

Proposed Changes to the WECC WT4 Generic Model for Type 4 Wind Turbine Generators

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1

INTRODUCTION

1.1 Background

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

As an active participant in these various industry groups, EPRI has been working closely with these industry groups and several of the wind turbine generator manufacturers, as well as with the National Renewable Energy Laboratory, to help in the process of both the development and validation of these generic models. This recent work is summarized in the EPRI 2011 report [2].

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

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

In this summary report, we provide the latest results associated with the development of the second generation of type 4 generic wind turbine generator (WTG) models.

The EPRI report [2] gives a brief outline of the history of these model developments as well as the issues identified with the first generation generic models and the various proposals discussed in the WECC REMTF and IEC TC88 WG27 groups. Here we do not delve into those detail discussions, but rather jump straight to the present proposal and model specification for the second generation generic type 4 mode – validation results are also presented.

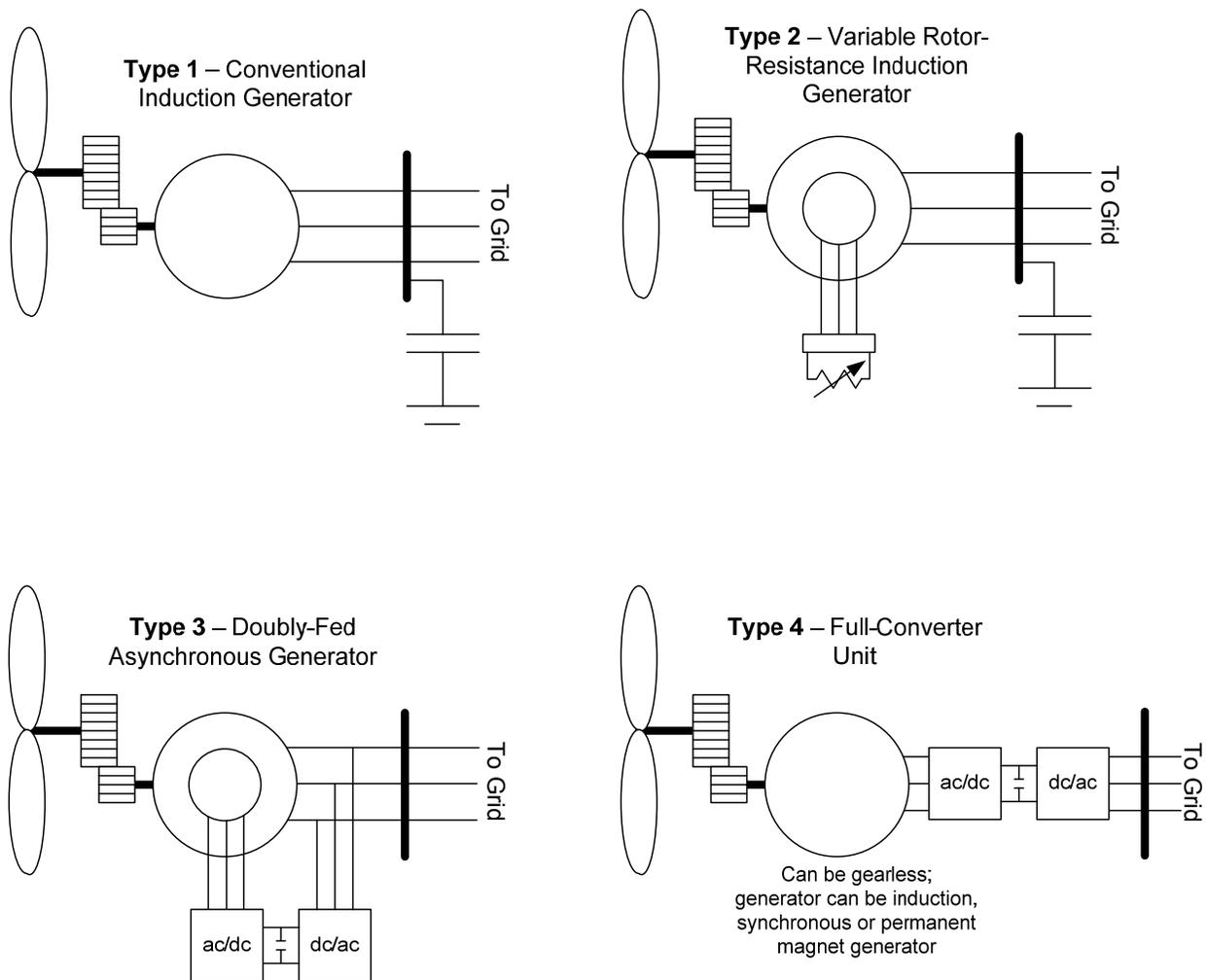


Figure 1-1: The four many wind turbine technologies.

Finally, with respect to the naming convention of the models, after the June 2012 WECC REMTF meeting it was agreed to change the names of these new model modules in order to make them truly generic and usable for any appropriate renewable generation. For example, the *wtgg* would be called the *regc_a* (renewable energy generator/converter model), etc. These changes are reflected here. Also, these models proposed here will have a version number designated by “_a” to allow for future revisions.

2

THE EXISTING FIRST GENERATION GENERIC WT4 MODEL

The generic WT4 model, as it stands presently in the two major commercial simulation tools used in the WECC (GE PSLF® and Siemens PTI PSS®E) is as shown in the figures below.

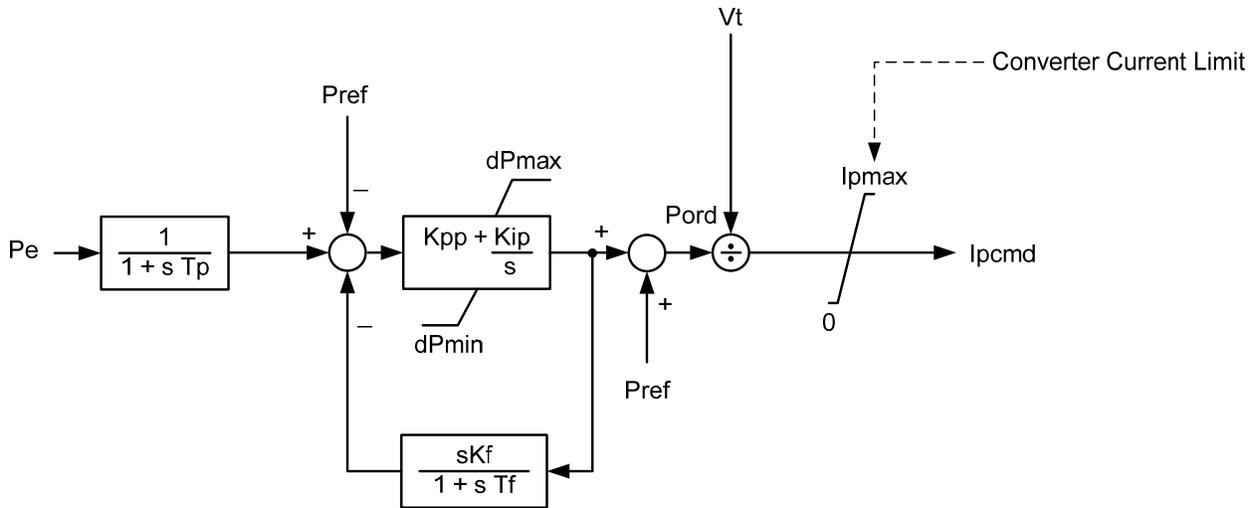


Figure 2-1: First generation type 4 generic model, P-control.

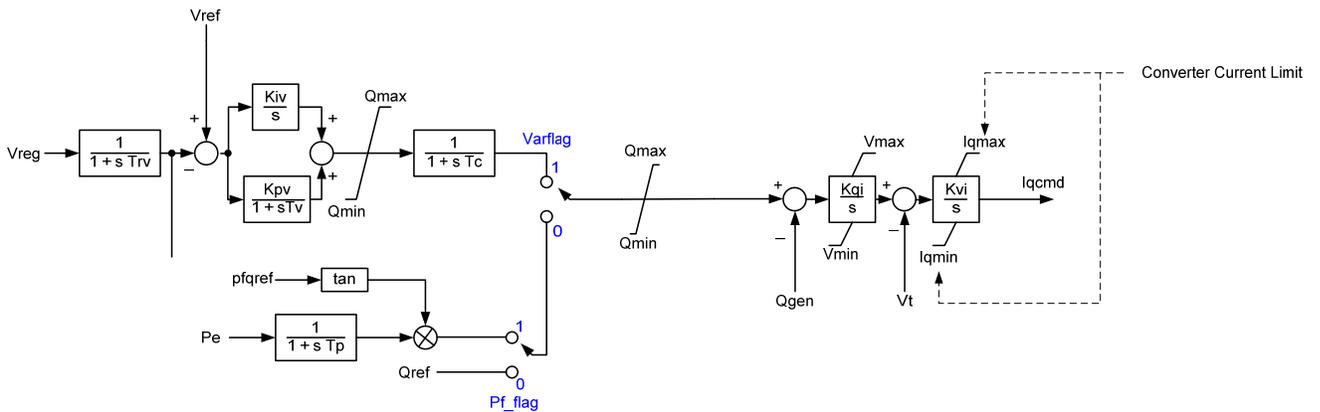


Figure 2-2: First generation type 4 generic model, Q-control.

