ELECTRIC POWER RESEARCH INSTITUTE

Model User Guide for Generic Renewable Energy System Models

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EPRI Project Manager

E. Farantatos

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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Power and Energy, Analysis, Consulting and Education, PLLC (PEACE)
2221 Justin Rd #119-414
Flower Mound, TX 75028

Principal Investigator
P. Pourbeik

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ABSTRACT

In the last several years, the Electric Power Research Institute (EPRI) has led the technical development, through a broad industry wide effort, of a new set of generic and public models for renewable energy systems. The work was done primarily within the Western Electricity Coordinating Council (WECC) Renewable Energy Modeling Task Force, and the models were adopted by several of the major commercial software vendors in North America and approved by WECC in 2013/2014. This brief report is a guide for the use of these models. References are provided to other publicly available documents that contain the detailed specification of the models. This second revision of the report replaces an earlier version. It is substantially the same with some updates and corrections, based on further development of the renewable energy systems models in the years since the 2015 version was published.

Keywords
Wind turbine generators
Photovoltaic generation
Energy storage
Dynamic models

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
INTRODUCTION

In recent years, at the culmination of extensive research and development, the Electric Power Research Institute (EPRI), working together with many stakeholders within the industry, helped to develop the second generation of generic stability models for wind generators and photovoltaic generation. These models were developed deliberately in a modular format to facilitate the ability to add to the library of these models, new features and functions without significant effort. For example, in the past couple of years a generic battery energy storage model, and a complex plant controller were developed as modules that were added to the library of models. Presently, work is continuing to develop further modules such as a voltage-source converter representation. Although EPRI has lead much of the technical development and testing of the models, the effort has been a broad industry effort with true collaboration among many stakeholders including several commercial power system simulation software vendors, equipment manufacturers, utilities, two national laboratories (NREL and Sandia) and many others. The collaborative community of stakeholders has worked under the Western Electricity Coordinating Council's (WECC) Renewable Energy Modeling Task Force (REMTF). Thus, at the culmination of the work, the models were WECC approved and have found their way into several of the major commercial software platforms, namely, Siemens PTI PSS®E, GE PSLF, PowerWorld Simulator and PowerTech Labs TSAT™.

The detailed model specifications may be found in [1], which is the WECC approved document and definitive model specification. References [2], [3], [4], [5] and [6] provide other details and the documentation of the gradual development of the models, as well as testing and validation results. We will not repeat any significant portion of these materials in this report, as all these documents are publicly available.

It should be noted that the International Electrotechnical Commission (IEC) Technical Committee (TC) 88, Working Group (WG) 27 is also working on developing specifications for an international standard on generic models for wind turbine generators. The development of the wind turbine generators model definitions has been completed[1], however, the work on the development of plant controller models is still in progress. EPRI has also been engaged in this work, particularly in the early stages of the work (2010 – 2013). The IEC models are for the most part very similar to the WECC approved models, but they do have some differences, particularly with respect to the type 3 wind turbine generators (see [4], [5] and [27]). It is outside the scope of this document to further discuss these issues. The WECC approved models have been deployed in many commercial software platforms, have been tested by multiple entities and validated against many cases of field data, and are already in use. The IEC models are still under development. Therefore, the WECC models are the subject of this document.

[1] IEC 61400-27-1 Ed.1: Wind turbines - Part 27-1: Electrical simulation models - Wind turbines 9/30/2016.

It should be noted that as of January 2018, at the WECC Modeling Validation Working Group (MVWG) an earnest dialogue has started to look at further revisions and additions to these second-generation generic models, and as such some of the details in the IEC models may yet be introduced into the models developed here in North America.

For those who may be unfamiliar with the four-main wind turbine generator technologies, they are shown pictorially in Figure 1-1. Today, to our knowledge, all the newly developed wind power plants, both in North America and overseas, are of the type 3 and 4 wind turbine generators (WTG). However, many type 1 and 2 WTG plants do still exist and so they too need to be modeled.

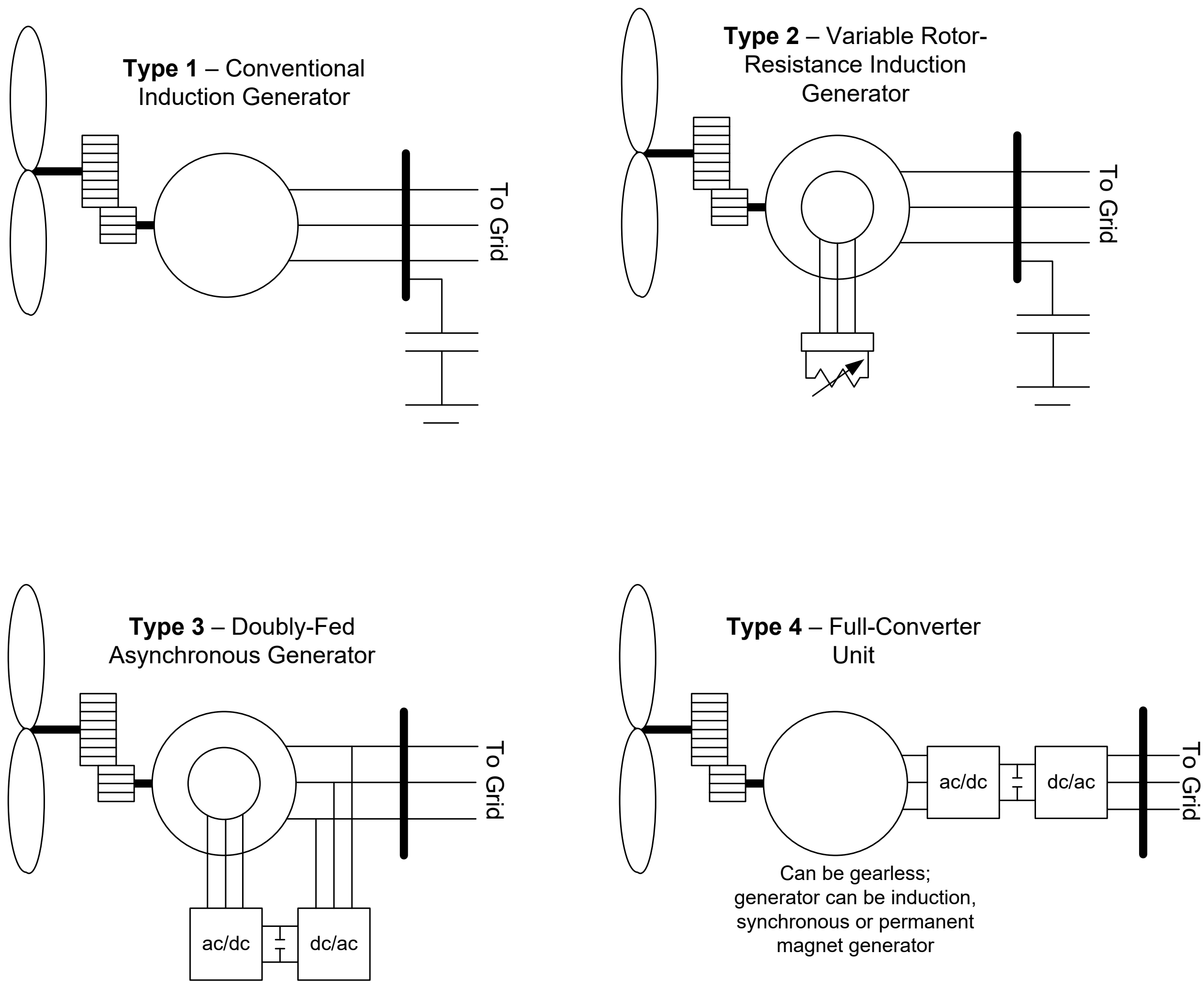


Figure 1-1
The four many wind turbine technologies

These so-called second generation generic models were developed with two goals in mind:

1. They were developed in a modular format to allow for easy implementation of new modules to build on the existing components to allow for the ever growing and changing technology, and

2. They were made significantly more flexible than the so-called first generation generic models to allow for emulation of a wider range of control philosophies and thus the ability to be parameterized for representing a wide range of equipment.

In June 2014, these models were officially released. Since that time several additions have also been made that will be discussed in this revised report. Several industry workshops, at WECC, NERC and other forums have also been held since that time to discuss the models. The goal of this document is to provide a user guide to allow for greater understanding of these models and more easy adoption.

The document is organized as follows:

Section 2 – gives an overview of the model library and how the various pieces can be put together to form the various types of renewable energy systems (RES).

Section 3 – describes in more detail the various options for control strategies associated with type 3 and 4 WTGs, PV plants and energy storage.

Section 4 – gives a brief statement, with references to other public reports, about the validations done with these models.

Section 5 – provides a very brief conclusion to the report.

Section 6 – is a list of the various references.

Appendices – provide various supporting information. Appendix E provides a detailed one to one translation of the 1st generation WTG models to the 2nd generation WTG models. It is hoped that this section might facilitate the great adoption of these models and the slow phasing out of the 1st generation models. The tables presented in appendix E, for converting from the older 1st generation models to the newer 2nd generation models, may in due course be adopted by the commercial software vendors to be made a part of an automated conversion process within their tools. Appendix F provides tables with indicative range of values for each parameter used in the 2nd generation renewable energy models.

2
THE SECOND GENERATION GENERIC RENEWABLE ENERGY MODELS

2.1 The Model Library

The second generation of generic renewable energy systems models consists, currently, of a library of ten models:

REGC_A
REEC_A
REEC_B
REEC_C
REPC_A
REPC_B
WTGT_A
WTGAR_A
WTGPT_A
WTGTRQ_A
WT1P_B[2]

The majority of these were developed between 2010 to 2013 [1], and since mid-2014 have been adopted by several commercial software vendors, including Siemens PTI PSS®E, GE PSLF, PowerWorld Simulator and PowerTech Labs TSAT™. The complex plant controller model (REPC_B) was developed latter, and the model specification can be found in reference [8].

In addition to the above models the following models, that have existed since the first-generation models were developed years ago, are still valid and useful:

WT1G
WT2G
WT2E
LHVRT
LHFRT

Collectively, these models may be used to model:

Type 1 WTG wind turbines or plants
Type 2 WTG wind turbines or plants
Type 3 WTG wind turbines or plants
Type 4 WTG wind turbines or plants
Photovoltaic (PV) plants
Battery Energy Storage Systems (BESS)

[2] This model has not been adopted yet by all the major software vendors, as of the writing of this report. It does, however, exist in a few of the major commercial tools.

In the following sections a description is given on how to develop these various WTG, PV and BESS devices and plants.

2.2 Naming of the Models in Various Software Platforms

Since the 2nd generation generic RES models were developed in a unified way within the broad collaborative effort hosted within the WECC REMTF, much effort was put forth by the REMTF to benchmark and verify the implementation of these models across the various major commercial software platforms in use in North America. Nonetheless, there are some slight differences in the naming convention of the models within the major software platforms, owing simply to the naming conventions uses by each software vendor. Appendix A provides a list of the model names across the four main commercial software tools used in North America.

2.3 Modeling Wind Turbine Generator (WTG) Plants

For bulk power system stability analysis, where the main concern is the dynamic behavior of the power plant at the point of common coupling (PCC), based on current industry practice, a simple model structure such as shown in Figure 2-1 may be used [10], [11]. A few additional comments are pertinent:

1. If the WTG plant is based on type 1 or 2 WTGs, then many of these technologies utilize switched shunt capacitor banks at the terminals of the WTGs. Thus, this will require an explicit model of the shunt capacitor banks at either the low-voltage (LV) or the medium-voltage (MV) bus at the turbine terminals. This must be explicitly modelled.
2. In many different plants there are switched or controller shunt compensation deployed at the MV bus at the substation. Again, these should be appropriately modeled.

If the shunt compensation devices are controlled, the dynamic behavior needs to be separately modeled and is not part of the generic models presented here. For example, SVCs and STATCOMs can be modeled using the generic models developed for Static Var Systems [9].

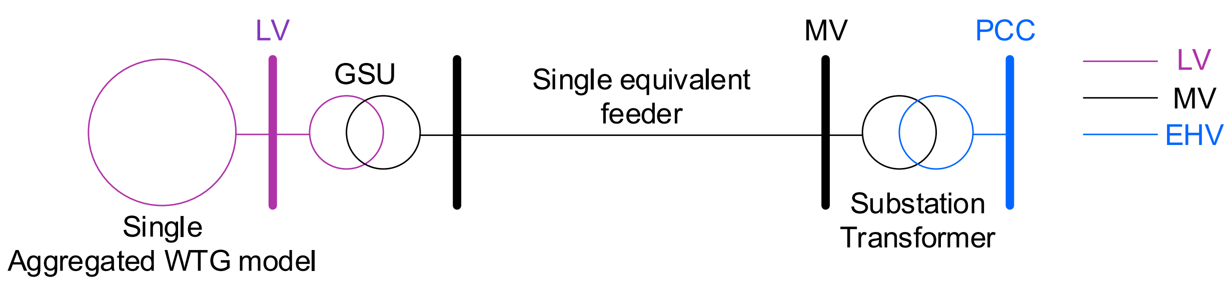


Figure 2-1
Simple aggregated model for a WTG power plant

Finally, it should be noted that more complex plants are possible and often more detailed models may be necessary, for example as shown in Figure 2-2. To model such complex plants the complex plant controller model may need to be used (REPC_B).

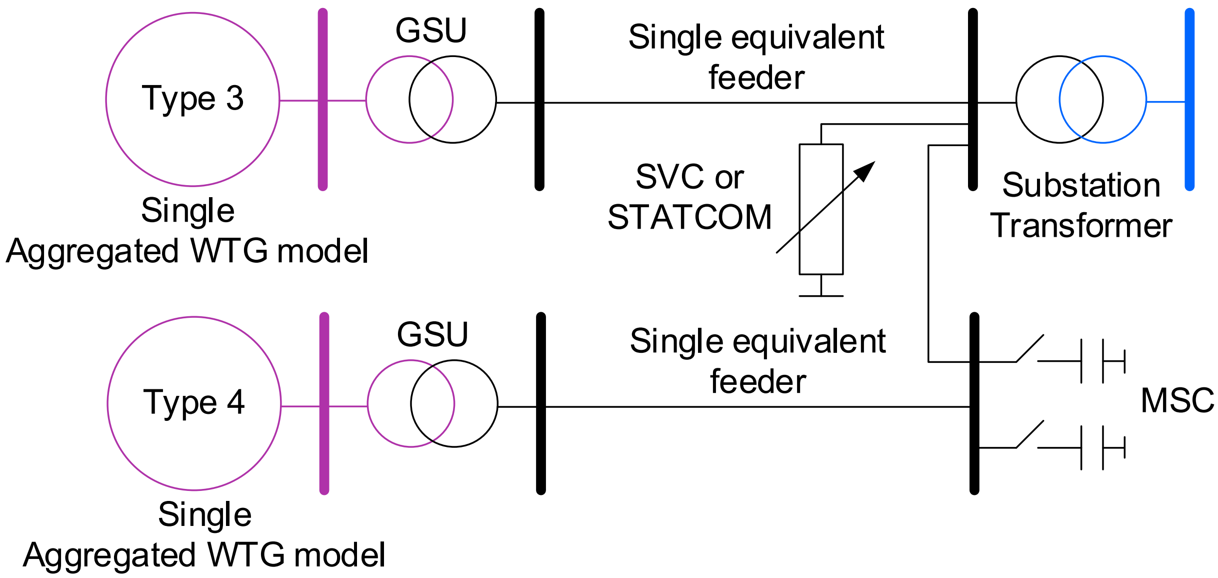


Figure 2-2
Complex plant aggregate model

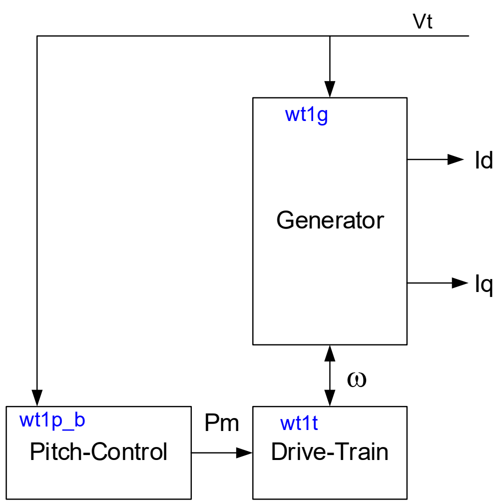
In all cases, unless otherwise stated, it is assumed that a wind or PV power plant is modeled as shown in Figure 2-1. The components are modeled in power flow as follows:

1. The substation transformer is modeled as usual using the transformer nameplate data. When modeling an existing wind/PV power plant, it is imperative to properly model the taps, and fixed-tap settings, as set in the field at the plant.
2. The equivalent single feeder model is calculated from the detailed collector system data using the National Renewable Energy Laboratory (NREL) methodology to reduce it to a single equivalent feeder model [12]. If the plant is a planned future plant with no present collector system data, a reasonable assumption might be $R = 0.011$ pu, $X = 0.027$ pu and $B = 0.069$ pu on 100 MVA base (this is an average value taken from the typical parameters [13]).
3. The generator step-up (GSU) transformer is based on the transformer name plate data, and the models MVA rating is simply scaled up by the number of turbines. For example, if a single GSU is 0.06 pu on 1.5 MVA and there are 100 turbines in the plant, then the GSU is modeled as $X = 0.06$ pu on 150 MVA.
4. The single aggregated WTG (or PV) is modeled with the appropriate parameters for the specific equipment and the models MVA rating is again scaled up by the number of turbines in service. For example, if a single WTG is rated at 1.65 MVA and there are 100 turbines in the plant, then the aggregated unit is modeled with the same parameters as the single WTG on 165 MVA.

2.4 Modeling Type 1 WTG

The simple aggregated WTG plant model is shown in Figure 2-1. For a type 1 WTG plant, the aggregated turbine model is represented as shown in Figure 2-3. As shown in the figure a type 1 WTG, which is a conventional induction generator, is developed using three models combined:

1. *wt1g* – this is the electrical model of the induction generator. This is the standard machine equations for a single (or double) cage induction machine and is available in most commercial software tools. The model parameters are the standard parameters of an induction machine, namely the electrical machine impedances (*Ls, Lp, Lpp, Ll*), time constants (*Tpo, Tppo*), armature resistance (*Ra*) and saturation parameters (*Se1, Se2*). The actual parameter names may vary between software platforms.
2. *wt1t* – the model of the turbine generator shaft, which may be modeled as either a single lumped mass or two masses representing the generator and turbine assembly. The parameters are the combined total shaft inertia (*H*), the fraction of the inertia that represents the turbine assembly (*Hfrac*), the frequency of the first torsional mode (*Freq1*) and the mechanical damping coefficients (*D, Dshaft*). For cases where one wishes to model a single equivalent mass, only H and D need to be specified.
3. *wt1p_b* – the emulation of the active pitch controller. See Appendix E.1 for a more detailed description of this module.



wt1g	Ls	Lp	Lpp	Ll	Ra	Tpo	Tppo	Se1	Se2					
wt1t	H	D	Htfrac	Freq1	Dshaft									
wt1p_b	Tr	To	rmax	rmin	Pmin	Pset	vt1	t1	vt2	t2	vt3	t3	vt4	t4

Figure 2-3
Type 1 WTG model

A few items should be noted:

- Typically, smaller and older type 1 WTGs (i.e. < 1 MW) where designed without active pitch control. These so-called "stall" design turbines have fixed blade pitch. In these cases, the only models needed are the *wt1g* and *wt1t*. Larger designs of type 1 WTGs employ active stall and will have associated pitch control, for which the *wt1p_b* model may be used. For an explanation of these control philosophies and their implications for system dynamic performance see, chapter 3 of [14].
- The first generation generic WTG models that were released many years ago had associated with them a pitch controller model called *wt1p*. This model was later identified as providing potentially erroneous response particularly for simulations resulting in system frequency events. Thus, it is recommended that this model should either be replaced with the *wt1p_b*

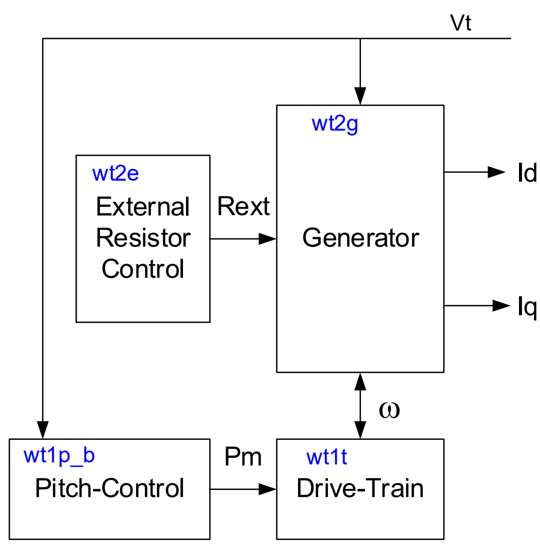
model or at least removed and not used. Another issue with the *wt1p* model is that it does not represent the fast ramp-down of mechanical power effected by the active-stall controls during nearby voltage dips. This is explained further in Appendix E.

- The model parameters, and an explanation of each of the parameters of the new active pitch controller model (*wt1p_b*) can be found in [1]. It has been shown that the *wt1p_b* model does reasonably emulate the behavior of actual type 1 and 2 WTG performance [6].

