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Specification of the Second Generation Generic Models for Wind Turbine Generators

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1

INTRODUCTION

1.1 Background

There are presently two major industry groups working towards the development of generic models for use in power system simulations for wind turbine generators – the Western Electricity Coordinating Council (WECC) Renewable Energy Modeling Task Force (REMTF) and the International Electrotechnical Commission (IEC) Technical Committee (TC) 88, Working Group (WG) 27. In 2010, the North American Electric Reliability Corporation (NERC), Integration of Variable Generation Task Force (IVGTF) Task 1-1 published a report [1] that outlines the need for such generic models for variable generation technologies such as wind and solar-photovoltaics (PV). The NERC IVGTF Task 1-1 document explains that the term “generic” refers to a model that is standard, public and not specific to any vendor, so that it can be parameterized in order to reasonably emulate the dynamic behavior of a wide range of equipment. Furthermore, the NERC document, as well as working drafts of the documents from WECC REMTF and IEC TC88 WG27, explains that the intended usage of these models is primarily for power system stability analysis. Those documents also discuss the range in which these models are expected to be valid and the models’ limitations. It is outside the scope of this report to discuss such details.

As an active participant in these various industry groups, EPRI has been working closely with these industry groups and several of the wind turbine generator manufacturers, as well as with the National Renewable Energy Laboratory, to help in the process of both the development and validation of these generic models.

In North America, much of this collaborative work culminated in the issuing of several reports in 2012 and 2013 ([2], [3] and [4]) that were then reviewed and collectively tested and approved by the WECC REMTF and Modeling Validation Working Group (MVWG) in early 2013. Subsequently the process started whereby the models are presently being implemented by the various commercial software vendors in North America.

At the last several WECC REMTF and MVWG meetings (i.e. March, 2013 and June, 2013) these reports and thus specifications were all approved and finalized. A few minor changes were made based on feedback during the process of implementation and testing of the models by GE and Siemens PTI. Thus, this document constitutes the final version of the specification for all these models as they related to wind turbine generators (WTG).

Although not explicitly covered in this report, it should be noted that the proposed building blocks for the type 4 WTG also forms the basis for the first generation utility scale photovoltaic (PV) models, with a few simplifications. This is covered in a separate report.

For those who may be unfamiliar with the four main wind turbine generator technologies, they are shown pictorially in Figure 1-1.

In general, the most commonly sold and installed technologies in today's market (both in the US and overseas) tend to be the type 3 and 4 units. All the major equipment vendors supply one or both of these technologies. There are, however, large numbers of the type 1 and 2 units in-service around the world, and so modeling them is also of importance. Some vendors do still supply the type 1 and 2 turbines as well.

The EPRI report [5] gives a brief outline of the history of these model developments as well as the issues identified with the first generation generic models and the various proposals discussed in the WECC REMTF and IEC TC88 WG27 groups, which was the initiation for the development of these second generation models. Here we do not delve into those detail discussions, but rather jump straight to the present the new model specification.

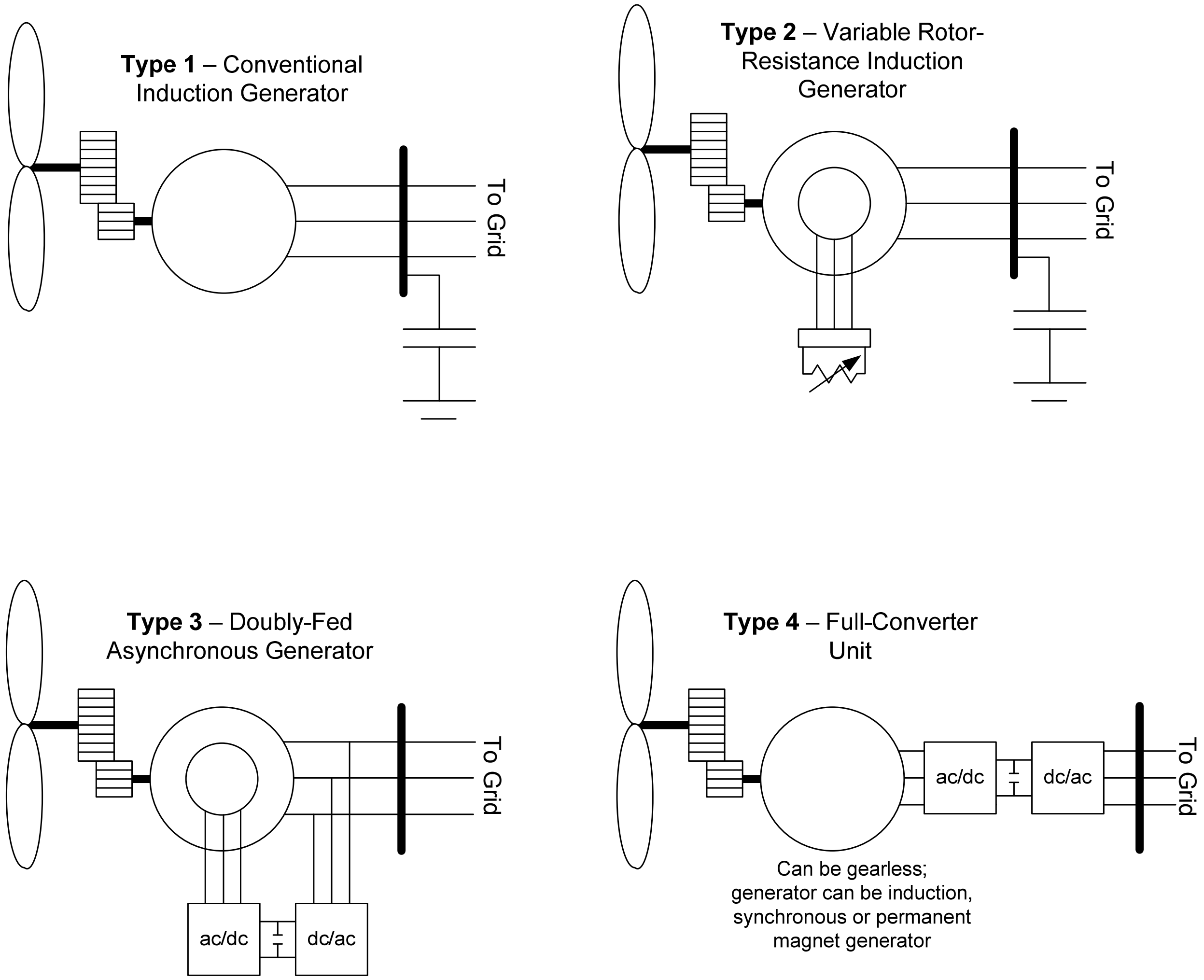


Figure 1-1: The four many wind turbine technologies.

Finally, with respect to the naming convention of the models, after the June 2012 WECC REMTF meeting it was agreed to change the names of these 2nd generation model modules in order to make them truly generic and usable for any appropriate renewable generation. For example, the *wtgg* would be called the *regc_a* (renewable energy generator/converter model), etc. These changes are reflected here. Also, these models proposed here will have a version number designated by "_a" to allow for future revisions. Need-less-to-say, it is almost inevitable that changes will be required as the technology advances.

2

TYPE 1 AND 2 WTG

2.1 The Type 1 WTG

The type 1 WTG is a conventional squirrel-cage induction generator. There are several possible variations [6], namely:

1. Fixed speed stall controlled type 1 WTGs. With stall design the blades of the turbine are bolted to the hub at fixed angle, and aerodynamically designed to stall (and stop the turbine) once wind speeds reach a certain level. Thus, these WTGs have no pitch control. These units should be modeled simply as an induction generator for the purpose of power system stability studies.
2. Fixed speed active-stall controlled type 1 WTG. With this design the turbine has pitch control. At low wind speeds by changing the blade pitch the overall turbine efficiency can be improved. At high wind speeds pitch control is used to better control the turbine. For sudden increases in wind speed the blades can be pitched in the opposite direction in order to force stalling quickly and bring the turbine to a stop. In this case a pitch controller should be modeled.

Thus, the generic model for a type 1 WTG consists of three components:

1. Generator Model – this is a conventional induction generator model. The preference is to use a two-cage model representing both transiency and sub-transiency. The state equations for a two-cage induction machine model may be found in many references. This is presently available in most of the commercial software platforms. In GE PSLF™ and Siemens PTI PSS®E, this is the *wt1g* model.
2. Drive Train Model – this is the standard two-mass drive train model, and already available in the standard commercial software platforms. Presently, for the type 1 generic WTG, this model is called the *wt1t* model. There is also the option of modeling the drive train by a single lumped mass, if desired.
3. The Pitch Controller – this model is new for the 2nd generation generic models and described below in more detail.

It is a known fact that many type 1 WTG with active-stall employ a scheme whereby the mechanical power is ramped down and then back up following a major voltage-dip (e.g. nearby transmission fault) when at or near rated power [6]. As discussed in [6], this is done to prevent the turbine from accelerating away and going unstable. The aim of the new generic pitch-controller model is to emulate this behavior. As shown in [7], through simulations comparing detailed vendor specific PSCAD models the actual control behavior is dependent on several factors:

1. the amount of over-speed of the turbine during the event,

2. the magnitude of the voltage dip, and
3. the initial turbine power.

In the actual controls there is a combination of monitoring of the shaft acceleration following an event together with the level of voltage dip. Furthermore, there are some variations in the control between various vendors as shown in [7]. Following discussions at the last WECC MVWG meeting is was agreed that the simpler version of this generic-pitch controller proposed in [4] is acceptable for the purposes of large interconnected studies.

The model is shown below in Figure 2-1.

A single integrator is used to ramp mechanical power down and back up. The rate limit parameter *rmin* together with P_{min} can then be used to effect the rate at which mechanical power is reduced and to what value during the disturbance. The rate limit *rmax* determines how quickly power is ramped back up after a given duration *T*. The time duration *T*, during which mechanical power is ramped down is based solely on voltage and determined from a four-piece curve (see table below). This is a very simple model and does not in any way represent actual controls, but it allows for an emulation of the behavior of typical type 1 WTG active-stall pitch control systems. The switch is automatically toggled by the model (*Flag1*) based on the following principles:

1. If *Vt* (after filtering) < *vt4* (last point on V/T curve) and *Po* ≥ *Pset* then Flag1 = 1, and remains in this position for the duration *T* seconds.
2. Otherwise, *Flag1* = 0.

