10 "dvtrp5" 0.15 /
"dvtrp6" 0.30 "dvtrp7" 0.30 "dvtrp8" 0.00 "dvtrp9" 0.00 "dvtrp10" 0.00 /
"dttrp1" 3.00 "dttrp2" 1.30 "dttrp3" 0.02 "dttrp4" 1.00 "dttrp5" 0.10 /
"dttrp6" 0.02 "dttrp7" 0.02 "dttrp8" 0.00 "dttrp9" 0.00 "dttrp10" 0.00

Input Data:

LHVRT is a Low/High Voltage Ride Through relay protection that can be used for wind turbine generator. The input format is given as follow:

lhvrt [<n>] {<name> <kv>} <id>} [<nr>] {<namer> <kvr>}: #<rl>

Where :

<n> = the bus number of the generator
{<name> <kv>} <id>} = the name , voltage rating, and the id of the generator

[<nr>] = the bus number of the remote bus where the voltage is monitored
{<namer> <kvr>} = the name and the voltage rating of the remote bus

Notes:
a) The Delta voltage trip levels (Dv) are computed as follows:
Dv = | Monitored voltage | - vref.
The default monitored bus used to compute Dv is the generator terminal bus. If there is a to-bus specified in the dyd file, then the to-bus is used to compute Dv.
b) The model should not be used with models that already include voltage protection, e.g., gewtg.
c) The data should be entered sequentially, e.g., dvtrp1 and dttrp1 with value zero, followed by non-zero entries is not allowed.

Parameters:

EPCL Variable	Default Data	Description
vref	1.0	Delta voltage is computed with respect to vref
dvtrp1	0.0	Delta voltage trip level, p.u.
dvtrp2	0.0	Delta voltage trip level, p.u.
dvtrp3	0.0	Delta voltage trip level, p.u.
dvtrp4	0.0	Delta voltage trip level, p.u.
dvtrp5	0.0	Delta voltage trip level, p.u.
dvtrp6	0.0	Delta voltage trip level, p.u.
dvtrp7	0.0	Delta voltage trip level, p.u.
dvtrp8	0.0	Delta voltage trip level, p.u.
dvtrp9	0.0	Delta voltage trip level, p.u.
dvtrp10	0.0	Delta voltage trip level, p.u.
dttrp1	0.0	Voltage trip time, sec.
dttrp2	0.0	Voltage trip time, sec.
dttrp3	0.0	Voltage trip time, sec.
dttrp4	0.0	Voltage trip time, sec.
dttrp5	0.0	Voltage trip time, sec.
dttrp6	0.0	Voltage trip time, sec.
dttrp7	0.0	Voltage trip time, sec.
dttrp8	0.0	Voltage trip time, sec.
dttrp9	0.0	Voltage trip time, sec.
dttrp10	0.0	Voltage trip time, sec.