2.5 Modeling Type 2 WTG

The simple aggregated WTG plant model is shown in Figure 2-1. For a type 2 WTG plant, the aggregated turbine model is represented as shown in Figure 2-4. As shown in the figure, a type 2 WTG, which is a wound rotor winding induction generator with an externally controller rotor resistance, is developed using four models combined:

1. *wt2g* – this is the electrical model of an induction generator with a wound rotor winding that is externally accessible. The model parameters are electrical machine impedances (*Ls, Lp, Ll*), time constant (*Tpo*), armature resistance (*Ra*), saturation parameters (*Se1, Se2*) and the initial rotor speed. The actual parameter names may vary between software platforms.
2. *wt2t* – the model of the turbine generator shaft as for the type 1 WTG.
3. *wt2e* – this is the model of the controller external rotor resistance. This is part of the 1st generation models and was never changed. The user's manual of the respective commercial software tool should be consulted for the description of the parameters.
4. *wt1p_b* – the emulation of the active pitch controller, as with the type 1 WTG.



wt2g	Ls	Lp	Ll	Ra	Tpo	Se1	Se2	spdrot										
wt1t	H	D	Htfrac	Freq1	Dshaft													
wt2e	Tw	Kw	Tp	Kp	Kpp	Kip	Rmax	Rmin	Slip1	Slip2	Slip3	Slip4	Slip5	Powr1	Powr2	Powr3	Powr4	Powr5
wt1p_b	Tr	To	rmax	rmin	Pmin	Pset	vt1	t1	vt2	t2	vt3	t3	vt4	t4				

Figure 2-4
Type 2 WTG model

A few items should be noted:

- All type 2 WTGs will have some form of pitch control. As for the type 1 WTG, the new *wt1p_b* model is recommended. The older pitch controller model (*wt1p*) should not be used. For an explanation of the control philosophy of the type 2 WTG and its implications for system dynamic performance see, chapter 3 of [14].
- The model parameters, and an explanation of each of the parameters, of the *wt2e* model can be found in the user's manual of the commercial software platforms.

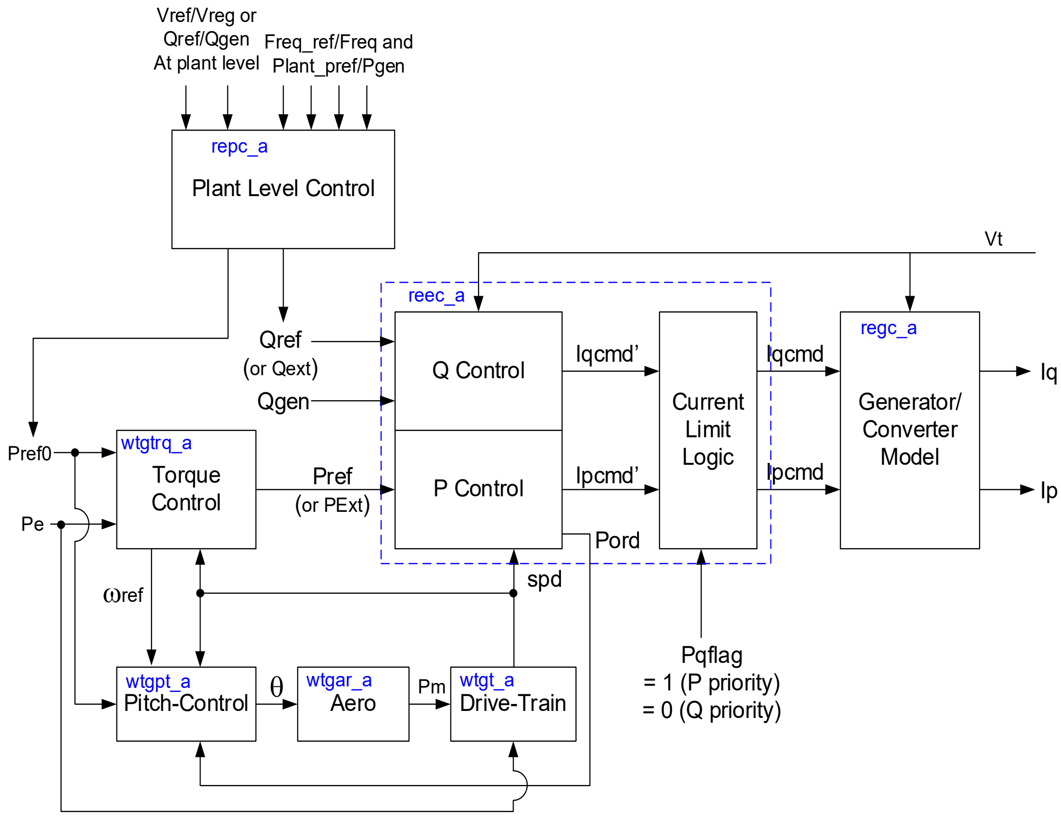
2.6 Modeling Type 3 WTG

The simple aggregated WTG plant model is shown in Figure 2-1. For a type 3 WTG plant, the aggregated turbine model is represented as shown in Figure 2-5. As shown in the figure a type 3 WTG, which is a doubly-fed asynchronous generator, is developed using seven models, all of which are among the second-generation generic models:

1. *regc_a* – which is the renewable energy generator/converter model and has inputs of real (*Ipcmd*) and reactive (*Iqcmd*) current command and outputs of real (*Ip*) and reactive (*Iq*) current injection into the grid model.
2. *reec_a* – which is the renewable energy electrical controls model *a*, and has inputs of real power reference (*Pref*) that can be externally controlled, reactive power reference[3] (*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.
3. *wtgt_a* – which is the emulation of the drive-train oscillations. The output of this model is speed (*spd*). In this case speed is assumed to be a vector $spd = [\omega_t \ \omega_g]$, where ω_t is the turbine speed and ω_g the generator speed. The inputs to the model are mechanical and electrical power.
4. *wtgar_a* – which is a simple linear model of the turbine aero-dynamics. This is based on reference [15]. The input to the model is pitch-angle (θ), and its output is mechanical power (*Pm*).
5. *wtgpt_a* – which is a simple pitch-control model. The inputs to the model are electrical power order (*Pord*), power reference (*Pref0*), speed reference (ω_{ref}) and speed (*spd*). The output is pitch-angle (θ).
6. *wtgtrq_a* – which is a simple torque controller. The inputs to the model are speed (*spd*), power reference (*Pref0*), electrical power (*Pe*) and the outputs are speed reference (ω_{ref}) and electrical power reference (*Pref*).
7. *repc_a* – which is the renewable energy plant controller model *a*. This model 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* in the

[3] The reactive power reference can also be an external voltage reference coming from the plant controller, depending on the selection of the various control options. This is explained later in the report.

reec_a model. In addition, the model can also emulate primary frequency response based on the measured total plant real power output at the point of common coupling and measured system frequency.



regc_a	lvplsw	rrpwr	brkpt	zerox	lvpl1	vtmax	lvpnt1	lvpnt0	qmin	tg	tfltr	iqrmax	iqrmin					
reec_a	Vdip	Vup	Trv	dbd1	dbd2	Kqv	Iqh1	Iql1	Vrefo	Iqfrz	Thld	Thld2	pfaref	Tp	Qmax	Qmin	Vmax	Vmin
	Kqp	Kqi	Kvp	Kvi	Vref1	Tiq	dPmax	dPmin	Pmax	Pmin	Imax	PfFlag	Vflag	Qflag	Pqflag	VDL1	VDL2	Tpord
wtgt_a	Ht	Hg	Dshaft	Kshaft														
wtgar_a	Ka	θo																
wtgpt_a	Kiw	Kpw	Kic	Kpc	Kcc	Tθ	θmax	θmin	dθmax	dθmin								
wtgtrq_a	Kip	Kpp	Tp	Tωref	Temax	Temin	Tflag	f(Pe)										
repc_a	Tfltr	Kp	Kic	Tft	Tfv	RefFlag	Vfrz	Rc	Xc	Kc	VcompFlag	emax	emin	dbd	Qmax	Qmin	Kpg	Kig
	Tp	fdbd1	fdbd2	femax	femin	Pmax	Pmin	Tlag	Ddn	Dup	Pgen_ref	Freq_ref	vbus	branch	Freq_flag			

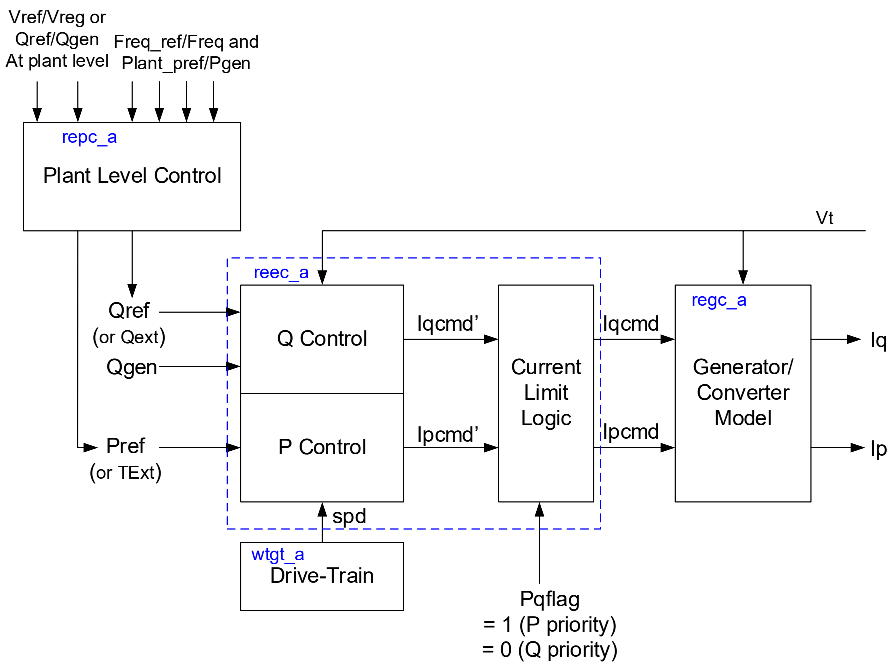
Figure 2-5
Type 3 WTG model

In the next section of the report a more detailed account is given of the various control strategies and functionalities of the type 3 WTG model. Reference [14] provides an account of the dynamic performance of type 3 WTGs and the various designs of these turbines. A detailed specification of the above models can be found in [1], together with an explanation of each parameter. However, for the sake of completeness, in Appendix F of this report an explanation is provided of all the parameters associated with each of the models and the typical expected range of values, as a guide to help avoid setting inappropriate values.

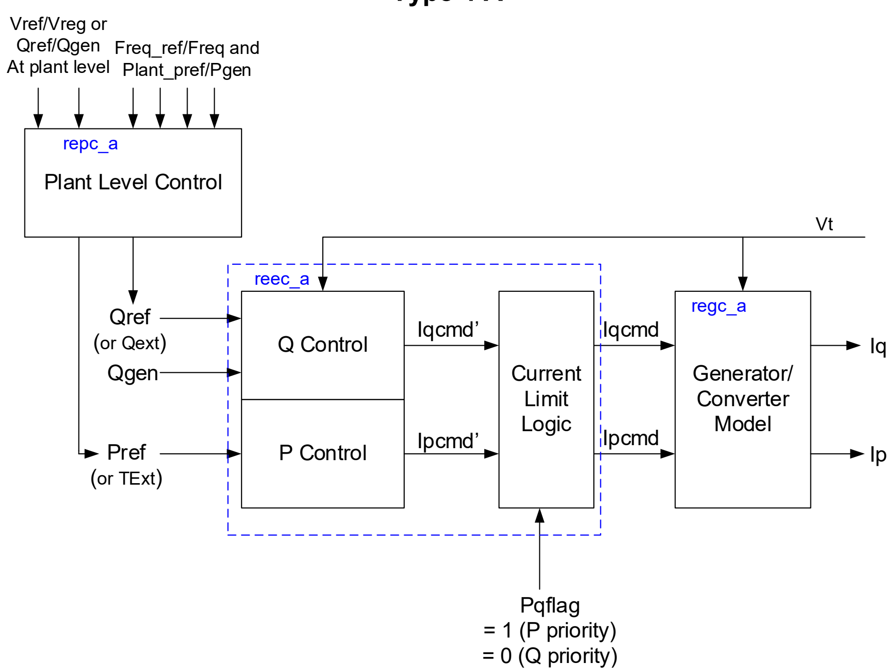
2.7 Modeling Type 4 WTG

The simple aggregated WTG plant model is shown in Figure 2-1. For a type 4 WTG plant, the aggregated turbine model is represented as shown in Figure 2-6. As shown in the figure a type 4 WTG, which is a full-converter interface asynchronous generator, is developed using either three or four models, all of which are among the second-generation generic models:

1. *regc_a* – which is the renewable energy generator/converter model and has inputs of real (*Ipcmd*) and reactive (*Iqcmd*) current command and outputs of real (*Ip*) and reactive (*Iq*) current injection into the grid model.
2. *reec_a* – which is the renewable energy electrical controls model *a*, and 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.
3. *wtgt_a* – which is the emulation of the drive-train oscillations. The output of this model is speed (spd). In this case speed is assumed to be a vector $spd = [\omega_t \; \omega_g]$, where ω_t is the turbine speed and ω_g the generator speed. The inputs to the model are mechanical and electrical power. This model may be used for type 4 A WTG plants where the torsional response of the turbine-generator assembly is observable in the electrical power output of the unit/plant.
4. *repc_a* – which is the renewable energy plant controller model *a*. This model 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 to the *reec_a* model. In addition, the model can also emulate primary frequency response base on the measured total plant real power output at the point of common coupling and measured system frequency.



Type 4 A



Type 4 B

regc_a	lvplsw	rrpwr	brkpt	zerox	lvpl1	vtmax	lvpnt1	lvpnt0	qmin	tg	tfltr	iqrmax	iqrmin					
reec_a	Vdip	Vup	Trv	dbd1	dbd2	Kqv	Iqh1	Iql1	Vrefo	Iqfrz	Thld	Thld2	pfaref	Tp	Qmax	Qmin	Vmax	Vmin
	Kqp	Kqi	Kvp	Kvi	Vref1	Tiq	dPmax	dPmin	Pmax	Pmin	Imax	PfFlag	Vflag	Qflag	Pqflag	VDL1	VDL2	Tpord
wtgt_a	Ht	Hg	Dshaft	Kshaft	**(optional)**													
repc_a	Tfltr	Kp	Kic	Tft	Tfv	RefFlag	Vfrz	Rc	Xc	Kc	VcompFlag	emax	emin	dbd	Qmax	Qmin	Kpg	Kig
	Tp	fdbd1	fdbd2	femax	femin	Pmax	Pmin	Tlag	Ddn	Dup	Pgen_ref	Freq_ref	vbus	branch	Freq_flag			

Figure 2-6
Type 4 WTG model

In the next section of the report a more detailed account is given of the various control strategies and functionalities of the type 4 WTG model. Reference [14] provides an account of the dynamic performance of type 4 WTGs and the various designs of these turbines. A detailed specification of the above models can be found in [1], together with an explanation of each parameter. Again, for completeness, Appendix F provides a list and explanation for all the parameters of the models and a range of typical values.

2.8 Modeling Photovoltaics (PV)

The simple aggregated PV plant model is also as shown in Figure 2-1. For a PV plant, the aggregated PV array model is represented as shown in Figure 2-7. As shown in the figure a PV plant is developed using three of the second-generation generic models:

1. *regc_a* – which is the renewable energy generator/converter model and has inputs of real (*Ipcmd*) and reactive (*Iqcmd*) current command and outputs of real (*Ip*) and reactive (*Iq*) current injection into the grid model.
2. *reec_a*[4] – which is the renewable energy electrical controls model *a*, and 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.
3. *repc_a* – which is the renewable energy plant controller model *a*. This model 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* to the *reec_a* model. In addition, the model can also emulate primary frequency response base on the measured total plant real power output at the point of common coupling and measured system frequency.

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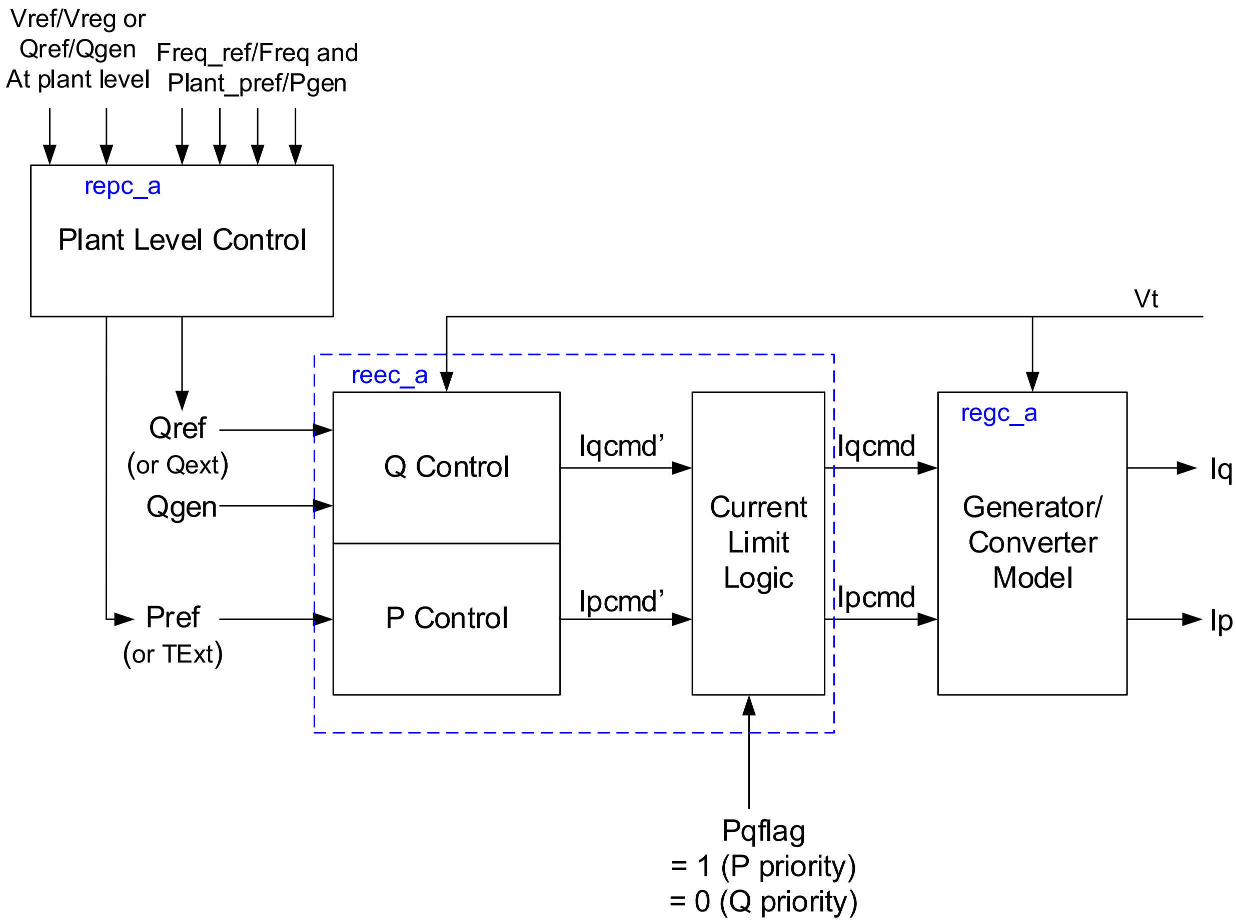
[4] We recommend using the *reec_a* model as it is more sophisticated and able to provide a means of modeling "momentary cessation" – see the recent NERC modeling notice: https://www.nerc.com/comm/PC/NERCModelingNotifications/Modeling_Notification_-_Modeling_Momentary_Cessation_-_2018-02-27.pdf. Originally, many PV plants were modeled using the *reec_b* model, but we recommend not using that model.



regc_a	lvplsw	rrpwr	brkpt	zerox	lvpl1	vtmax	lvpnt1	lvpnt0	qmin	tg	tfltr	iqrmax	iqrmin						
reec_a	Vdip	Vup	Trv	dbd1	dbd2	Kqv	Iqh1	Iql1	Vrefo	Iqfrz	Thld	Thld2	pfaref	Tp	Qmax	Qmin	Vmax	Vmin
	Kqp	Kqi	Kvp	Kvi	Vref1	Tiq	dPmax	dPmin	Pmax	Pmin	Imax	PfFlag	Vflag	Qflag	Pqflag	VDL1	VDL2		
repc_a	Tfltr	Kp	Kic	Tft	Tfv	RefFlag	Vfrz	Rc	Xc	Kc	VcompFlag	emax	emin	dbd	Qmax	Qmin	Kpg	Kig
	Tp	fdbd1	fdbd2	femax	femin	Pmax	Pmin	Tlag	Ddn	Dup	Pgen_ref	Freq_ref	vbus	branch	Freq_flag				

Figure 2-7
PV plant model

In the next section of the report a more detailed account is given of the various control strategies and functionalities of the PV model. The user may also consult [16].