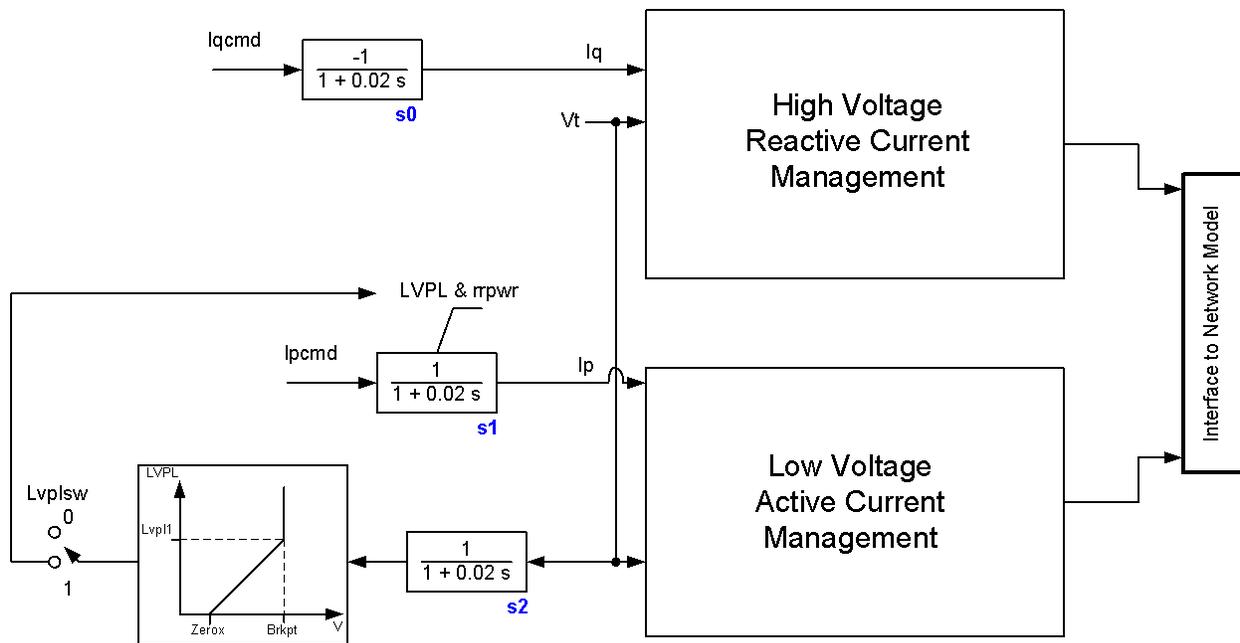


Figure 2-3: First generation type 4 generic model, generator/converter. See Appendix D for an explanation of the logic inside the two blocks “high-voltage reactive current management” and “low-voltage active current management”.

The real and reactive current limits (I_{qmax} , I_{qmin} and I_{pmax}) are then determined by the logic provided in Appendix A.

Through various discussions, particularly at the IEC TC88 WG27, proposed changes to this model have been made in order to make it more suitable for simulating a wider range of possible type 4 WTGs. The history of these proposed changes and discussions may be found in references [3] to [8], with validation cases provided in [6], [7] and [8]. A concise summary of all these efforts is provided in [2], which is available on-line for download.

Here we will not go over the details of the various proposals but will in the next section present the final proposal and subsequently illustrate some validation cases. The final proposal presented here has some additional changes as compared to [8], based on further discussions within the IEC TC88 WG27 group. Furthermore, here the model is presented in a modular format that is similar to the previous WECC implementation. This is presented in the next section.

3

THE PROPOSED SECOND GENERATION GENERIC WT4 MODEL

Figure 3-1 shows the overall structure of the second generation type 4 WTG model. That is, we are proposing that the model should have four (4) parts:

1. The renewable energy generator/converter model (*regc_a*), which has inputs of real (*Ipcmd*) and reactive (*Iqcmd*) current command and outputs of real (*Ip*) and reactive (*Iq*) current injection into the grid model.
2. The renewable energy electrical controls model (*reec_a*), which has inputs of real power reference (*Pref*) that can be externally controlled, reactive power reference (*Qref*) that can be externally controlled and feedback of the reactive power generated (*Qgen*). The outputs of this model are the real (*Ipcmd*) and reactive (*Iqcmd*) current command.
3. The emulation of the driven-train (*wtgt_a*) for simulating drive-train oscillations. The output of this model is speed (*spd*).
4. A simple renewable energy plant controller (*repc_a*), which has inputs of either voltage reference (*Vref*) and measured/regulated voltage (*Vreg*) at the plant level, or reactive power reference (*Qref*) and measured (*Qgen*) at the plant level. It also has inputs of reference power (*Plant_pref*) and measure generated power (*Pgen*), and reference frequency (*Freq_ref*) and measured frequency (*Freq*). The outputs of the *repc_a* model are the reactive power and real power command that connect to *Qref* and *Pref* on the *reec_a* model.

Figure 3-2, Figure 3-3, Figure 3-4, and Figure 3-5 show, respectively, these four models. Appendix B provides the logic for the current limit shown in Figure 3-3 . Appendix C provides the list of parameters for each of the four models and describes there use.

Note that here these model have not been specifically named WT4 since it is believed that it is quite plausible that some of these models will be equally applicable to building the second generation type 3 WTG model – which is presently being worked on – and so it may be appropriate to keep the names generic as presented here. For example, the *reec_a* model is applicable to both type 3 and 4 wind turbine generators, as well as solar PV.

The *repc_a* model has been refined in this revision of the document with the addition of a simple droop control for emulating primary frequency control. This is intended mainly for emulating down-regulation for over-frequency events, but an up-regulation feature has also been provided. This is a simple model and is not based on any validation work and is based on recommendations at the last WECC REMTF meeting of 3/20/12. This may be refined in the future. ***Care must be taken not to simulate up-regulation (i.e. increasing plant output with decreasing frequency) where it is not physically meaningful – e.g. when the plant is converting the available incident wind energy to electrical power, which is certainly the typical operating condition of a wind power plant.***

For completeness, and based on various comments from the WECC REMTF and IEC group members, various options (voltage, Q or pf control, with and without deadband etc.) have been provided for the control options at the plant level. None of these have been tested with any data yet at the plant level controller. Thus, care must be taken with the selection of these options and appropriately setting the controller parameters so as to not produce an undesired response.

In the next section validation cases are presented to illustrate the use and validity of this model for representing at least four (4) different vendors equipment.

Table 3-1 and Table 3-2 provide a simply summary of the various control strategies that can be emulated by this model.