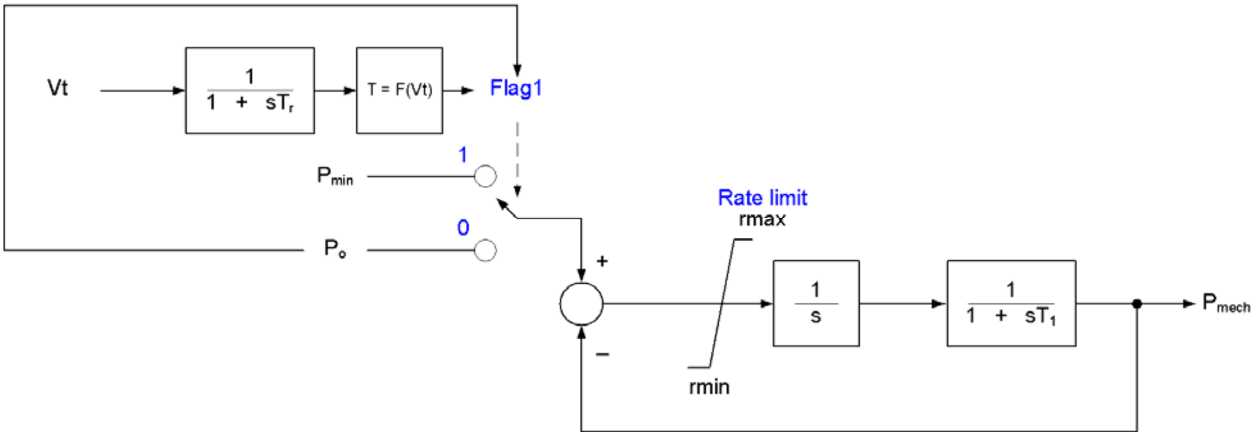
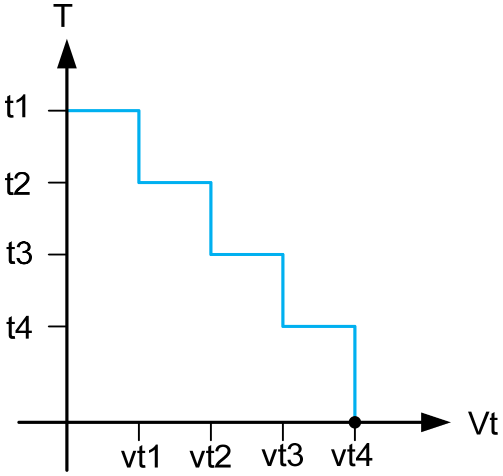


Figure 2-1: Overall model structure for new proposed type 1 (and 2) wind turbine pitch controller – WT1P_B.

The parameter list for this model is provided below. The user should realize that this model is a simplified model for the purpose of emulating the general behavior of type 1 WTGs during electrical disturbances. It does not claim to in anyway represent the actual control strategy associated with the pitch control of such turbines.

Parameter	Description	Typical Range of Values	Units
T_r	Voltage measurement time constant	N/A	s
rmax	Rate limit for increasing power	N/A	MWs/MVA
rmin	Rate limit for decreasing power	N/A	MWs/MVA
T_1	Lag time constant	N/A	pu
Pmin	Minimum power setting	N/A	pu
Po	Initial turbine mechanical power (Initialized by the model from power flow – **not user defined**)	N/A	pu
Flag	= 1 if Vt < vt4 & Po ≥ Pset, else = 0 **not user defined, set by model**	N/A	N/A
Pset	If Po <= Pset then ramp power	N/A	pu
F(Vt)= [vt1,t1; vt2,t2; vt3,t3; vt4,t4]	 This is the look-up table that determines the duration in seconds of the power ramping after a dip based on the size of the voltage dip.	N/A	[pu,s]

2.2 The Type 2 WTG

The type 2 WTG is a wound-rotor induction generator, with a variable resistor in the rotor circuit which is typically controlled using power electronics [6]. Typically, type 2 WTGs employed pitch control and so a pitch controller should be modeled.

Thus, the generic model for a type 2 WTG consists of three components:

1. Generator Model – this is a conventional induction generator model, including access to the external rotor resistance variable. This is presently available in most of the commercial software platforms. In GE PSLF^{TM} and Siemens PTI PSS®E, this is the *wt2g* model.
2. External Resistance Controller – a simple model of the external resistance controller. This model already exists in the GE PSLF^{TM} and Siemens PTI PSS®E programs as *wt2e.*
3. Drive Train Model – this is the standard two-mass drive train, and already available in the standard commercial software platforms. Presently, for the type 2 generic WTG, this model is called the *wt2t* model. There is also the option of modeling the drive train by a single lumped mass, if desired.
4. The Pitch Controller – this model is new for the 2nd generation generic models and is as described above, i.e. wt1p_b.

3

TYPE 3 AND 4 WTG

3.1 Overview

The 2nd generation type 3 and 4 models are built up of several generic modules that are put together to either constitute a type 3 or 4 WTG. There are seven (7) modules, or building block models. These are:

1. The renewable energy generator/converter model (*regc_a*), which has inputs of real (*Ipcmd*) and reactive (*Iqcmd*) current command and outputs of real (*Ip*) and reactive (*Iq*) current injection into the grid model. This is also used in the PV models.
2. The renewable energy electrical controls model (reec_a), which has inputs of real power reference (*Pref*) that can be externally controlled, reactive power reference (*Qref*) that can be externally controlled and feedback of the reactive power generated (*Qgen*). The outputs of this model are the real (*Ipcmd*) and reactive (*Iqcmd*) current command. A simplified version of this model (reec_b) is used in the PV models..
3. The emulation of the wind turbine generator driven-train (*wtgt_a*) for, simulating drive-train oscillations. The output of this model is speed (*spd*). In this case speed is assumed to be a vector *spd* = [ωt ωg], where ωt is the turbine speed and ωg the generator speed.
4. A simple linear model of the wind turbine generator aero-dynamics (*wtgar_a*). This is based on reference [8], and the same as the 1st generation generic models.
5. A simplified representation of the wind turbine generator pitch-controller (*wtgpt_a*). This is similar to the 1st generation type 3 pitch-control model, with the addition of one parameter *Kcc*. This parameter was added through consultation and discussions within the IEC group.
6. A simple emulation of the wind turbine generator torque control (wtgtrq_a)[1].
7. A simple renewable energy plant controller (*repc_a*), which has inputs of either voltage reference (*Vref*) and measured/regulated voltage (*Vreg*) at the plant level, or reactive power reference (*Qref*) and measured (*Qgen*) at the plant level. The output of the *repc_a* model is a reactive power command that connects to Qref on the *reec_a* model. Note: presently this plant controller can control **ONLY** one aggregated WTG model representing a single plant with the same type of WTG. Future versions may need to be considered for having a controller that controls multiple adjacent plants or multiple types of WTGs in a single plant. This model can also be used for PV plants.

The *repc_a* model includes a simple droop control for emulating primary frequency control. This is intended mainly for emulating down-regulation for over-frequency events, but an up-

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[1] The version shown in this final specification is based on an earlier version of the model discussed in March, 2012. At the last WECC REMTF meeting the members agreed to go to this earlier and simpler version.

regulation feature has also been provided. This is a simple model and is not based on any validation work and is based on recommendations among the various stakeholders and vendors participating in the WECC REMTF. This may be refined in the future. ***Warning:*** ***Care must be taken not to simulate up-regulation (i.e. increasing plant output with decreasing frequency) where it is not physically meaningful – e.g. when the plant is converting the available incident wind energy to electrical power, which is certainly the typical operating condition of a wind power plant.***

Warning: ***For completeness, and based on various comments from the WECC REMTF and IEC group members, various options (voltage, Q or pf control, with and without deadband etc.) have been provided for the control options at the plant level. Very preliminary tests have been done with data just recently made available in the last month. This work is very preliminary and so the plant level model is not yet necessarily fully validated. Plant level data has been scarce up to this point. Thus, care must be taken with the selection of these options and appropriately setting the controller parameters so as to not produce an undesired response. Further work and research with plant level model validation may in the future suggest changes to these model features.***

In the next few sections each of these building block models is described. In section 3.9 a description is given on how to build a type 4 WTG or type 3 WTG from these building block models.

3.2 REGC_A

The *regc_a* model is shown in Figure 3-1. This model is similar to the existing 1st generation *wt4g* model in GE PSLF™ and Siemens PTI PSS®E, with the following exceptions:

1. The time constants for the real and reactive current injection are a model parameter *Tg*, instead of being hardcoded.
2. The time constant for the voltage filter is also a parameter *Tfltr*, instead of being hardcoded.
3. A rate limit has been added to the reactive current block. It is important to understand how this rate limit is effected:
    a. If the model initializes with an initial reactive power output that is greater than zero (i.e. reactive power being injected into the grid), then upon fault clearing the recovery of reactive current is limited at the rate of *Iqrmax*. In this case the rate limit (*Iqrmin*) on reducing reactive current is not effective, reactive current can be reduced as quickly as desired.
    b. If the model initializes with an initial reactive power output that is less than zero (i.e. reactive power being absorbed from the grid), then upon fault clearing the recovery of reactive current back down to its original value is limited at the rate of *Iqrmin*. In this case the rate limit (*Iqrmax*) on increasing reactive current is not effective, reactive current can be increased as quickly as desired.

The action of this reactive current limit is best illustrated by the simulations shown in [3] (see Figure 4-4 and 4-5 in [3]).

The rest of the parameters and functionality of the *regc_a* model is as already described and implemented in GE PSLF^{TM} and Siemens PTI PSS®E. The logic behind the "high Voltage Reactive Current Management" and the "Low Voltage Active Current Management" are provided in Appendix A.

