Generic Wind Turbine Generator Models for WECC – A Second Status Report

WECC Renewable Energy Modeling Task Force

Abstract **– This paper describes the latest generic wind turbine generator models of types 3 and 4 developed for implementation in the Western Electricity Coordinating Council (WECC) base cases.**

Key Words – Generic wind turbine models, wind power.

I. INTRODUCTION

Recognizing the need for transient stability models suitable for representing different types of wind turbine generators (WTGs), WECC, through its Renewable Energy Modeling Task Force (REMTF), has been leading a concerted effort to develop such models. The work carried out by the REMTF spans several years and has resulted in the implementation of WTG models in several transient stability programs used extensively in North America for power system planning studies. These models have been termed "generic" to underline the fact that they are intended to allow for the representation of equipment built by different manufactures.

This paper is a sequel to a previous publication, Ref. [1] and [2], where the rationale behind the development of generic wind turbine generator (g-WTG) models and their intrinsic attributes were described. Reference [1] also described the generic models used in the WECC data sets, circa 2011. These models are referred to as "first generation generic WTG models". The first generation g-WTG models provided the power industry, for the first time, with models that shared common notation and were implemented in widely used commercial power system transient stability programs. Although these developments represented a significant improvement on modeling capabilities of WTGs, the conditions under which the first generation WTG models were created were far from ideal. Of particular significance was the scarcity of publicly available information regarding commercial WTG models which made it impossible for the generic models to be truly generic. Under these circumstances, it was readily acknowledged that the first generation g-WTG models, particularly WTGs of Types 3 and 4, needed to be updated as additional information became available. This was clearly stated in the conclusions of the work reported in [1].

Additional information provided by several equipment manufacturers has indeed become available since the publication of [1] and this has allowed for the development of a "second generation" of g-WTGs of Types 3 and 4. The second generation g-WTG models have recently been implemented in several transient stability programs used for planning studies in North America and have also been added to the list of models sanctioned by WECC for planning studies [3], [4].

The purpose of this paper is to provide a concise description of the main features of the second generation g-WTG models, their block diagrams, and simulation results validating the models. For those wishing to implement these new models, a detailed specification can be found in [4], and test case data and simulations results in [5].

II. MODULES AND CONNECTIVITY

The model structure of wind power plants of Types 3 and 4 consist of seven and four modules, respectively (Figures 1 and 2). This modular approach was adopted to allow for the representation of different plant topologies and to facilitate updating individual model components as technology evolves and/or more information becomes available.

The modules used to represent a generic wind power plant of Types 3 are: Renewable Energy Generator/Converter (regc), Renewable Energy Electrical Control (reec), Aerodynamic Conversion (wtgar), Pitch Controller (wtgp), Drive-Train (turbine) (wtgt), Torque Controller (wtgq), and Plant-level Controller (repc). The modules required to represent a Type 4 WTG power plant are a subset of those required to model a Type 3 WTG plant. Modules with names beginning with the letters "r" and "e" (these letters stand for renewable energy) are modules that can also be used to represent photovoltaic power plants.