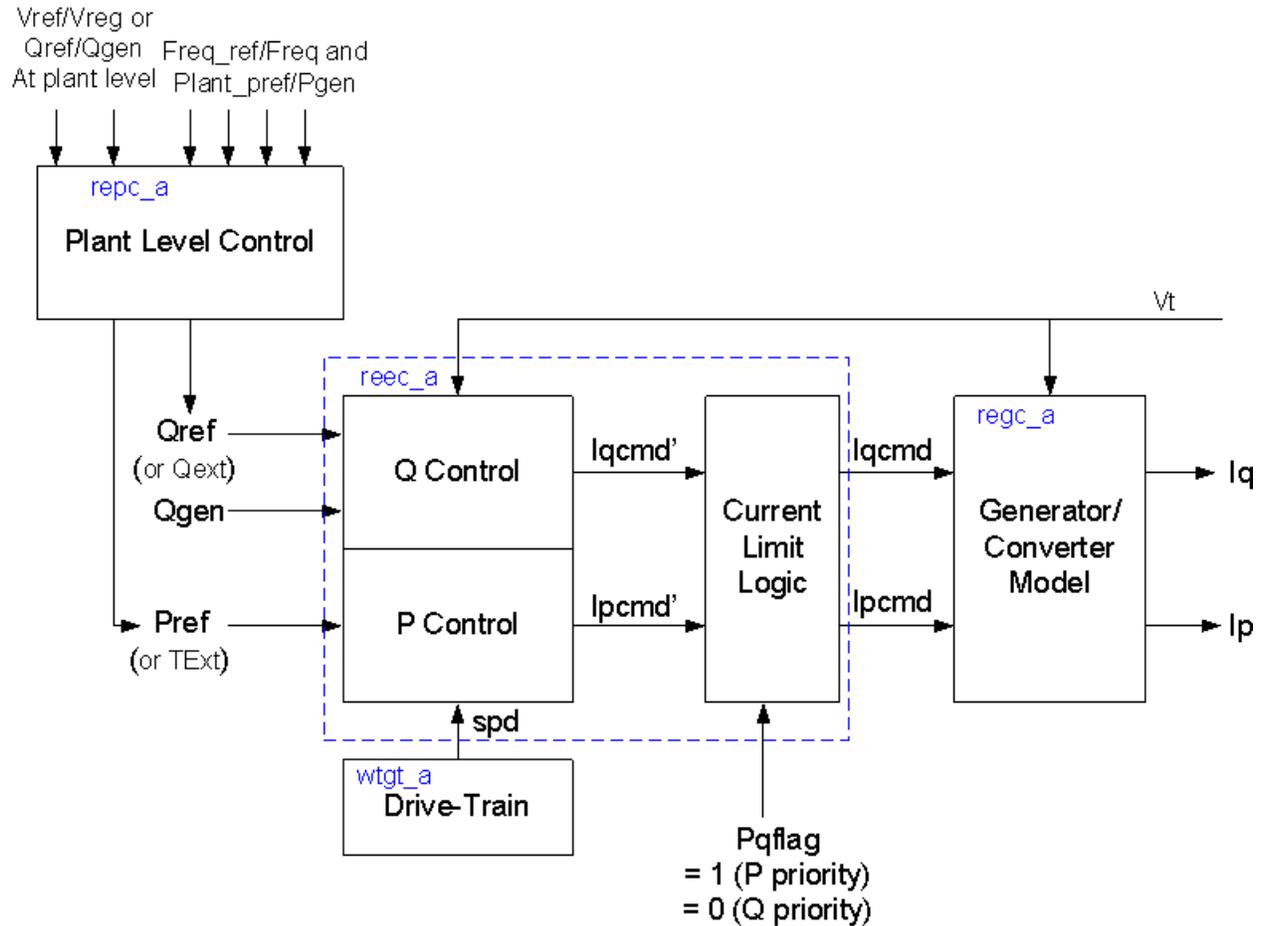


Figure 3-1: Overall model structure for type 4 wind turbine generator.

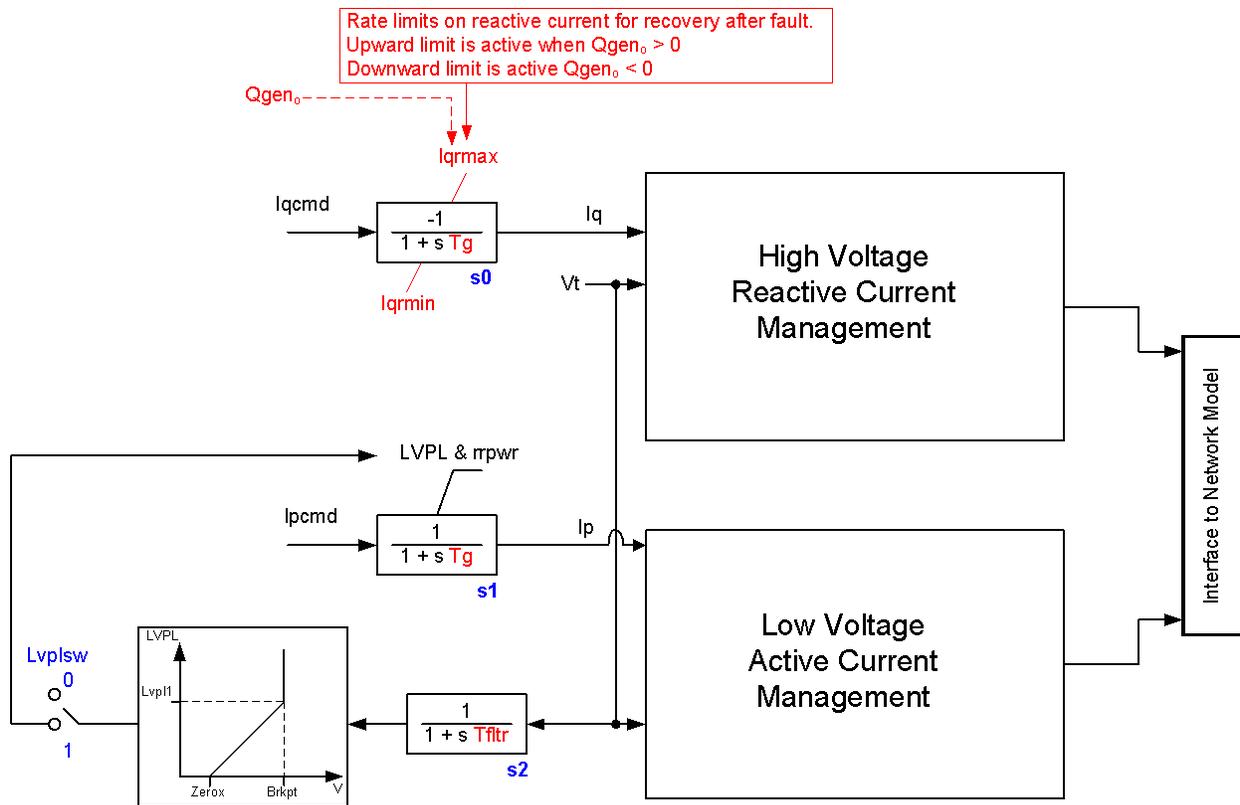


Figure 3-2: Modified renewable energy generator/converter model (**regc_a**). Items shown in RED are the only changes compared to the existing **wt4g** model.

Warning!!
 Extreme care should be taken in coordinating the parameters dbd1, dbd2 and Vdip, Vup so as not to have an unintentional response from the reactive power injection control loop.

State Transition – switch position:
 State 0 - If Voltage_dip = 0; normal operation (Iqinj = 0)
 State 1 - If Voltage_dip = 1; Iqinj goes to position 1
 State 2 - If Thld > 0, then after voltage_dip goes back to zero, set value to Iqfrz for t = Thld, after which go back to state 0
 - If Thld < 0, then after voltage_dip returns to zero stay in State 1 for t = Thld, after which go back to state 0.