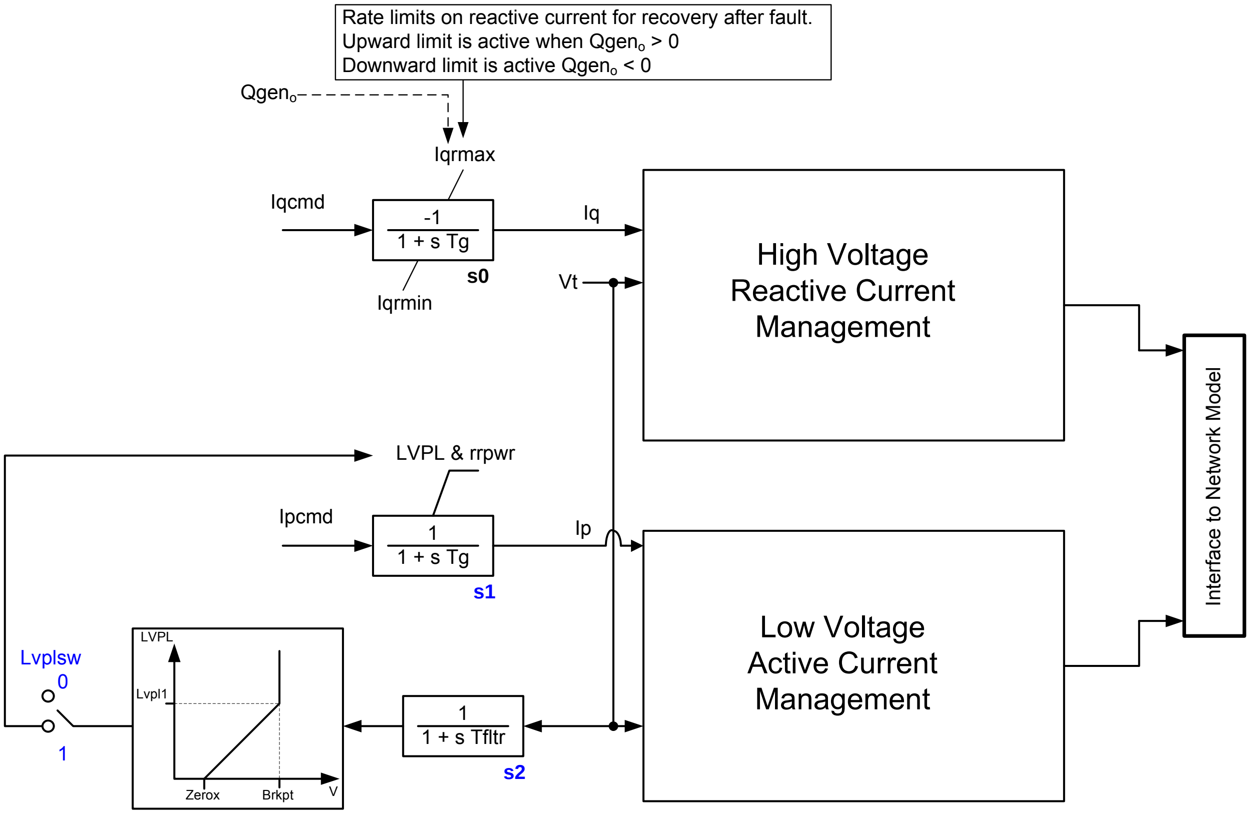


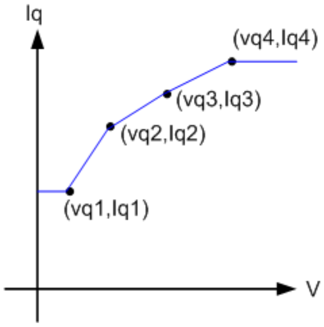
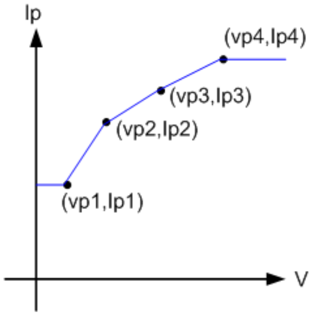
Figure 3-1: Renewable energy generator/converter model (regc_a).

3.3 REEC_A

The *reec_a* model is shown in Figure 3-2. The table below is a list of all the parameters of the model. The user must take great care to consult with equipment vendors to identify what is appropriate for an actual installation. The typical range of values are give only as guidance and should not be interpreted as a strict range of values, numbers outside of these typical ranges may be plausible. Where "N/A" is listed in the typical range of values column this indicates that there is no typical range to be provided. This model is per unitized on its own MVA BASE. Note: the details of the current limit logic are provided in Appendix B.

Parameter	Description	Typical Range of Values	Units
MBASE	Model MVA base	N/A	MVA
Vdip	The voltage below which the reactive current injection (Iqinj) logic is activated (i.e. voltage_dip = 1)	0.85 – 0.9	pu
Vup	The voltage above which the reactive current injection (Iqinj) logic is activated (i.e. voltage_dip = 1)	>1.1	pu
Trv	Filter time constant for voltage measurement	0.01 – 0.02	s

Parameter	**Description**	**Typical Range of Values**	**Units**
dbd1	Deadband in voltage error when voltage dip logic is activated (for overvoltage – thus overvoltage response can be disabled by setting this to a large number e.g. 999)	-0.1 – 0	pu
dbd2	Deadband in voltage error when voltage dip logic is activated (for undervoltage)	0 – 0.1	pu
Kqv	Gain for reactive current injection during voltage dip (and overvoltage) conditions	0 – 10	pu/pu
Iqh1	Maximum limit of reactive current injection (*Iqinj*)	1 – 1.1	pu
Iql1	Minimum limit of reactive current injection (*Iqinj*)	-1.1 – 1	pu
$Vref_o$	The reference voltage from which the voltage error is calculated. ***This is set by the user. If the user does not specify a value it is initialized by the model to equal to the initial terminal voltage.***	0.95 – 1.05	pu
Iqfrz	Value at which *Iqinj* is held for *Thld* seconds following a voltage dip if *Thld* > 0	-0.1 – 0.1	pu
Thld	Time delay for which the state of the reactive current injection is held after *voltage_dip* returns to zero: 1. If *Thld* > 0, then once *voltage_dip* goes back to 0 *Iqinj* is held at *Iqfrz* for *Thld* seconds. 2. If *Thld* < 0, then once *voltage_dip* goes back to 0 *Iqinj* remains in its current injection state (i.e. *Iqinj = (Vrefo – Vt) x Kqv)* for *Thld* seconds. 3. If *Thld* = 0 then *Iqinj* goes back to zero immediately after the *voltage_dip* is turned off.	-1 – 1	s
Thld2	Time delay for which the active current limit (Ipmax) is held after *voltage_dip* returns to zero for Thld2 seconds at its value during the voltage dip.	0	s
pfaref	Power factor angle. ***This parameter is initialized by the model based on the initial powerflow solution (i.e. initial P and Q of the model).***	N/A	rad
Tp	Filter time constant for electrical power measurement	0.01 – 0.1	s
Qmax	Reactive power limit maximum	0.4 – 1.0	pu
Qmin	Reactive power limit minimum	-1.0 – -0.4	pu
Vmax	Voltage control maximum	1.05 – 1.1	pu
Vmin	Voltage control minimum	0.9 – 0.95	pu
Kqp	Proportional gain	N/A	pu
Kqi	Integral gain	N/A	pu
Kvp	Proportional gain	N/A	pu
Kvi	Integral gain	N/A	pu
$Vref_1$	User-define reference/bias on the inner-loop voltage control (default value is zero)	N/A	pu
Tiq	Time constant on lag delay	0.01 – 0.02	s
dPmax	Ramp rate on power reference	N/A	pu/s
dPmin	Ramp rate on power reference	N/A	pu/s
Pmax	Maximum power reference	1	pu

Parameter	Description	Typical Range of Values	Units
Pmin	Minimum power reference	0	pu
Imax	Maximum allowable total converter current limit	1.1 – 1.3	pu
PfFlag	Power factor flag (1 – power factor control, 0 – Q control, which can be commanded by an external signal)	N/A	N/A
VFlag	Voltage control flag (1 – Q control, 0 – voltage control)	N/A	N/A
QFlag	Reactive power control flag (1 – voltage/Q control, 0 – constant pf or Q control)	N/A	N/A
Pqflag	P/Q priority selection on current limit flag	N/A	N/A
VDL1			
vq1	 User-define pairs of points	N/A	pu
Iq1		N/A	pu
vq2		N/A	pu
Iq2		N/A	pu
vq3		N/A	pu
Iq3		N/A	pu
vq4		N/A	pu
Iq4		N/A	pu
VDL2			
vp1	 User-define pairs of points	N/A	pu
Ip1		N/A	pu
vp2		N/A	pu
Ip2		N/A	pu
vp3		N/A	pu
Ip3		N/A	pu
vp4		N/A	pu
Ip4		N/A	pu