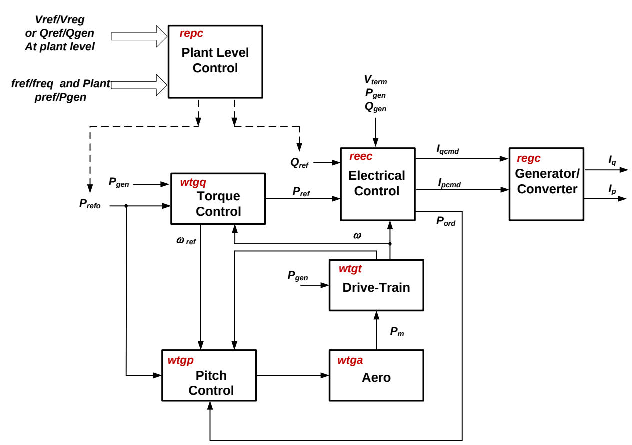

Figure 1. Structure of a WTG of Type 3

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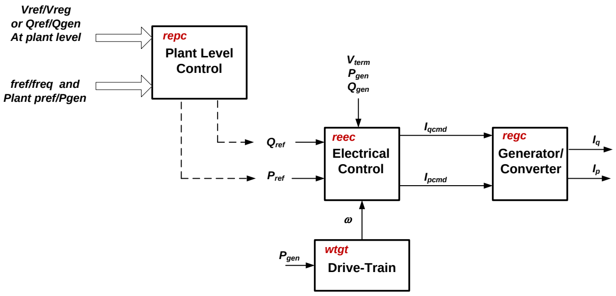

Figure 2. Structure of WTG of Type 4

II.1 Generator/converter Module for Type 3 and 4 WTGs

The Generator/converter module is shown in Figure 3. This module is a simplified representation of fast controls; its inputs are the commands from the electrical controller. The module represents a high bandwidth current regulator that injects real and reactive components of inverter current into the external network during the network solution in response to real and reactive current commands. Current injection includes the following capabilities:

- User settable reactive current management during high voltage events at the generator (inverter) terminal bus
- Active current management during low voltage events to emulate in a very simple and approximate way, the response of the inverter PLL controls during voltage dips
- Power logic during low voltage events to allow for a controlled response of active current during and immediately following voltage dips

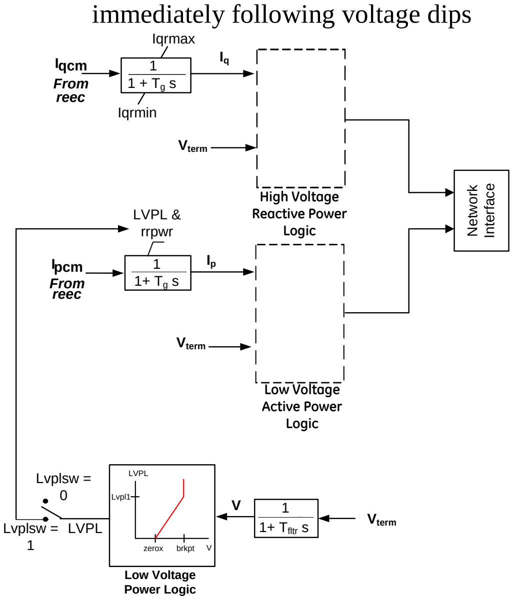

Figure 3. Generator/Converter Model

The "high voltage reactive power logic" block limits the reactive current injected into the network equations such that the terminal voltage of the machine does not exceed a given limit, as long as the converter is within current limits. The "low voltage active power logic" block is designed to capture the characteristic of active power under very low voltages. This limit is designed to reduce active current in a linear fashion. These two blocks are of numerical nature, i.e., they do not represent a physical element; their main function is to ameliorate numerical issues that arise due to the approximation by a simple model to a high bandwidth hardware component.

II.2 Electrical Control Module for Type 3 and 4 WTGs

The Renewable Energy Electrical Control module emulates the active and reactive power controls implemented in a WTG converter (Figure 4). It provides options for reactive power control, including constant power factor, voltage regulation and reactive power reference through the *Qref* input. Two PI loops represent the reactive control and local voltage response. These local controls may be bypassed by proper setting of user-defined flags. The model allows for the specification of a prescribed reactive control response during a voltage dip scenario, i.e., when a voltage dip condition is detected, the state of the active and reactive power PI controllers is frozen, and the reactive current injection *iqinj* is set according to the operation of the dynamic switch *SW* (*iqinj* is the output of switch SW in Figure 4). The model includes a current limiter; the limiter allows for the selection of active or reactive power priority.

II.3 Aerodynamic Module for Type 3 WTG

The aerodynamic module used in the second generation g-WTG model is the same as the aerodynamic module implemented in the first generation g-WTG models. The module has been described in references [1] and [6].