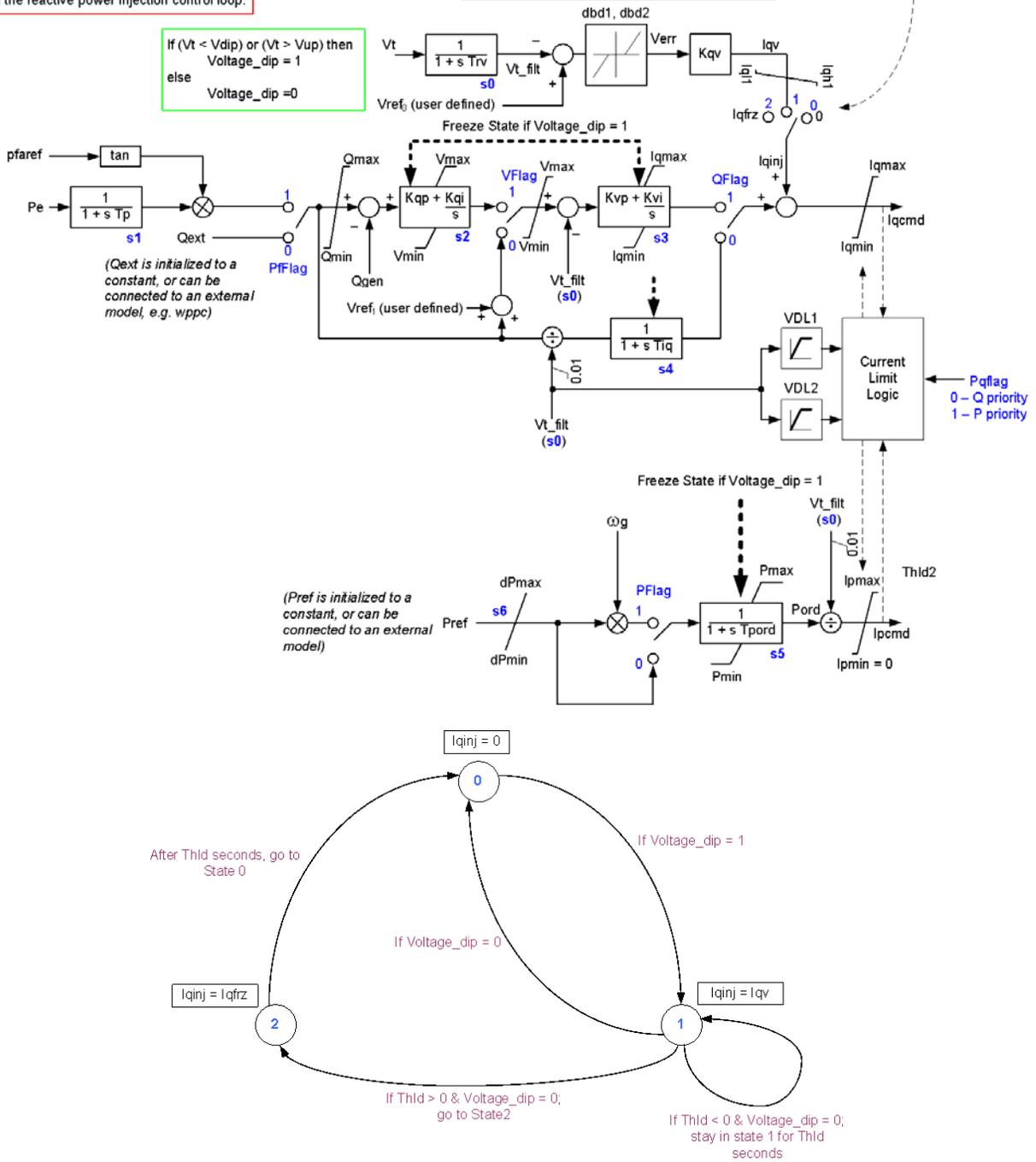


Figure 3-3: New P/Q Control model (reec_a)¹.

¹ The non-windup integrators for s3 and s2 are linked as follows: if s3 hits its maximum limit and ds3 is positive, then ds3 is set to 0; if ds2 is also positive, then it is also set to 0 to prevent windup, but, if ds2 is negative, then ds2 is

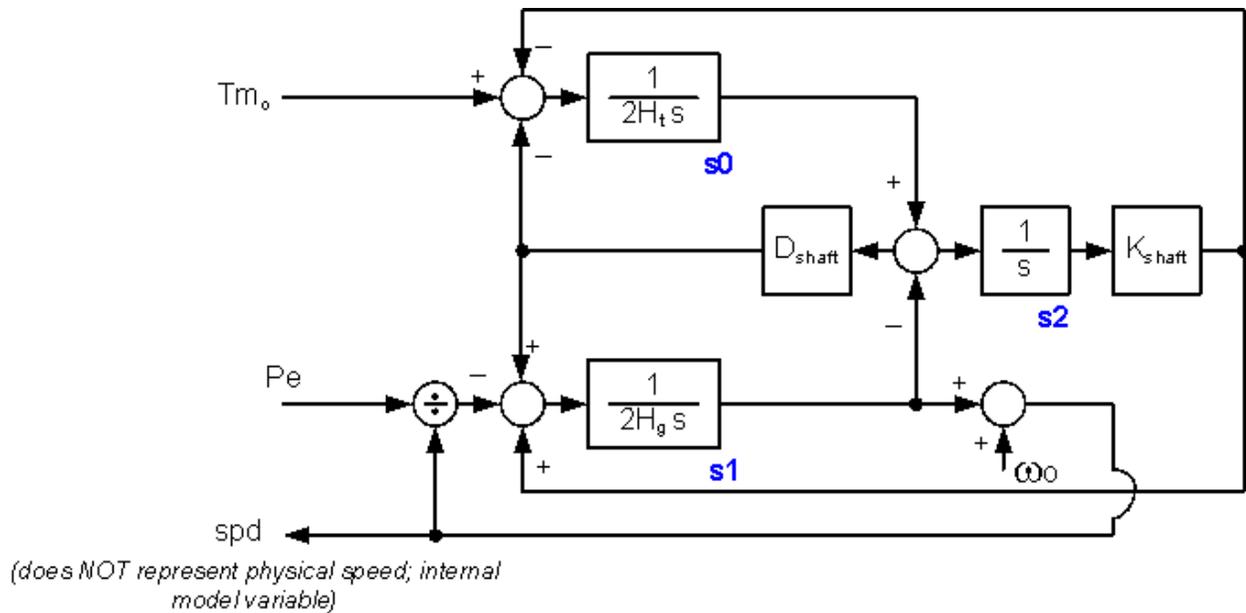


Figure 3-4: New drive-train model (wtgt_a).

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

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

Finally, for s5, if T_{pard} is zero then the time constant and freezing of the state are by-passed, however, the P_{max}/P_{min} limits are still in effect.

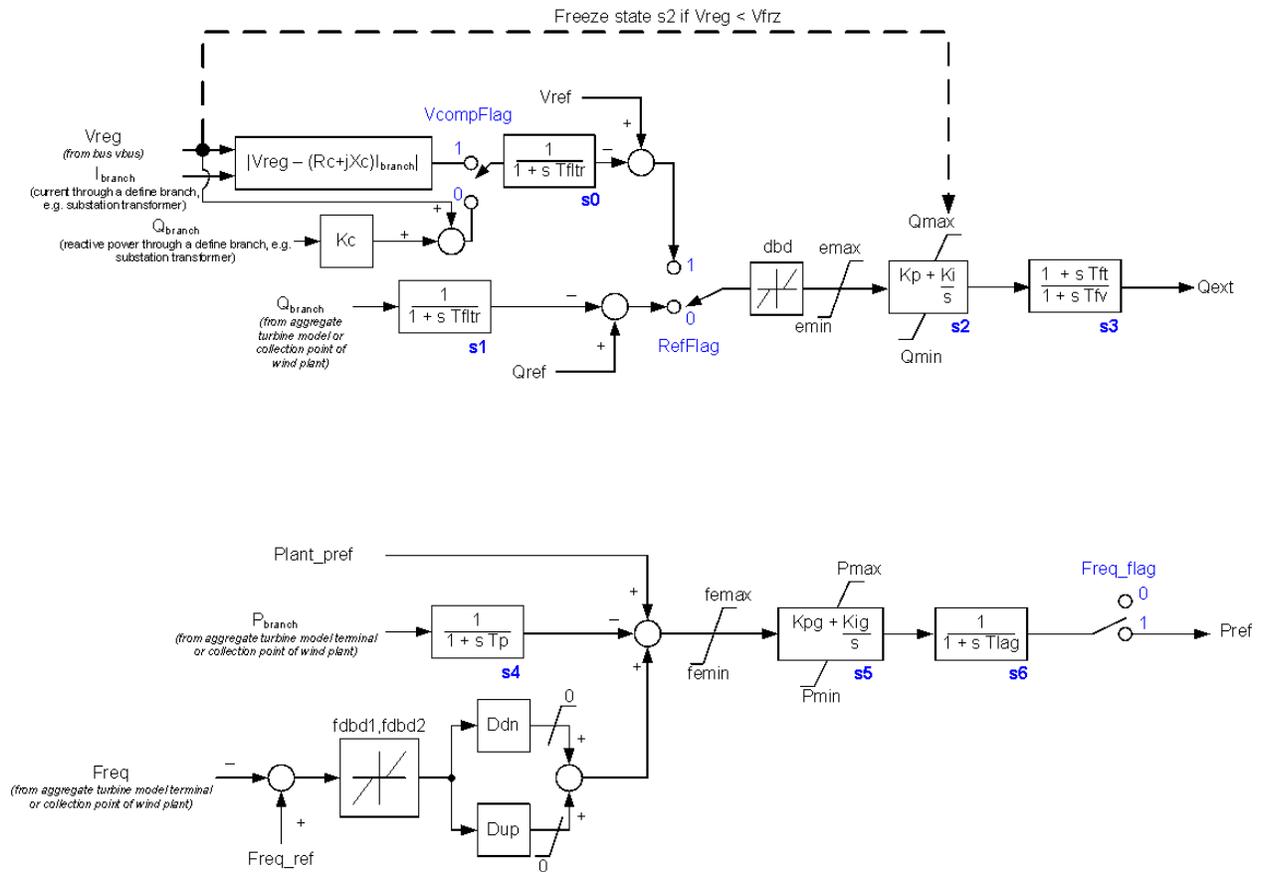


Figure 3-5: New simple plant level control model (**repc_a**).

Table 3-1: Reactive power control options

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

Table 3-2: Real power control options

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

The protection models associated with the wind turbine generator (i.e. low/high voltage and low/high frequency tripping) has not been addressed in this document since the existing generic

protection models (*lhvrt* and *lhfrt*) that exist in GE PSLF® (and similar models in Siemens PTI PSS®E) are adequate for application with this generic model.

4

EXAMPLE SIMULATION CASE

As has been done several times now, by EPRI, all cases in [6], [7] and [8] were simulated again using this new proposed model and gave similar responses as reported previously. This is also documented in [2], which is a freely available report. A perusal of the simulation in [2] will show that a wide range of operating conditions have been simulated based on measured data from several vendors.