2.9 Modeling Battery Energy Storage Systems (BESS)

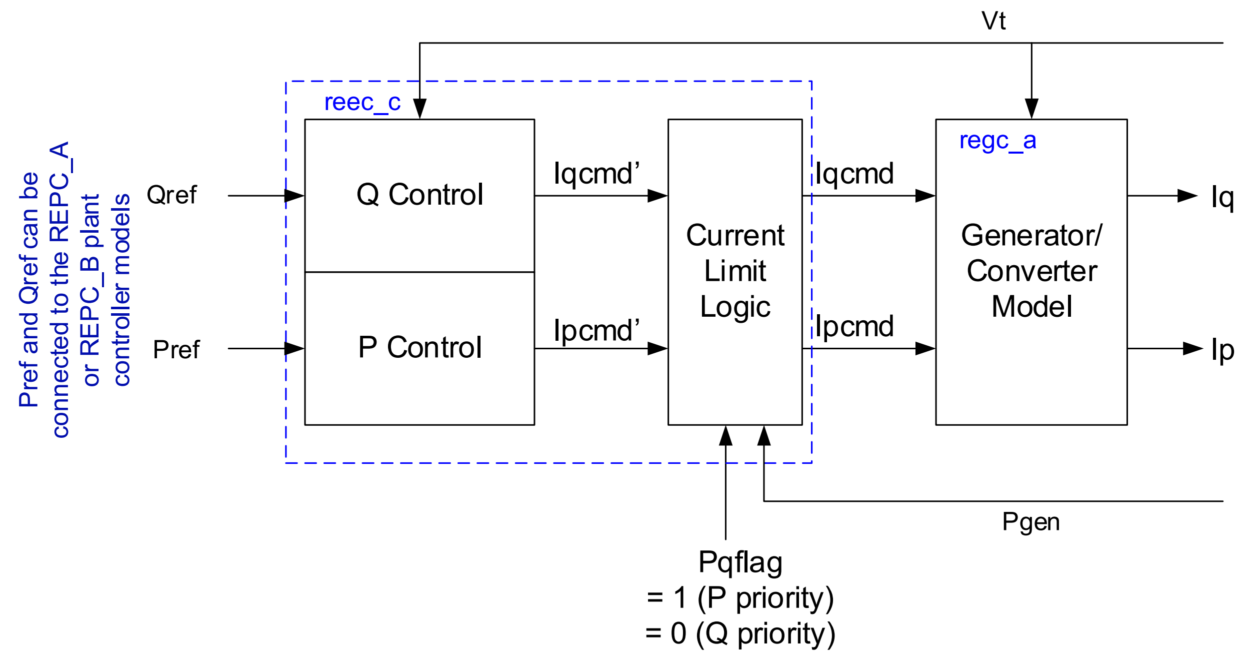
For a BESS, the device model is represented as shown in Figure 2-8. As shown in the figure a BESS unit is modeled using two of the second-generation generic models:

1. *regc_a* – which is the renewable energy generator/converter model and 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 represents the inverter interface for the BESS unit.

2. *reec_c* – which is the renewable energy electrical controls model *c*, and 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. This represents the BESS inverter controls and includes a basic representation of the charging/discharging dynamics.

In addition to the above models, a *repc_a* (renewable energy plant controller model *a*) model may also be used together with this configuration to allow for voltage and frequency control at a point of common coupling (see for example reference [23]). A detailed description of the *reec_c* model is given in [7].



regc_a	lvplsw	rrpwr	brkpt	zerox	lvpl1	vtmax	lvpnt1	lvpnt0	qmin	tg	tfltr	iqrmax	iqrmin					
reec_c	Vdip	Vup	Trv	dbd1	dbd2	Kqv	Iqh1	Iql1	Vrefo	SOCini	SOCmax	SOCmin	pfaref	Tp	Qmax	Qmin	Vmax	Vmin
	Kqp	Kqi	Kvp	Kvi	Tpord	Tiq	dPmax	dPmin	Pmax	Pmin	Imax	PfFlag	Vflag	Qflag	Pqflag	VDL1	VDL2	T

Figure 2-8
Simple BESS model

In the next section of the report a more detailed account is given of the various control strategies and functionalities of the BESS model.

2.10 Limitations of the Generic Positive Sequence Stability Models and On-going Work to Continue to Improve Them

A detailed discussion on the limitations of the generic positive sequence stability models developed for modeling renewable energy systems (RES) in time-domain stability analysis is outside the scope of this document. A more detailed account can be found in reference [22]. However, it is pertinent to identify some key aspects of the limitations of the models presented here for the general information of the reader. The models presented here were developed primarily for public use and benefit, and to eliminate the long-standing issues around many vendor specific models being proprietary and thus neither publicly available nor easily disseminated among the many stakeholders. Furthermore, using multiple user-defined non-standard models within large interconnection studies, in many cases, presented huge challenges and problems with effectively and efficiently running the simulations. Therefore, the intended use of these models is for positive-sequence large interconnected power system stability simulations. These models may be adequate for other uses as well, but the user must understand the context of his/her study and use engineering judgement in applying the models.

These models are in general not applicable for the following:

1. They cannot adequately represent the detailed behavior of the equipment for nearby unbalanced faults, since by their very nature these models are positive sequence models and developed for use with positive sequence simulation tools. This is even more so in the case of these RES models because many of the RES technologies interface with the power system using power electronic converters. To analyze the behavior of power electronic converters in detail, to unbalanced faults, in many cases will require three-phase modeling with a thorough understanding of the converter control strategy.
2. These generic models are not adequate for modeling the behavior of the RES technologies where they are interconnected to a very weak grid – that is, typically a short circuit ratio of 2 to 3 or less. It is difficult to provide an exact short circuit ratio below which the models are not applicable, the numbers presented here are only a guide.
3. Although these models may be used to adequately emulate low and high voltage ride-through for large interconnected studies, when used in conjunction with the *lhvrt* relay models, they are not adequate for use in designing the low/high voltage ride-through systems. The representation is a simple emulation, based on vendor supplied information, on the expected behavior of the equipment.
4. These models are not adequate for special studies for frequency phenomena outside of the typical range of dynamics studied in transient stability analysis. For example, they would not be adequate for the analysis of subsynchronous torsional interactions.

It is important at this point to highlight a developing aspect in relation to item 2. There are two issues at hand with respect to item 2 above. Firstly, the positive sequence models do not have the details of the converter inner-current control loops and synchronization circuitry (i.e. phase-lock loop) represented. Nor can these aspects be represented in detail in a positive sequence program, as they are outside of the band-width of positive-sequence tools. Therefore, these aspects cannot be captured in detail, and in weak-grid applications proper tuning of these controls will be necessary – see reference [24]. The second issue in positive-sequence tools is one of numerical stability. Both the first and second generation generic models use a “current source” model approach for modeling the algebraic interface between the network model and the dynamic RES model. A current source interface is inherently numerically unstable when applied in a low-short circuit node of the network. This can be easily understood because low-short circuit implies high impedance. Thus, when one changes the current being injected into the high-impedance node by a small amount, the voltage will change by a large amount. Thus, solving the boundary conditions for voltage can become problematic. To resolve this numerical issue, work is presently being done on a voltage-source model for representing the inverter interface. This new model, called *regc_b* (see Figure 2-9), is still in the process of being developed and tested among the software vendors through a similar collaborative effort in WECC MVWG [25]. The concept is based on reference [26]. Once developed, the hope is that this model will offer an alternative interface for full-converter type RES to mitigate some of the numerical stability issues. Nonetheless, it must be understood that even with this model in use the limitations of the positive-sequence models are still present, and detailed analysis of control interactions and weak-grid tuning of converter controls will still need close collaboration with the vendors and possibly initial investigation and simulation work in 3-phase EMT type vendor specific models, with then appropriately parameterizing the positive-sequence models to provide adequate performance for grid-wide simulations.

Furthermore, to the discussion above, at the latest WECC modeling and validation working group meeting, EPRI presented an alternative model for REGC_B, as shown in Figure 2-10 [28]. The idea behind this proposal is to introduce a simple representation of both the inner-current control loops and the PLL, in order to hopefully increase the fidelity of the voltage-source model even further by making it somewhat mimic the actual controls of inverter-based generation. This is still under study by EPRI and WECC, and may be adopted in time if proven to be a fruitful exercise. It comes, of course, with all the caveats mentioned earlier, that we cannot truly represent the full details of these controls in a positive-sequence program due to the bandwidth difference between the actual controls and the simulation platform. None-the-less, initial simulations have shown that with some manipulation of the parameters of this simplified representation, there may be some benefits derived therefrom [28].

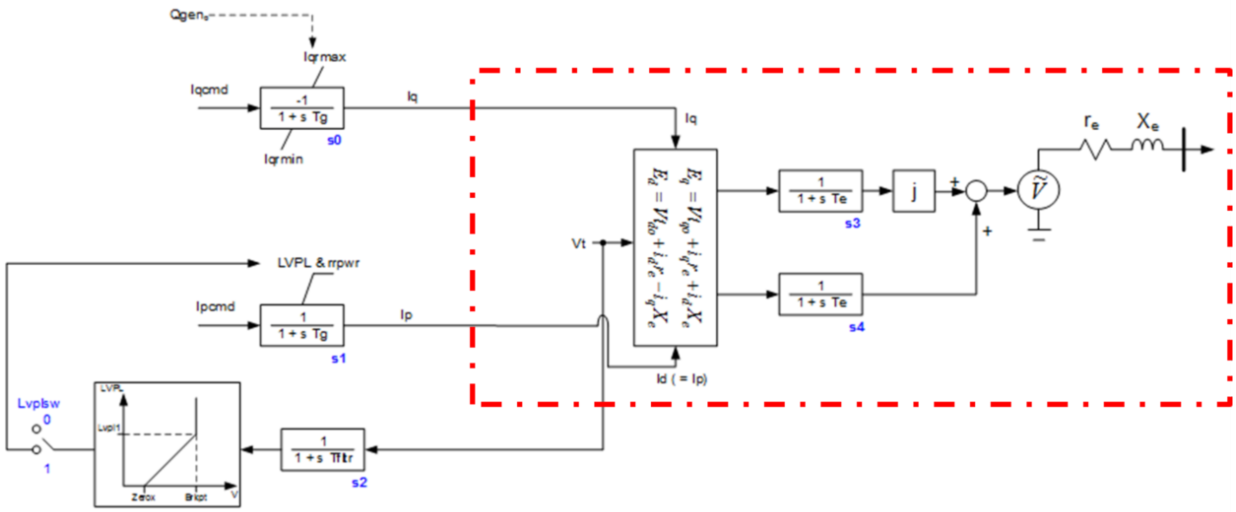


Figure 2-9
Block diagram of proposed *REGC_B* model which shows the voltage-source interface

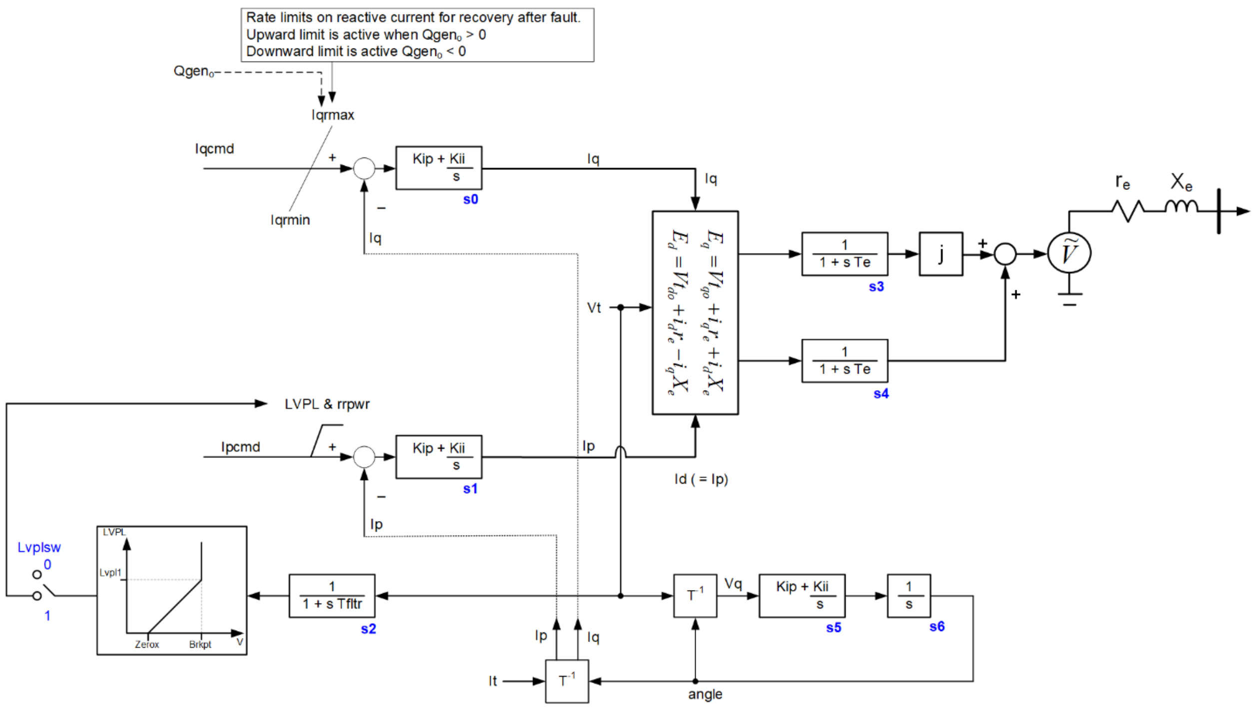


Figure 2-10
A revised proposal for *REGC_B* model, based on work done by EPRI in [28]

In addition to the above, there has been significant discussion at the WECC modeling and validation working group [29] to continue to develop new modules and improvements to the 2nd generation generic models. This can be found in [29], but for the sake of completeness is summarized here in bullet format:

- Development of the new generator/converter model (REGC_B mentioned above)
- Expanded features for converter electrical controls models (REEC_*), such as:
  - More points in the VDL tables
  - Allowing for delays in reactive current recovery (to model momentary cessation)
  - Allowing for droop control at the local-voltage control loop level
  - Etc.
- Adjustments to the torque-controller and pitch-controller per suggestions by equipment vendors.
- Expanded features for the plant controller, e.g. to allow for coordinated shunt compensation switching at the point of interconnection, and simulating ramps on reactive power, etc.
- Other modules such as, inertia-based fast-frequency response.

EPRI is engaged in these developments and will continue to work with the industry on these technical updates.

2.11 Tabular Summary of the RES Models

The following two tables summarize the list of RES models and how they are combined to make up the various RES.

Table 2-1
List of RES models

Model	Function	1st or 2nd Generation
regc_a	RES Generator/Converter Model (current source)	2nd
regc_b	*RES Generator/Converter Model (voltage source)*	*2nd (in development)*
reec_a	RES Electrical Controls Model A	2nd
reec_b	RES Electrical Controls Model B	2nd
reec_c	RES Electrical Controls Model C	2nd
repc_a	RES Plant Controls Model A	2nd
repc_b	RES Plant Controls Model B	2nd
wtgt_a	WTG Turbine Shaft Model A	2nd
wtgar_a	WTG Aero-dynamice Model A	2nd
wtgpt_a	WTG Pitch Controller Model A	2nd
wtgtrq_a	WTG Torque Controller Model A	2nd
wt1p_b	Pitch Controller for type 1 WTG Model B	2nd
wt1g	Type 1 WTG generator model	1st
wt1t	Type 1 WTG turbine shaft model	1st
wt2g	Type 2 WTG generator model	1st
wt2e	Type 2 WTG variable external rotor resistance controller	1st
wt2t	Type 2 WTG turbine shaft model	1st
lhvrt	low/high voltage ride-through relay model	1st
lhfrt	low/high frequency ride-through relay model	1st

Table 2-2
Combinations of the models for modeling various RES

RES	Model Combination
Type 1 WTG	wt1g, wt1t, wt1p_b
Type 2 WTG	wt2g, wt2e, wt2t, wt1p_b
Type 3 WTG	regc_a, reec_a, repc_a, wtgt_a, wtgar_a, wtgpt_a, wtgtrq_a
Type 4 WTG	regc_a, reec_a, repc_a (optional: wtgt_a)
PV plant	regc_a, reec_a, repc_a
BESS	regc_a, reec_c (optional: repc_a)

1. For PV plant modeling the *reec_a* model is the recommended model, since it is able to give some representation of inverter blocking or so-called "momentary cessation" (see NERC modeling notice https://www.nerc.com/comm/PC/NERCModelingNotifications/Modeling_Notification_-_Modeling_Momentary_Cessation_-_2018-02-27.pdf).
2. The *lhvrt* and *lhfrt* models may be used with any of the wind or PV plant representation to emulate low/high voltage and frequency ride-through characteristics, as specified by the equipment vendor.

3

CONTROL STRATEGY OPTIONS USING THE NEW RES MODELS

3.1 Overview

The new renewable energy system (RES) models incorporate at their heart three core systems:

1. The *regc_a* model which represents the interfacing electrical generator/converter,
2. the *reec_** models which model the local P/Q controls associated with the power converter interface of the RES[5], and
3. the *repc_** models which model the plant level controls associated with one or more active devices.

If we consider the bulk of the rest of the model library associated with the new RES models, one will see that they are relatively self-explanatory. For completeness, let us first examine those in brief.

WTGT_A – this is a simple two mass equivalent emulation of the turbine-generator shaft used to emulate the first and dominant torsional mode of the drive-train. The parameters are *Ht* (turbine inertia), *Hg* (inertia of the generator), *Kshaft* (spring constant of the shaft) and *Dshaft* (damping coefficient). The block diagram in shown in Figure C-1, Appendix C. It should be noted that [5] the shaft damping coefficient (*Dshaft*) is a fitted parameter to capture the net damping of the torsional mode seen in the post fault electrical power response of the machine. In the actual equipment, the drive train oscillations are damped through filtered signals and active damping controllers, which obviously are significantly different from a simple generic two mass drive train model. However, for the purposes of large scale power system simulations, the collective decision of the Western Electricity Coordinating Council's, Modeling and Validation Working Group (which approved these models) was that the added complexity to try to model active drive train damping was not warranted [4]. A detailed analysis of the torsional model, and particularly if one wishes to perform small-signal stability analysis, requires a different modeling approach. See for example, Appendix A of reference [14].

WTGAR_A – this is a very simple linear approximation of the aero-dynamic behavior of the wind turbine based on [15]. There is only one parameter *Ka*, which represents the linear relationship between a change in pitch-angle (in degrees) and the change in mechanical power (in pu). The block diagram is shown in Figure C-2, Appendix C. A typical value for Ka is 0.007 pu/degree.

WTGPT_A – this is a model of the pitch-controller. It is the same as that used in the first-generation generic wind turbine generator models with one exception, the addition of the cross term (*Kcc*) for increased flexibility. The block diagram is shown in Figure C-3, Appendix C.

[5] This is used whether the converter is a full converter (e.g. type 4 WTG or PV) or a partially rated converter (e.g. type 3 WTG).

WTGTRQ_A – this is a model of the emulation of torque control. It is similar to that in the first-generation wind turbine generator generic models but has an additional feature of allowing torque to be regulated based on torque error as well as speed error. The block diagram is shown in Figure C-4, Appendix C.

WT1P_B – this is the improved pitch-controller for a type 1 or 2 WTG using active-stall [6]. The block diagram is shown in Figure C-5, Appendix C. Reference [6] gives a detailed explanation of the models features.

With this brief introduction, let us now turn to the details of the substantially new models, the *re***** family of models, in order to understand their features and usage.

3.2 The Generator/Converter Model *regc_a*

The *regc_a* model is shown in Figure D-4 (Appendix D). The two blocks shown on the right "high-voltage reactive-current management" and "low-voltage active-current management" are mainly for numerical reasons. In Appendix A of reference [1] flow-charts are provided for both blocks. The actual detailed implementation may vary slightly among various commercial software platforms. The purpose of these blocks is to provide for a smooth and reasonable transition between the dynamic emulation of the current controls and the algebraic network equations. The "high voltage reactive power logic" performs the action of limiting the reactive current injected into the network equations in such a way as to prevent the terminal voltage of the machine from exceeding a given limit. The "low voltage active power logic" is designed to capture the characteristic of active power under very low voltages, that is, it reduces active current in a linear fashion as voltage drops to very low levels. These two blocks are of a numerical nature. They do not exactly represent a physical element in the controls. Their main function is to minimize numerical issues that arise due to the approximation by a simple model of what are essentially high bandwidth hardware components. In physical reality the power converter is an extremely fast control device with switching speeds typically in the kilo-hertz. These high-frequency phenomena cannot be adequately modelled with large scale positive sequence simulation tools for many reasons. The foremost reason is that the network equations are modeled with a static admittance matrix[6], thus the inherent assumption here is that the phenomena being modeled and studied do not drift more than a hertz or so from fundamental network frequency, for if they do then the network model is significantly deficient. Thus, exposing the network model to high-frequency phenomena will yield grossly erroneous results.

The time constant *Tg* is an emulation of the delay in the power converter switching process. In reality, this is a pure transport delay in the range of a few milliseconds. Again, modeling such detail is typically unnecessary for large scale power system simulations, particularly when the integration time step of typical simulations of this nature tend to be in the range of ¼ to ½ of a cycle (i.e. 4.16 to 8.3 ms). Typically, *Tg* is set to a value of between 0.01 to 0.02 s.

The time constant *Tfltr* is simply an emulation of the filtering time constant associated with measuring terminal voltage. A typical value would be in the range of 0.01 to 0.02 s.

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[6] It is fully understood that the admittance matrix changes during re-factorizations where lines/elements are switched in or out. By static and lumped model here is meant that the reactances and capacitances are represented by fixed lumped impedances as seen at fundamental network frequency.