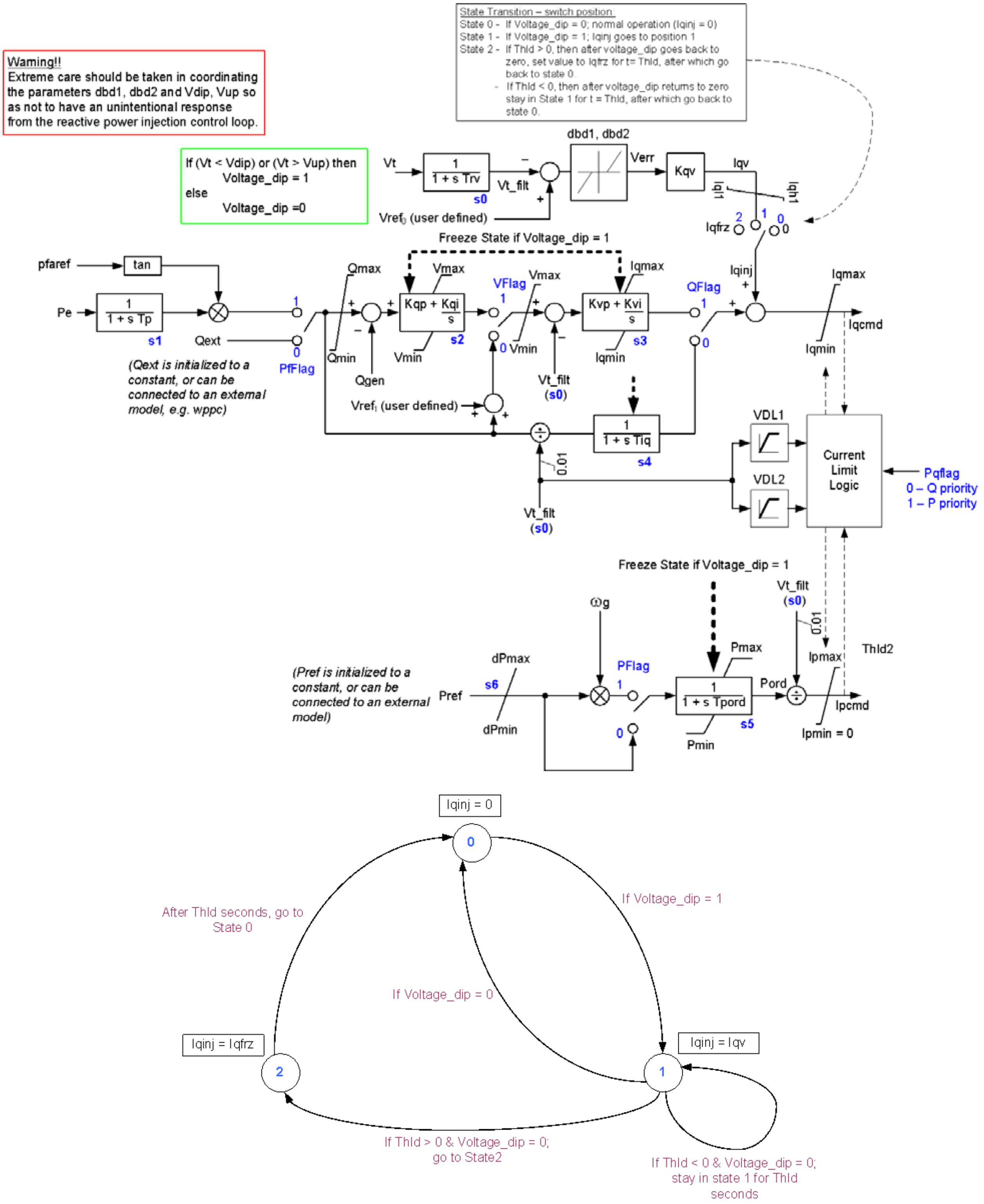


Figure 3-2: Renewable energy electrical control model (reec_a)[2].

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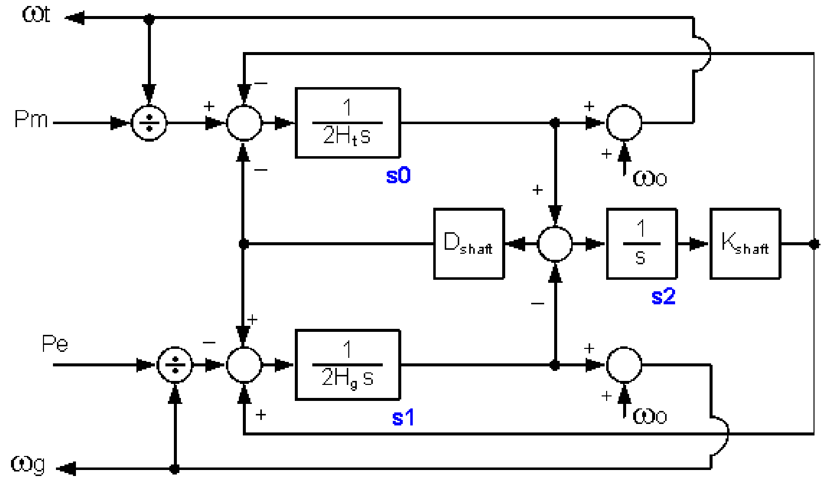
[2] The non-windup integrators for s3 and s2 are linked as follows: if s3 hits its maximum limit and ds3 is positive, then ds3 is set to 0; if ds2 is also positive, then it is also set to 0 to prevent windup, but, if ds2 is negative, then ds2 is

3.4 WTGT_A

The *wtgt_a* model is shown in Figure 3-3. The table below is a list of all the parameters of the model. The user should realize that this model is a simplified model for the purpose of emulating the behavior of torsional mode oscillations. The shaft damping coefficient (*Dshaft*) in the drive-train model is fitted to capture the net damping of the torsional mode seen in the post fault electrical power response. In the actual equipment, the drive train oscillations are damped through filtered signals and active damping controllers, which obviously are significantly different from the simple generic two mass drive train model used here. Therefore, the parameters (and variables) of this simple drive-train model cannot necessarily be compared with actual physical quantities directly. See reference [2] for a discussion of the active damping controllers, as they pertain for example to the type 3 WTG.

Parameter	Description	Typical Range of Values	Units
MBASE	Model MVA base	N/A	MVA
Ht	Turbine inertia	N/A	MWs/MVA
Hg	Generator inertia	N/A	MWs/MVA
Dshaft	Damping coefficient	N/A	pu
Kshaft	Spring constant	N/A	pu



(does NOT necessarily represent physical speed; internal model variable)

Figure 3-3: Wind turbine generator drive-train model (wtgt_a).

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not set to 0. A similar rule is applied for s3 hitting the lower limit, but the check is whether ds3 and ds2 are negative.

Also, note that for the freezing of the states s2, s3, s4 and s5, only the states are frozen, thus in the case of s1 and s2 the proportional gain, if non-zero, still acts during the voltage dip.

Finally, for s5, if Tpord is zero then the time constant and freezing of the state are by-passed, however, the Pmax/Pmin limits are still in effect.

3.5 WTGAR_A

The table below is a list of all the parameters of the *wtgar_a* model shown in Figure 3-4. The user must define the initial pitch angle based on the current conditions being simulated.

Parameter	Description	Typical Range of Values	Units
Ka	Aero-dynamic gain factor	0.007	pu/degrees
θ_o	Initial pitch angle	0	degrees

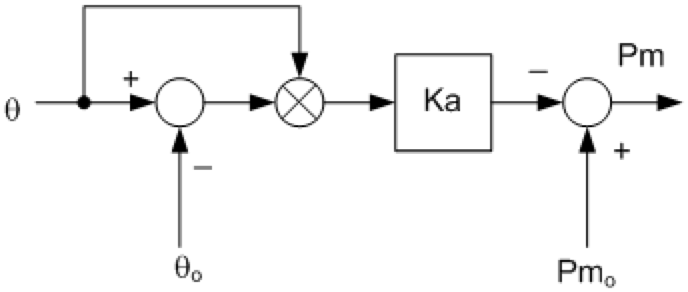

Figure 3-4: Wind turbine generator aero-dynamic model (wtgar_a).

3.6 WTGPT_A

The table below is a list of all the parameters of the *wtgpt_a* model shown in Figure 3-5.

Parameter	Description	Typical Range of Values	Units
Kiw	Pitch-control integral gain	N/A	pu/pu
Kpw	Pitch-control proportional gain	N/A	pu/pu
Kic	Pitch-compensation integral gain	N/A	pu/pu
Kpc	Pitch-compensation proportional gain	N/A	pu/pu
Kcc	Proportional gain	N/A	pu/pu
Tθ	Pitch time constant	0.3	s
θmax	Maximum pitch angle	27 – 30	degrees
θmin	Minimum pitch angle	0	degrees
dθmax	Maximum pitch angle rate	5 to 10	degrees/s
dθmin	Minimum pitch angle rate	-10 to -5	degrees/s

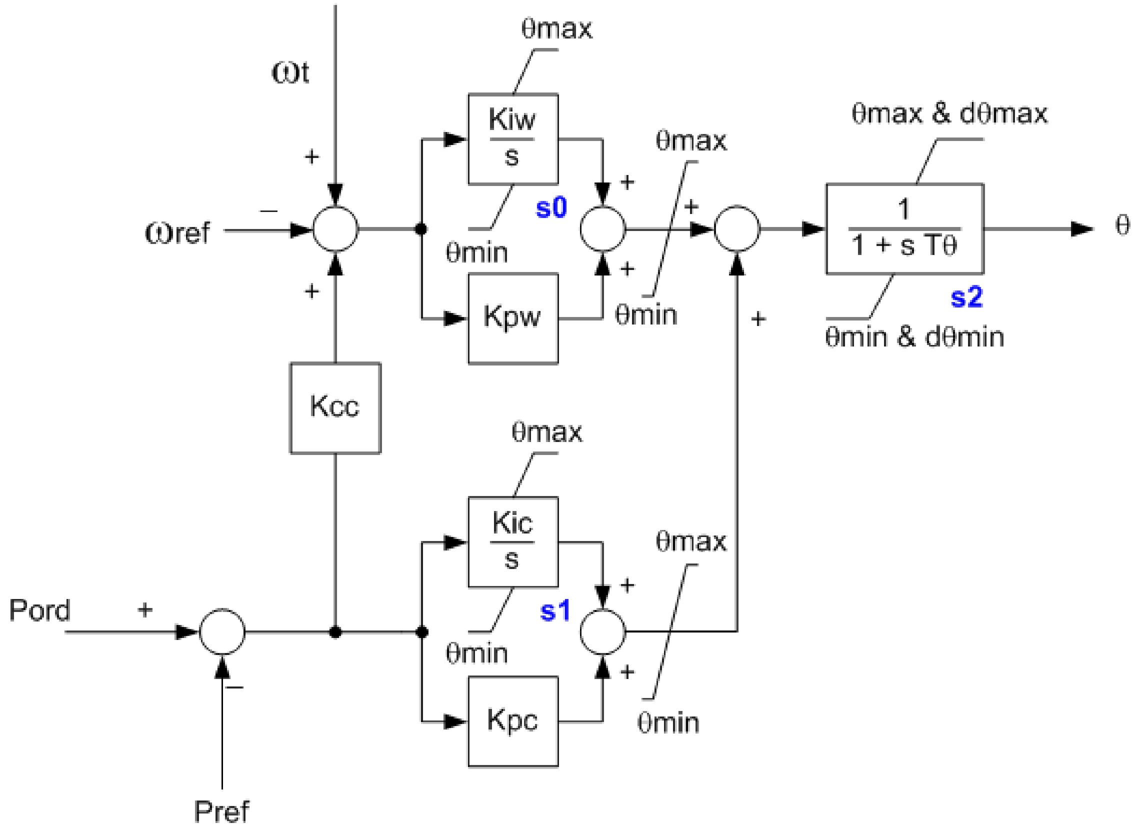

Figure 3-5: Wind turbine generator pitch-controller model (wtgpt_a).