The data used here (and in [2], [6], [7], [8]) was provide to EPRI under non-disclosure agreements (NDA) with the various turbine manufacturers for the purpose of research and investigation of the suitability of the various model structures being developed and proposed. These vendors graciously agreed to allow the public dissemination of the research results, as presented here and in the other references. The actual data, however, is covered under the NDA and cannot be disclosed.

For completeness we present a few example simulations in this report.

In addition, as shown below we have also simulated a few cases from a fourth vendor, Enercon. In the case of Enercon, we do not have any data provided by Enercon, but rather Enercon graciously provided a few “plots” of simulated results of their controls and we have simulated those cases with the proposed generic model and superimposed the two plots. Therefore, for the Enercon case these are not actual measured events or data but just a comparison of plots.

The following should be noted:

1. By refereeing to [2] the reader can see that actually many cases have been simulated for the ABB, Siemens and Vestas turbines. Here we are only showing an example case. The model in [2] is an earlier version of what is shown here. The key differences are:
 - a. The model here is more modular (e.g. `repc_a` is broken out as a separate model).
 - b. The model here is more generalized with the addition of a few more features after input from the IEC group. However, it can easily be reduced to the model in [2] with the appropriate settings.
2. The cases for ABB, Siemens and Vestas are comparisons of simulations, using the model presented here, with actual measured response of wind turbine generators to voltage dips. For the Siemens and Vestas case, the measurements are from actual in-service wind turbine generators (type 4) for commercially operational wind power plants in Europe. For ABB the measurements are from a full factory test of a type 4 wind turbine generator.
3. For some of the cases, we do have to re-initialize the P-controller states upon fault clearing to get a perfect match as shown here – this was discussed before (e.g. see [2]). This may not be necessary for the actual software implementation of the model as it is perhaps an unnecessary detail for power system studies.
4. In the Enercon case two different control modes are simulated. This is achieved by setting the model flags etc. appropriately.

5. The rate limit of reactive current is only needed for the Enercon mode 1 cases. Also, the maximum rate limit is effected only for an initial Qref that is positive and the minimum rate limit if the initial Qref is negative.

With these results presented it is believed that this proposal is reasonable, since it has now been tested against the four key type 4 vendors, ABB, Enercon, Siemens and Vestas. Also, by appropriately switching out certain components, the model can be made to match the generic type 4 for the GE turbine previously tested in WECC. So this model should be able to cover all the major vendors of type 4.

Note that the spikes in P and Q upon inception and clearing of the voltage dip are still present, but this is an artifice of simulation as explained in detail previously [2]. Methods are presently under discussion for taking care of this issue in the power system simulation software.

The user should realize that this model (as with any positive sequence models used in interconnected power system simulations) is a simplified model for the purpose of emulating the behavior of equipment for system wide planning studies. As such, for the most part the fitted model parameters do not directly correspond to actual equipment settings or physical quantities. For example, the shaft damping coefficient (D_{shaft}) in the drive-train model is fitted to capture the net damping of the torsional mode seen in the post fault electrical power response in Figure 4-2. In the actual equipment, the drive train oscillations are damped through filtered signals and active damping controllers, which obviously are significantly different from the simple generic two mass drive train model used here.

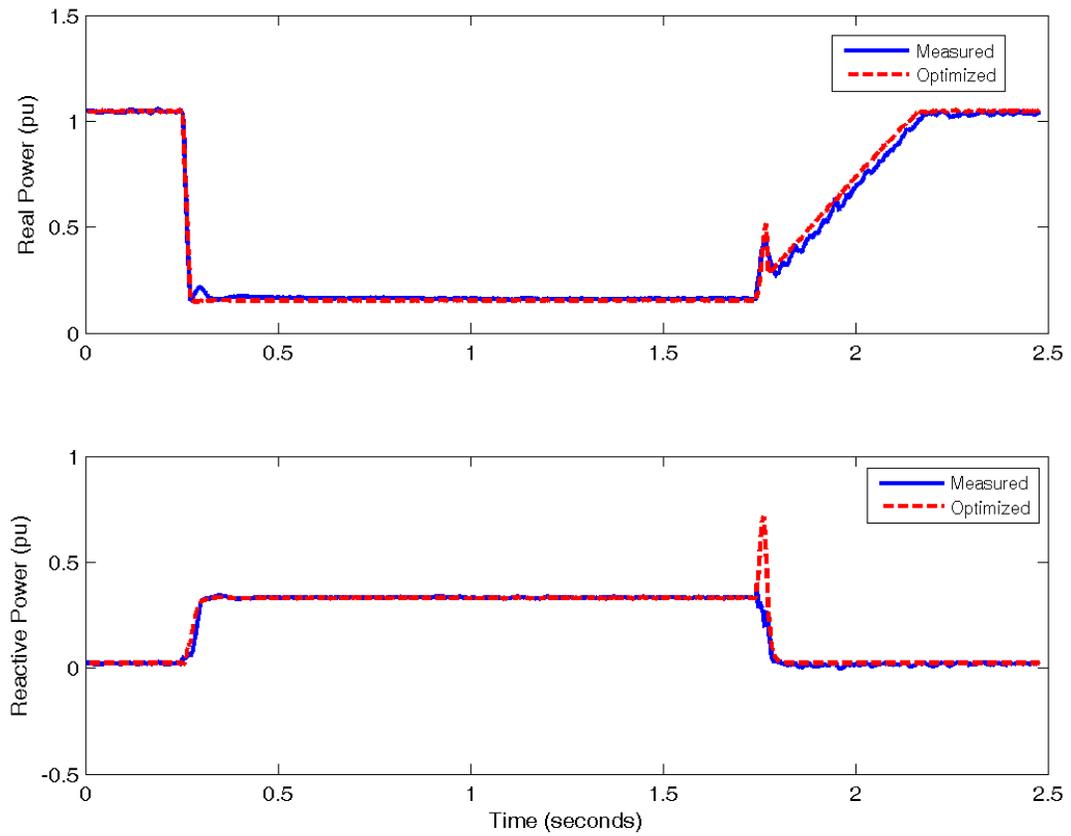


Figure 4-1: Validation result of simulation versus measured real and reactive power for vendor 1 (ABB).

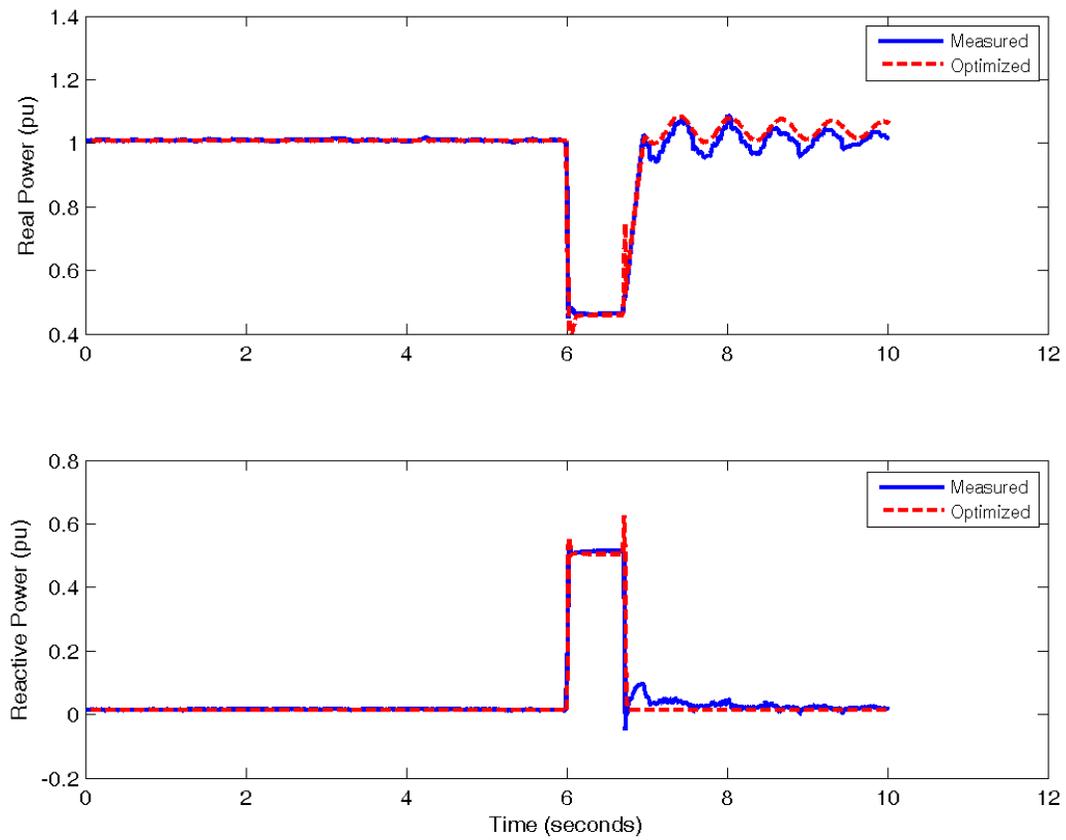


Figure 4-2: Validation result of simulation versus measured real and reactive power for vendor 2 (Siemens).