The reactive current command (*Iqcmd*) passes through not only the lag time constant *Tg*, but also the rate-limits *Iqrmax* and *Iqrmin*. These rate limits on reactive power were used by only one of the original equipment manufacturers (OEMs) that we studied [5]. Furthermore, in that one case they were invoked when the turbine is operating in local constant Q control for this vendor. That is, the turbine is holding a constant reactive power output. In this case these limits are imposed post fault. *Iqrmax* is active if the initial reactive output of the unit was above zero, and *Iqrmin* is active if the initial reactive output is negative. The purpose of the rate limits is to limit rate of recovery of the reactive power to its initial value after fault clearing. The user is cautioned not to use this feature unless instructed by the OEM or if they are certain of what they wish to accomplish.

The Low Voltage Power Limiter (LVPL) logic is used to emulate in a simple way the tendency of some vendors to limit the active power output of the converter at low voltages. In fact, in almost all cases when the voltage is depressed to extreme values (i.e. below 5% residual voltage) the converters ability to produce active power will be severely limited.

Finally, the parameter *rrpwr* can be used to emulate the rate of rise in active power output following a grid disturbance. This parameter acts on active current, so it is not an exact representation of a rate limit on active power output.

3.3 The Renewable Energy Electrical Controls Models

There are presently three *reec_** models:

1. *reec_a* – the most complex, used typically with type 3 and 4 WTGs, and recommended for PV,
2. *reec_b* – the simpler version, originally used with PV plants is no longer recommended to be used since it lacks some of the needed features of the *reec_a* model, and
3. *reec_c* – specifically built to represent a battery energy storage system (BESS).

The block diagram for all three are shown in Appendix D. Note that *reec_b* is a subset of *reec_a*. Furthermore, *reec_c* is also a subset of *reec_a*, with the addition of a few extra parameters around the active power portion which facilitates modeling energy storage. In general, based on more recent experience (see NERC modeling notice https://www.nerc.com/comm/PC/NERCModelingNotifications/Modeling_Notification_-_Modeling_Momentary_Cessation_-_2018-02-27.pdf) the use of *reec_b* is not recommended any longer.

First consider *reec_a*, the most general model. There are three parts to the model:

- active current controls which develop the active current command *Ipcmd*
- reactive current controls which develop the reactive current command *Iqcmd*
- the converter current limit logic which limits the active and reactive current to within the ratings of the converter[7]

[7] The current limit logic is shown in Appendix B. It assumes a full-converter unit. For the sake of simplicity, it was decided, during the development of this model, by the WECC MVWG to not make a distinction between stator current limits for the type 3 WTG and converter current limits for the type 4 WTG.

Active Power Control: Let us first look at the active power control. In this part there are two options *PFlag* = 1, or *PFlag* = 0. For type 3 WTGs *PFlag* must equal 1, because the power developed by the turbine is modulated by perturbations in the shaft speed since the electrical generator is directly coupled to the grid. In this case, the *wtgtrq_a* model develops electrical torque, and so torque times speed yields power. ***EXTREMELY IMPORTATN NOTE:* in most, if not all, commercial software platforms the implementation of the models is slightly different than that shown in the original model specifications [1], and thus also shown here. That is, the output of the torque controller model (e.g. wtgq_a model in GE PSLF) is already equal to power, since the multiplication of torque and speed is done within the model. Therefore, PFlag must be set to 0 in reec_a for a type 3 WTG, in programs like GE PSLF, Siemens PTI PSS®E, etc., for otherwise one would be multiplying torque by speed squared which is of course incorrect. This is still the exact same model, it is just that some software vendors for internal software reasons, decided to place the torque × speed calculation in the torque model. SO PLEASE DOUBLE CHECK THIS IN THE SOFTWARE USER'S MANUAL.**

For type 4 WTGs either option may be valid depending on the type of unit. For a type 4A WTG the electrical power output of the unit is perturbed by the torsional oscillations of the turbine-generator shaft (see [5] for example validation cases) and so *PFlag* can be set to 1 and the *wtgt_a* model used to approximately emulate this behavior[8]. For type 4B WTGs there is no appreciable observation of electrical power perturbation due to torsional oscillations in the turbine generator shaft, due to the converter design, and so PFlag is set to zero and no *wtgt_a* model used.

The rest of the parameters associated with the active power control are the maximum and minimum power ratings of the unit (*Pmax/Pmin*), the maximum and minimum rate of change of power reference (*dPmax/dPmin*) and the time constant associated with the controls (*Tpord*).

Since this model is for use with WTGs (or PV) the minimum active current command is clearly zero (*Ipmin = 0*), and this is not changeable by the user.

The maximum active current command limit is determined by the current limit logic (*Ipmax*).

Reactive Power Control: There are several options for reactive power control. This is shown diagrammatically in Figure 3-1. These are:

- Local constant Q control – *PfFlag* = 0 and *QFlag* = 0; *VFlag* = 1 or 0 (irrelevant)
- Local constant power factor (pf) control – *PfFlag* = 1 and *QFlag* = 0; *VFlag* = 1 or 0 (irrelevant)
- Local terminal voltage control – *PfFlag* = 0, *VFlag* = 0 and *QFlag* = 1
- Local coordinated Q/V control – *PfFlag* = 0, *VFlag* = 1 and *QFlag* = 1

In addition to all this, there is a separate proportional, with deadband, current injection control which can be used either as proportional voltage control during a voltage dip (deadband set to zero) or a proportional current injection with deadband during a voltage dip. To disable this

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[8] The *wtgt_a* model when used with the type 4 WTG is intended solely for emulating the observed torsional oscillations post-fault in some type 4 equipment, where this occurs. In these cases, the mechanical power (*Pm*) of the *wtgt_a* model is assumed to be constant. Therefore, this model should not be used for cases where the primary frequency response feature is used or other external models that change *Pref*, since keeping *Pm* constant while *Pe* is being change is not realistic.

path, *Kqv* can be set to zero, and *Vup* and *Vdip* set to 2 and 0, respectively to disable the voltage dip logic (see Appendix F). The parameters *Iqfrz* and *Thld* can be used in association with this current injection loop to create various state transitions, as shown in Figure 3-2. These state transitions were implemented to accommodate various original equipment manufacturer (OEM) requests during the model development process. The user should use these only as instructed by OEMs or if he/she clearly understands their implications, as shown in the Figure 3-2. There is also a parameter, *Thld2*, which when set to a non-zero value will hold the active current command (*Ipcmd*) at the value it has been frozen at during a voltage dip, after the fault clears. That is, when *Voltage_dip = 1*, the active current command will be frozen to a given value. If *Thld2* were set to for example 0.1 s, then once the disturbance is over and *Voltage_dip =0*, the value of the active current command remains at its frozen value for another 0.1s, before being released.

For the local voltage control option, the user-defined reference bias *Vref1* is typically set to the default value of zero (0). This bias was provided again at the request of one OEM. It should only be used if so instructed, otherwise we advise always setting it to zero.

Thus, the various control options are summarized in the table below.

Table 3-1
Reactive power control modes for the *reec_a* model

Control Mode	PfFlag	VFlag	QFlag
Local constant Q control	0	0 or 1	0
Local constant power factor (pf) contorl	1	0 or 1	0
Local voltage control	0	0	1
Local coordinated Q/V control	0	1	1

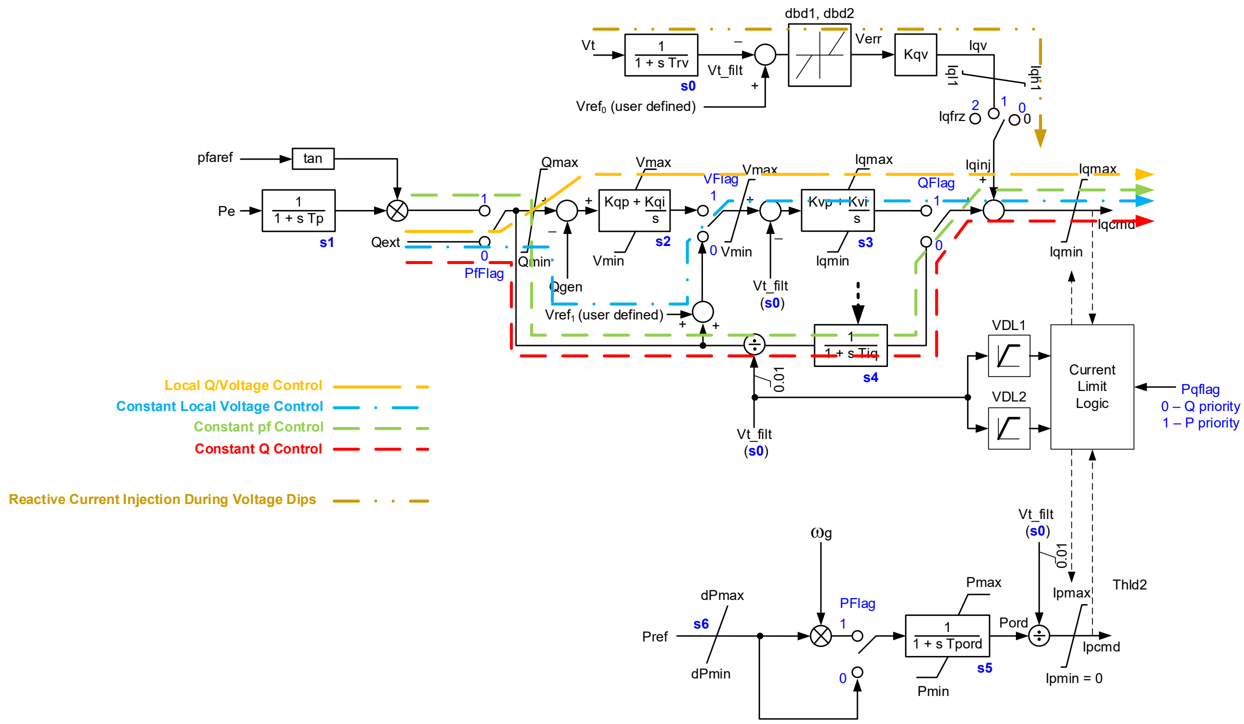

Figure 3-1
Options for the reactive power control path in the *reec_a* model

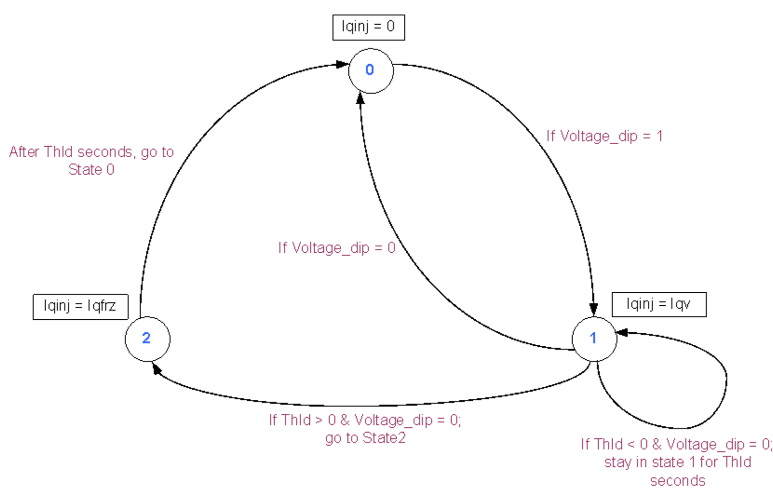

Figure 3-2
Renewable energy electrical control model state transition diagram for the (reec_a)

Current Limit Logic: The current limit logic implementation is given in Appendix B. In its most basic form the current limit is a semi-circle around quadrants 1 and 4, as shown in Figure 3-3. That is, only positive active current is allowed (*Ipmin* = 0) since this is a model for a generator, and the total current must be less than or equal to *Imax*. The selection of the *Pqflag* determines whether priority is given to active or reactive current. The *VDL1* and *VDL2* tables are two look-up tables with four pairs of numbers that define a piece-wise linear curve. These tables define the reactive and active current limits, respectively, as a function of voltage. Therefore, in addition to the basic current limit shown in Figure 3-3, the voltage-dependent limit (*VDL*) tables can be used to effect further limits on either active or reactive current as a function of voltage. The values of these tables need to come either directly from the OEM or based on fitting the values from factory (or field tests) that clearly show the reactive and active power output of a single WTG (or PV) as a function of various voltage dips. To disable these tables (or if data is not available) then simply set all the values to *Imax* for four different voltage settings, e.g. *Vq1* = 0, *Iq1* = *Imax*; *Vq2* = 0.2; *Iq2* = *Imax*; *Vq3* = 0.5, *Iq3* = *Imax* and *Vq4* = 1.0, *Iq4* = *Imax* etc. The tables could also be used to effect limiting (reducing) reactive output at high voltage levels. Since the original release of these models, it has become apparent that there would be great benefit to having a significantly larger number of point in these tables (more than four). As such, this is currently an item under discussion, to be considered in revisions of the model in the commercial software platforms – see section 2.10. The *VDL* tables are critical to representing so-called "momentary-cessation", and in general the voltage dependent current characteristics of the inverter, therefore for actual power plant installations it is important that these tables be reasonably parameterized rather than being disabled or ignored.

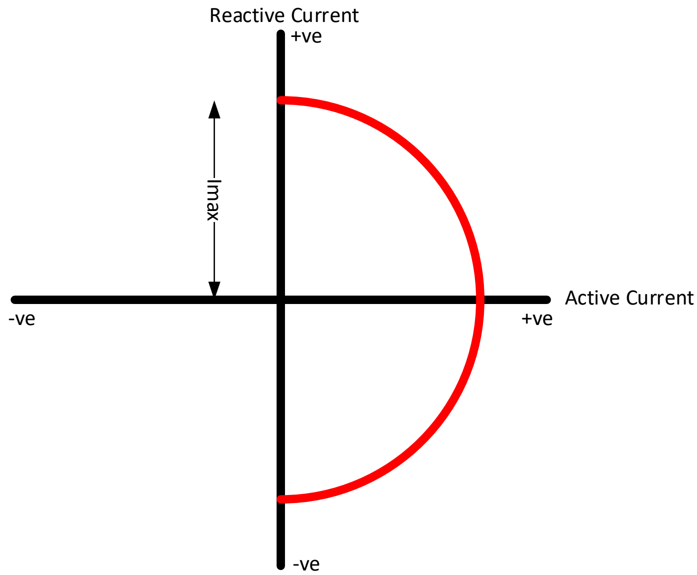

Figure 3-3
Current limit for *reec_a* model

<u>*REEC_B and REEC_C Models:*</u> Consider the *reec_b* model shown in Figure D-2 in Appendix D. The differences between this model and the *reec_a* model are as follows:

1. It does not contain the *VDL1* and *VDL2* tables, thus the current limit logic is defined entirely by a semi-circle as shown in Figure 3-3.
2. It does not have the parameters and functionality of the *reec_a* model associated with the state-transitions around the reactive current injection loop shown in Figure 3-2.
3. The active power path cannot be modulated by speed and so this model cannot be used with the *wtgt_a* model.

Other than the above points, the model is identical to *reec_a*. It is thus a simpler version of the *reec_a* model. These changes were decided by majority vote at one of the WECC REMTF meetings for the sake of creating a simpler alternative to the *reec_a* model for use for PV plants.

However, given recent developments around the so-called momentary cessation[9] issue it is not recommended that this model be used for PV plants, but rather the *reec_a* model still be used even for PV plants.

Consider the *reec_c* model shown in Figure D-3 in Appendix D. The differences between this model and the *reec_a* model are as follows:

1. It does not have the parameters and functionality of the *reec_a* model associated with the state-transitions around the reactive current injection loop shown in Figure 3-2.
2. The active power path cannot be modulated by speed and so this model cannot be used with the *wtgt_a* model.
3. It contains an additional path with a simple representation for a charging/discharging mechanism (energy storage).
4. The minimum active current (*Ipmin*) is equal to *–Ipmax*; that is, the model allows power to be both generated and absorbed, and therefore can be used to model energy storage.

Other than the above points, the model is identical to *reec_a*. Let us consider in a little more detail the additional features of this model. The additional part of the model is shown in Figure 3-4. This added feature has the following key aspects:

1. A user defined parameter which specifies the initial state of charge (*SOC*) of the battery. This tells the model how much charge the battery has prior to starting the simulation.
2. A representation of the maximum and minimum allowable state of charge (shown as *SOCmax* and *SOCmin*). Most battery OEMs recommend that the battery not be left in a state of full-charge or full-discharge in order to preserve the battery's longevity and performance. The model simulates this through the user specified values for the maximum (*SOCmax*) and minimum (*SOCmin*) allowed state of charge during operation. Many vendors recommend operating the batteries within a range of 20% to 80% state of charge.
3. The simple integrator block, with the time constant *T*, represents the process of charging and discharging. The level of charge in the battery is proportional to stored energy. Energy is the time integral of power since power is specified in units of watts = joules (energy) per second. Thus, by integrating the power coming out of (or going into when charging) the device, we get a representation of the state of charge.
4. The logic block at the end of the model represents the action of collapsing the output of the converter (i.e. forcing its active current output) to zero once the maximum or minimum state of charge has been reached. So, for example, if the SOC is greater than the allowable *SOCmax*, then *Ipmin* is forced to zero, meaning that the battery cannot absorb/store any more electrical energy.

Consider a simple example of how the *reec_c* model might be parameterized to represent a BESS. Assume we have a BESS that is rated at 40 MVA, with an energy rating of 30 MW for 4 hours (120MWh). Also, let us assume that when in operation the BESS is required by the

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[9] https://www.nerc.com/comm/PC/NERCModelingNotifications/Modeling_Notification_-_Modeling_Momentary_Cessation_-_2018-02-27.pdf

vendor to always be in a state of charge between 20% to 80%, with the same charging rate (i.e. 4 hours).

Then,

$SOCmax = 0.8$

$SOCmin = 0.2$

The total energy of the device = 30×4 = 120 MWh, thus in operation it can go from 0.8×120 (96 MWh) to 0.2×120 (24 MWh), which means that the maximum output would be (96 – 24)/4 = 18 MWh for 4 hours.

Therefore,

T = ((18/30) × (60×60×4)) / (0.8 – 0.2) = 14,400

Pmax = 18/30 = 0.6

Pmin = - Pmax = -0.6

Imax = 40/30 = 1.33

The model MVA = 30 MVA. All other parameters would be set per the OEM data.

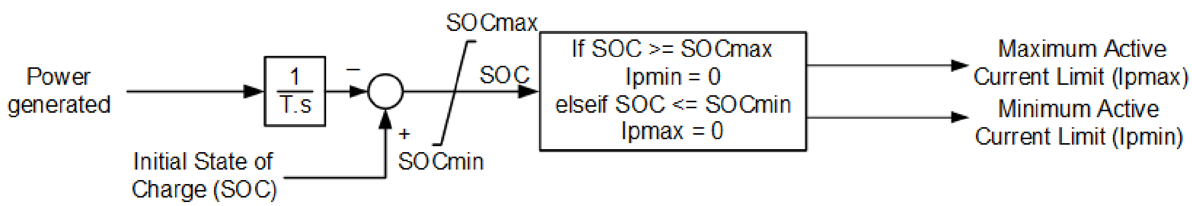

Figure 3-4
Extra part of the *reec_c* model for simulating charging and discharging of a storage mechanism

A more detailed account of modeling battery energy storage with these generic models, and a comparison of the performance of the generic models to detailed proprietary 3-phase models can be found in [23].

3.4 The Renewable Energy Plant Controller Model

There are two renewable energy plant controller models: *repc_a* and *repc_b*.

The renewable energy plant controller model *a* (*repc_a*) is shown in Figure 3-5. The model connects to the *reec_a*, *reec_b* or *reec_c* models. There are two separate and independent paths in the model, the reactive power control path that culminates in the variable *Qext*, and the active power control path that culminates in the variable *Pref*. These variables, *Qext* and *Pref*, then connect to the reec_* models and appropriately adjust the inputs to those models. If *PfFlag* is set to 1 in the reec_* models to effect local power factor control, then the output of the *repc_a* model does not in any way influence the reactive power of the reec_* model.

Now consider the reactive power control path of the *repc_a* model. There are two general options:

1. Voltage control: by setting *RefFlag* = 1 the voltage at a remote bus (*Vreg*) can be regulated, typically the voltage at the point of common coupling, which is commonly

either the high- or low-voltage side of the plants substation transformer. Furthermore, either line drop compensation (using *Rc, Xc*) can be used with *VcompFlag* set to 1, or reactive droop (*Kc*) can be used with *VcompFlag* set to 0.

2. Constant Q control: by setting *RefFlag* = 0 the reactive power through a branch can be controlled, typically the reactive power through the substation transformer which represents the reactive power output of the plant.

The proper selection of the deadband (*dbd*), input (*emax/emin*) and output (*Qmax/Qmin*) limits and gains (*Kp/Ki*) of this controller is critical to having stable and proper operation of the controls. The time constants *Tft* and *Tfv* can be used to represent any intentional phase lead (*Tft*) – typically none – or lag/delay (*Tfv*) in the communication process between the plant controller and the turbines. The table below provides a summary of the reactive power control possibilities.

<u>IMPORTANT NOTE:</u> depending on the settings within the reec_* model down stream of the plant controller, Qext (the output of repc_a) can be either a "Q-command" or "Voltage-command". Therefore, the values of Qmax/Qmin must be set appropriately to respect the nature of the output signal. For example, if in the downstream reec_* model Pfflag = 0, Vflag =0 and Qflag = 1 (see Table 3-1) then Qext will be a voltage-set-point and so Qmx/Qmin in the repc_a model need to be set to values such as 1.1/0.9 (maximum and minimum voltage ste-point values). While, if Pfflag = 0, Vflag = 1 or 0, and Qflag = 0 (see Table 3-1) then Qext will be a Q-reference and so Qmx/Qmin in the repc_a model need to be set to values such as 0.3/-0.3 (maximum and minimum Q-reference).