3.7 WTGTRQ_A

The table below is a list of all the parameters of the *wtgtrq_a* model (Figure 3-6).

Parameter	Description	Typical Range of Values	Units
Kip	Integral gain	N/A	pu/pu
Kpp	Proportional gain	N/A	pu/pu
Tp	Power measurement lag time constant	0.05 to 0.1	s
Tωref	Speed reference time constant	30 to 60	s
Temax	Maximum torque	1.1 to 1.2	pu
Temin	Minimum torque	0	pu
Tflag	1 - for power error, and 0 – for speed error	0	N/A
p1	User-define pairs of points, function f(Pe)	0.2	pu
spd1		0.58	pu
p2		0.4	pu
spd2		0.72	pu
p3		0.6	pu
spd3		0.86	pu

Parameter	**Description**	**Typical Range of Values**	**Units**
p4		0.8	pu
spd4		1.0	pu

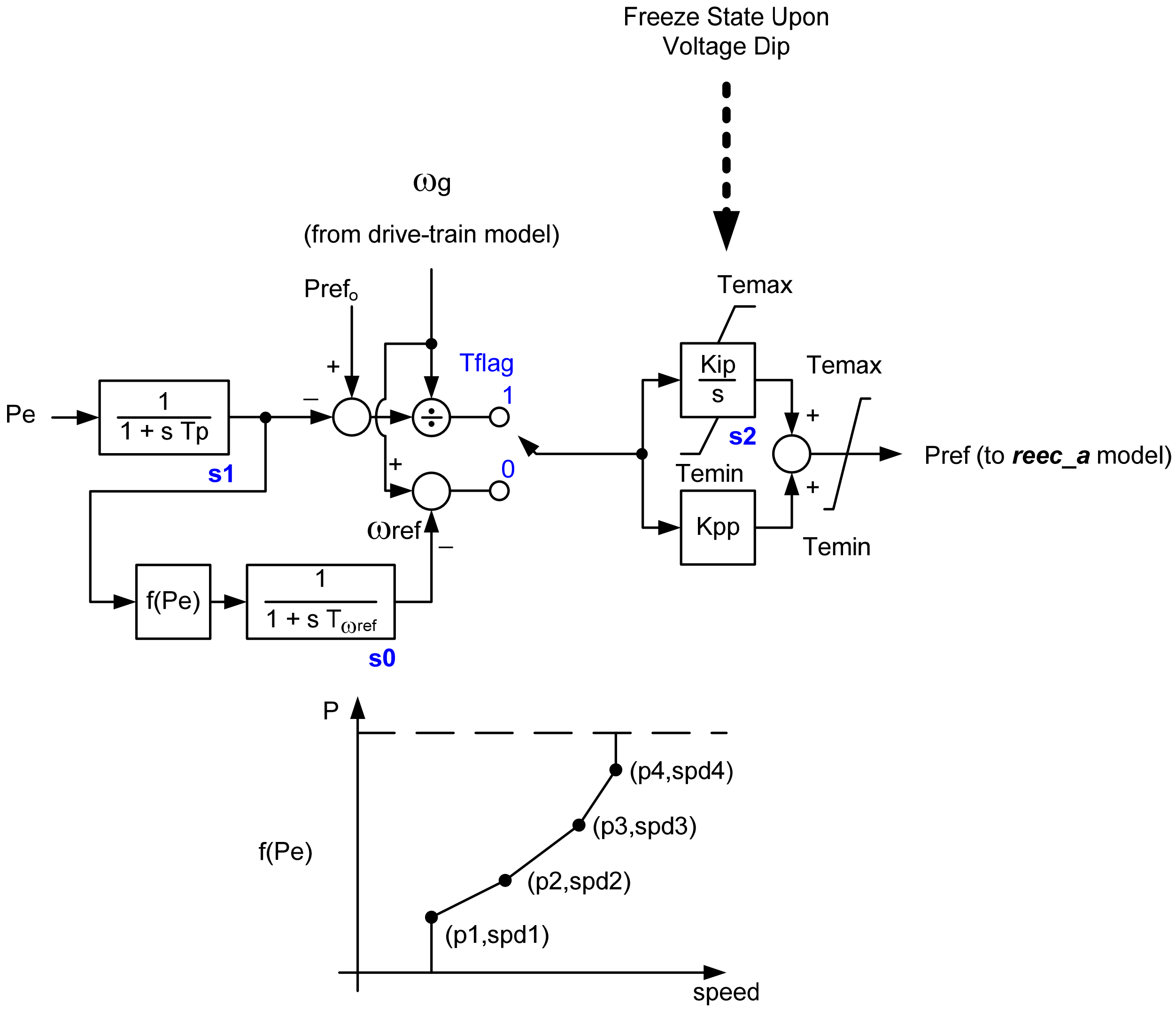

Figure 3-6: Wind turbine generation torque model (wtgtrq_a).

3.8 REPC_A

The table below is a list of all the parameters of the *repc_a* model shown in Figure 3-7.

Parameter	Description	Typical Range of Values	Units
MBASE	Model MVA base	N/A	MVA
Tfltr	Voltage or reactive power measurement filter time constant	0.01 – 0.05	s
Kp	Proportional gain	N/A	pu/pu
Ki	Integral gain	N/A	pu/pu
Tft	Lead time constant	N/A	s
Tfv	Lag time constant	N/A	s
RefFlag	1 – for voltage control or 0 – for reactive power control	N/A	N/A
Vfrz	Voltage below which plant control integrator state (s2) is frozen	0 – 0.7	pu
Rc	Line drop compensation resistance	0	Pu
Xc	Current compensation constant (to emulate droop or line drop compensation)	-0.05 – 0.05	pu
Kc	Gain on reactive current compensation	N/A	pu
VcompFlag	Selection of droop (0) or line drop compensation (1)	N/A	N/A
emax	Maximum error limit		pu
emax	Minimum error limit		pu
dbd	Deadband in control	0	pu
Qmax	Maximum Q control output		pu
Qmin	Minimum Q control output		pu
Kpg	Proportional gain for power control		pu/pu
Kig	Integral gain for power control		pu/pu
Tp	Lag time constant on Pgen measurement		s
fdbd1	Deadband downside		pu
fdbd2	Deadband upside		pu
femax	Maximum error limit		pu
femin	Minimum error limit		pu
Pmax	Maximum Power		pu
Pmin	Minimum Power		pu
Tlag	Lag time constant on Pref feedback		s
Ddn	Downside droop	20	pu/pu
Dup	Upside droop	0	pu/pu
Pgen_ref	Initial power reference	From powerflow	pu
Freq_ref	Frequency reference	1.0	pu

Parameter	Description	Typical Range of Values	Units
vbus	The bus number in powerflow from which Vreg, Freq is picked up (i.e. the voltage being regulated and frequency being controlled; it can be the terminal of the aggregated WTG model or the point of interconnection)	N/A	N/A
branch	The branch (actual definition depends on software program) from which I_{branch}, Q_{branch} and P_{branch} is being measured.	N/A	N/A
Freq_flag	Flag to turn on (1) or off (0) the active power control loop within the plant controller	0	N/A

Note: Vref and Qref are initialized by the model based on Vreg and Qgen in the initial powerflow solution, and Qext is initialized based on the initialization of the initial Q reference from the down-stream aggregated WTG model.

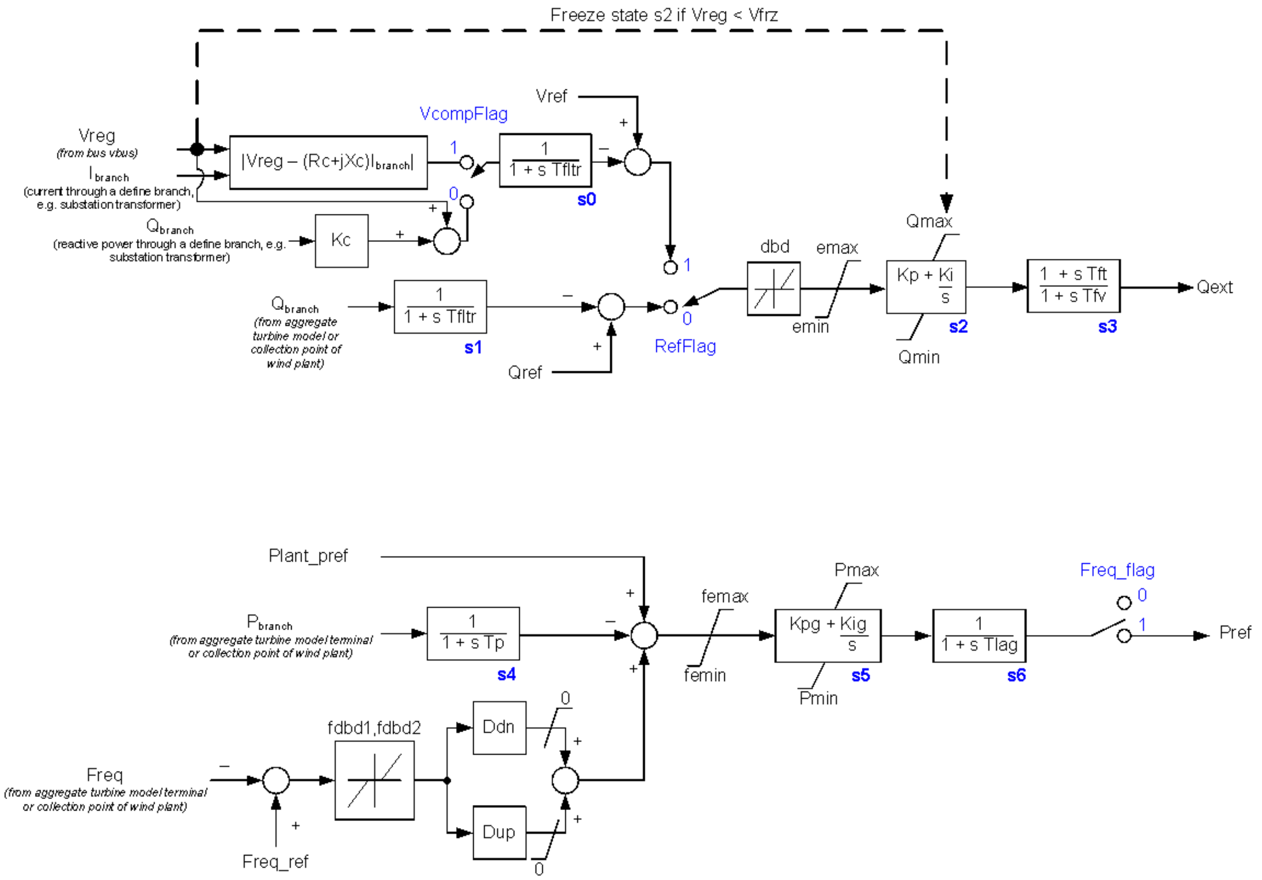

Figure 3-7: Renewable energy plant control model (repc_a).