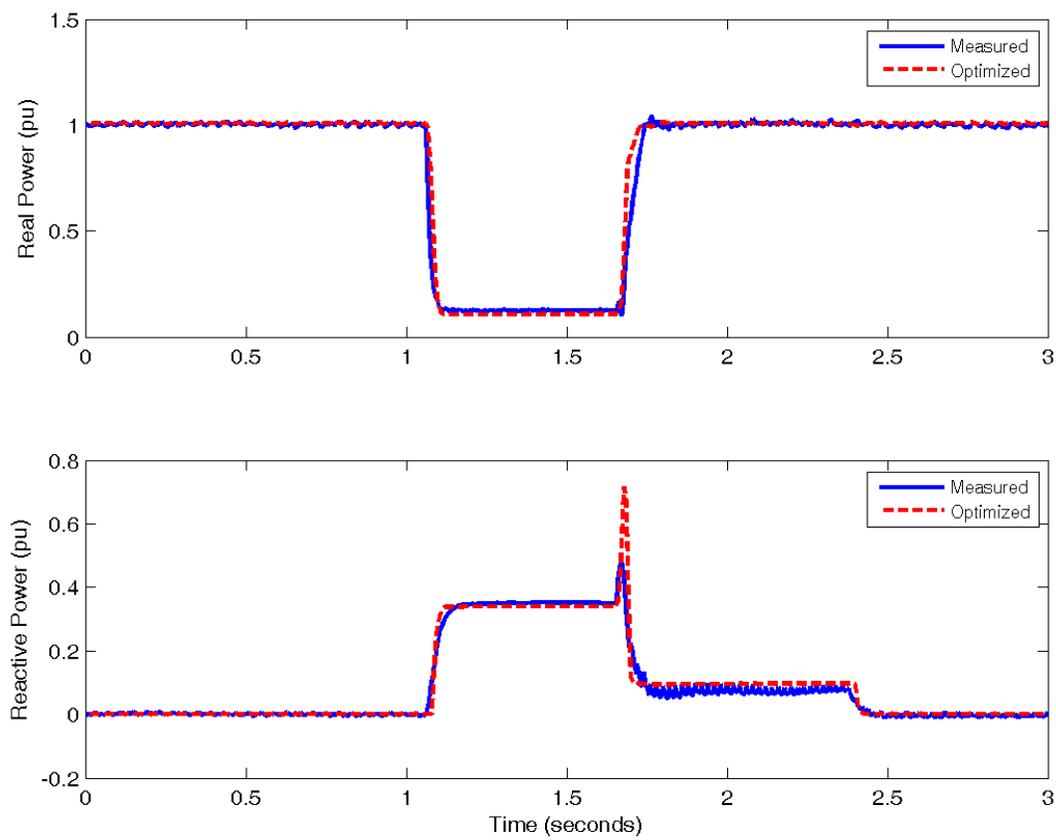


Figure 4-3: Validation result of simulation versus measured real and reactive power for vendor 3 (Vestas).

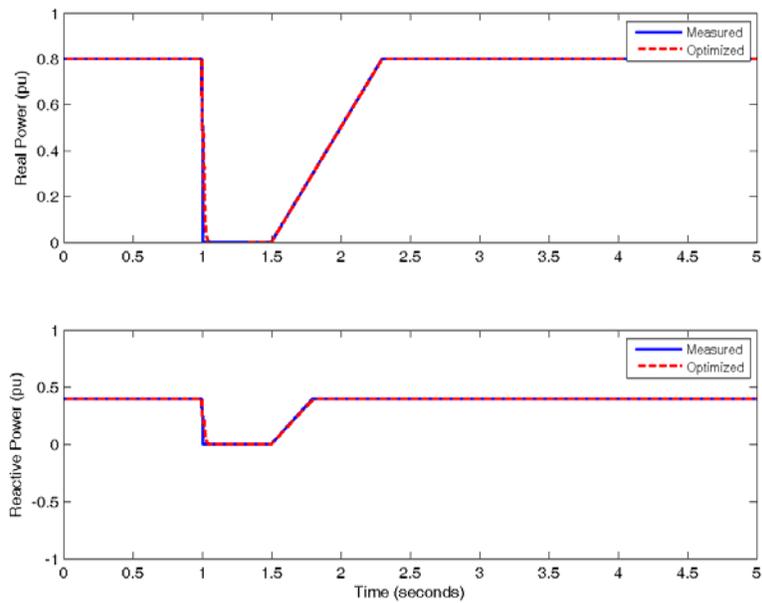


Figure 4-4: Validation result of simulation (red trace – using the generic model) versus the vendor specific model simulation (blue trace - called measured in figure legend) real and reactive power for vendor 4 (Enercon) – Control Mode1.

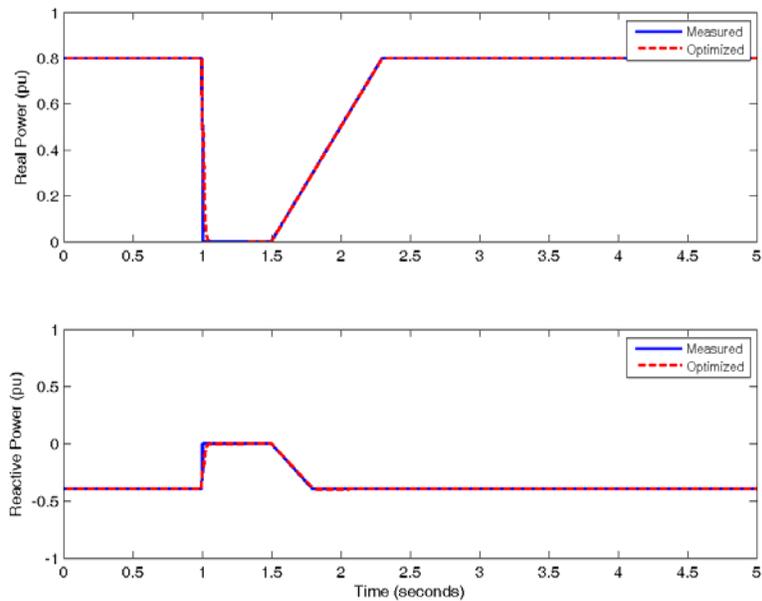


Figure 4-5: Validation result of simulation (red trace – using the generic model) versus the vendor specific model simulation (blue trace - called measured in figure legend) real and reactive power for vendor 4 (Enercon) – Control Mode1.

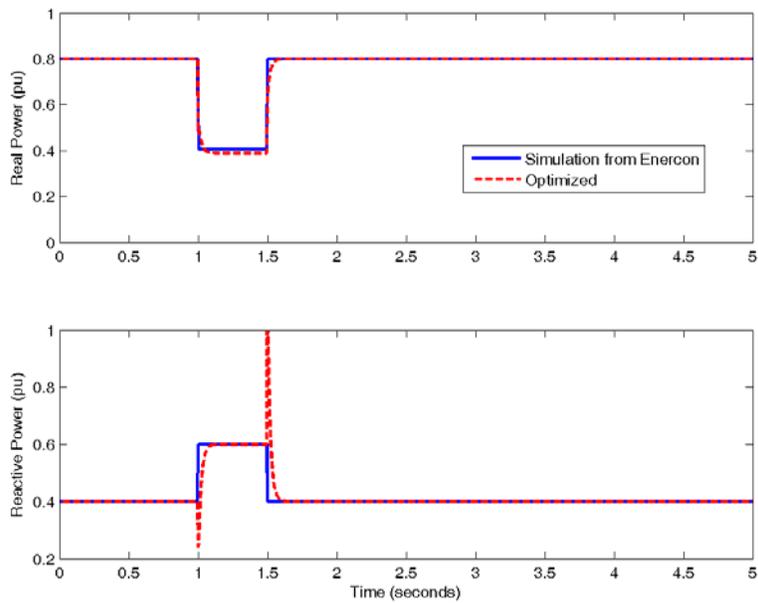


Figure 4-6: Validation result of simulation (red trace – using the generic model) versus the vendor specific model simulation (blue trace) real and reactive power for vendor 4 (Enercon) – Control Mode 2.