II.4 Pitch Controller Module for Type 3 WTG

This controller, depicted in Figure 5, consists of two PI controllers, a time constant and rate limit associated with the blade angle (pitch). The input to one of the PI controllers is power deviation; the input to the other PI controller is speed deviation, this signal may be augmented with a signal proportional to the power deviation. The difference between this model and the first generation model is the constant Kcc.

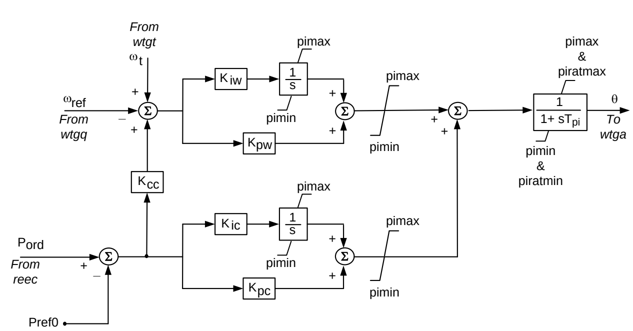

Figure 5. Pitch Controller

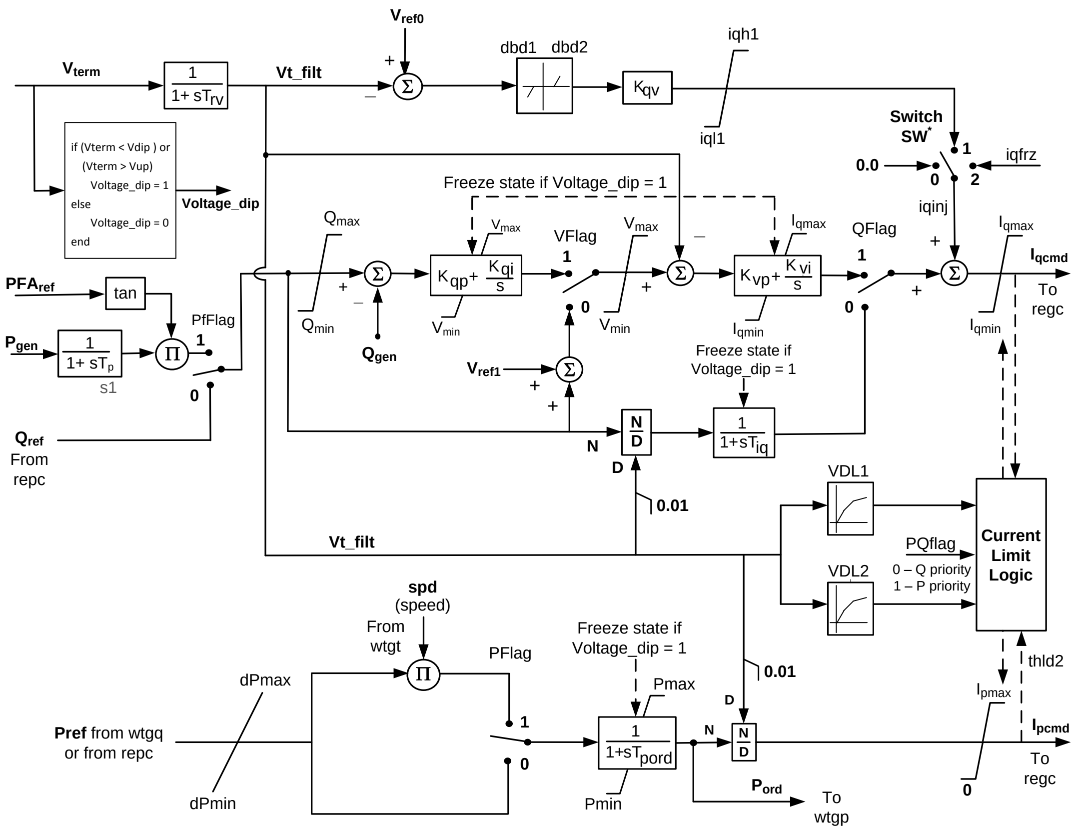

Figure 4. Electrical Controls

II.5 Drive-Train Module for Type 3 and 4 WTGs

The drive-train module represents the inertial components of the wind turbine-generator and it allows for the use of one or two masses. This module is also used in the representation of generic Type 1 and 2 WTG models; depending on the equipment characteristics, this module may or may not be needed to represent a Type 4 wind power plant. This module has been documented in References [1] and [4].

II.6 Torque Controller Module for Type 3 WTG

The torque controller is essentially a PI controller whose function is to set the power reference for the electrical controller (Figure 6). Two modes of operation are allowed: 1) the reference power is computed based on a user-defined speed vs. power curve (switch in position 0); 2) the reference power is computed based on the power command, Pref0, which is one of the outputs of master controller module, repc, shown in Figure 7.

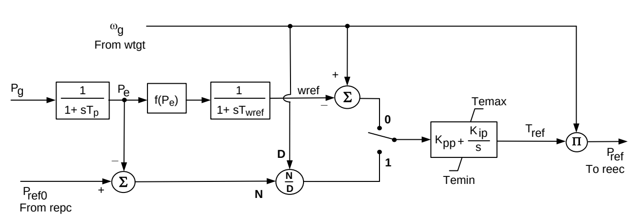

Figure 6. Torque Controller

II.7 Plant-level Controller Module for Type 3 and 4 WTGs

The plant-level controller is an optional module used when plant-level control of active and/or reactive power is desired (Figure 7). The module incorporates the following features:

– Closed loop voltage regulation at a user-designated bus. The voltage feedback signal has provisions for line drop compensation, voltage droop response and a user-settable dead band on the voltage error signal.

– Active power control to provide primary-frequency response. It should be noted that although many vendors have clearly demonstrated the ability to provide primary frequency response from WTGs, very few actual wind power plants in North America and other regions presently have such controls in place. Thus, at this time due to a lack of data this feature of the model has not been extensively tested and validated and should be used with caution. It may require further enhancements in the future.

The plant controller presently accommodates the ability to control one aggregated wind turbine generator. Augmenting the plant controller to allow it to control multiple devices is a future endeavor presently under consideration.

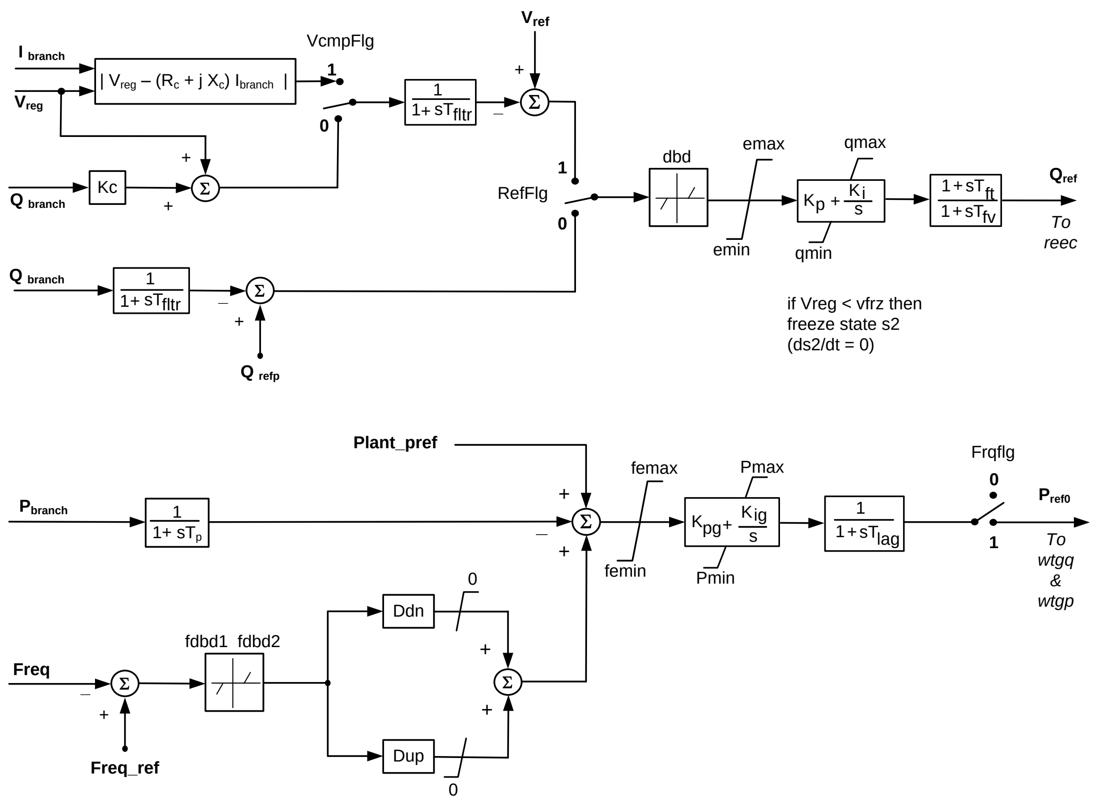

Figure 7. Plant-level Controller

III. DYNAMIC PERFORMANCE EVALUATIONS

The second generation g-WTG models have undergone extensive testing. One set of tests compares the response of the generic models against measured system variables following a disturbance. Another set of tests consists of comparing system simulation results generated by different transient stability programs. For reasons of space, only representative results are included here.

Figure 8 shows the results of a stage test where a shunt capacitor bank is switched in at 15 seconds and switched out at 98 seconds. There are four traces plotted in Figure 8: measured data (blue), simulated response from a detailed GE-specific model (red), response of the first generation g-WTG model (green) and the response of the second generation g-WTG model (violet). As the capacitor bank is switched in, voltage rises suddenly. The wind farm attempts to regulate the voltage at the point of interconnection (POI) by reducing the reactive power output to return the voltage at the POI to its reference value. The reverse happens as the capacitor bank is switched out. Throughout the test, the simulation results closely follow the measured voltage and reactive power. The close correlation between the first generation g-WTG models and the measured response was expected since, unlike the second generation g-WTG model, the first generation g-WTG model was based on the GE-specific WTG model.

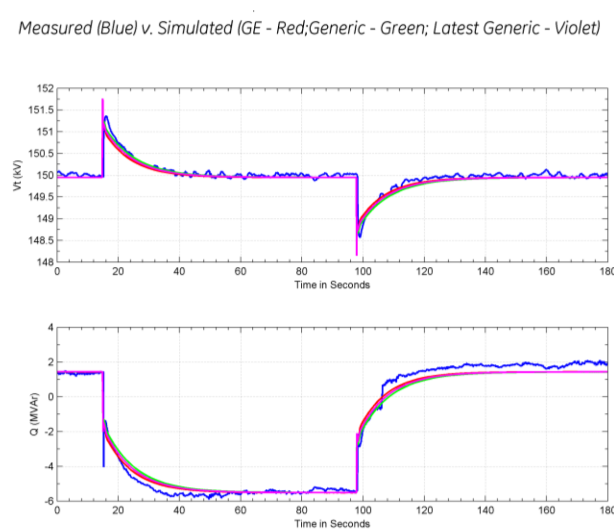

Figure 8. Capacitor Bank Switching Response

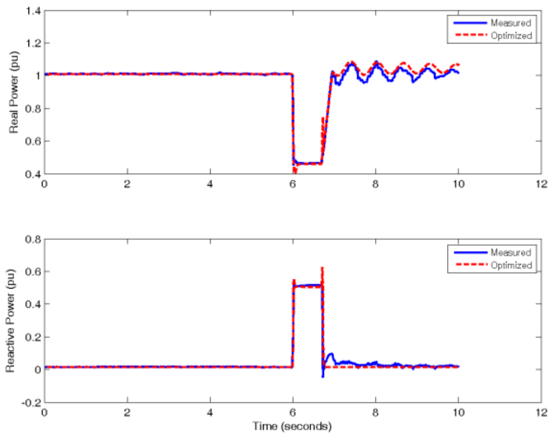

Figure 9. Type 4A WTG response to a fault

Figure 9 shows the optimized simulated (red dotted line) and actual field measured response (blue line) of a Type 4A WTG, in response to a fault on the high-side of the turbine generator step-up transformer. For this vendor the Type 4 model uses the drive-train model (wtgt) to emulate the observed torsional ripple in the active power following the fault. Figure 10 shows the response of a different vendor's equipment; this is a Type 4B WTG, that is there is no need for the drive-train model since the torsional ripple is not observed on the active power post-fault.

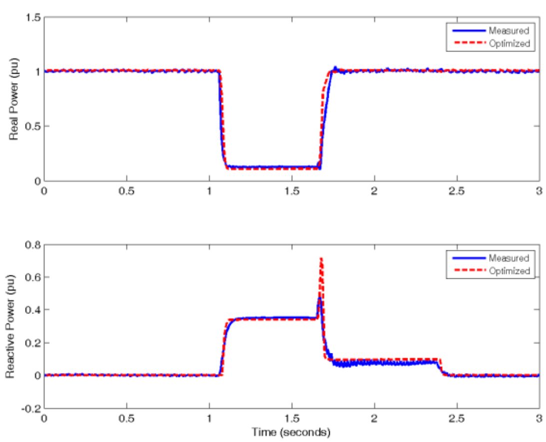

Figure 10. Type 4B WTG response to a fault

IV. CONCLUSSIONS AND LESSONS LEARNED

The work performed over the course of several years leading to the current generic WTG models, underlines the evolving nature of the wind power industry. It is recognized that the WTG models will continue to evolve as a result of changes in technology and interconnection

The evidence continues to show that the generic wind turbine generator models that exclude proprietary information can be used successfully in power system planning studies.

REFERENCES

1. A. Ellis, Y. Kazachkov, E. Muljadi, P. Pourbeik, J.J. Sanchez-Gasca, "Description and Technical Specifications for Generic WTG Models – A Status Report", Proc. IEEE PES 2011 Power Systems Conference and Exposition (PSCE), March 2011, Phoenix, AZ USA.

2. P. Pourbeik, A. Ellis, J. Sanchez-Gasca, Y. Kazachkov, E. Muljadi, J. Senthil, D. Davies, "Generic Stability Models for Type 3 & 4 Wind Turbine Generators for WECC", Proc. IEEE PES 2013 General Meeting, July 2013, Vancouver, BC, Canada.

3. WECC Wind Power Plant Dynamic Modeling Guide, prepared by: WECC Renewable Energy Modeling Task Force, April, 2014.

4. Specification of the Second Generation Generic Models for Wind Turbine Generators, WECC Approved Document, 1/23/14. (http://www.wecc.biz/Reliability/WECC%20Second%20Generation%20Wind%20Turbine%20Models%20012314.pdf)

5. Technical Update – Generic Model for Wind Turbine Generators and Photovoltaic Generation and Model Validation. EPRI, Palo Alto, CA: 2013. Product ID# 3002001002. (http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002001002&Mode=download)

6. W. W. Price, J.J. Sanchez-Gasca, "Simplified Wind Turbine Generator Aerodynamic Models for Transient Stability Studies", Proc. IEEE PES 2006 Power Systems Conference and Exposition (PSCE), Oct. 29-Nov. 1, 2006, Atlanta, GA, pp. 986-992.