3.9 Creating Type 3 and 4 WTG Models

The above set of building block models can be put together to create a type 3 or 4 WTG. As shown in [3], there are actually two classes of type 4 WTG. The first class, which is called type 4 WTG A, is designed such that for nearby grid faults there are some visible torsional oscillations that appear in electrical power output of the unit. The second class, is called type 4

WTG B, is designed such that for nearby grid faults there are no noticeable torsional oscillations that appear in electrical power output of the unit. Thus, for the type 4 WTG A the drive-train model is needed, and for type 4 WTG B it is not needed. Table 3-1 shows the make-up for a type 4 WTG A, type 4 WTG B and a type 3 WTG model. Figure 3-8, Figure 3-9 and Figure 3-10 show how these blocks come together to form the type 3, type 4 A and type 4 B WTG models.

Table 3-1: Building the type 3 and 4 WTG form the building block models.

Device	regc_a	reec_a	wtgt_a	wtgar_a	wtgpt_a	wtgtrq_a	repc_a
Type 4 WTG A	X	X	X				X
Type 4 WTG B	X	X					X
Type 3 WTG	X	X	X	X	X	X	X

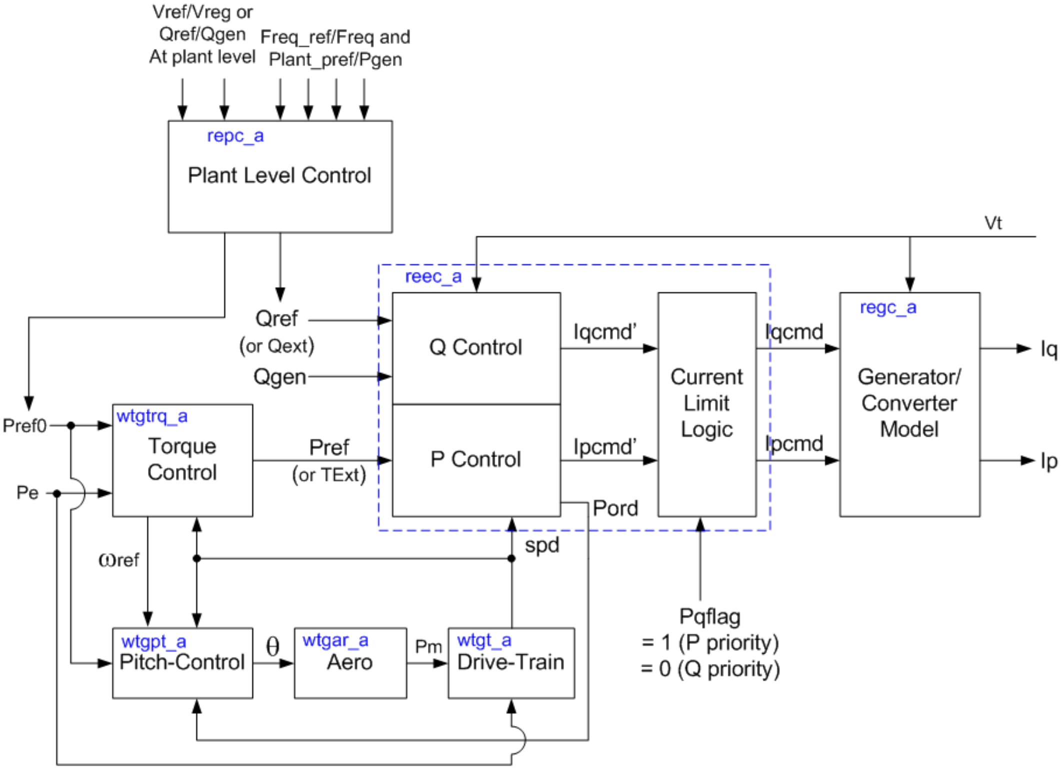

Figure 3-8: A type 3 WTG model.

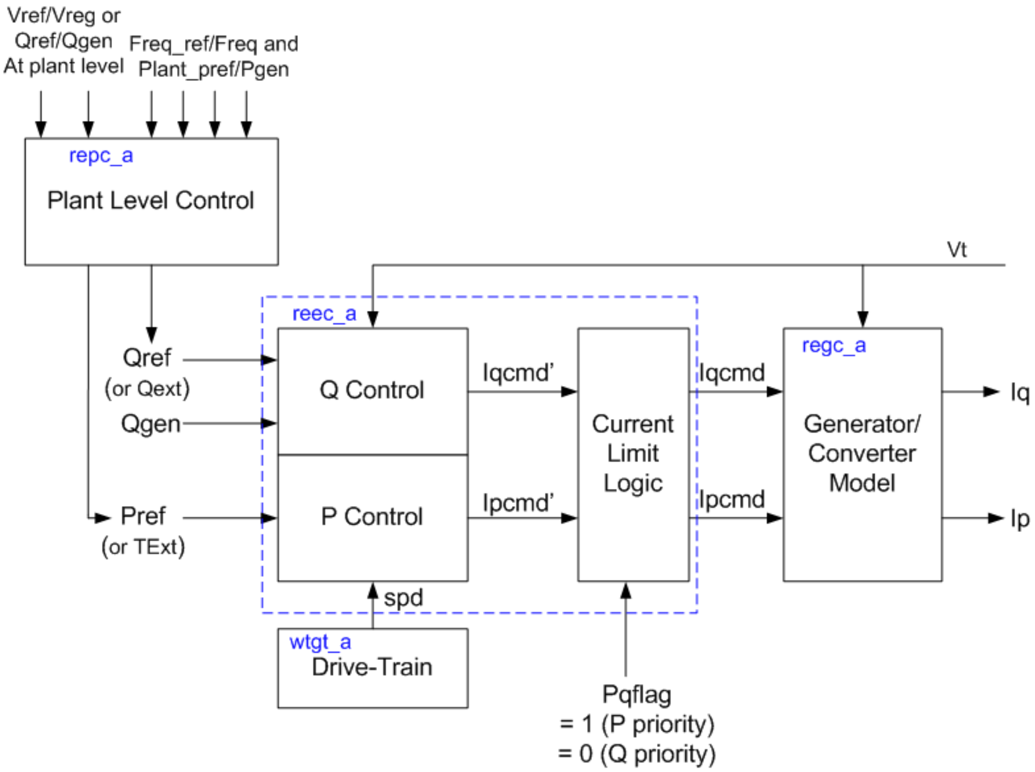

Figure 3-9: A type 4 A WTG model.

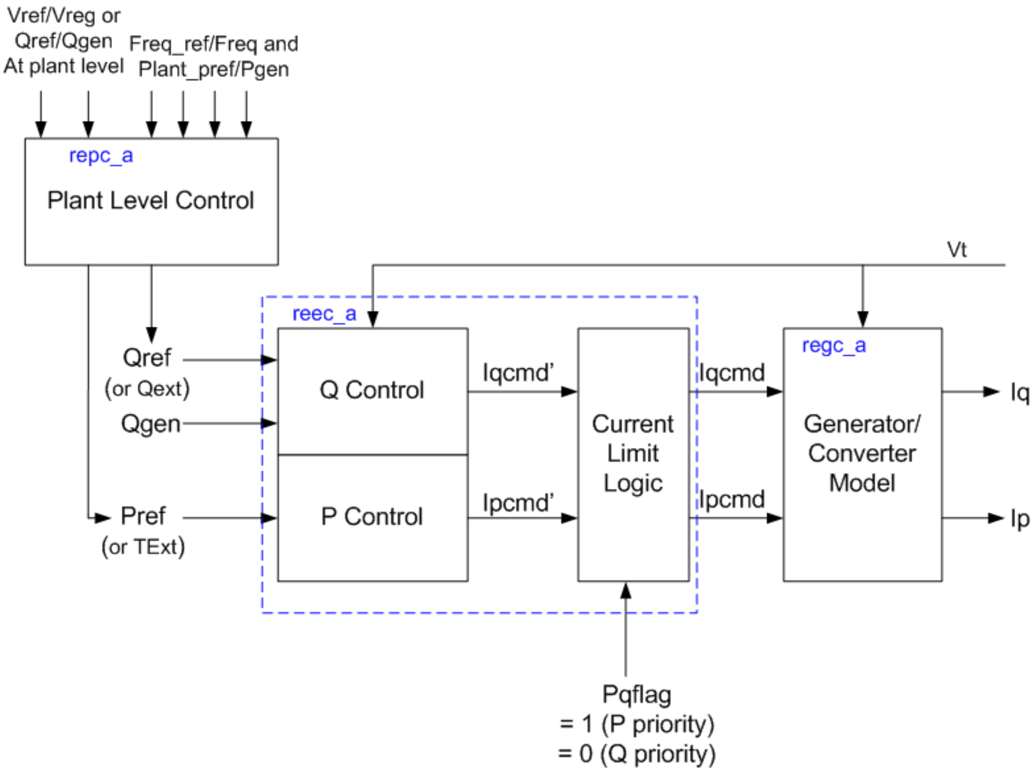

Figure 3-10: A type 4 B WTG model.

Table 3-2 and Table 3-3 provide a simply summary of the various control strategies that can be emulated by these models – namely, the combination of the *reec_a* and *repc_a* model features.

Table 3-2: Reactive power control options

Functionality	Models Needed	PfFlag	Vflag	Qflag	RefFlag
Constant pf control	reec_a	1	N/A	0	N/A
Constant Q control	reec_a	0	N/A	0	N/A
Local V control only	reec_a	0	0	1	N/A
Local coordinated Q/V control only	reec_a	0	1	1	N/A
Plant level Q control	reec_a + repc_a	0	N/A	0	0
Plant level Vcontrol	reec_a + repc_a	0	N/A	0	1
Plant level V Control + coordinated local Q/V control	reec_a + repc_a	0	1	1	1
Plant level Q Control + coordinated local Q/V control	reec_a + repc_a	0	1	1	0

Table 3-3: Real power control options

Functionality	Models Needed	PFlag
Do not Emulate torsioanl oscillation	reec_a	0
Emulated torsional oscillations in power output	reec_a + wtgt_a	1

The protection models associated with the wind turbine generator (i.e. low/high voltage and low/high frequency tripping) has not been addressed in this document since the existing generic protection models (*lhvrt* and *lhfrt*) that exist in GE PSLF^{TM} (and similar models in Siemens PTI PSS®E) are adequate for application with this generic model.

Important Note: ***The actual implementation of these models in software may require subtle adjustment to accommodate the way the models need to be initialized in commercial tools.***

4

EXAMPLE SIMULATION CASES

The previous documents [2] and [3] provide many examples of simulations performed by EPRI using the EPRI WTGMV tool [9] using data for single wind turbine generators. The data used in those cases were provide to EPRI under non-disclosure agreements (NDA) with the various turbine manufacturers for the purpose of research and investigation of the suitability of the various model structures being developed and proposed. These vendors graciously agreed to allow the public dissemination of the research results, as presented here and in the other references. The actual data, however, is covered under the NDA and cannot be disclosed. Those examples show that the models presented here, for modeling a single WTG, appear to be reasonable and adequate. Another vendor has performed their own internal work and reported at WECC REMTF meetings that in general they found reasonable response from these new generic models for emulating their equipment. These results can be found in the previous references and are not presented again here.

More importantly, recently as the commercial vendors have started to implement these models into the commercial software tools (i.e. PowerWorld, GE PSLF^{TM}, Siemens PIT PSS®E, PowerTech Labs TSAT, etc.) some extensive testing has been done to both:

1) Test the models from an implementation perspective in the commercial tools (i.e. identifying bugs and fixing them), and
2) Tests the commercial models against the benchmark simulation cases in [2] and [3].

This work was reported at the June 2013 WECC REMTF meeting [10]. Below are a few example simulations from that work that illustrates that the commercial models are also able to reasonably capture the actual turbine behavior – for a single WTG.

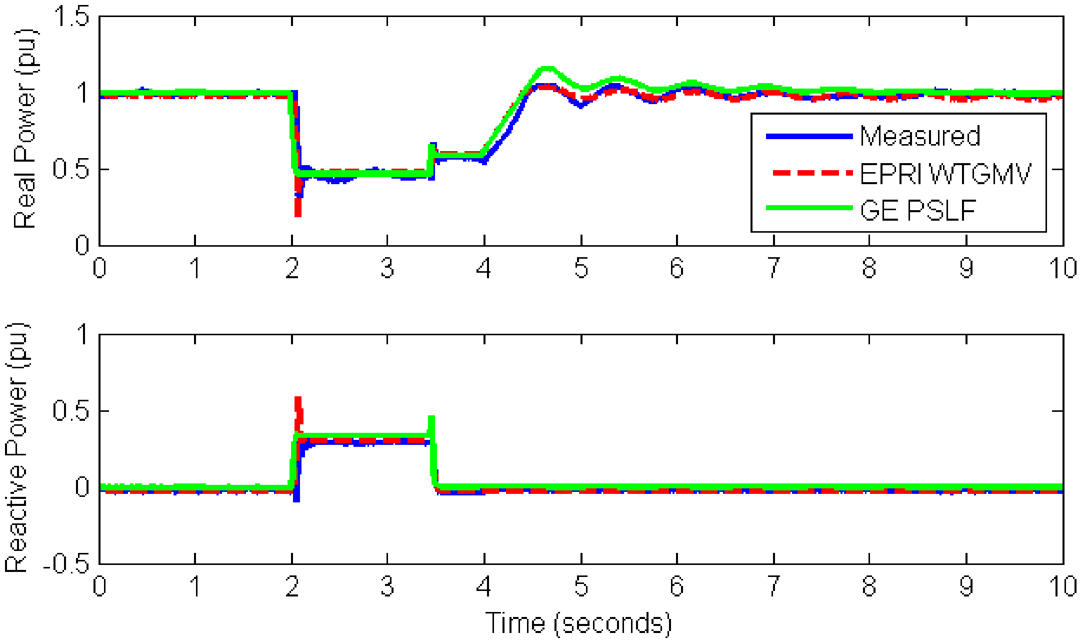

Figure 4-1: Validation result of simulation versus measured real and reactive power for a type 3 WTG. The comparison shown is between EPRI implementation, the commercial tool and the actual field measured response.

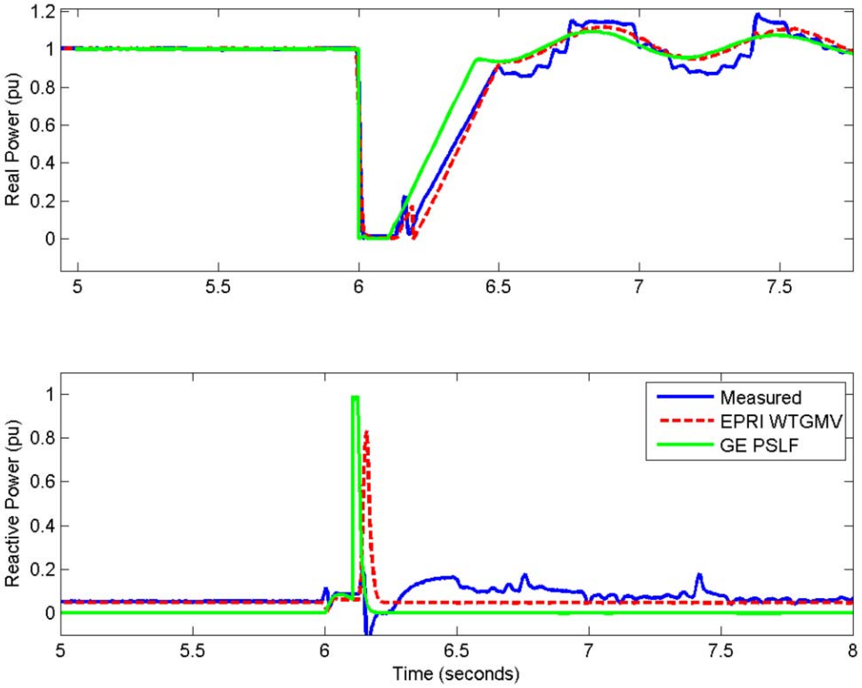

Figure 4-2: Validation result of simulation versus measured real and reactive power for a type 4 WTG A. The comparison shown is between EPRI implementation, the commercial tool and the actual field measured response.

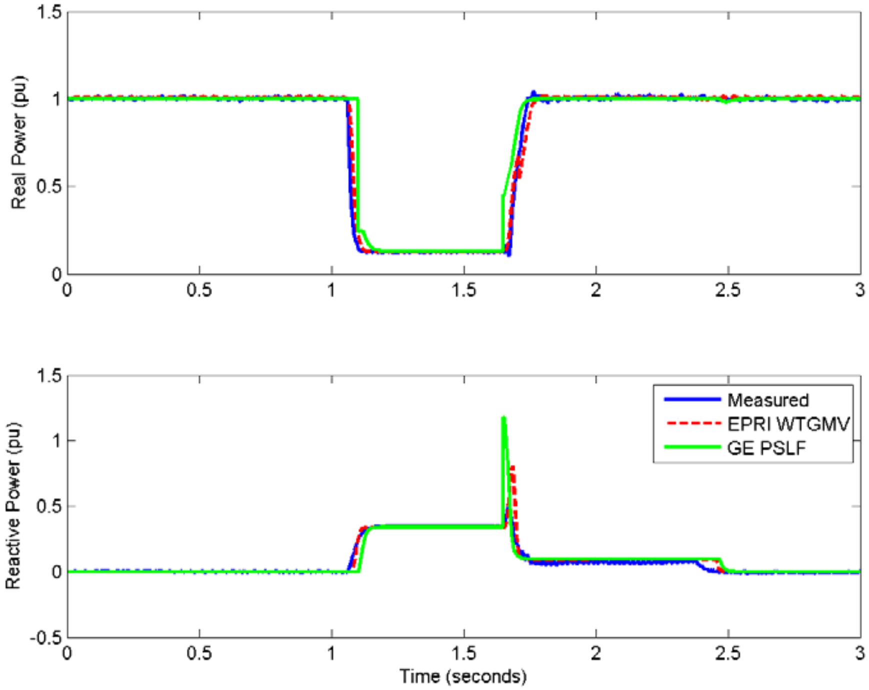

Figure 4-3: Validation result of simulation versus measured real and reactive power for a type 4 WTG B. The comparison shown is between EPRI implementation, the commercial tool and the actual field measured response.

5

CONCLUSION AND SUMMARY

At this point, with the gracious input of the various equipment vendors, this specification for the 2nd generation generic models has been established. Much dialogue has occurred in the process of coming to a collective agreement on the final specification. It is certain that further refinements are likely to be identified through further discussions, particularly for the plant level controller. However, it is believed that what is presented here makes enough of a significant improvement to warrant implementing it as soon as possible in order to reap the benefits of being able to model a variety of WTGs.

Finally, it should be kept in mind that the model under discussion here is a “generic” model for interconnected power system stability simulations and so one must keep the models simple, while catering to as wide a possible range of equipment. It would be an insurmountable task to try to achieve a model that would cater to every possible equipment configuration. Therefore, when doing detailed plant specific studies, vendor specific models (obtained directly from the equipment vendors) will still always be the best option. The “generic” models are for bulk system studies performed by TSOs, TOs, reliability entities, etc.

6

REFERENCES

[1] NERC IVGTF 1-1, Standard Models for Variable Generation, May 18, 2010, http://www.nerc.com/docs/pc/ivgtf/IVGTF_Report_PhaseII_Task1-1_Final(5.24).pdf

[2] P. Pourbeik, "Proposed Changes to the WECC WT3 Generic Model for Type 3 Wind Turbine Generators", Prepared under Subcontract No. NFT-1-11342-01 with NREL, Issued: 03/26/12 (revised 6/11/12, 7/3/12, 8/16/12, 8/17/12, 8/29/12, 1/15/13, 1/23/13, 9/27/13)

[3] P. Pourbeik, "Proposed Changes to the WECC WT4 Generic Model for Type 4 Wind Turbine Generators", Prepared under Subcontract No. NFT-1-11342-01 with NREL, Issued: 12/16/11 (revised 3/21/12, 4/13/12, 6/19/12, 7/3/12, 8/16/12, 8/17/12, 8/29/12, 1/15/13, 1/23/13)

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[5] Generic Models and Model Validation for Wind and Solar PV Generation: Technical Update. EPRI, Palo Alto, CA: 2011, 1021763. (Available for free download at www.epri.com)

[6] CIGRE Technical Brochure 328, *Modeling and Dynamic Behavior of Wind Generation as it Relates to Power system Control and Dynamic Performance*, August 2007, CIGRE WG C4.601. (www.e-cigre.org)

[7] *Pseudo Governor Model for Type 1 and 2 Generic Turbines*, October 2012; prepared by Enernex (B. Zavadil); Work supported by Sandia National Laboratories and the US Department of Energy under Sandia Contract #1257843

[8] W. W. Price and J. J. Sanchez-Gasca, "Simplified Wind Turbine Generator Aerodynamic Models for Transient Stability Studies", *Proceedings of the IEEE PSCE 2006.*

[9] *Wind Turbine Generator Model Validation (WTGMV) Software*; EPRI Product ID 1024346; http://my.epri.com/portal/server.pt?Abstract_id=000000000001024346

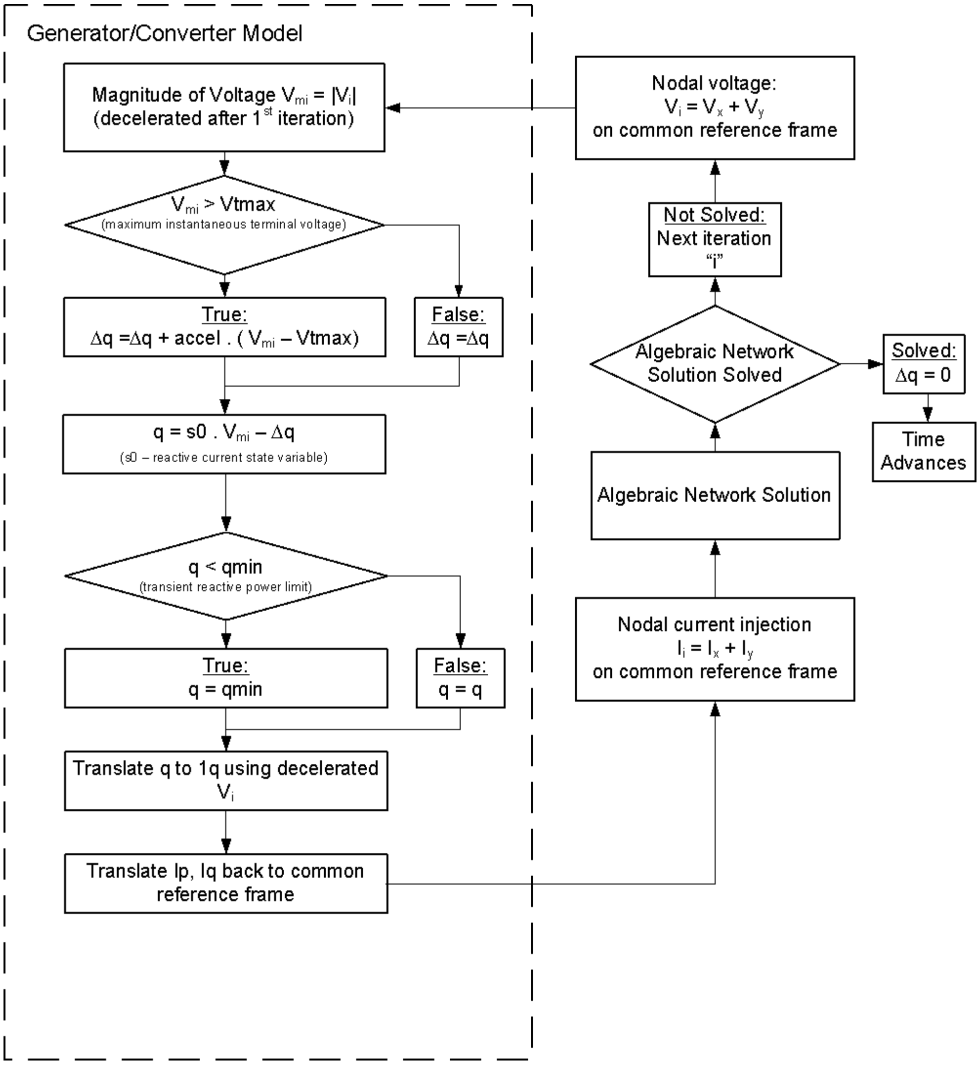
[10] P. Pourbeik, "Update of Model Testing in GE PSLF for Latest Generic Wind and PV Models", presentation at June 18, 2013 WECC REMTF meeting.

A

CONVERTER MODEL GRID INTERFACE

In the generator/converter model block diagram there are two blocks labeled, “high-voltage reactive current management” and “low-voltage active current management”. These blocks represent logic associated with the dynamic model and the ac network solution. The actual implementation of this logic may be software dependant. In the past a simple block diagram was provide in an effort to attempt to explain the logic, this however seemed to have caused more confusion. Here we provide a flow chart, provided by GE[3], for greater clarification.

High-Voltage Reactive Current Management:



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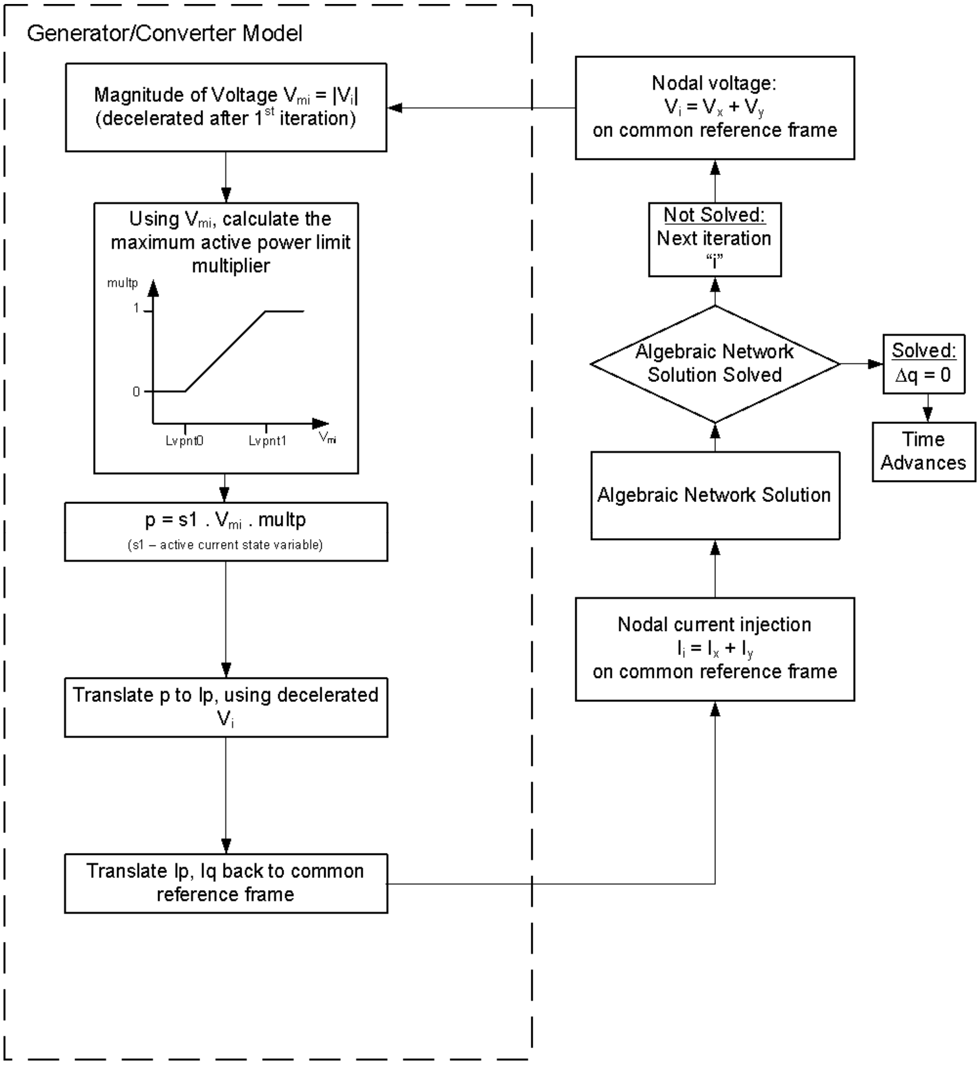
[3] N. Miller, “High and Low Voltage Algebraic Network solution flowcharts”, Version 2, November 16, 2012 (revised and provided in an email on 1/11/13).

Low-Voltage Active Current Management:



B

CURRENT LIMIT LOGIC

VDL1 is a piecewise linear curve define by four pairs of numbers:
{(vq1,Iq1), (vq2,Iq2), (vq2,Iq3), (vq4,Iq4),}

VDL2 is a piecewise linear curve define by four pairs of numbers:
{(vp1,Ip1), (vp2,Ip2), (vp2,Ip3), (vp4,Ip4),}

```
If (Pqflag = 0)            % Q – priority
    Iqmax = min {VDL1, Imax}
    Iqmin = -1×Iqmax
    Ipmax = min{ VDL2, $\sqrt{Imax^2 - Iqcmd^2}$ )
    Ipmin = 0
Else                       % P – priority
    Iqmax = min {VDL1, $\sqrt{Imax^2 - Ipcmd^2}$ }
    Iqmin = -1×Iqmax
    Ipmax = min{VDL2, Imax)
    Ipmin = 0
End
```