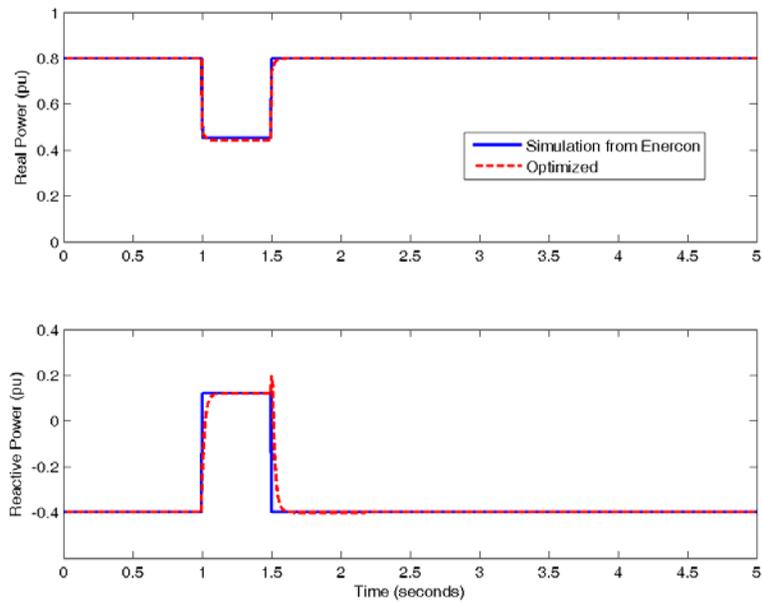


Figure 4-7: Validation result of simulation (red trace – using the generic model) versus the vendor specific model simulation (blue trace) real and reactive power for vendor 4 (Enercon) – Control Mode 2.

5

CONCLUSION AND SUMMARY

At this point, with the gracious input of the various equipment vendors for type 4 wind turbine generators, a proposed model is on the table that appears to cater to at least four major type 4 vendors. At this point the recommendation is to lock this model down and approach the software vendors within WECC to consider implementing this second generation generic model. Much dialogue has gone on in coming to this point, and it is certain that further refinements are likely through further discussions, particularly for the plant level controller. However, it is believed that what is present here make enough of a significant improvement to warrant implementing it as soon as possible in order to reap the benefits of being able to model a variety of WTGs. Other improvements, as they get discussed, can be added in the future.

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

6

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- [2] Generic Models and Model Validation for Wind and Solar PV Generation: Technical Update. EPRI, Palo Alto, CA: 2011, 1021763. (available for free download at www.epri.com)
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- [5] P. Pourbeik, J. Fortmann, R. Hendriks, A. Mendonca, Y. Kazachkov, B. Badzadeh, N. Miller, N. Goldenbaum, and J. Marques, “Modeling Sub-Group Report: IEC TC88 WG27”, Memorandum for Review by IEC TC88 WG27, August 26th, 2011 (revised 8/30 and 8/31).
- [6] P. Pourbeik, “Example Case of Using Field Data for Model Calibration of a Type 4 Wind Turbine Generator”, Memorandum to IEC TC88 WG27, WECC REMTF and EPRI P173, 10/24/11.
- [7] P. Pourbeik, “Using Field Data for Model Validation of a Vestas Type 4 Wind Turbine Generator”, Memorandum to IEC TC88 WG27, WECC REMTF and EPRI P173, 11/3/11.
- [8] P. Pourbeik, “Further Proposed Simplifications to the WT4 Generic Model”, Memorandum to IEC TC88 WG27, WECC REMTF and EPRI P173, 11/16/11 (revised 11/8 and 11/21).

A

CURRENT LIMITS AS PRESENTLY IMPLEMENTED IN THE WECC MODLE

ImaxTD, Iphl, Iqhl and pqflag are user input values

If (Vt >= 1)

 Iqmxv = qmax

Else

 Iqmxv = qmax + (1.8 - qmax) × (1 - Vt)

Endif

If (pqflag = 0) % Q - priority

 Iqmax = min { Iqmxv, Iqhl, ImaxTD }

 Iqmin = -1 × Iqmax

 Ipmax = min { Iphl, $\sqrt{\text{ImaxTD}^2 - \text{Ipcmd}^2}$ }

 Ipmin = 0

Else % P - priority

 Iqmax = min { Iqmxv, Iqhl, $\sqrt{\text{ImaxTD}^2 - \text{Ipcmd}^2}$ }

 Iqmin = -1 × Iqmax

 Ipmax = min { Iphl, ImaxTD }

 Ipmin = 0

End

B

NEW CURRENT LIMIT LOGIC

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

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

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

Note: for the sake of simplicity the decision was made at the June 2012 REMTF meeting to change the total converter current limit to I_{max}, instead of I_{max} TD.

C

PARAMETER LIST FOR THE MODEL

C.1 REGC_A Model – Generator/Converter

Figure 3-2 shows the generator/converter model – *regc_a*. This model is essentially identical to the existing *wt4g* model in GE PSLF® and Siemens PTI PSS®E, with the following exceptions:

1. The time constants for the real and reactive current injection are a model parameter Tg , instead of being hardcoded to 0.02.
2. The time constant for the voltage filter is also a parameter $Tfltr$, instead of being hardcoded to 0.02.
3. A rate limit has been added to the reactive current block. It is important to understand how this rate limit is effected:
 - a. If the model initializes with an initial reactive power output that is greater than zero (i.e. reactive power being injected into the grid), then upon fault clearing the recovery of reactive current is limited at the rate of $Iqrmax$. In this case the rate limit ($Iqrmin$) on reducing reactive current is not effective, reactive current can be reduced as quickly as desired.
 - b. If the model initializes with an initial reactive power output that is less than zero (i.e. reactive power being absorbed from the grid), then upon fault clearing the recovery of reactive current back down to it original value is limited at the rate of $Iqrmin$. In this case the rate limit ($Iqrmax$) on increasing reactive current is not effective, reactive current can be increased as quickly as desired.

The action of the reactive current limit is best illustrated by the simulations in Figure 4-4 and Figure 4-5.

The rest of the parameters and functionality of the generator/converter model is as already described and implemented in GE PSLF® and Siemens PTI PSS®E.

C.2 REEC_A Model – Electrical Controls

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

One extra parameter was added since the last report being issued. This is “Thld2”. It is a delay that if non-zero means that the active current limit ($Ipmax$) is held at its value during the fault, post fault for Thld2 seconds.

Parameter	Description	Typical Range of Values	Units
Mbase	Model MVA base	N/A	MVA
Vdip	The voltage below which the reactive current injection (I_{qinj}) logic is activated (i.e. $voltage_dip = 1$)	0.85 – 0.9	pu
Vup	The voltage above which the reactive current injection (I_{qinj}) logic is activated (i.e. $voltage_dip = 1$)	>1.1	pu
Trv	Filter time constant for voltage measurement	0.01 – 0.02	s
dbd1	Deadband in voltage error when voltage dip logic is activated (for overvoltage – thus overvoltage response can be disabled by setting this to a large number e.g. 999)	-0.1 – 0	pu
dbd2	Deadband in voltage error when voltage dip logic is activated (for undervoltage)	0 – 0.1	pu
Kqv	Gain for reactive current injection during voltage dip (and overvoltage) conditions	0 – 10	pu/pu
Iqh1	Maximum limit of reactive current injection (I_{qinj})	1 – 1.1	pu
Iql1	Minimum limit of reactive current injection (I_{qinj})	-1.1 – 1	pu
Vref ₀	The reference voltage from which the voltage error is calculated. <i>This is set by the user. If the user does not specify a value it is initialized by the model to equal to the initial terminal voltage.</i>	0.95 – 1.05	pu
Iqfrz	Value at which I_{qinj} is held for $Thld$ seconds following a voltage dip if $Thld > 0$	-0.1 – 0.1	pu
Thld	Time delay for which the state of the reactive current injection is held after $voltage_dip$ returns to zero: <ol style="list-style-type: none"> 1. If $Thld > 0$, then once $voltage_dip$ goes back to 0 I_{qinj} is held at $Iqfrz$ for $Thld$ seconds. 2. If $Thld < 0$, then once $voltage_dip$ goes back to 0 I_{qinj} remains in its current injection state (i.e. $I_{qinj} = (Vref_0 - V_t) \times Kqv$) for $Thld$ seconds. 3. If $Thld = 0$ then I_{qinj} goes back to zero immediately after the $voltage_dip$ is turned off. 	-1 – 1	s
Thld2	Time delay for which the active current limit (I_{pmax}) is held after $voltage_dip$ returns to zero for $Thld2$ seconds at its value during the voltage dip.	0	s
pfaref	Power factor angle. <i>This parameter is initialized by the model based on the initial powerflow solution (i.e. initial P and Q of the model).</i>	N/A	rad