Table 3-2
Reactive power control modes for the *reec_ + *repc_a* models**

Control Mode	reec_* model			repc_a model
	PfFlag	VFlag	QFlag	RefFlag
Plant level Q control	0	0 or 1	0	0
Plant level Vcontrol	0	0 or 1	0	1
Plant level V Control + coordinated local Q/V control	0	1	1	1
Plant level Q Control + coordinated local Q/V control	0	1	1	0

The active power control loop can be used to simulate primary frequency response. This loop can be enabled by setting *Freq_flag* = 1, or disabled by setting the flag to 0. The upward (*Dup*) and downward (*Ddn*) regulation droop settings can be different, as well as the deadband on either side. In addition, a plant power reference *Plant_ref* is accessible by the user, which can be used to ramp the plant or controlled by other external models (e.g. AGC).

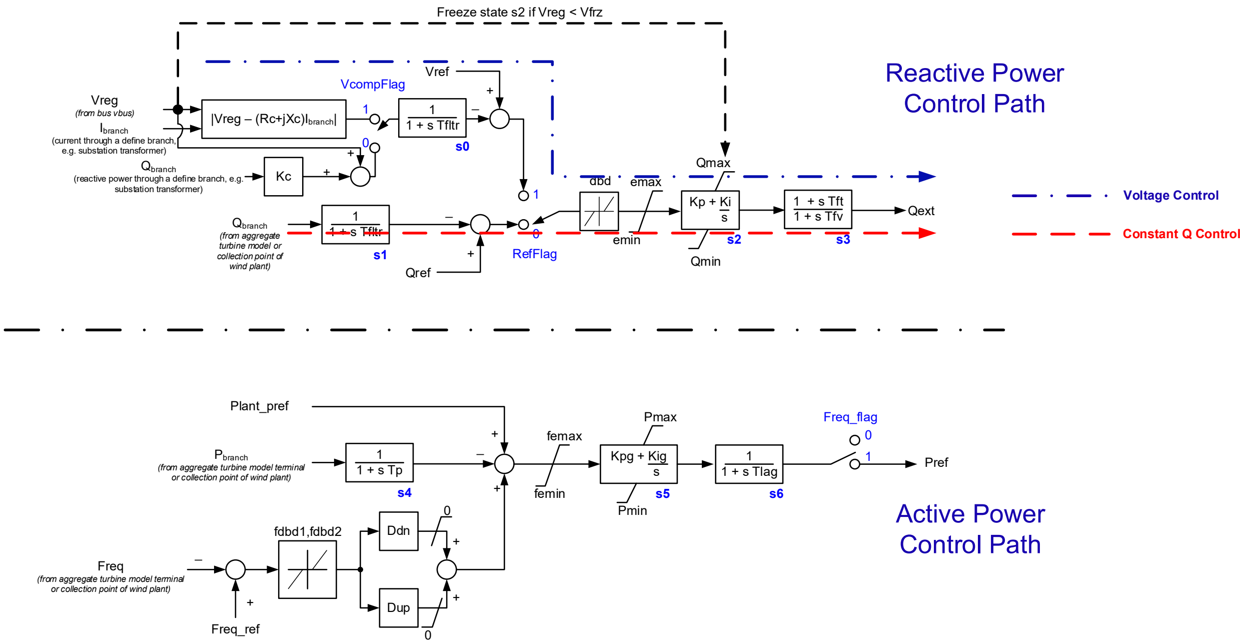

Figure 3-5
The plant controller model *repc_a*

<u>Warning:</u> 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 (or solar energy for PV) to electrical power, which is certainly the typical operating condition of a wind power plant in most of North America today. In these cases, the primary frequency response (PFR) should be disabled in simulation or Dup or Pmax, or other appropriate parameters, adjusted to not allow for PFR. Our recommendation is to set Pmax equal to the initial output of the plant model, from power flow, which would then not allow further increase of the plant output for under-frequency events, which better emulates reality.

<u>Important Note:</u> 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. So, the user should also carefully read the respective commercial software user's manual for the usage of the repc_a model.

The plant controller model b (*repc_b*) is shown in Figure 3-6 [8]. The differences between model *b* an *a* are high-lighted in red. These differences are as follows:

1. The *repc_b* model allows also for power factor control of the plant. By setting *RefFlag* to 2, the user may select a constant power factor control mode. Upon initialization, the model sets the parameter *pfaref = arctan(Qbranch/Pbranch)* (i.e. the initial power factor angle from the power flow solution). In hind-sight, this feature should also have been made available perhaps in *repc_a*, but it is not. Consideration, among other things, are presently been given to new modular components that may include updates such as this to the *repc_a* model.
2. Three auxiliary inputs (*Vaux*, *Qaux* and *Paux*) have been added, which should be accessible to the user and always initialized to zero. These can be used for adding user-

written components by users for introducing any specialized controllers that may be unique to specific installations.

3. The output of the model can link to up to fifty (50) other dynamic devices to allow for coordinate control of multiple active devices in a plant. A few pertinent comments are warranted about these outputs. For a detailed account, including initialization of the model, see reference [8].

    a. For each leg (reactive and active power) the output can interface with up to fifty (50) different devices. Each pair of outputs, e.g. *Po1* and *Wo1* go to the same device (defined by a bus number and device id). When the output is going to a reactive device (e.g. SVC, STATCOM or synchronous condenser) then *Poi* is ignored and *Kzi* is set to 0. The reactive outputs are designated "*Woi*" since they can be either a reactive power bias (e.g. going into an aggregate wind/PV unit so configured or a voltage reference bias (e.g. going into a SVC, STATCOM or exciter summing junction).

    b. The model's *Woi* outputs can connect to *Qref* on *reec_a*, *reec_b* and *reec_c*, or the *Vsig* of *svsmo1*, *svsmo2* and *svsmo3*, or *Vsig* on exciter models on *esst1a*, *esst4*b, *esac7b* and *esac8b* on a synchronous condenser.

    c. The model's *Poi* outputs can connect to Pref on *reec_a*, *reec_b* and *reec_c*.

    d. It is assumed that the time lag associated with the signals is the same for the reactive and active power signals. Therefore, one set of up to fifty-time constants is needed (*Tw1* to *Tw50*).

    e. The weights *Kw1* to *Kw50* and *Kz1* to *Kz50* are not normalized – the user may of course normalize them him/herself prior to entering the numbers. These gains are not renormalized, changed or reconfigured automatically by the model after initialization, for example if during a simulation a device trips and thus one of the outputs is no longer controlling anything, then it simply floats, and the remaining gains also remain unchanged. In practice some vendors may renormalize the gains and set the gain of the tripped device to zero, but this is too complicated for the present intended model.

It is our understanding, that the implementation of this model is slightly different in one of the commercial tools (Siemens PTI PSS®E) such that in that tool, the commercial vendor decided to split the core plant controller and the lag blocks (shown in red). Thus, the number of controllable devices is not limited to fifty. Also, clearly the user would need to instantiate several models to implement the so-called *repc_b* model. Thus, users should also closely consult the user's manual of the commercial tool they are using to understand the instantiation of the model.

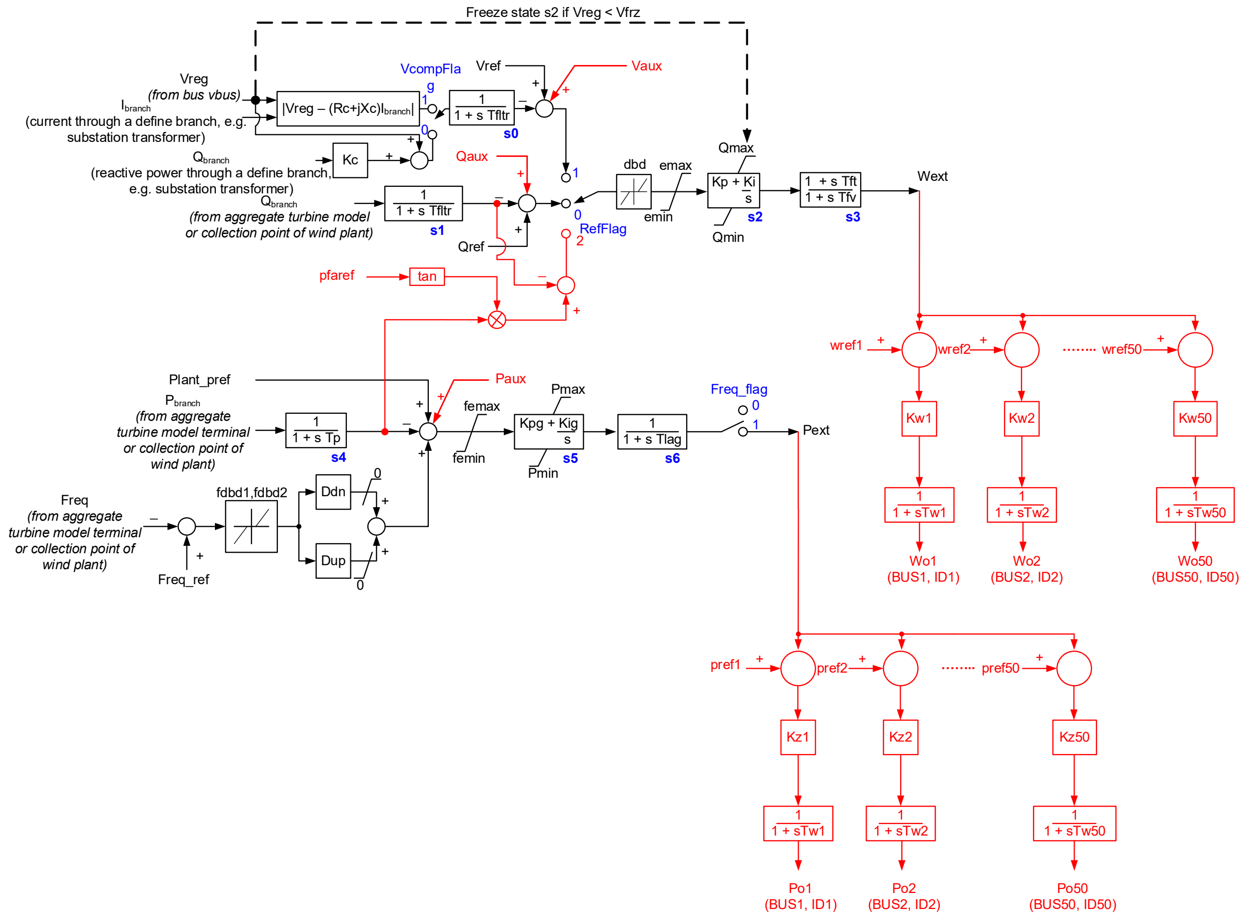

Figure 3-6
The plant controller model *repc_b*

3.5 Low and High Voltage and Frequency Rde-Through

The protection models associated with the wind turbine generator (i.e. low/high voltage and low/high frequency tripping) have not been addressed in this document since the existing generic protection models (*lhvrt* and *lhfrt*) that exist in GE PSLF (and similar models in Siemens PTI PSS®E, PowerWorld Simulator, PowerTech Labs TSAT™ etc.) are adequate for application with these generic models.

4
VALIDATION OF THE MODELS

The intent of this document is to present a guide on the usage of these models and not the process of validation. NERC is presently undertaking, in a broad collaborative way, in preparing a guide on model validation of RES models. This report should be publicly available in the next few months.

Many of the reference documents provided in section 6 provide examples of simulations performed by EPRI using the EPRI validation software tools for single wind turbine generators and in one case a wind power plant with these new generic models. Furthermore, the models have been used by solar energy developers and a few wind turbine OEMs and validations shown and reported at various WECC and IEEE meetings. EPRI has also used the model in validating PV inverters with data from one OEM. All this work has shown the models to be useful and applicable for large scale interconnected power system stability studies. The reader can consult references [1], [2], [3], [4], [5], [7] and [18] which show many such validation results.

Since the first version of this report was released in 2015, much recent experience has been gained with performing model validation of large wind and PV power plants using these generic models, including validation of primary frequency response. Examples of such results may be found in references [19], [20], [21], [22] and [23].

There are certainly additional improvements to be made to the models to capture other functionalities of the ever-evolving renewable energy technologies. However, given the modular format of these models this should hopefully be an achievable task for continued research and development.

5
CONCLUSION AND SUMMARY

This document provides a concise guide to the use of the second-generation generic, and public, renewable energy system models for use in positive sequence stability simulation programs. Further work continues to be done on adding new features and extending some of the existing features of the models, as briefly discussed in section 2.10. Thus, it is anticipated that this document may need to be revised again in due course.

6
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A

MODEL NAMES IN THE MAJOR SOFTWARE PLATFORMS USED IN NORTH AMERICA

The models presented in this report have slightly different names in the various commercial software platforms simply because of the inherent naming conventions used by the software vendors. The table below gives a cross-reference for the model names in the four most commonly used tools in North America. The table below is current as of February 2018.

Table A-1
Model names across four main commercial software tools used in North America

Model Name in the Model Specification Document	Model Name in GE PSLF™	Model Name in Siemens PTI PSS®E	Model Name in PowerWorld Simulator	PowerTech Labs TSAT™
New Models (developed 2011 - present)				
REGC_A	regc_a	REGCAU1 (V33); REGCA1 (V34)	REGC_A	REGC_A
REEC_A	reec_a	REECAU1 (V33); REECA1 (V34)	REEC_A	REEC_A
REEC_B	reec_b	REECBU1 (V33); REECB1 (V34)	REEC_B	supported*
REEC_C	reec_c	REECCU1 (V33 & V34)	REEC_C	supported*
REPC_A	repc_a	REPCTAU1 & REPCAU1 (V33); REPCTA1 & REPCA1 (V34)	REPC_A	REPC_A
WTGT_A	wtgt_a	WTDTAU1 (V33); WTDTA1 (V34)	WTGT_A	WTGT_A
WTGAR_A	wtga_a	WTARAU1 (V33); WTARA1 (V34)	WTGA_A	WTGA_A
WTGPT_A	wtgp_a	WTPTAU1 (V33); WTPTA1 (V34)	WTGP_A	WTGP_A
WTGTRQ_A	wtgq_a	WTTQAU1 (V33); WTTQA1 (V34)	WTGTRQ_A	WTGQ_A
WT1P_B	wt1p_b	not yet part of the standard model library	WT1P_B	not yet supported
REPC_B	repc_b	PLNTBU1 (V33 & V34)	REPC_B	supported**
Existing Models (developed prior to 2009)				
WT1G	wt1g	WT1G1	WT1G & WT1G1	WGNA
WT2G	wt2g	WT2G1	WT2G & WT2G1	WGNB
WT2E	wt2e	WT2E1	WT2E & WT2E1	WGNAE
LHVRT	lhvrt	VTGTPAT (trips machine), VTGDCAT (disconnects bus)	LHVRT	supported*
LHFRT	lhfrt	FRQTPAT (trips machine), FRQDCAT (disconnects bus)	LHFRT	supported*
*supports PSS®E and PSLF formats				
** supports PSLF format				

Note: In the TSAT™ column for some of the models it is said supported and no model name is given. As explained by the software vendors there are no equivalent models in DSATools™ (or TSAT™) format. However, the mentioned models are supported. That is, if user's dynamic data are in GE PSLF or Siemens PTI PSS®E format, TSAT™ recognizes the said models and uses them in the simulation. Contact the specific software vendor for more details.

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) $\quad Q-priority$

$Iqmax = \min\{VDL1, Imax\}$

$Iqmin = -1 \times Iqmax$

$Ipmax = \min\{VDL2, \sqrt{Imax^2 - Iqcmd^2})$

$Ipmin = 0$

Else $\quad P-priority$

$Iqmax = \min\{VDL1, \sqrt{Imax^2 - Ipcmd^2}\}$

$Iqmin = -1 \times Iqmax$

$Ipmax = \min\{VDL2, Imax)$

$Ipmin = 0$

End

C
BLOCK DIAGRAMS FOR THE WIND TURBINE RELATED MODELS

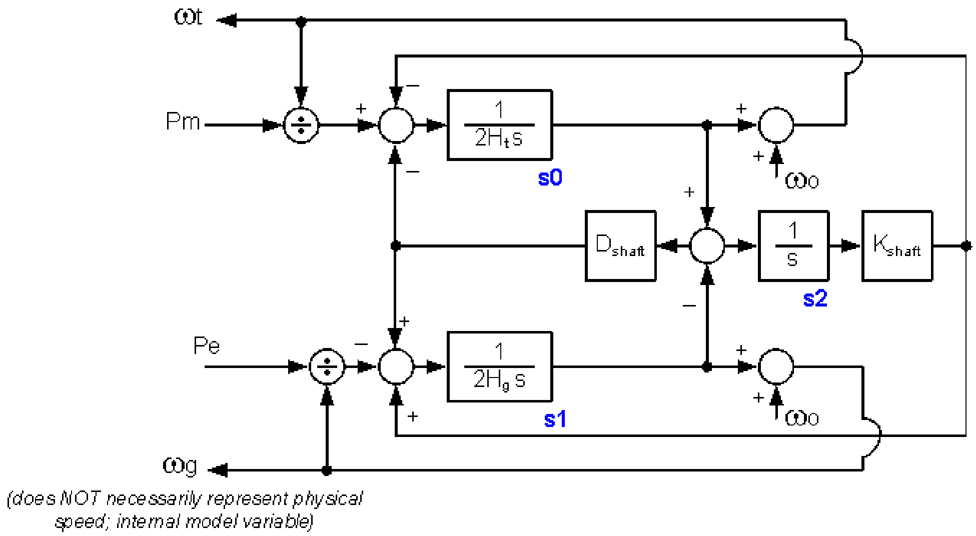

Figure C-1
Wind turbine generator drive-train model (wtgt_a)

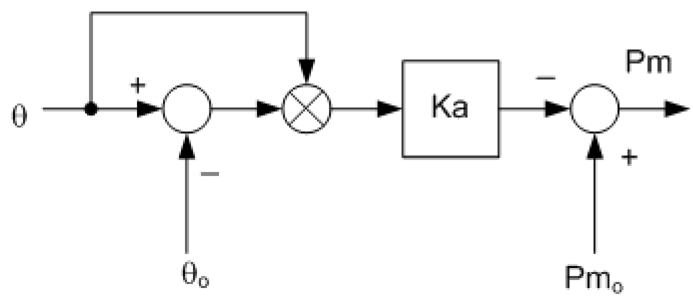

Figure C-2
Wind turbine generator aero-dynamic model (wtgar_a)

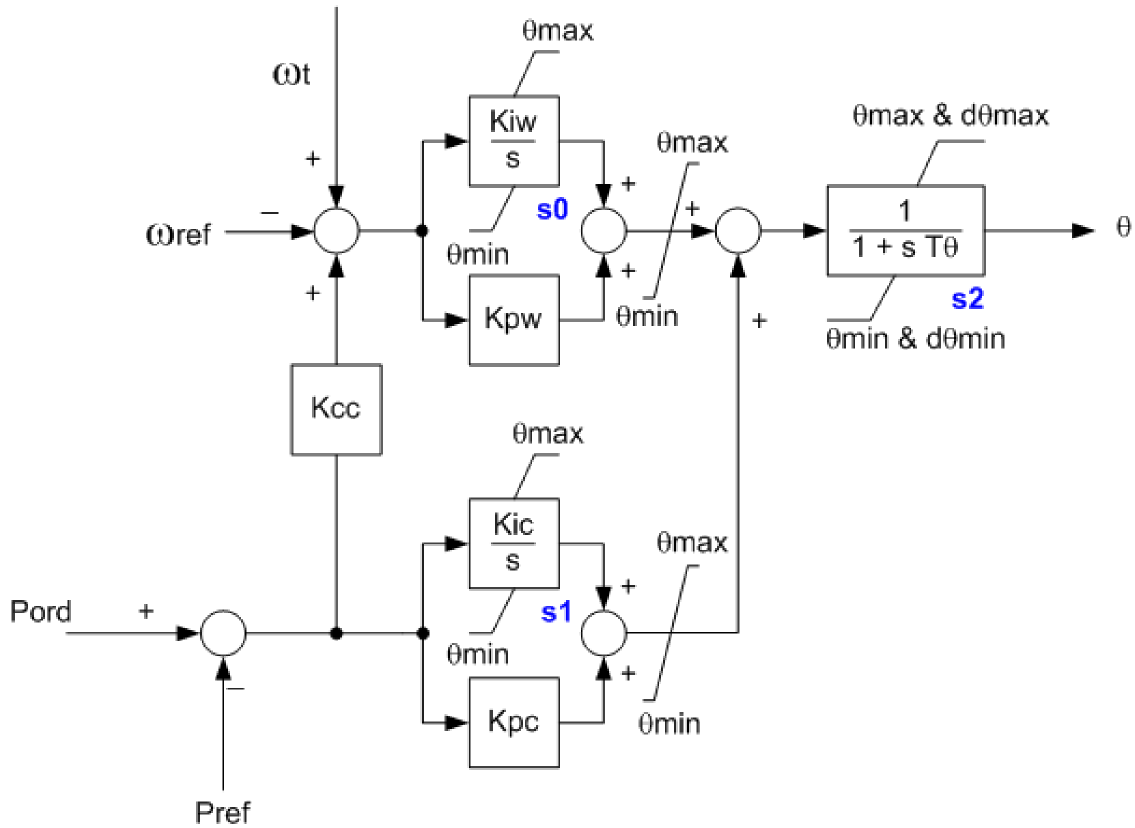

Figure C-3
Wind turbine generator pitch-controller model (wtgpt_a)

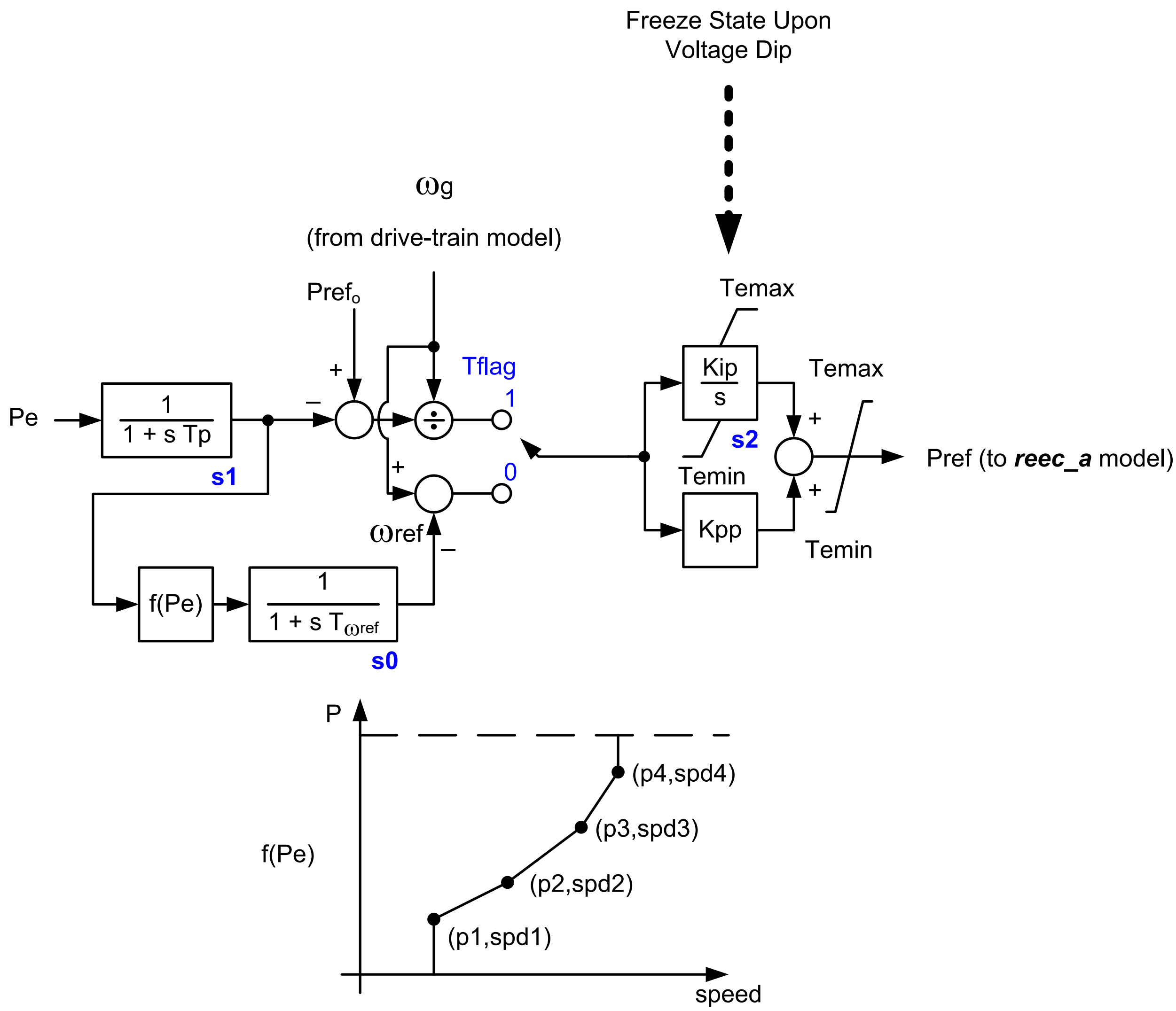

Figure C-4
Wind turbine generation torque model (wtgtrq_a)

D

BLOCK DIAGRAMS FOR RE*** MODELS

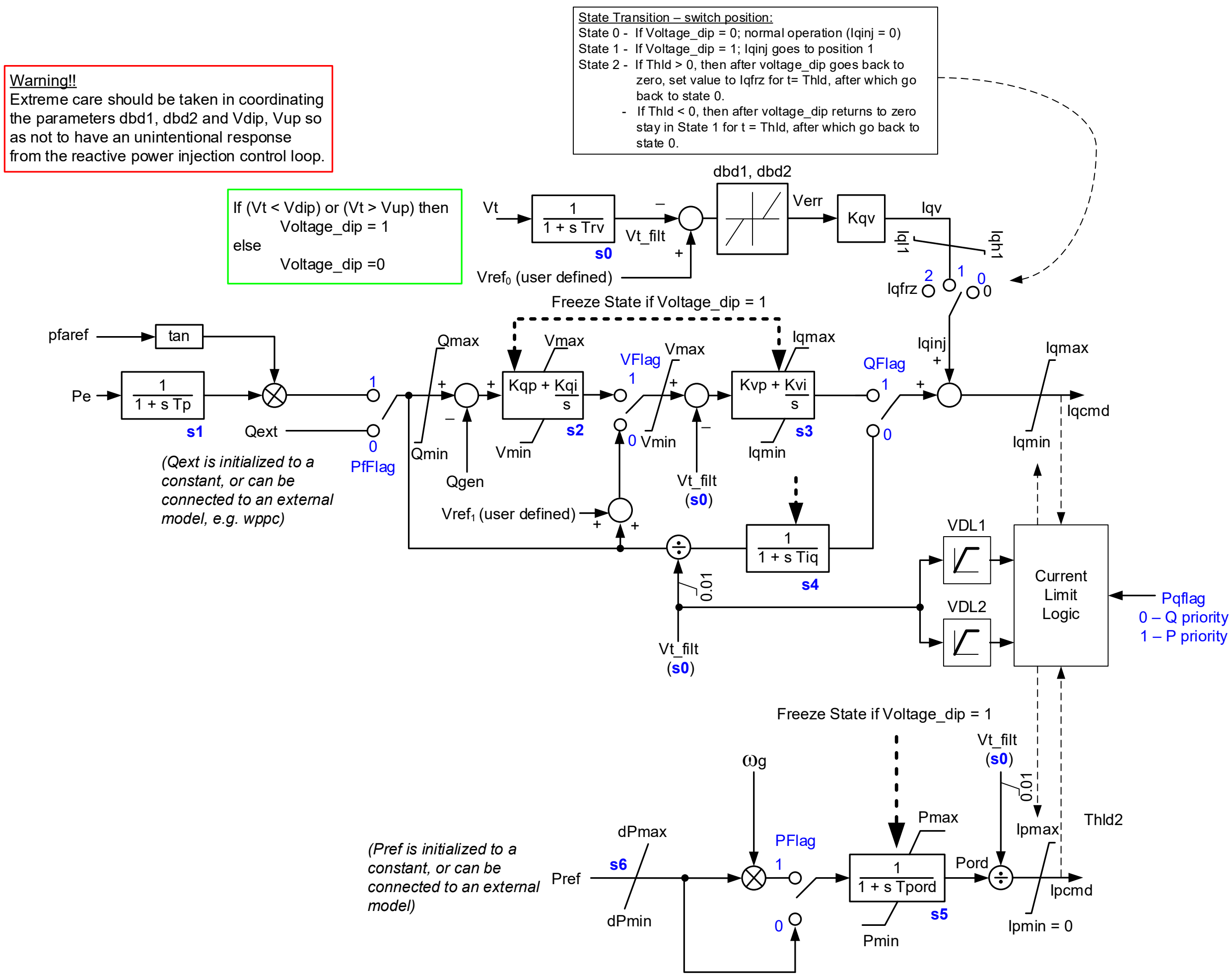

Figure D-1
Renewable energy electrical controls model *a* (reec_a)

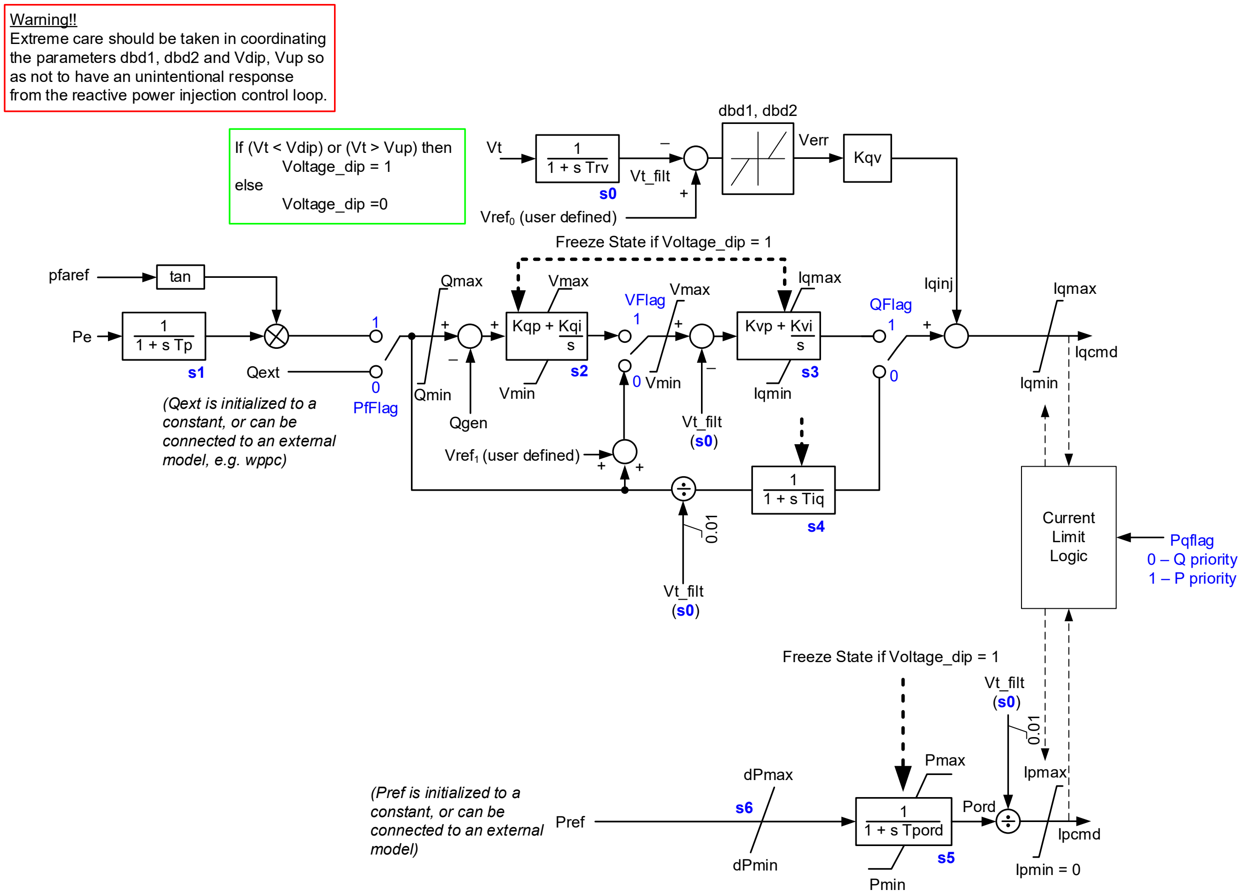

Figure D-2
Renewable energy electrical controls model B (reec_b)

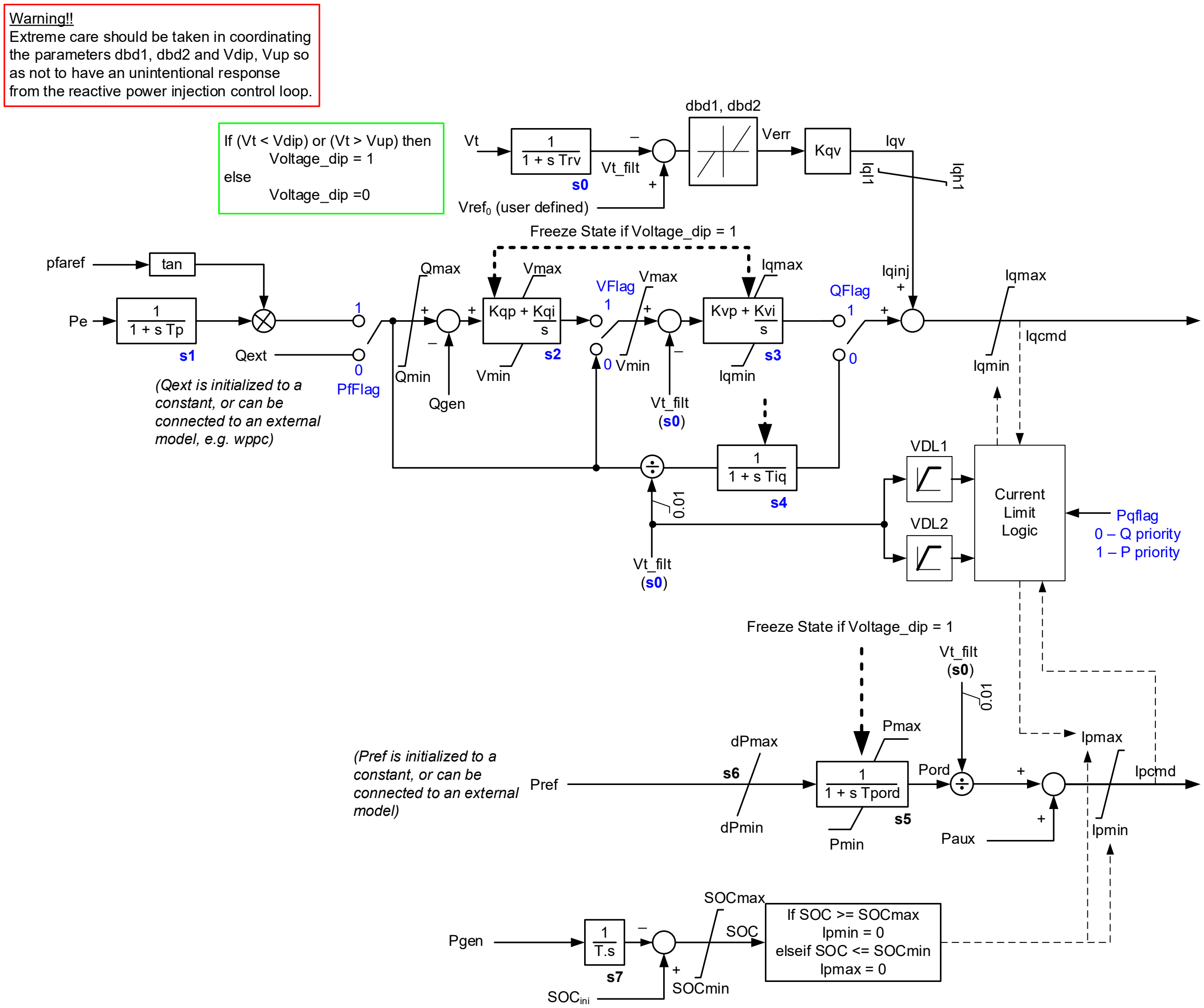

Figure D-3
Renewable energy electrical controls model C (reec_c)

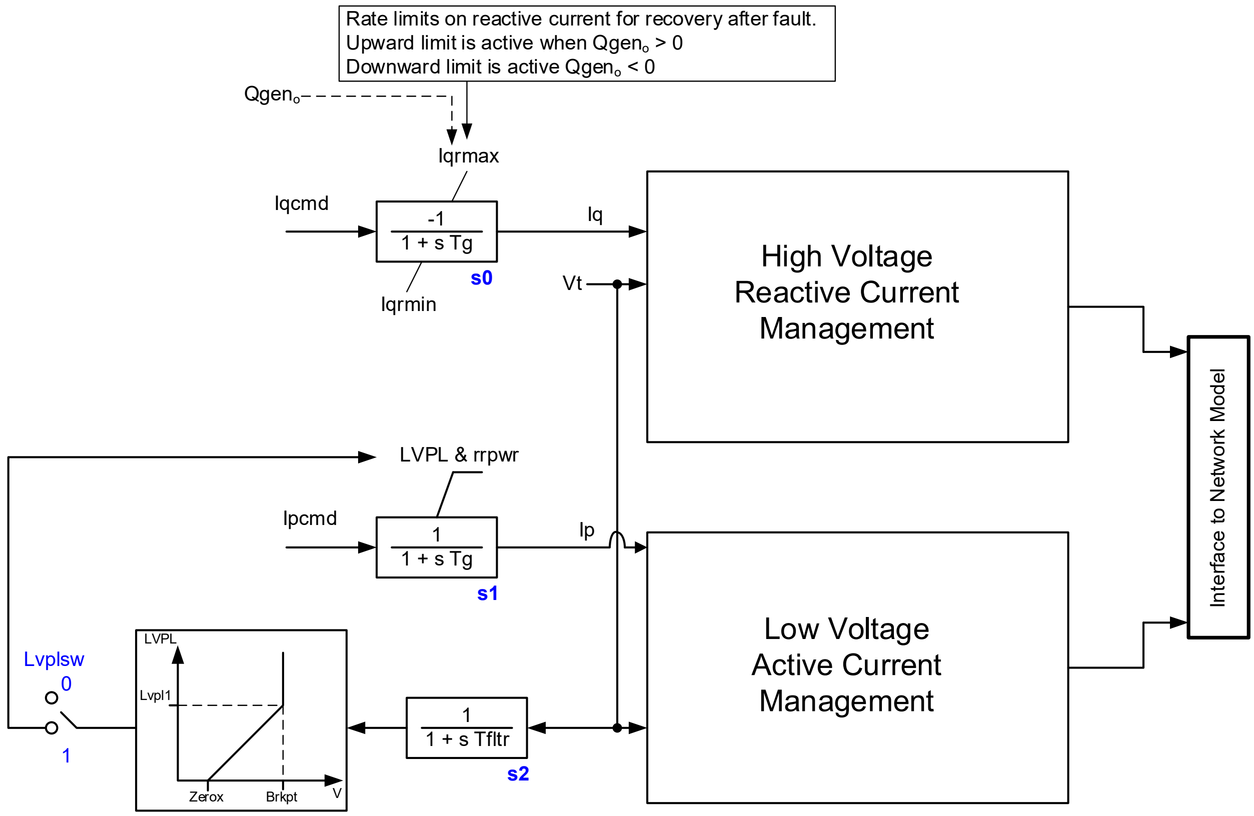

Figure D-4
Renewable energy generator/converter model A (regc_a)

E
CONVERSION BETWEEN THE 1ST AND 2ND GENERATION WIND TURBINE GENERATOR MODELS

E.1 Type 1 and Type 2WTG

For the type 1 WTG, the *wt1g* and *wt1t* models are still valid. The only change is to remove and replace the *wt1p* model with the *wt1p_b* model. The *wt1p* and *wtp1_b* models are incompatible. The reason is that the *wt1p* model was found, in early 2010 or so, to be deficient and not able to properly represent certain aspects of type 1 WTG controls. Thus, *wt1p_b* was developed as a simple and generic emulation of the general behavior of the pitch-control functionality used in type 1 WTGs with active-stall control (see [6], [17] and [14]).

If a type 1 or 2 WTG model is to be converted to the newer generation models and no data exists for using the *wt1p_b* model, it is suggested that at minimum the *wt1p* model be removed and no turbine controls be modeled. This may give conservative results, but it is certainly less likely to cause erroneous or optimistic results that may otherwise be yielded using the *wt1p* model. Furthermore, if it is known that the type 1 WTG being modeled is a stall regulated unit (i.e. with fix blades) then most certainly no turbine controls should be modeled at all since none exist on the actual WTG.

Although this has been explained elsewhere (e.g. [6]) for the sake of completeness, we will present a brief explanation here of the above statements. Figure E-1 shows the block diagram of the old *wt1p* so-called pseudo-governor model. As can be seen the model changes mechanical power based on changes in speed from the system reference frequency and the machines electrical power from the initial power reference. The issues with this model are therefore twofold:

- For cases where system frequency events are simulated the change in the slip-speed of the unit due to system frequency variations can results in a governor type action from the model. This was observed in some simulations in WECC and noted as an issue, since the type 1 and 2 turbines do not generally provide primary frequency response.
- Many type 1 OEMs provide functionality that quickly ramps down mechanical power when a nearby severe voltage dip (e.g. electrical fault) is detected in order to help with the low-voltage ride-through of the unit (see [14], Figure 2-12). This is not represented by this older model.

In contrast the simpler and newer model shown in Figure E-2, overcomes these concerns. First, it does not exhibit the unexpected behavior for frequency event simulations. Secondly, it provides for a rather simple emulation of the mechanical power ramp-down for nearby faults. See [6] and [17] for a more detailed explanation. In brief terms, this model emulates the fact that for many type 1WTGs with active-pitch control, the turbine controls will ramp down mechanical power when a nearby fault is observed, as described above. The model emulates this by looking at filtered terminal voltage (filter time constant *Tr*). If the voltage falls below specific set-points (see [1] of the applicable software user's manual for a full listing of the model parameters for the look-up table *F(Vt)*), then *Flag1* is changed by the model from 0 to 1. This then initiates the ramping down of the mechanical power at a rate of *rmin* to the P_{min}. This occurs for the amount of time determined from the look-up table *F(Vt)*[10]. Then once the timer times-out, Flag1 switches back to position 0, and the mechanical power ramps back up to the initial value *Po*, at a rate of *rmax*.

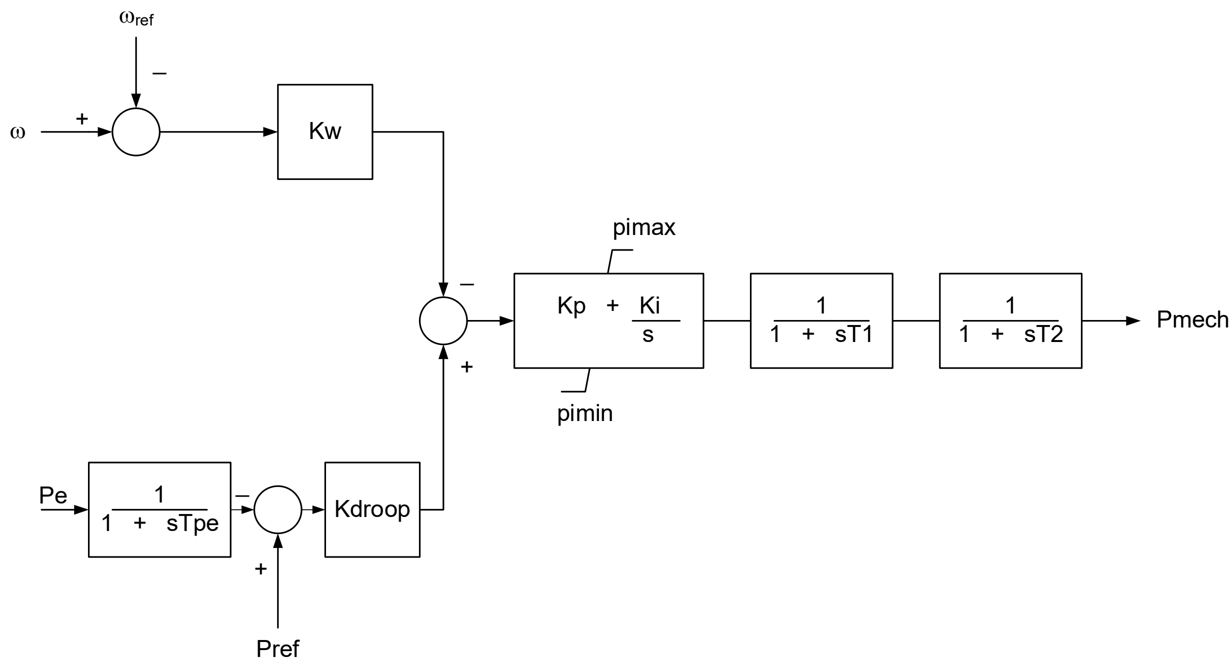

Figure E-1
Model *wt1p* which was part of the 1st generation generic WTG models and is no longer recommended for use.

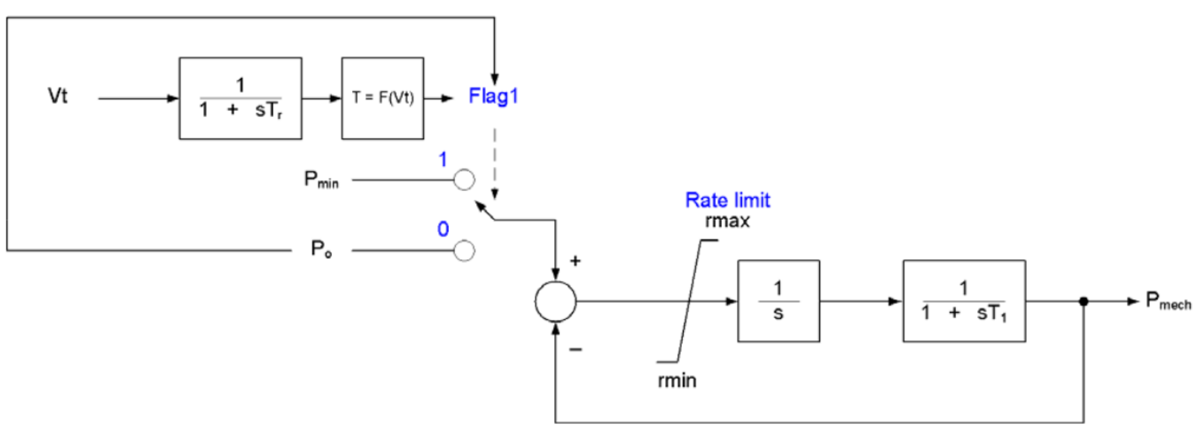

Figure E-2
Model *wt1p_b*, which is the new pitch-controller for the type 1 and 2 WTGs and the recommended model for use with these turbines.

[10] Briefly, the look-up table consists of four (4) voltage levels (v1, v2, v3, v4) and four-time settings (t1, t2, t3 and t4). If Vt falls below v1, then the time is set to t1. If it is below v2 and above v1, it is set to t2, and so on.

Summary:

- Continue to use *wt1g*, *wt1t* for type 1 WTGs, and *wt2g*, *wt2e*, and *wt2t* for type 2 WTGs.
- Do not use the *wt1p* and *wt2p* models – removed them from your data sets.
- Use the *wt1p_b* model, where data is available, for representing the behavior of the pitch-controller.
- For "stall" type 1 WTGs do not use any pitch-controller/pseudo-governor model at all.

<u>Disclaimer:</u> This report, and the organization/author that produced this report, make no guarantees or warranties, expressed or implied, with respect to the accuracy or applicability of the proposed conversion from the old to the new models for the type 1 and 2 WTGs. In all cases the best approach is to consult the equipment vendor to come up with appropriate parameters for the 2nd generation models to represent existing wind power plants.

E.2 Type 3 WTG

The following tables show how to convert the old (1st generation) generic stability models for type 3 WTGs to the new (2nd generation) models. The 1st generation models are a subset of the more general 2nd generation models, with a few exceptions:

1. The older model did not have a current limit on the output; this is estimated based on the flux limit.
2. The older model had the ability to bypass the second integrator in the reactive control path (i.e. set *vltflg* = 0 in the old model). This is not available in the new *reec_a* model, since at the time of developing the *reec_a* model the consensus was that this option is rarely if ever used.
3. The new RES suite of models were developed through a collaborative effort and so a single central model specification was developed [1]; this meant that the new models are essentially identical among the commercial software platforms that have adopted them. Much effort was made to ensure a one to one correspondence in the parameter lists and to compare simulations across the platforms. This is not necessarily true of the older (1st generation) models. As such, the user will quickly notice significant differences between the implementation of the 1st generation models across some of the software platforms. We clearly cannot address these issues now, since we neither had an influence on the initial development of the older (1st generation) models, nor is it wise to try to address the differences now when those models are to be in time replaced by the newer models.

Therefore, with the above in mind, the conversion tables developed here are based on the GE PSLF implementation of the 1st generation (older) generic models. The response of the converted model will ***<u>not be exactly the same</u>*** due to the differences explained above. In particular, if a two-mass shaft model is used *Dshaft* may have to be slightly modified in the 2nd generation model to yield the same level of damping.

The reader should also remember that the 2nd generation models were developed and validated against multiple measured field response of individual turbines from various OEMs (see [1], [2], [3] and [4]).

<u>Disclaimer:</u> This report, and the organization/author that produced this report, make no guarantees or warranties, expressed or implied, with respect to the accuracy or applicability of the conversion tables below. It should also be noted that the new 2nd generation models were developed with the expressed intention of making them more flexible to allow modeling of a larger variety of equipment. With that in mind where older (1st generation) models exist in dynamic databases to represent existing equipment, they may not necessarily have been very representative of the equipment performance (particularly for none GE units); thus, converting them through the conversion tables presented below will not yield a better representation of the units. In all cases the best approach is to consult the equipment vendor to come up with appropriate parameters for the 2nd generation models to represent the actual wind power plants (even in the case of GE units).

New Model	Older Model
regc_a	wt3g
reec_a	wt3e (part of)
repc_a	wt3e (part of)
wtgp_a	wt3p
wtgt_a	wt3t (part of)
wtga_a	wt3t (part of)
wtgq_a	wt3e (part of)

New Model	Old Model	Explanatory Comments
regc_a	**wt3g**	**Comment**
Lvplsw	Lvplsw	
Rrpwr	Rrpwr	
Brkpt	Brkpt	
Zerox	Zerox	
Lvpl1	Lvpl1	
Vtmax	Volim	
Lvpnt1	Lvpnt1	
Lvpnt0	Lvpnt0	
qmin	Iolim	
accel	Khv	
Tg	Td	
Tfltr	Tfltr	
iqrmax	999	disable limit; no equivalent in old model
iqrmin	-999	disable limit; no equivalent in old model
Xe	Lpp	disable limit; no equivalent in old model
wtgp_a	**wt3p**	**Comments**
Kiw	Kip	
Kpw	Kpp	
Kic	Kic	
Kpc	Kpc	
Kcc	0	disable; no equivalent in old model
Tpi	Tpi	
Pimax	Pimax	
Pimin	Pimin	
Piratmx	Pirat	
Piratmn	-Pirat	
wtgt_a	**wt3t**	**Comments**
Ht	Hfrac * H	
Hg	H - Ht	
Dshaft	Dshaft	In the wtgt_a model D does not exist; Dshaft may also need to be adjusted to get the same result as in the wt3t model
Kshaft	2*(2*pi*Freq1)^2*Ht*(Hg/H)	
wo	1	this value will be set to ωref upon initialization by the *wtgq_a* model
wtga_a	**wt3t**	**Comments**
Ka	Kaero	
Theta0	0	set to default; no equivalent in old model
wtgq_a	**wt3e**	**Comments**
Kip	Kitrq	
Kpp	Kptrq	
Tp	0	not available in old model so disable
Twref	Tsp	
Temax	Pmax/Wp100	
Temin	Pmin/Wpmin	
p1	Pmin	
spd1	Wpmin	
p2	0.2	
spd2	Wp20	
p3	0.6	
spd3	Wp60	
p4	Pwp100	
spd4	Wp100	
Tflag	0	not available in old model so disable

New Model	Old Model	Explanatory Comments
reec_a	**wt3e**	**Comments**
vdip	0	not available in old model so disable
vup	2	not available in old model so disable
Trv	Tr	
dbd1	-1	not available in old model so disable
dbd2	1	not available in old model so disable
kqv	0	not available in old model so disable
iqh1	0.001	not available in old model so disable
iql1	-0.001	not available in old model so disable
vref0	1	not available in old model so disable
iqfrz	0	not available in old model so disable
thld	0	not available in old model so disable
thld2	0	not available in old model so disable
Tp	Tp	
Qmax	Qmax	
Qmin	Qmin	
Vmax	Vmax	
Vmin	Vmin	
kqp	0	not available in old model so disable
kqi	Kqi	
kvp	0	not available in old model so disable
kvi	Kqv	
vref1	0	not available in old model so disable
tiq	0.02	set to default value
dpmax	Pwrat	
dpmin	-Pwrat	
Pmax	Pmax	
Pmin	Pmin	
imax	Xiqmax/Lpp	wt3e had no current limit so set to estimated current limit based on flux limit; Lpp comes from wt3g model
Tpord	Tpc	
pfflag	1 if varflg = -1 or 0 if varflg = 0 or 1	
vflag	1	set to 1 since no equivalent in old model
qflag	1 if vltflg = 1	for the case that vltflg = 0 in the old model, this option is not available in the new models; this was rarely used
pflag	0	must be set to 0 for the implementation in GE PSLF®
pqflag	1	set to 1 since no equivalent in old model
vq1	0	not available in old model so set to constant value across all voltages
iq1	Xiqmax	
vq2	0.1	
iq2	Xiqmax	
vq3	0.9	
iq3	Xiqmax	
vq4	1	
iq4	Xiqmax	
vp1	0	
ip1	ipmax	
vp2	0.1	
ip2	ipmax	
vp3	0.9	
ip3	ipmax	
vp4	1	
ip4	ipmax	
repc_a	**wt3e**	**Comments**
Tfltr	Tr	
Kp	Kpv	
Ki	Kiv	
Tft	0	not available in old model so disable
Tfv	Tc	
refflg	1	not available in old model so disable
vfrz	0	not available in old model so disable
rc	0	not available in old model so disable
xc	Xc	not available in old model so disable
Kc	0	not available in old model so disable
vcmpflg	1	the branch for monitoring the voltage is set differently in various software platforms; check the software user's manual
emax	99	not available in old model so disable
emin	-99	not available in old model so disable
dbd	0	not available in old model so disable
Qmax	Qmax	
Qmin	Qmin	
kpg	0	not available in old model so disable
kig	0	not available in old model so disable
Tp	Tp	
fdbd1	0	not available in old model so disable
fdbd2	0	not available in old model so disable
femax	0	not available in old model so disable
femin	0	not available in old model so disable
pmax	Pmax	not available in old model so disable
pmin	Pmin	not available in old model so disable
tlag	0	not available in old model so disable
ddn	0	not available in old model so disable
dup	0	not available in old model so disable
frqflg	0	not available in old model so disable
outflag	0	not available in old model so disable

E.3 Type 4 WTG

The following tables show how to convert the old (1st generation) generic stability models for type 4 WTGs to the new (2nd generation) models. It should be noted that the 1st generation models are essentially a subset of the more general 2nd generation models, with a few exceptions:

1. The older model had a rather more complex current limit, which was specific to one vendor. This can now be emulated using the current limit logic together with the *VDL1* and *VDL2* tables. This is shown below.
2. The *wt4t* model in the 1st generation (older) generic models has no real counterpart in the new 2nd generation generic RES models.
3. The new RES suite of models were developed through a collaborative effort and so a single central model specification was developed [1]; this meant that the new models are essentially identical among the commercial software platforms. Much effort was made to ensure a one to one correspondence in the parameter lists and to compare simulations across the platforms. This is not necessarily true of the older (1st generation) models. As such, the user will quickly notice significant differences between the implementation of the 1st generation models across some of the software platforms. We clearly cannot address these issues now, since we neither had an influence on the initial development of the older (1st generation) models, nor is it wise to try to address the differences now when those models are to be in time replaced by the newer ones.

Therefore, with the above in mind, the conversion tables developed here are based on the GE PSLF implementation of the 1st generation (older) generic models. The response of the converted model will not be exactly the same due to the differences explained above.

<u>Disclaimer:</u>* This report, and the organization/author that produced this report, make no guarantees or warranties, expressed or implied, with respect to the accuracy or applicability of the conversion tables below. It should also be noted that the new 2nd generation models were developed with the expressed intention of making them more flexible to allow modeling of a larger variety of models. With that in mind where older (1st generation) models exist in dynamic databases to represent existing equipment, they may not necessarily have been very representative of the equipment performance (particularly for none GE units); thus, converting them through the conversion tables presented below will not yield a better representation of the units. In all cases the best approach is to consult the equipment vendor to come up with appropriate parameters for the 2nd generation models to represent the actual wind power plants (even in the case of GE units).

New Model	Older Model
regc_a	wt4g
reec_a	wt4e (part of)
repc_a	wt4e (part of) and wt4t (part of)

New Model	Old Model	Explanatory Comments
regc_a	**wt4g**	**Comments**
Lvplsw	Lvplsw	
Rrpwr	Rrpwr	
Brkpt	Brkpt	
Zerox	Zerox	
Lvpl1	Lvpl1	
Vtmax	Volim	
Lvpnt1	Lvpnt1	
Lvpnt0	Lvpnt0	
qmin	Iolim	
accel	Khv	
Tg	Td	
Tfltr	Tfltr	
iqrmax	99	disable limit; no equivalent in old model
iqrmin	-99	disable limit; no equivalent in old model
Xe	0	disable; no equivalent in old model
reec_a	**wt4e**	**Comments**
vdip	0	disable; no equivalent in old model
vup	2	disable; no equivalent in old model
Trv	Tr	
dbd1	-1	disable; no equivalent in old model
dbd2	1	disable; no equivalent in old model
kqv	0	disable; no equivalent in old model
iqh1	0.001	disable; no equivalent in old model
iql1	-0.001	disable; no equivalent in old model
vref0	1	disable; no equivalent in old model
iqfrz	0	disable; no equivalent in old model
thld	0	disable; no equivalent in old model
thld2	0	disable; no equivalent in old model
Tp	Tpwr	
Qmax	Qmax	
Qmin	Qmin	
Vmax	Vmax	
Vmin	Vmin	
kqp	0	disable; no equivalent in old model
kqi	Kqi	
kvp	0	disable; no equivalent in old model
kvi	Kvi	
vref1	0	disable; no equivalent in old model
tiq	0.02	disable; no equivalent in old model
dpmax	99	disable; no equivalent in old model
dpmin	-99	
Pmax	1/fn	set so as to respect number of units online for representing the aggregate unit
Pmin	0	assume zero; no equivalent variable in old model
imax	ImaxTD	
Tpord	0	disable; no equivalent in old model; (could set Tpord to reasonable small value = 0.02 s)
pfflag	if (varflg =1 and pfaflg =1) then pfflag = 1; else pfflag = 0	set appropriate value
vflag	1	set appropriate value
qflag	1	set appropriate value
pflag	0	set appropriate value
Pqflag	Pqflag	
vq1	0	
iq1	Iqh1	if Iqh1 > Viqlim; then set this to Viqlim and if Iqh1 < qmax there is an error with the model
vq2	(Viqlim - Iqh1)/(Viqlim - qmax)	if Iqh1 > Viqlim; then set this to 0.5
iq2	Iqh1	if Iqh1 > Viqlim; then set this to (Viqlim -qmax)*0.5
vq3	1	
iq3	qmax	
vq4	1.05	
iq4	qmax	
vp1	0	
ip1	Iph1	
vp2	0.1	
ip2	Iph1	
vp3	0.9	
ip3	Iph1	
vp4	1	
ip4	Iph1	

New Model	Old Model	Explanatory Comments
repc_a	**wt4e**	**Comments**
Tfltr	Tr	
Kp	Kpv	
Ki	Kiv	
Tft	0	disable since no equivalent in old model
Tfv	Tc	
refflg	1	disable since no equivalent in old model
vfrz	0	disable since no equivalent in old model
rc	0	disable since no equivalent in old model
xc	0	disable since no equivalent in old model
Kc	0	disable since no equivalent in old model
vcmpflg	1	disable since no equivalent in old model
emax	99	disable since no equivalent in old model
emin	-99	disable since no equivalent in old model
dbd	0	disable since no equivalent in old model
Qmax	Qmax	
Qmin	Qmin	
kpg	0	disable since no equivalent in old model
kig	0	disable since no equivalent in old model
Tp	Tpwr	
fdbd1	0	disable since no equivalent in old model
fdbd2	0	disable since no equivalent in old model
femax	0	disable since no equivalent in old model
femin	0	disable since no equivalent in old model
pmax	0	disable since no equivalent in old model
pmin	0	disable since no equivalent in old model
tlag	0	disable since no equivalent in old model
ddn	0	disable since no equivalent in old model
dup	0	disable since no equivalent in old model
frqflg	0	disable since no equivalent in old model
outflag	0	disable since no equivalent in old model

F

PARAMETER LIST FOR THE 2ND GENERATION GENERIC MODELS

The following tables were initially developed as a spreadsheet through collaboration with the WECC Renewable Energy Modeling Task Force (REMTF) and receiving comments and input from various equipment vendors and other stake holders. We are truly grateful to them all.

These tables are provided simply as a guide. They are not to be taken as definitive and final. In the end the values of the parameters of the models must be based on thorough consultation with the equipment vendor, and evidence from testing and/or model validation exercises.

REGC_A:

regc_a	Range	Comment	Units
Xe	0 - 1	For type 4 WTGs typically it is set to 0; for type 3 WTGs some vendors will supply a number, typically around 0.5 to 0.8 pu	pu
Lvplsw	1 or 0	Either value appropriate; set as instructed by OEM	N/A
Rrpwr	1 to 20	Rate at which active current (power) recovers after a fault; typical values are between 2 to 10 pu/sec	pu/s
Brkpt	0.05 - 0.9	Used only when Lvplsw = 1; voltage point below which active current is linearly reduced as a function of voltage until it reaches zero at Zerox	pu
Zerox	0.02 - 0.5	Used only when Lvplsw = 1; voltage point below which active current become zero	pu
Lvpl1	1.1 - 1.5	Active current limit at Brkpt voltage and above; typically set to a value such as 1.22	pu
Vtmax	1.1 - 1.3	These parameters are all associated with the numerical interface between the "current source" and the network equations. They are essential for maintaining numerical stability and convergence of the network solution. Vtmax, Lvpnt1, Lvpnt0, qmin and accel should not be set to "zero".	pu
Lvpnt1	0.1 - 0.8		pu
Lvpnt0	0.05 - 0.4		pu
qmin	-1.3		pu
accel	0.7 - 1.0	numerical acceleration factor	N/a
Tg	0.02 - 0.05	Emulated delay in converter controls	s
Tfltr	0.02 - 0.05	Filtering time constant for voltage measurement	s
iqrmax	1 - 999	Rate at which reactive current (power) recovers after a fault when the initial reactive output of the unit is less than zero; typically set to -999	pu/s
iqrmin	-999 to -1	Rate at which reactive current (power) recovers after a fault when the initial reactive output of the unit is greater than zero; typically set to -999	pu/s
Relational Requirements	Xe >= 0		
	rrpwr > 0		
	Brkpt > Zerox		
	Lvpnt1 > Lvpnt0		
	qmin < 0		
	accel > 0		
	iqrmax > 0		
	iqrmin < 0		
	time constants	check software user's manual; typically can be zero, but if greater than zero must be at least three to four times integration time-step	

REEC_A:

reec_a	Range	Comment	Units
vdip	0 - 0.9	**Note: to disable vdip it is typical to set it to -1;** The voltage below which voltage-dip logic is initiated	pu
vup	1.1 - 1.3	**Note: to disable vup it is typical to set it to 2;** The voltage above which voltage-dip/up logic is initiated	pu
trv	0 - 0.1	voltage measurement transducer time constant	s
dbd1	-0.1 - 0	lower deadband in voltage error	pu
dbd2	0 - 0.1	upper deadband in voltage error	pu
kqv	0 - 20	reactive current injection proportional gain; active only during a voltage-dip/rise; 0 to disable	pu/pu
iqh1	1 to Imax	maximum limit on reactive current injection during a voltage-dip/rise	pu
iql1	-Imax to -1	minimum limit on reactive current injection during a voltage-dip/rise	pu
vref0	N/A	if vref0 is left as zero most commercial software tools will initialize it appropriately; otherwise typically set to 1 pu (nominal voltage)	pu
iqfrz	0 - Iqh1	Value at which reactive current injection (during a voltage-dip) is held for *thld* seconds following a voltage dip if *thld* > 0, p.u.; 0 to disabl	pu
thld	-1 to 1	Time for which reactive current injection is held at some value following termination of the voltage-dip; if value is +ve, then current is held at *iqfrz* , if -ve then held at the value just prior to ending of the voltage-dip; 0 to disable	s
thld2	0 - 1	Time for which active current is held at its value during a voltage-dip, following the termination of the voltage-dip; 0 to disable	s
tp	0 - 1	Electrical power transducer time constant	s
qmax	0 - 1	Maximum reactive output limit (to disable set to 9999)	pu
qmin	-1 - 0	Minimum reactive output limit (to disable set to -9999)	pu
vmax	1.05 - 1.1	Voltage control maximum limit; typically 110% (higher values than shown may be used in some cases)	pu
vmin	0.8 - 0.95	Voltage control minimum limit; typically 90% (lower values than shown may be used in some cases)	pu
kqp	0 - 999	These are tunable PI gains of the local q-control	pu/pu
kqi	0 - 999		pu/pu/s
kvp	0 - 999	These are tunable PI gains of the local v-control	pu/pu
kvi	0 - 999		pu/pu/s
vref1	0	Typically set to zero; only change if instructed by OEM data, in some cases may be set to 1 or other appropriate value	pu
tiq	0 - 0.02	Controller time-constant	s
dpmax	0.1 - 99	Up ramp-rate on power reference; typically set to 99 to disable	pu/s
dpmin	-99 to -0.1	Down ramp-rate on power reference; typically set to -99 to disable	pu/s
pmax	1.0 - 1.15	maximum power reference (high values than shown may be used in some cases)	pu
pmin	0 - 0.05	minimum power reference	pu
imax	1 to 2	Maximum current limit of the device	pu
tpord	0.02 - 1.0	time constant for power order	s
pfflag	0 or 1	See spreadsheet tab on flag settings	N/A
vflag	0 or 1		N/A
qflag	0 or 1		N/A
pflag	0 or 1		N/A
pqflag	0 or 1		N/A
vq1	N/A	These are the voltage-dependent limits on active and reactive current. There is no typical set of values. Presently, looking at extending these to ten (10) points and to extend their features. However, as they stand today, the following guidelines should be followed: (i) do not set any iq/ip values to a negative number, (ii) the values should generally be monotonically increasing, and (iii) to disable the block simply set all iq/ip values to Imax for a set of monotonically increases voltage values. Recommendation: use values from OEM data - be aware that the number of points and some functionally needs to be improved in future model updates before these tables can emulate certain OEM data.	pu
iq1			pu
vq2			pu
iq2			pu
vq3			pu
iq3			pu
vq4			pu
iq4			pu
vp1			pu
ip1			pu
vp2			pu
ip2			pu
vp3			pu
ip3			pu
vp4			pu
ip4			pu
Relational Requirements	vup > vdip		
	iqh1 > iql1		
	dbd2 >= dbd1		
	iqfrz >= 0		
	qmax > qmin; qmax > 0		
	pmax > pmin > 0		
	vmax > vmin		
	Kqv >= 0		
	dpmax > dpmin		
	imax > 0		
	kqp, kqi, kvp, kvi >= 0	These are tunable gains so any value within reason, that is greater than zero and tuned to give a good response is acceptable.	
	time constants	check software user's manual; typically can be zero, but if greater than zero must be at least three to four times integration time-step	

REEC_B: (model not recommended for use any more – table provided for completeness)

reec_b	Range	Comment	Units
vdip	0 - 0.9	**Note: to disable vdip it is typical to set it to -1;** The voltage below which voltage-dip logic is initiated	pu
vup	1.1 - 1.3	**Note: to disable vup it is typical to set it to 2;** The voltage above which voltage-dip/up logic is initiated	pu
trv	0 - 0.1	voltage measurement transducer time constant	s
dbd1	-0.1 - 0	lower deadband in voltage error	pu
dbd2	0 - 0.1	upper deadband in voltage error	pu
kqv	0 - 20	reactive current injection proportional gain; active only during a voltage-dip/rise; 0 to disable	pu/pu
iqh1	1 to Imax	maximum limit on reactive current injection during a voltage-dip/rise	pu
iql1	-Imax to -1	minimum limit on reactive current injection during a voltage-dip/rise	pu
vref0	N/A	if vref0 is left as zero most commercial software tools will initialize it appropriately; otherwise typically set to 1 pu (nominal voltage)	pu
tp	0 - 1	Electrical power transducer time constant	s
qmax	0 - 1	Maximum reactive output limit (to disable set to 9999)	pu
qmin	-1 - 0	Minimum reactive output limit (to disable set to -9999)	pu
vmax	1.05 - 1.1	Voltage control maximum limit; typically 110% (higher values than shown may be used in some cases)	pu
vmin	0.8 - 0.95	Voltage control minimum limit; typically 90% (lower values than shown may be used in some cases)	pu
kqp	0 - 999	These are tunable PI gains of the local q-control	pu/pu
kqi	0 - 999		pu/pu/s
kvp	0 - 999	These are tunable PI gains of the local v-control	pu/pu
kvi	0 - 999		pu/pu/s
tiq	0 - 0.02	Controller time-constant	s
dpmax	0.1 - 99	Up ramp-rate on power reference; typically set to 99 to disable	pu/s
dpmin	-99 to -0.1	Down ramp-rate on power reference; typically set to -99 to disable	pu/s
pmax	1 - 1.15	maximum power reference	pu
pmin	0 - 0.05	minimum power reference	pu
imax	1 to 2	Maximum current limit of the device	pu
tpord	0 - 1	power order time constant	s
pfflag	0 or 1	See spreadsheet tab on flag settings	N/A
vflag	0 or 1		N/A
qflag	0 or 1		N/A
pflag	0 or 1		N/A
pqflag	0 or 1		N/A
Relational Requirements	vup > vdip		
	iqh1 > iql1		
	dbd2 >= dbd1		
	iqfrz >= 0		
	qmax > qmin; qmax > 0		
	vmax > vmin		
	pmax > pmin > 0		
	Kqv >= 0		
	dpmax > dpmin		
	imax > 0		
	kqp, kqi, kvp, kvi >= 0	These are tunable gains so any value within reason, that is greater than zero and tuned to give a good response is acceptable.	
	time constants	check software user's manual; typically can be zero, but if greater than zero must be at least three to four times integration time-step	

REEC_C:

reec_c	Range	Comment	Units
vdip	0 - 0.9	**Note: to disable vdip it is typical to set it to -1;** The voltage below which voltage-dip logic is initiated	pu
vup	1.1 - 1.3	**Note: to disable vup it is typical to set it to 2;** The voltage above which voltage-dip/up logic is initiated	pu
trv	0 - 0.1	voltage measurement transducer time constant	s
dbd1	-0.1 - 0	lower deadband in voltage error	pu
dbd2	0 - 0.1	upper deadband in voltage error	pu
kqv	0 - 20	reactive current injection proportional gain; 0 to disable	pu/pu
iqh1	1 to Imax	maximum limit on reactive current injection	pu
iql1	-Imax to -1	minimum limit on reactive current injection	pu
vref0	N/A	if vref0 is left as zero most commercial software tools will initialize it appropriately; otherwise typically set to 1 pu (nominal voltage)	pu
SOCini	SOCmin to SOCmax	Initial state of charge; must be between SOCmin and SOCmax	pu
SOCmax	0.8 - 1	Maximum allowable state of charge in pu (these are typical ranges, they could be different for various projects)	pu
SOCmin	0 - 0.2	Minimum allowable state of charge in pu (these are typical ranges, they could be different for various projects)	pu
T	N/A	Time it takes for the battery to discharge when putting out 1 pu power; typically set to 9999 since most batteries are large as compared to the typical simulation time in a transient stability study	s
tp	0 - 1	Electrical power transducer time constant	s
qmax	0 - 1	Maximum reactive output limit (to disable set to 9999)	pu
qmin	-1 - 0	Minimum reactive output limit (to disable set to -9999)	pu
vmax	1.05 - 1.1	Voltage control maximum limit; typically 110% (higher values than shown may be used in some cases)	pu
vmin	0.8 - 0.95	Voltage control minimum limit; typically 90% (lower values than shown may be used in some cases)	pu
kqp	0 - 999	These are tunable PI gains of the local q-control	pu/pu
kqi	0 - 999		pu/pu/s
kvp	0 - 999	These are tunable PI gains of the local v-control	pu/pu
kvi	0 - 999		pu/pu/s
vref1	0	Typically set to zero; only change if instructed by OEM data	pu
tiq	0 - 0.02	Controller time-constant	s
dpmax	0.1 - 99	Up ramp-rate on power reference; typically set to 99 to disable	pu/s
dpmin	-99 to -0.1	Down ramp-rate on power reference; typically set to -99 to disable	pu/s
pmax	1 - 1.15	maximum power reference	pu
pmin	-1 to 0	minimum power reference	pu
imax	1 to 2	Maximum current limit of the device	pu
tpord	0 - 1	power order time constant	s
pfflag	0 or 1	See spreadsheet tab on flag settings	N/A
vflag	0 or 1		N/A
qflag	0 or 1		N/A
pflag	0 or 1		N/A
pqflag	0 or 1		N/A
vq1	N/A	These are the voltage-dependent limits on active and reactive current. There is no typical set of values. Presently, looking at extending these to ten (10) points and to extend their features. However, as they stand today, the following guidelines should be followed: (i) do not set any iq/ip values to a negative number, (ii) the values should generally be monotonically increasing, and (iii) to disable the block simply set all iq/ip values to Imax for a set of monotonically increases voltage values. Recommendation: use values from OEM data - be aware that the number of points and some functionally needs to be improved in future model updates before these tables can emulate certain OEM data.	pu
iq1			pu
vq2			pu
iq2			pu
vq3			pu
iq3			pu
vq4			pu
iq4			pu
vp1			pu
ip1			pu
vp2			pu
ip2			pu
vp3			pu
ip3			pu
vp4			pu
ip4			pu
Relational Requirements	vup > vdip		
	iqh1 > iql1		
	dbd2 >= dbd1		
	iqfrz >= 0		
	qmax > qmin; qmax > 0		
	pmax > pmin	Note Pmax should be greater than zero; but since this model is typically used for Energy Storage Pmin will be negative	
	vmax > vmin		
	Kqv >= 0		
	dpmax > dpmin		
	imax > 0		
	kqp, kqi, kvp, kvi >= 0	These are tunable gains so any value within reason, that is greater than zero and tuned to give a good response is acceptable.	
	SOCmax >= SOCini >= SOCmin		
	time constants	check software user's manual; typically can be zero, but if greater than zero must be at least three to four times integration time-step	

REPC_A (and REPC_B):

repc_a	Range	Comments	Units	
tfltr	0 - 0.05	Filtering time constant for transducers; **Note:** to represent delays in communication or other aspects this time constant can sometimes be set as high as 2 seconds	s	
kp	0 - 20	Proportional control gain	pu/pu	
ki	0 - 10	Integral control gain	pu/pu/s	
tft	0	Lead time constant; typically set to zero unless otherwise specified by OEM	s	
tfv	0.02 - 0.2	Lag time constant	s	
refflg	0 or 1	0 - constant Q control; 1 - voltage control	N/A	**Note with repc_b a third option (=2) for power factor control here**
vfrz	0 - 0.9	Voltage below which the integrator state (of the volt/var controller) is frozen	pu	
rc	0	Resistive part of current compensation (typically set to zero)	pu	
xc	0 to 0.05	Reactive part of current compensation	pu	
Kc	0 to 0.15	Reactive droop	pu	
vcmpflg	0 or 1	0 - reactive droop; 1 - current compensation		
emax	0.05 to 99	Maximum voltage/var error		
emin	-99 to -0.05	Minimum voltage/var error		
dbd	0 - 0.1	deadband; typically zero or a small number, e.g. 0.01		
qmax	N/A	**IMPORTANT NOTE:** qmax/qmin is the maximum/minimum reactive limits at the plant level if the down-stream reec_* model is in local Q/V or Q control, however, if the reec_* model is in local V-control (i.e. Vflag = 0 and Qflag = 1 in the reec_* model) then qmax/qmin become voltage limits. So when they are reactive limits, typical values might be 0.4/-0.4, while if they are voltage limits typical values might be 1.1/0.9	pu	
qmin	N/A		pu	
kpg	0 - 10	Proportional control gain	pu/pu	
kig	0 - 10	Integral control gain	pu/pu/s	
tp	0 - 1	Power measurement transducer time constant	s	
fdbd1	-0.01 to 0	Frequency deadband, downside; a typical value might be -0.0003 pu	pu	
fdbd2	0 to 0.01	Frequency deadband, downside; a typical value might be 0.0003 pu	pu	
femax	0.01 to 99	Maximum frequency error	pu	
femin	-99 to -0.01	Minimum frequency error	pu	
pmax	1 to 1.15	Maximum power; **IMPORTANT NOTE:** when modeling a RES power plant operating at it maximum available resource limit (e.g. producing maximum power from current available wind or solar energy) then Pmax may be set to a value below the "nameplate" maximum capability of the plant to avoid the plant responding to a simulate under-frequency event. Thus, a value less than 1 may be reasonable in many cases. This, however, is a decision to be made by the planner using the model, rather than the GO providing the model. The model, as provided by a GO, should indicate here the maximum "nameplate" capability of the plant.	pu	
pmin	0 - 0.1	Minimum power	pu	
tlag	0 - 1	Frequency response lag time constant	s	
ddn	0 - 30	Downside droop gain; typically, wind and PV plants will have a droop of 4 to 5% thus ddn = 1/0.04 to 1/0.05, i.e. 25 to 20.	pu/pu	
dup	0 - 30	Upside droop gain; typically, wind and PV plants will have a droop of 4 to 5% thus ddn = 1/0.04 to 1/0.05, i.e. 25 to 20.	pu/pu	
frqflg	0 or 1	0 - no primary frequency response; 1 - with primary frequency response	N/A	
outflag	0 or 1	0 - if output of the model is a Qref; 1 - if output of the model is Vref (see important note under qmax/qmin above)	N/A	**Note these two parameters do not apply to repc_b since it is always on system MVA base; it has a set of parameters that follow which link it to**
puflag	0 or 1	0 - Pbranch and Qbranch feedback to model are on system MVA base; 1 - Pbranch/Qbranch are on the model MVA base	N/A	
Relational Requirements	kp, ki, kpg, kig	These are tunable gains so any value within reason, that is greater than zero and tuned to give a good response is acceptable.		
	emax > emin			
	qmax > qmin; qmax > 0			
	pmax > pmin	Note Pmax should be greater than zero, but Pmin might be negative for an Energy Storage Plant		
	femax > femin			
	femax > 0			
	femin < 0			
	fdbd1 >=0			
	fdbd2 <= 0			
	ddn and dup >= 0			
	time constants	check software user's manual; typically can be zero, but if greater than zero must be at least three to four times integration time-step		

Flag Settings in REEC_* and REPC_* models:

Functionality	Models Needed	reec_* flags			repc_a flag	Comments
		PfFlag	Vflag	Qflag	RefFlag	
Constant pf control at unit level	reec_*	1	0 or 1	0	N/A	
Constant Q control at unit level	reec_*	0	0 or 1	0	N/A	
V-control only at unit level	reec_*	0	0	1	N/A	
Q/V control only at unit level	reec_*	0	1	1	N/A	
Plant level Q control + unit level Q control	reec_* + repc_a	0	0 or 1	0	0	
Plant level V control + unit level V control	reec_* + repc_a	0	0 or 1	0	1	**In this case see note on qmax/qmin and setting outflag, in repc_a**
Plant level Vcontrol + unit level Q control	reec_* + repc_a	0	0	1	1	
Plant level V Control + coordinated unit level Q/V control	reec_* + repc_a	0	1	1	1	
Plant level Q Control + coordinated unit level Q/V control	reec_* + repc_a	0	1	1	0	

WTGP_A:

wtgp_a	Range	Comments	Units
kiw	1 - 50	pitch controller integral gain	deg/pu/s
kpw	1 - 200	pitch controller proportional gain	deg/pu
kic	1 - 50	pitch controller integral gain	deg/pu/s
kpc	1 - 10	pitch controller proportional gain	deg/pu
kcc	0 - 1	cross term gain	pu/pu
tpi	0.1 - 1	pitch time constant	s
pimax	25 - 35	maximum pitch angle	deg
pimin	-5 - 0	minimum pitch angle	deg
piratmx	5 - 15	maximum rate of increase of pitch angle	deg/s
piratmn	-15 to -5	maximum rate of decrease of pitch angle	deg/s
Relational Requirements	kiw, kpw, kic, kpc	These are tunable gains so any value within reason, that is greater than zero and tuned to give a good response is acceptable.	
	kcc >= 0		
	pimax > pimin		
	piratmx > 0		
	piratmn < 0		
	time constants	check software user's manual; typically can be zero, but if greater than zero must be at least three to four times integration time-step	

WTGT_A:

wtgt_a	Range	Comments	Units
Ht	4 to 6	The inertia of the turbine. **MUST** be obtained form OEM; typically quite high and around 5 or so.	MWs/MVA
Hg	0.5 to 1	The inertia of the generator. **MUST** be obtained form OEM; typically low and around 0.7 or so.	MWs/MVA
Dshaft	1 to 2	The estimated damping factor; in reality much of this is achieved by the active-drive train damping controls in type 3 & 4 machines that is not explicitly modeled.	pu/pu
Kshaft	90 - 150	Shaft spring constant. This should be either obtained from the OEM or calculated based on the following information from the OEM: Kshaft = 2*(2*pi*Freq1)^2*Ht*(Hg/H), where Freq1 = frequency in Hz of the first torsional mode, H = Ht + Hg = total shaft inertia in MWs/MVA	pu/pu
wo	0.7 - 1.3	**Note:** this value will be set to Wref upon initialization by the *wtgq_a* model; if the model is being used with a type 4A model, then typically this is set to 1 pu	pu
Relational Requirements	Ht > Hg		
	Dshaft > 0		
	Kshaft > 0		
	1.4 > wo > 0.6	suggested check; typically neither type 3 nor type 4 WTGs will be able to operate outside this range of speeds	

WTGA_A:

wtga_a	Range	Comments	Units
Ka	0.005 - 0.008	Aerodynamics gain factor (provided by OEM); a typical value is 0.007	pu/deg^2
Theta0	0 - 10	The initial pitch angel; it is typically set to 0 to indicate WTG is producing maximum available power. When modeling primary frequency response, and using this model, set Theta0 to a non-zero value such as 10.	deg
Relational Requirements	Ka > 0		
	Theta0 >= 0		

WTGQ_A:

wtgq_a	Range	Comments	Units
kip	0.1 - 1	Integral gain of torque controller	pu/pu/s
kpp	1 to 10	Proportional gain of torque controller	pu/pu
tp	0.05 - 1	Power measurement time constant	s
twref	10 to 60	Speed reference time constant	s
temax	0.8 - 1.2	Maximum torque	pu
temin	0.05 - 0.08	Minimum torque	pu
p1	N/A	OEM provided speed versus power curve. A typical curve might be: ps = [0.2 0.4 0.6 0.74] and spds = [0.69 0.78 0.98 1.2]	pu
spd1	N/A		pu
p2	N/A		pu
spd2	N/A		pu
p3	N/A		pu
spd3	N/A		pu
p4	N/A		pu
spd4	N/A		pu
Tflag	0 or 1	From OEM; type of torque control	N/A
Relational Requirements	kip, kpp >= 0	These are tunable gains so any value within reason, that is greater than zero and tuned to give a good response is acceptable.	
	twref > 0		
	temax > temin		
	1.4 > spd4 > spd3 > spd2 > spd1 > 0.6	suggested check; typically neither type 3 nor type 4 WTGs will be able to operate at speeds below 0.6 pu or above 1.4 pu	
	1.0 > p4 > p3 > p3 > p1 > 0.1	suggested check; typical range the values of the p's should lie	

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com