Parameter	Description	Typical Range of Values	Units
Tp	Filter time constant for electrical power measurement	0.01 – 0.1	s
Qmax	Reactive power limit maximum	0.4 – 1.0	pu
Qmin	Reactive power limit minimum	-1.0 – -0.4	pu
Vmax	Voltage control maximum	1.05 – 1.1	pu
Vmin	Voltage control minimum	0.9 – 0.95	pu
Kqp	Proportional gain	N/A	pu
Kqi	Integral gain	N/A	pu
Kvp	Proportional gain	N/A	pu
Kvi	Integral gain	N/A	pu
Vref ₁	User-define reference/bias on the inner-loop voltage control (default value is zero)	N/A	pu
Tiq	Time constant on lag delay	0.01 – 0.02	s
dPmax	Ramp rate on power reference	N/A	pu/s
dPmin	Ramp rate on power reference	N/A	pu/s
Pmax	Maximum power reference	1	pu
Pmin	Minimum power reference	0	pu
I _{max}	Maximum allowable total converter current limit	1.1 – 1.3	pu
PfFlag	Power factor flag (1 – power factor control, 0 – Q control, which can be commanded by an external signal)	N/A	N/A
VFlag	Voltage control flag (1 – Q control, 0 – voltage control)	N/A	N/A
QFlag	Reactive power control flag (1 – voltage/Q control, 0 – constant pf or Q control)	N/A	N/A
Pqflag	P/Q priority selection on current limit flag	N/A	N/A

VDL1

User-define pairs of points		Typical Range of Values	Units
vq1		N/A	pu
lq1		N/A	pu
vq2		N/A	pu
lq2		N/A	pu
vq3		N/A	pu
lq3		N/A	pu
vq4		N/A	pu
lq4		N/A	pu

VDL2

User-define pairs of points		Typical Range of Values	Units
vp1		N/A	pu
lp1		N/A	pu

Parameter	Description	Typical Range of Values	Units
vp2		N/A	pu
lp2		N/A	pu
vp3		N/A	pu
lp3		N/A	pu
vp4		N/A	pu
lp4		N/A	pu

C.3 WTGT_A Model – Drive-Train

The table below is a list of all the parameters of the *wtgt_a* model (Figure 3-4). The user should realize that this model is a simplified model for the purpose of emulating the behavior of torsional mode oscillations. The shaft damping coefficient (D_{shaft}) in the drive-train model is fitted to capture the net damping of the torsional mode seen in the post fault electrical power response. In the actual equipment, the drive train oscillations are damped through filtered signals and active damping controllers, which obviously are significantly different from the simple generic two mass drive train model used here. Therefore, the parameters (and variables) of this simple drive-train model cannot necessarily be compared with actual physical quantities directly.

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

C.4 REPC_A Model – Power Plant Controller

The table below is a list of all the parameters of the *repc_a* model (Figure 3-5).

Parameter	Description	Typical Range of Values	Units
MBASE	Model MVA base	N/A	MVA
Tfltr	Voltage or reactive power measurement filter time constant	0.01 – 0.05	s
Kp	Proportional gain	N/A	pu/pu
Ki	Integral gain	N/A	pu/pu
Tft	Lead time constant	N/A	s
Tfv	Lag time constant	N/A	s
RefFlag	1 – for voltage control or 0 – for reactive power control	N/A	N/A

Parameter	Description	Typical Range of Values	Units
Vfrz	Voltage below which plant control integrator state (s2) is frozen	0 – 0.7	pu
Rc	Line drop compensation resistance	0	Pu
Xc	Current compensation constant (to emulate droop or line drop compensation)	-0.05 – 0.05	pu
Kc	Gain on reactive current compensation	N/A	pu
VcompFlag	Selection of droop (0) or line drop compensation (1)	N/A	N/A
emax	Maximum error limit		pu
emin	Minimum error limit		pu
dbd	Deadband in control	0	pu
Qmax	Maximum Q control output		pu
Qmin	Minimum Q control output		pu
Kpg	Proportional gain for power control		pu/pu
Kig	Integral gain for power control		pu/pu
Tp	Lag time constant on Pgen measurement		s
fdbd1	Deadband downside		pu
fdbd2	Deadband upside		pu
femax	Maximum error limit		pu
femin	Minimum error limit		pu
Pmax	Maximum Power		pu
Pmin	Minimum Power		pu
Tlag	Lag time constant on Pref feedback		s
Ddn	Downside droop	20	pu/pu
Dup	Upside droop	0	pu/pu
Pgen_ref	Initial power reference	From powerflow	pu
Freq_ref	Frequency reference	1.0	pu
vbus	The bus number in powerflow from which Vreg, Freq is picked up (i.e. the voltage being regulated and frequency being controlled; it can be the terminal of the aggregated WTG model or the point of interconnection)	N/A	N/A
branch	The branch (actual definition depends on software program) from which I_{branch} , Q_{branch} and P_{branch} is being measured.	N/A	N/A
Freq_flag	Flag to turn on (1) or off (0) the active power control loop within the plant controller	0	N/A

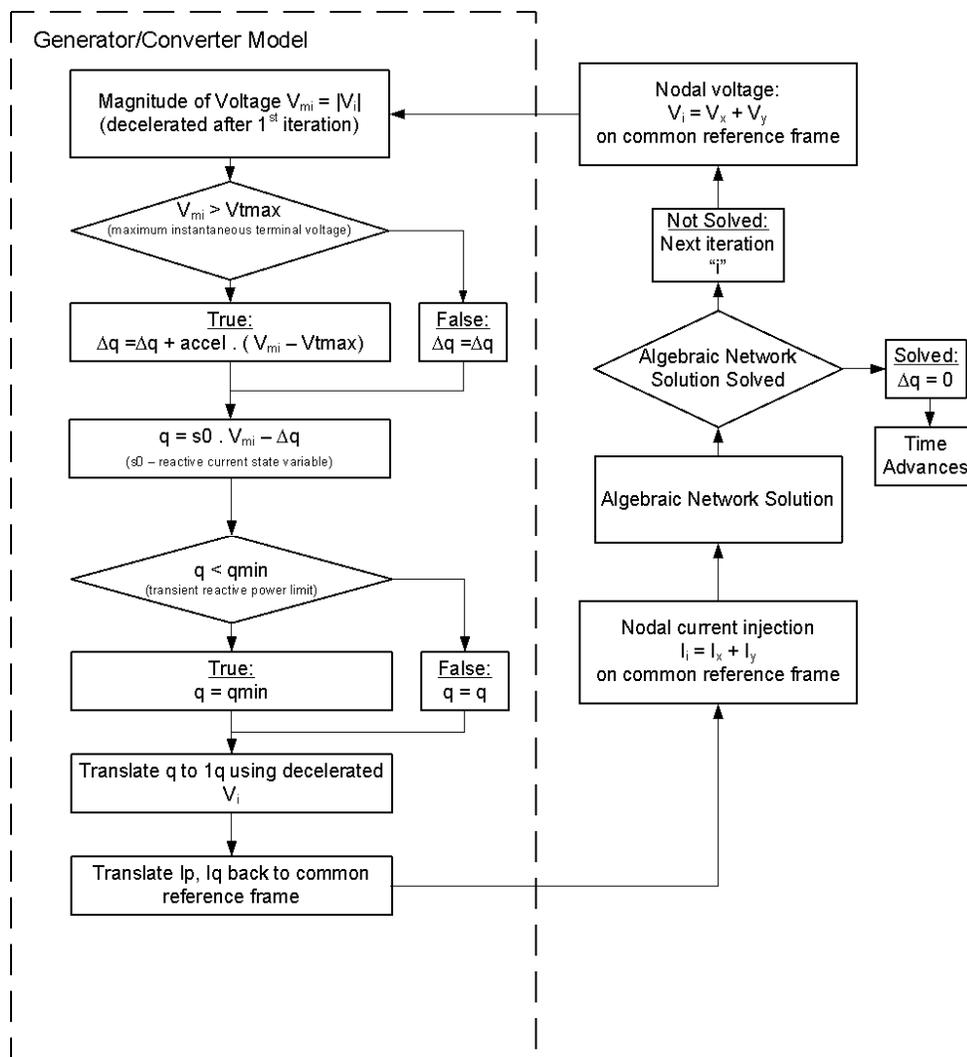
Note: Vref and Qref are initialized by the model based on Vreg and Qgen in the initial powerflow solution, and Qext is initialized based on the initialization of the initial Q reference from the down-stream aggregated WTG model.

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CONVERTER MODEL GRID INTERFACE

In the generator/converter model block diagram (see **Error! Reference source not found.** or Figure 3-2) there are two blocks labeled, “high-voltage reactive current management” and “low-voltage active current management”. These blocks represent logic associated with the dynamic model and the ac network solution. The actual implementation of this logic may be software dependant. In the past a simple block diagram was provide in an effort to attempt to explain the logic, this however seemed to have caused more confusion. Here we provide a flow chart, provided by GE², for greater clarification.

High-Voltage Reactive Current Management:



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

Low-Voltage Active Current Management:

