

Proposed Changes to the WECC WT3 Generic Model for Type 3 Wind Turbine Generators

Proposed Changes to the WECC WT3 Generic Model for Type 3 Wind Turbine Generators

Prepared under Subcontract No. NFT-1-11342-01 with NREL

Issued: 03/26/12 (revised 6/11/12, 7/3/12, 8/16/12, 8/17/12, 8/29/12, 1/15/13, 1/23/13)

Prepared by:

Pouyan Pourbeik
942 Corridor Park Boulevard
Knoxville, TN 37932
USA
Ph: (919) 794 7204
ppourbeik@epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI) FOR THE NATIONAL RENEWABLE ENERGY LABORATORY (NREL). NEITHER EPRI, NREL, ANY MEMBER OF EPRI, ANY COSPONSOR, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE OR NREL OR ANY NREL REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

Electric Power Research Institute and EPRI are registered service marks of the Electric Power Research Institute, Inc.

Copyright © 2013 Electric Power Research Institute, Inc. All rights reserved.

ACKNOWLEDGMENTS

EPRI wishes to acknowledge the Western Electricity Coordinating Council (WECC) Renewable Energy Modeling Task Force and the International Electrotechnical Commission Technical Committee 88, Working Group 27, and all the members of these groups, as forums through which the author was able to participate as an active member to contribute to the development of the models described herein. The comments, feedback, support and encouragement of these groups and their respective members are gratefully acknowledged.

EPRI expresses its sincere gratitude also to ABB and Vestas for sharing, under non-disclosure agreements, data from their field measurements of their equipment which significantly helped in this research effort to improve the generic wind turbine models. In particular, the author is grateful to the following individuals for fruitful and insightful discussions:

Babak Badrzadeh, Vestas

Thomas Schmidt Grau, Vestas

Tony Yip, Vestas

Jouko Niiranen, ABB

Slavomir Seman, ABB (presently no longer with ABB)

CONTENTS

1 INTRODUCTION	1-1
1.1 Background.....	1-1
2 THE EXISTING FIRST GENERATION GENERIC WT3 MODEL.....	2-1
3 THE PROPOSED SECOND GENERATION GENERIC WT3 MODEL	3-1
4 EXAMPLE SIMULATION CASE	4-1
5 SOME ADDITIONAL PROPOSED CHANGES FOR CONSIDERATION FOR FUTURE IMPLEMENTATION.....	5-1
6 CONCLUSION AND SUMMARY	6-1
7 REFERENCES	7-1
A CURRENT LIMITS AS PRESENTLY IMPLEMENTED IN THE WECC MODLE.....	A-1
B NEW CURRENT LIMIT LOGIC.....	B-1
C PARAMETER LIST FOR THE MODEL	C-1
C.1 REGC_A Model – Generator/Converter	C-1
C.2 REEC_A Model – Electrical Controls	C-1
C.3 WTGT_A Model – Drive-Train	C-1
C.4 WTGAR_A Model – Aero-Dynamics	C-1
C.5 WTGPT_A Model – Pitch-Controller.....	C-2
C.6 WTGTRQ_A Model – Torque-Controller	C-2
C.7 REPC_A Model – Power Plant Controller	C-3
D CONVERTER MODEL GRID INTERFACE	D-1

1

INTRODUCTION

1.1 Background

A discussion of the background of the generic wind turbine generator (WTG) model development activities are provided in [1], [2] and [3].

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.

Figure 1-1 shows the four main wind turbine generator technologies. 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 3 generic wind turbine generator (WTG) models. Based on the earlier version of this report and the results presented in [4] at the WECC Renewable Energy Modeling Task Force (REMTF) meeting on June 18th, 2012, the WECC REMTF made a final decision to freeze the second generation type 3 model at the point that is presented in this report. This work thus constitutes the basis for the development of the next set generation of type 3 generic models to be implemented by commercial software vendors for use in North America. The model is purposefully of a modular nature to allow flexibility for future additions or augmentation. Validation performed on data provided by type 3 equipment vendors is also presented.

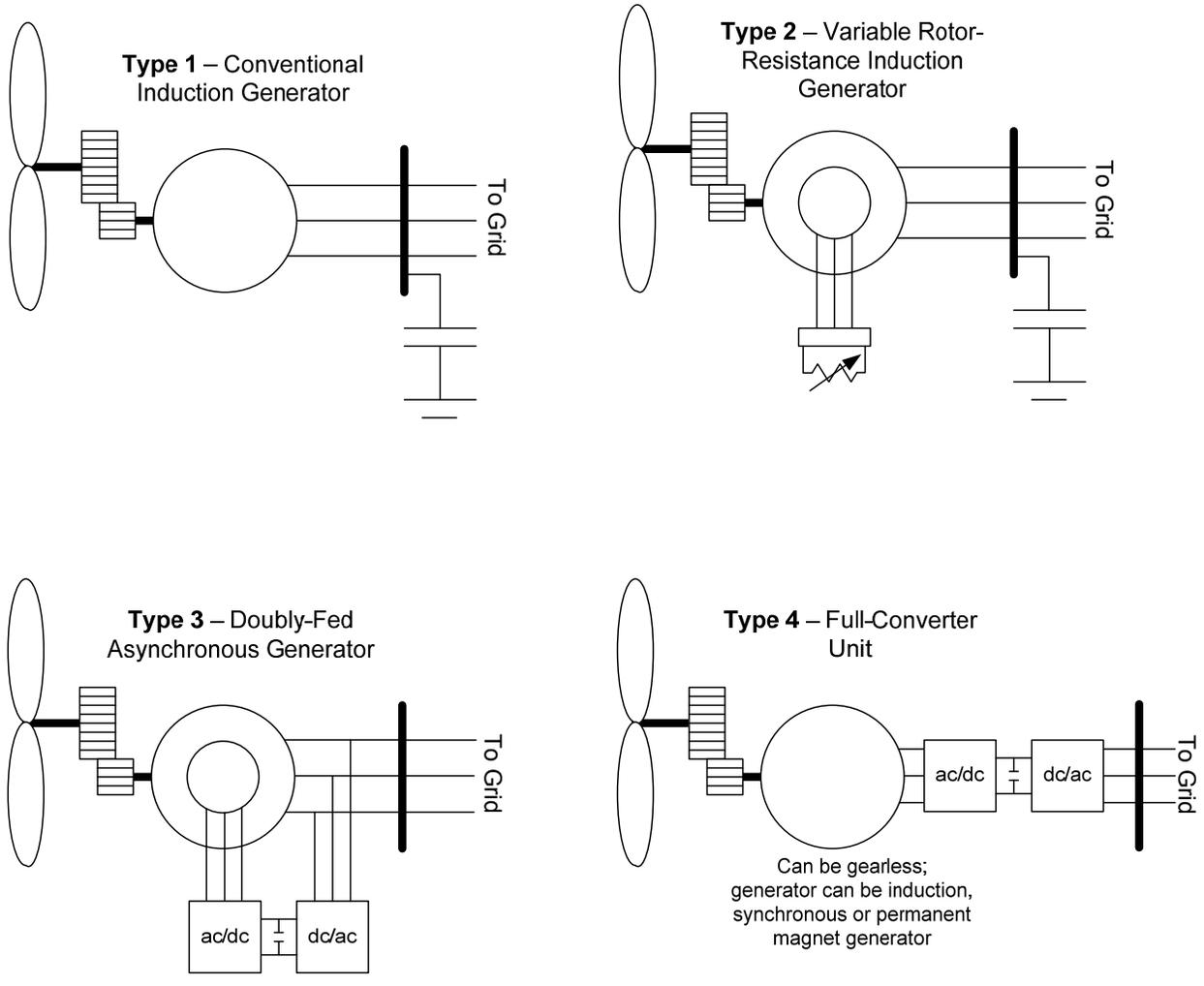


Figure 1-1: The four many wind turbine technologies.

2

THE EXISTING FIRST GENERATION GENERIC WT3 MODEL

The block diagrams for the generic WT3 model, as it stands presently in the two major commercial simulation tools use in the WECC (GE PSLF® and Siemens PTI PSS®E) are shown below.

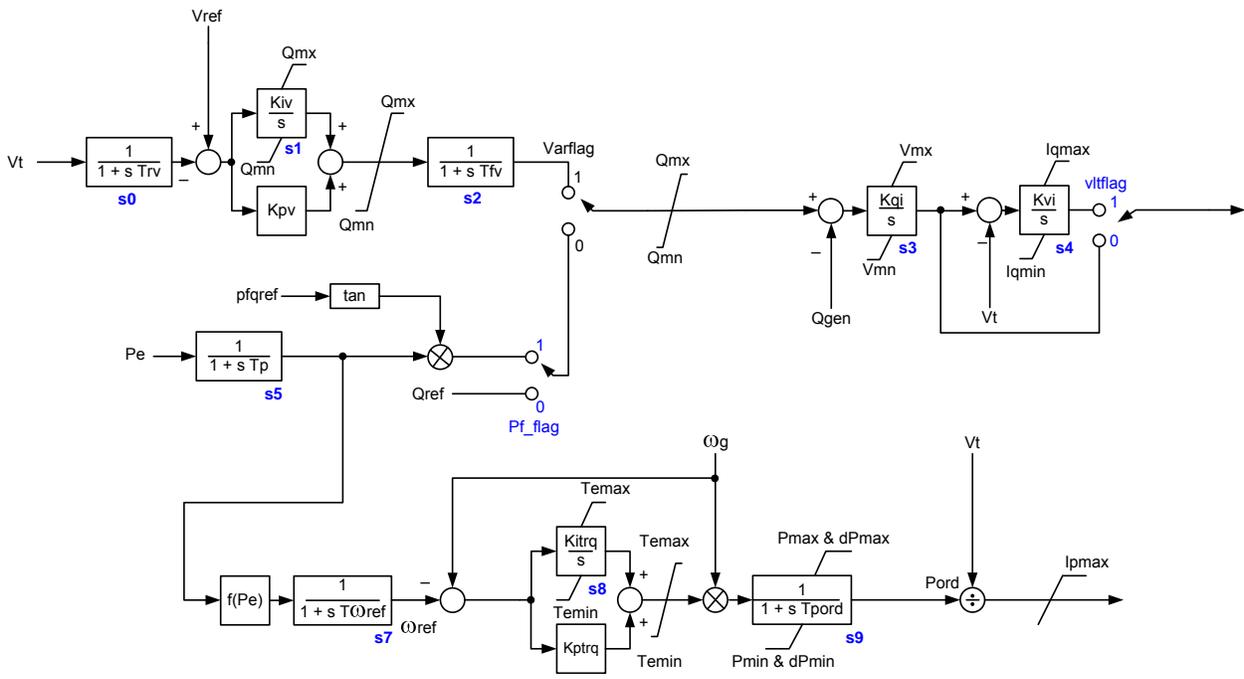


Figure 2-1: First generation type 3 generic model, P and Q-control.

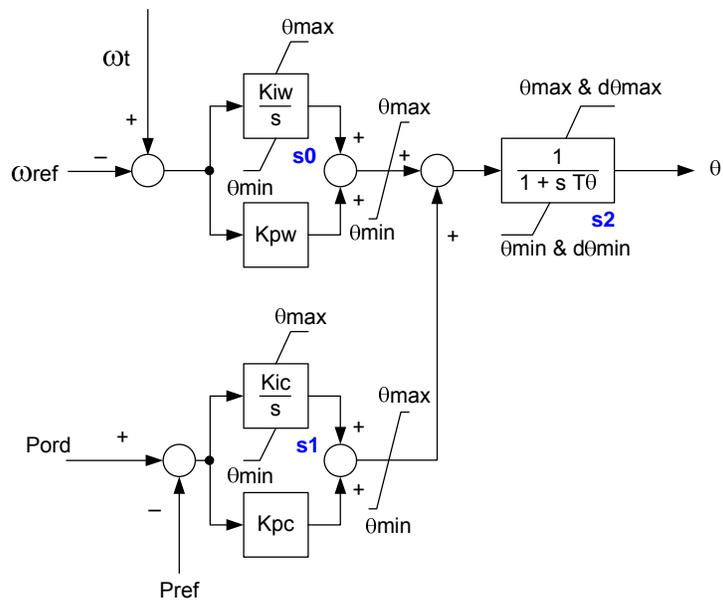


Figure 2-2: First generation type 3 generic model, pitch-control.

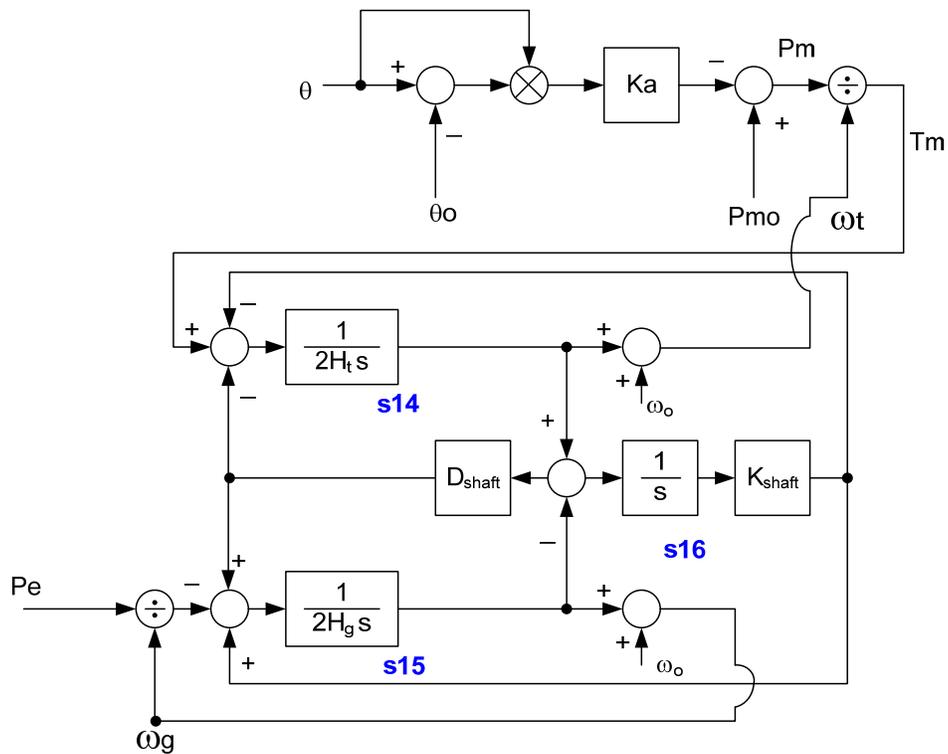


Figure 2-3: First generation type 3 generic model, drive-train and aero-dynamics.

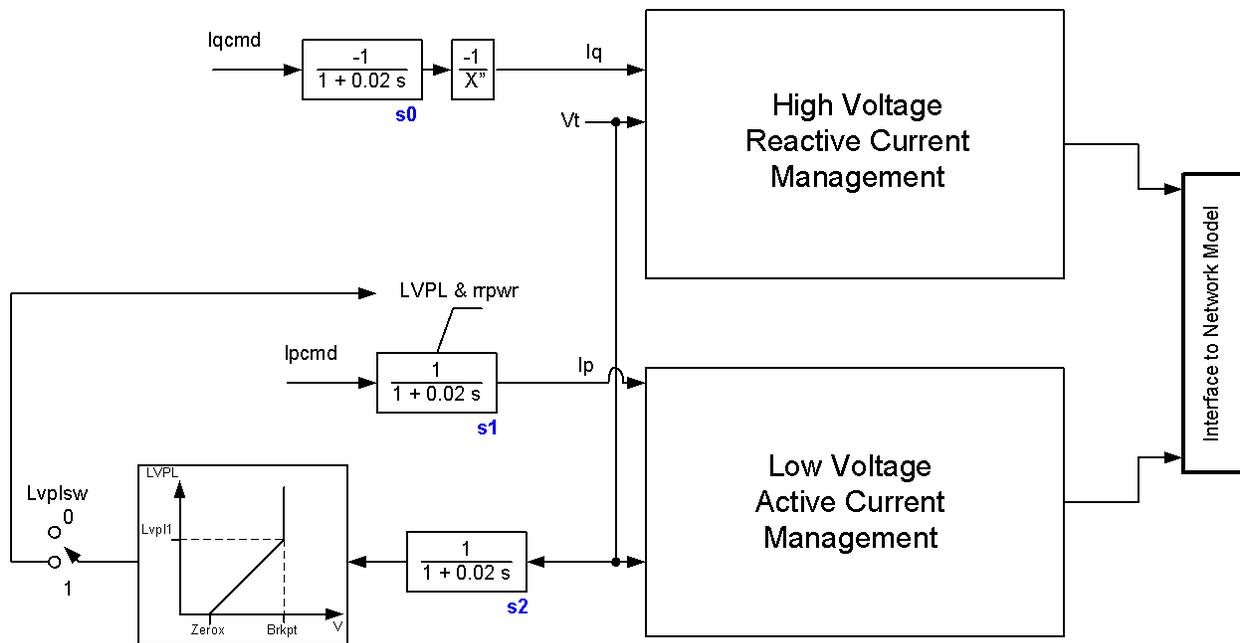


Figure 2-4: First generation type 3 generic model, generator/converter. See Appendix D for an explanation of the logic inside the two blocks “high-voltage reactive current management” and “low-voltage active current management”.

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

Through various discussions, particularly at the IEC TC88 WG27 and WECC REMTF meetings, proposed changes to this model have been made in order to make it more suitable for simulating a wider range of possible type 3 WTGs. The history of these proposed changes and discussions may be found in reference [2] or [5]. Here we will not go over the details of the various proposals. In the next section we simply present the latest validation results using the current type 3 model proposal, which is describe in detail in the following sections.

3

THE PROPOSED SECOND GENERATION GENERIC WT3 MODEL

Figure 3-1 shows the overall structure of the second generation type 3 WTG model. This model follows the same modular approach as that presented previously for the new type 4 model [3]. The model has seven (7) parts:

1. The generator/converter model (*regc_a*), which has inputs of real (*Ipcmd*) and reactive (*Iqcmd*) current command and outputs of real (*Ip*) and reactive (*Iq*) current injection into the grid model. This is identical to that proposed for the type 4 WTG, see [3].
2. The 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. This is identical to that proposed for the type 4 WTG, see [3].
3. The emulation of the driven-train (*wtgt_a*) for, simulating drive-train oscillations, the *wtgt* model. 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. Furthermore, as opposed to the type 4 model, in this case the incident mechanical power/torque is not assumed to be constant, but can be varied through the action of the connected aero-dynamic model.
4. A simple linear model of the turbine aero-dynamics (*wtgar_a*). This is based on reference [6], and the existing WT3 generic model.
5. A simplified representation of the pitch-controller (*wtgpt_a*). This is similar to the existing type 3 pitch-control model, with the addition of one parameter *Kcc*. This parameter was added through consultation and discussions within the IEC group.
6. A simple emulation of torque control (*wgtrq_a*).
7. A simple wind power plant controller (*repc_a*), which has inputs of either voltage reference (*Vref*) and measured/regulated voltage (*Vreg*) at the plant level, or reactive power reference (*Qref*) and measured (*Qgen*) at the plant level. The output of the *repc_a* model is a reactive power command that connects to *Qref* on the *reec_a* model. This is the same as that proposed for the type 4 WTG. *Figure 3-2* through *Figure 3-8* shows these models, respectively. 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 seven models.

Finally, note that here these model have not been specifically named WT3 since several of the module are identical to those used for the newly proposed type 4 WTG [3]. Also, the plant controller and a simplified version of the electrical controls [8] are to be used for modeling solar PV. Thus, by keeping this modular approach we can work towards a library of individual modular blocks that can be appropriately combined to formulate the various types of renewable energy generation technologies. Also, this leaves room for future expansion, where certain

modules, such as the wind plant controller, can be revised, updated or made available in several versions.

In the next section validation cases are presented for two different type 3 WTGs. Table 3-1 provides a simple summary of the various control strategies that can be emulated by this model.

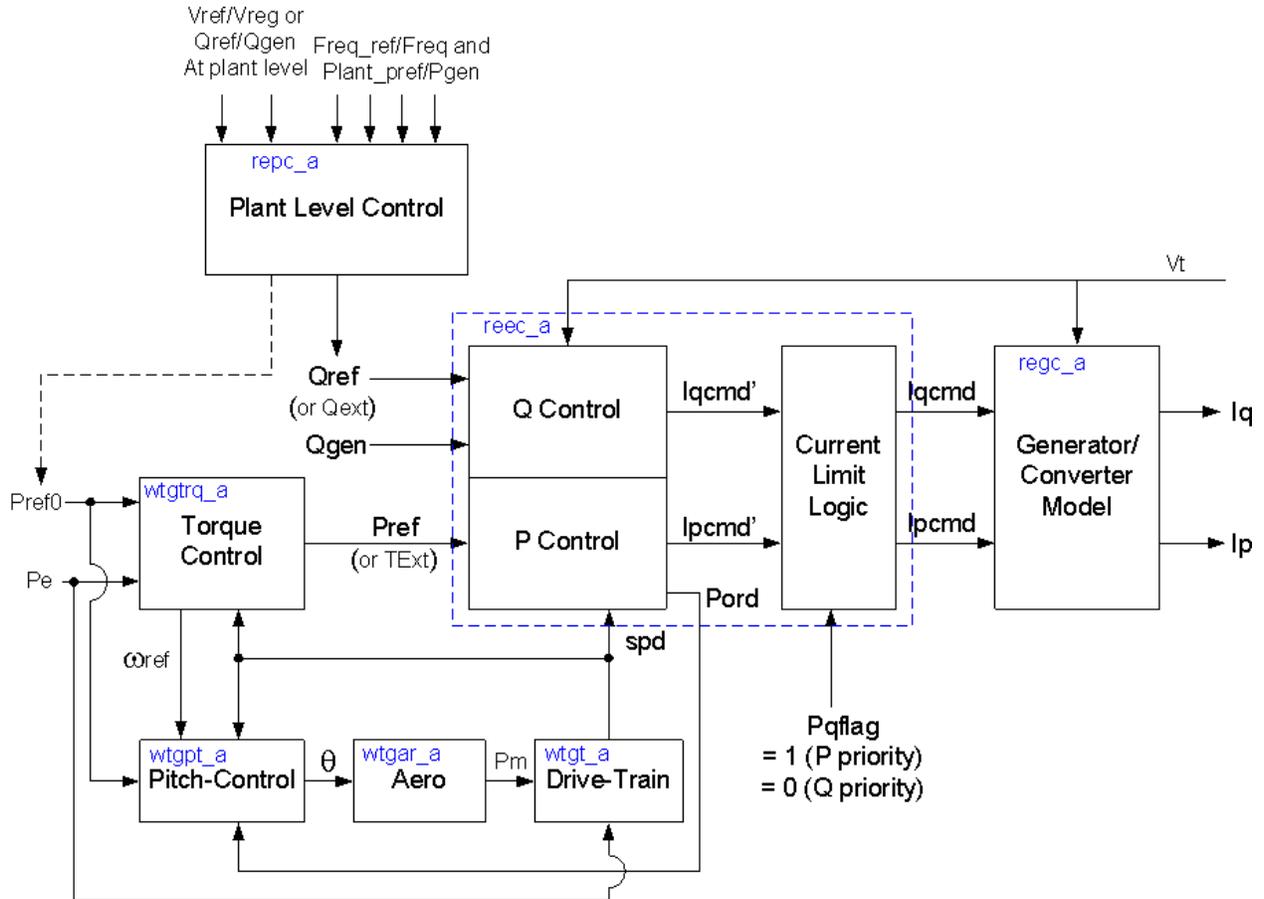


Figure 3-1: Overall model structure for type 3 wind turbine generator. The dashed line from the plant controller to $Pref0$ represents the active power control component of the $repc_a$ model which can be enabled, but is typically disabled for this model as it has not yet been fully tested and validated.

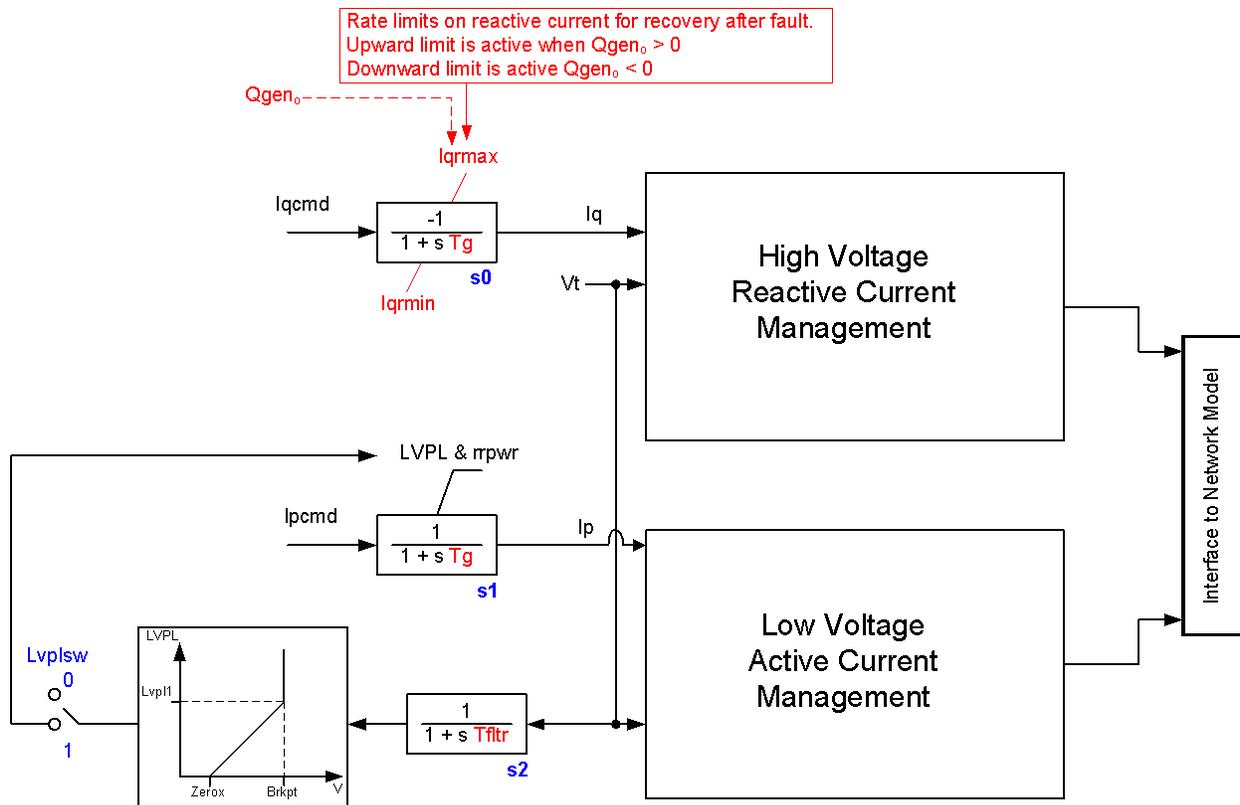


Figure 3-2: Modified generator/converter model (*regc_a*). Items shown in RED are the changes compared to the existing *wt3g* model. Note this is identical to the *regc_a* model in [3]. See Appendix D for an explanation of the logic inside the two blocks “high-voltage reactive current management” and “low-voltage active current management”.

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 ($I_{qinj} = 0$)
 State 1 - If Voltage_dip = 1; I_{qinj} goes to position 1
 State 2 - If $Thid > 0$, then after voltage_dip goes back to zero, set value to I_{qfrz} for $t = Thid$, after which go back to state 0
 - If $Thid < 0$, then after voltage_dip returns to zero stay in State 1 for $t = Thid$, after which go back to state 0.

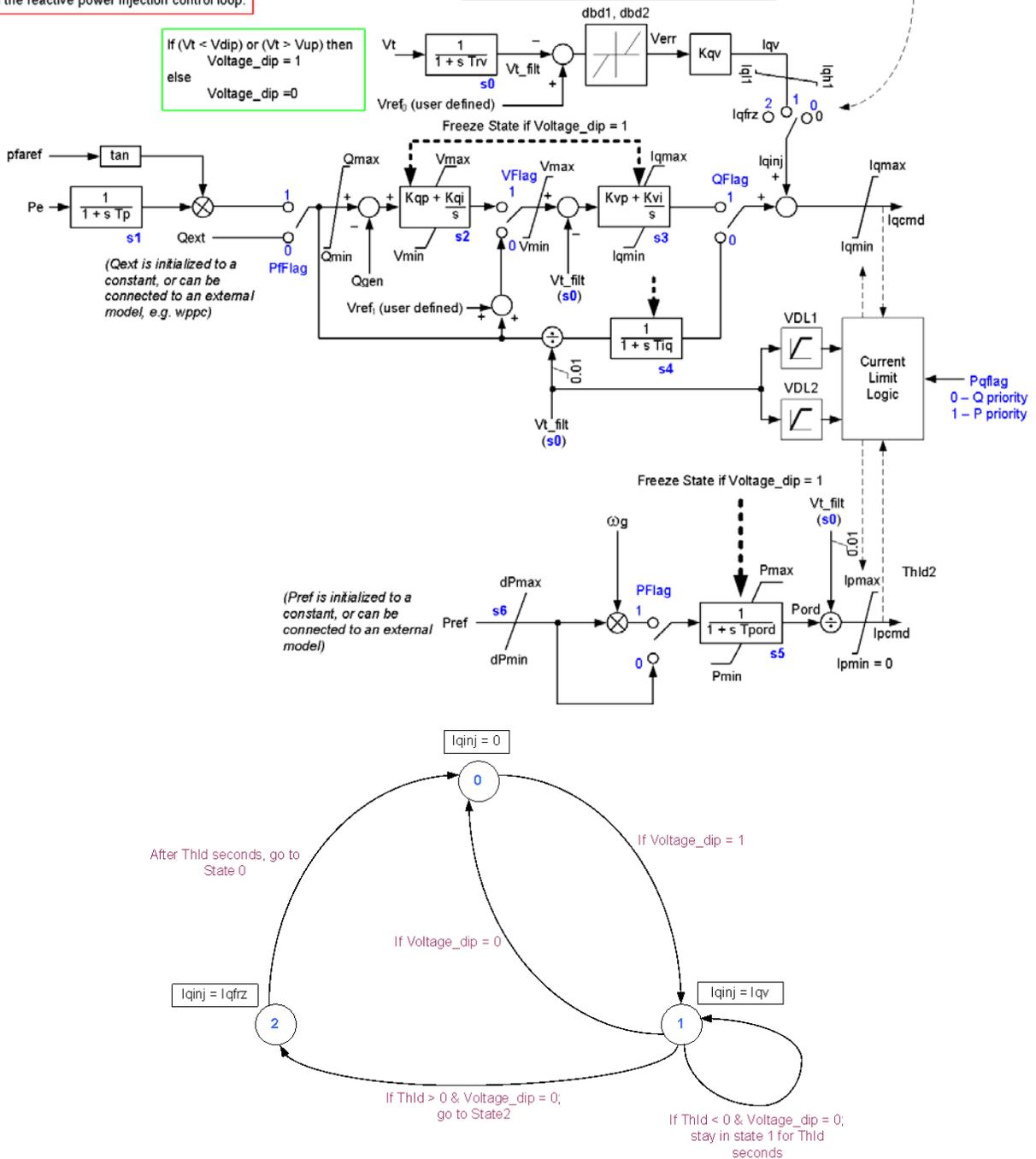
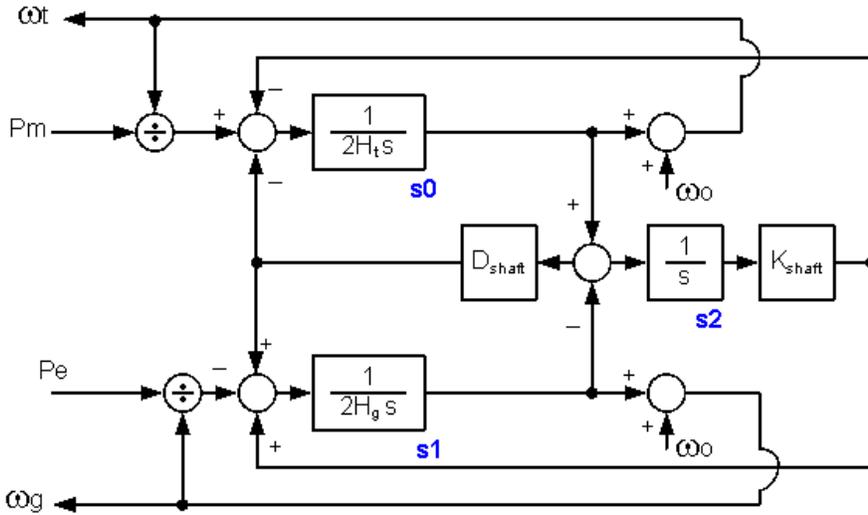


Figure 3-3: New P/Q Control model (rec_a)¹.

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



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

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

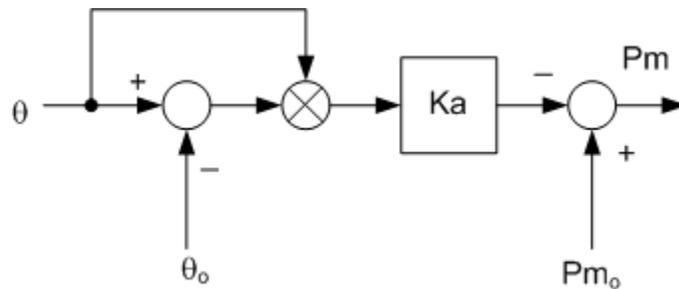


Figure 3-5: Simple aero-dynamic model ([wtgar_a](#)).

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

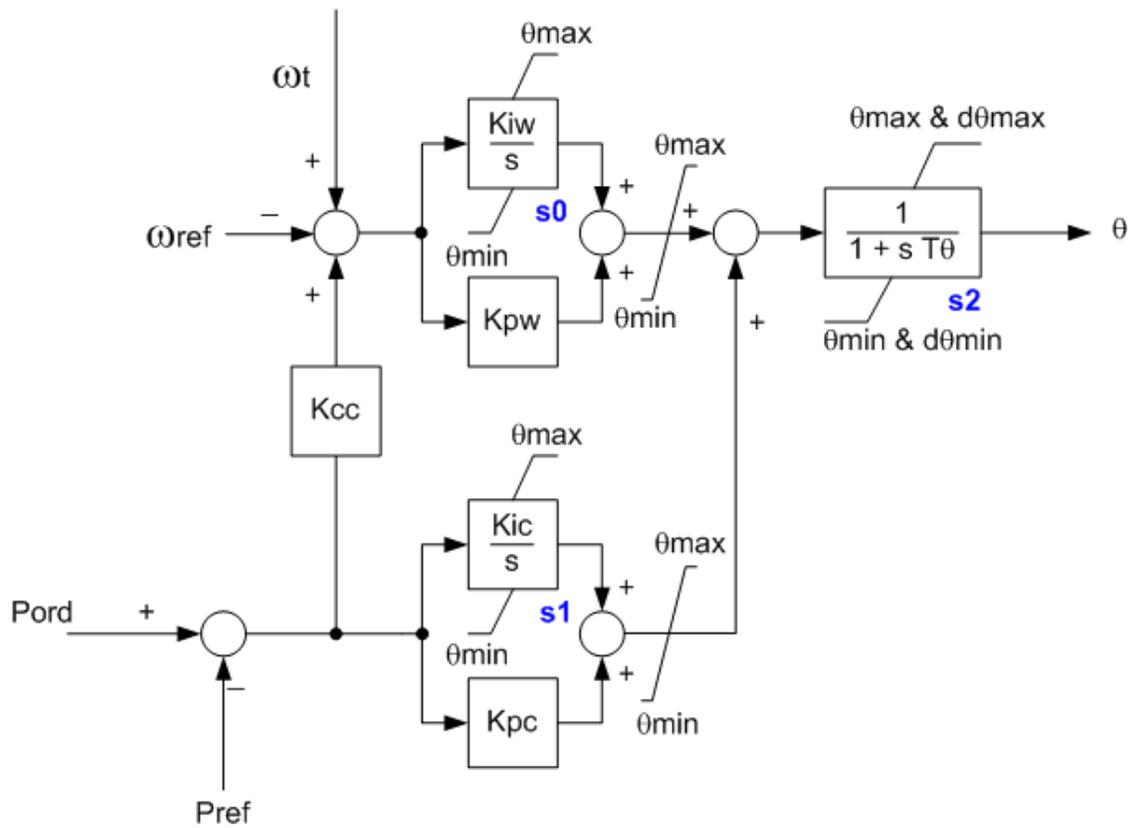
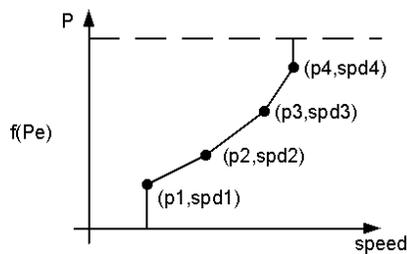
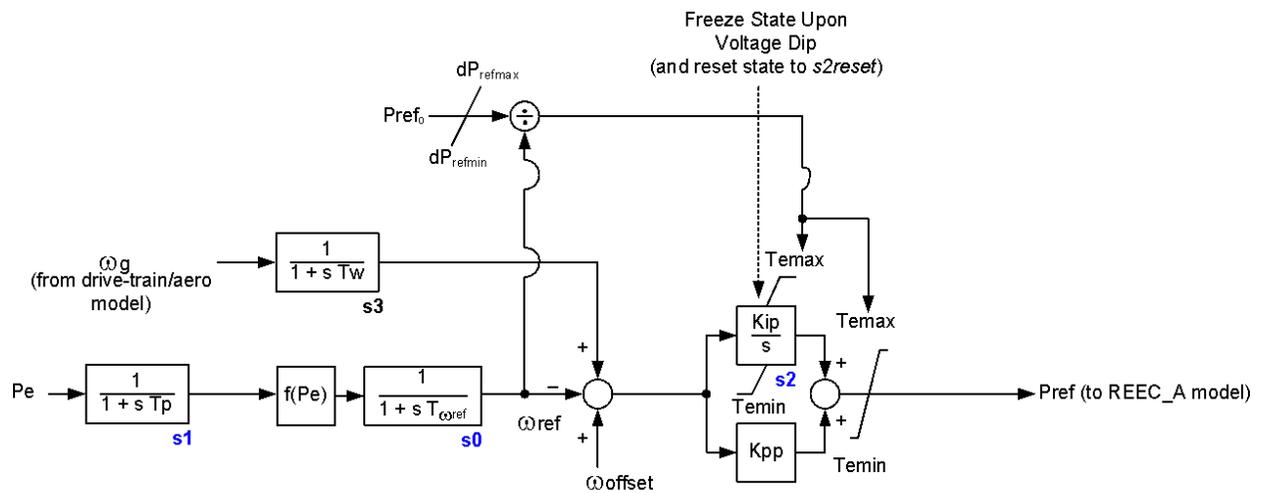


Figure 3-6: New pitch-controller model ([wtgpt_a](#)).



validated. Thus, at present $\text{Freq_flag} = 0$ is perhaps the recommended setting for particularly the type 3 WTG until testing and validation is done, which may very well lead to modifications of the model for better representation of active power control response.

4

EXAMPLE SIMULATION CASE

As performed with the type 4 WTG [3], here we present simulations using the newly proposed type 3 model and provide a comparison between simulation and measured turbine response.

The data used here was provided 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.

All the measured responses of WTGs shown here are for type 3 WTGs as measured on the low-voltage side of the generator step-up transformer. That is, voltages and currents as measured on the low-voltage side of the generator transformer (points MP2 and MP3 in Figure 4-1). In all the cases below the real (P) and reactive (Q) power were calculated at point MP2 and MP3 using the three phase voltages and currents measured at those points, and then the total P and Q calculated by adding these quantities. Also, the voltage dips quoted here are as measured on the low-voltage side of the generator transformer.

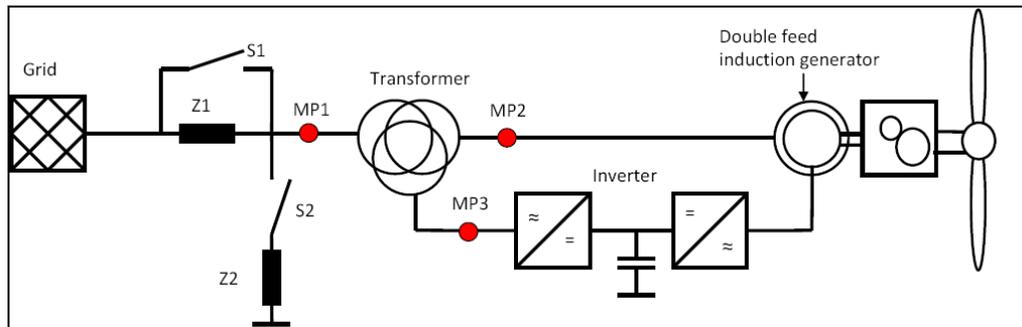


Figure 4-1: Doubly-fed WTG.

In the case of the measurements for the ABB unit, the data was measured for full factory tests of a doubly-fed asynchronous wind turbine generator while connected to the local utility grid through the generator step-up transformer. The unit was driven by a motor. In the case of the measurements for the Vestas units, the data was measured from a single doubly-fed asynchronous wind turbine generator in commercial operation inside a wind power plant, while connected to the power system.

The following should be noted:

1. The cases simulated for the first vendor (ABB) are shown in Figure 4-2 to Figure 4-4. In general the fits look reasonable. The fits for voltage dips of 20% or so are extremely good. For the deeper voltage dips, since the active-crow bar circuit is engaged momentarily at the inception of the fault for purposes of protecting the power electronics, the initial transient in the real and reactive power are not emulated that well. This is because we have no representation of this control mechanism, or other similar controls

used for protecting the power electronics during severe dips. The same set of model parameters were used to simulate all three events. In the next section a proposal for capturing the behavior of the crow-bar is discussed, however, at this stage the WECC REMTF decided not to pursue implementation of this proposal for the next release of the type 3 generic model.

2. The cases simulated for the second vendor (Vestas) are shown in Figure 4-5 to Figure 4-13. In general the fits look good. There are two sets of cases for two different designs of the type 3 machine. The fits for the reactive power response are quite good and we believe as good as the type 4 fits in the previous work [3]. There are several pertinent comments to be made:
 - a. The oscillations in real power post fault do not match perfectly. The reason for this, we believe, is the simplicity of the generic models. There are two issues that we believe cannot be adequately modeled with the generic models. The damping of the torsional oscillation in the actual equipment is achieved by active damping controls and so is not a simple constant as modeled here. Secondly, the details of the electrical coupling of the machine to the grid, through the stator of the generator, and the details of the controls associated with the grid interaction are very much simplified. In the next section a proposal for augmenting the model to allow for a simple representation of the active damping control is discussed to try to address one of these issues. However, at this stage the WECC REMTF decided not to pursue implementation of this proposal for the next release of the type 3 generic model.
 - b. Another issue is that we can see, particularly in cases 34 and 23, that there appears to be a delay from when the fault clears to when the real power starts to ramp back up to its pre-fault value. To emulate this behavior, we introduced a new parameter (*Thld2*) which is simply a time delay during which the maximum real current limit is kept at the value during the fault before it is released. This was set to 0.5 seconds in all cases.
 - c. Finally, we noticed that for case 23 the gain on the reactive current injection during the fault (*Kqv*) seems to be different to the other cases. This was confirmed by Vestas – namely, for that particular test this value was apparently changed.

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 necessarily directly correspond to actual equipment settings or physical quantities. In addition, further analysis was done on partial load conditions as well as another type 3 design for Vestas; some example simulations for these cases are also shown below.

All the cases presented here, and in the previous work [3], are for balanced disturbances. For unbalanced conditions positive sequence models will likely not be suitable. This is particularly true for the type 3 machines [7]. Such applications (i.e. for unbalanced faults) require further investigation.

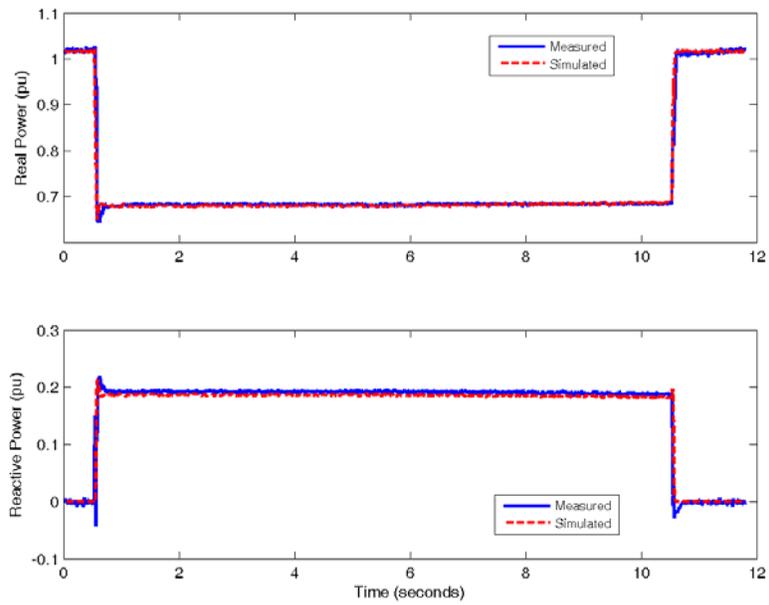


Figure 4-2: Validation result of simulation versus measured real and reactive power for vendor 1 (ABB). The case is for a balanced 3-phase voltage dip of 20% at full-load.

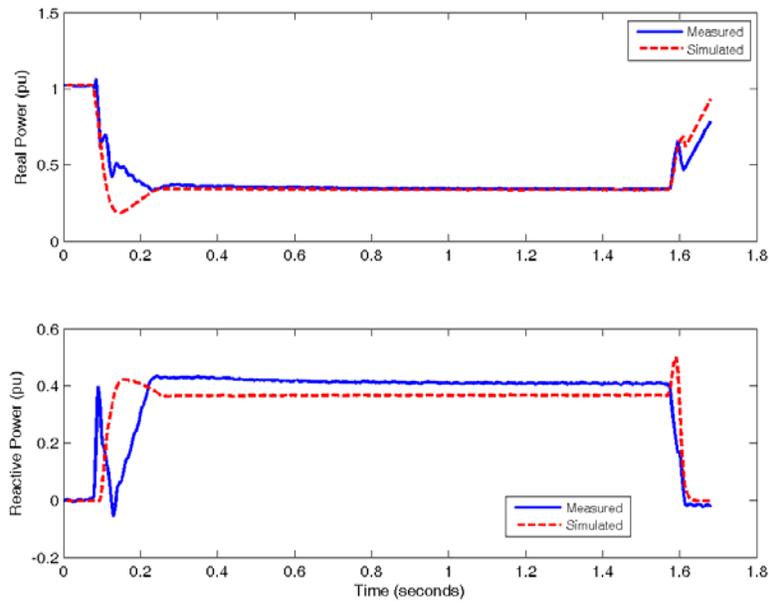


Figure 4-3: Validation result of simulation versus measured real and reactive power for vendor 1 (ABB). The case is for a balanced 3-phase voltage dip of 40% at full-load.

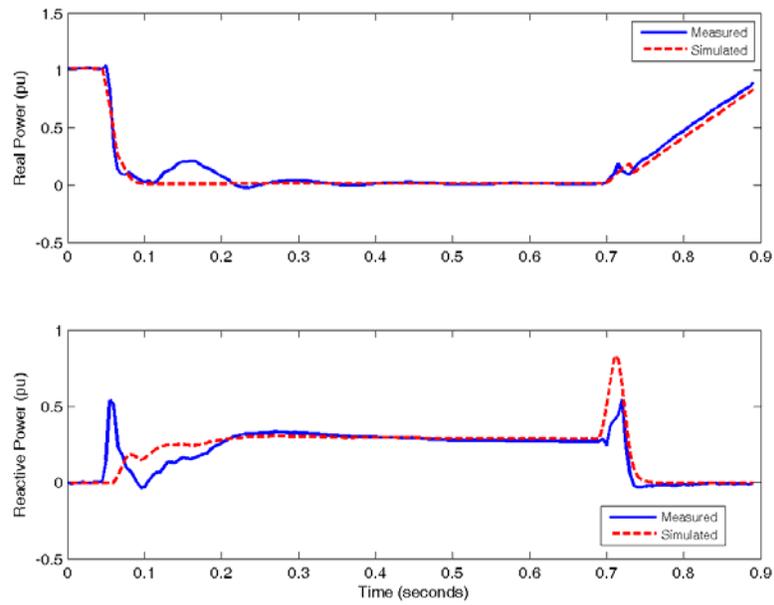


Figure 4-4: Validation result of simulation versus measured real and reactive power for vendor 1 (ABB). The case is for a balanced 3-phase voltage dip of 75% at full-load.

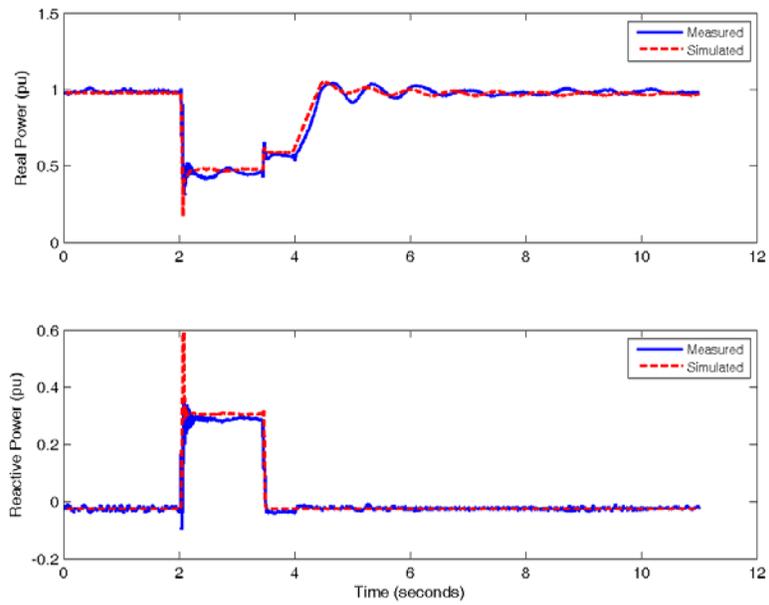


Figure 4-5: Validation result of simulation versus measured real and reactive power for vendor 2 (Vestas) – Case 34, the case is for a balanced 3-phase voltage dip of 20-30% at full-load.

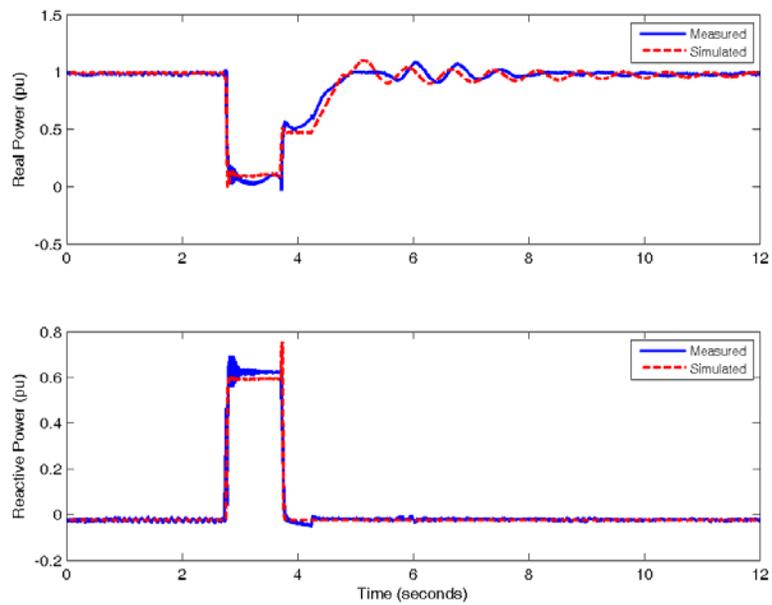


Figure 4-6: Validation result of simulation versus measured real and reactive power for vendor 2 (Vestas) – Case 23, the case is for a balanced 3-phase voltage dip of 30-40% at full-load.

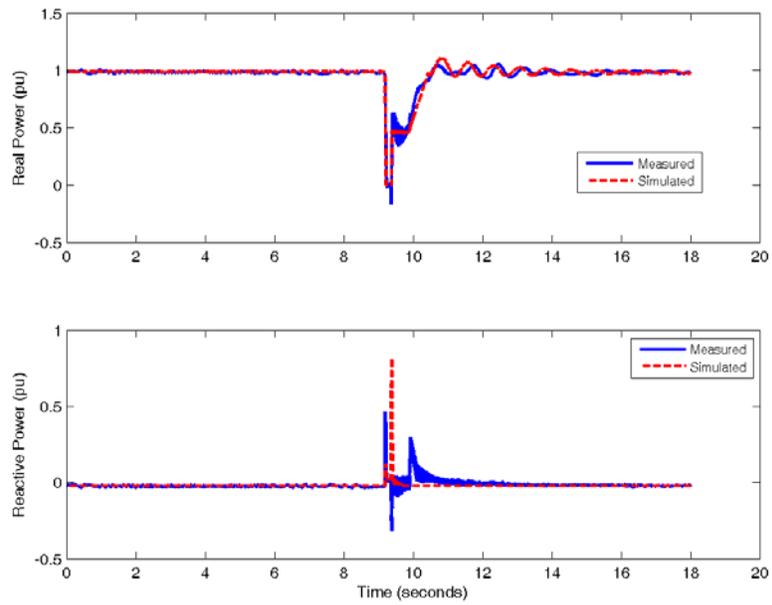


Figure 4-7: Validation result of simulation versus measured real and reactive power for vendor 2 (Vestas) – Case 5, the case is for a balanced 3-phase voltage dip of >95% at full-load.

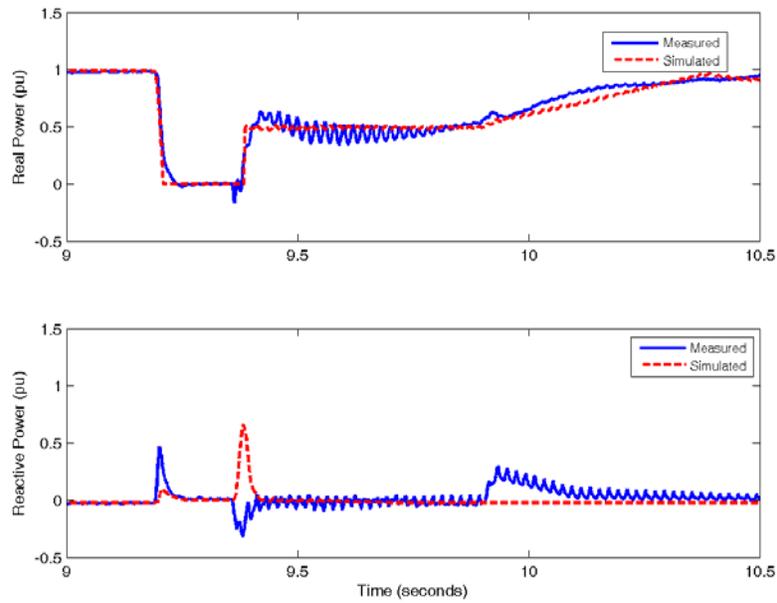


Figure 4-8: As above, expanded view of the initial period of fault inception and clearing.

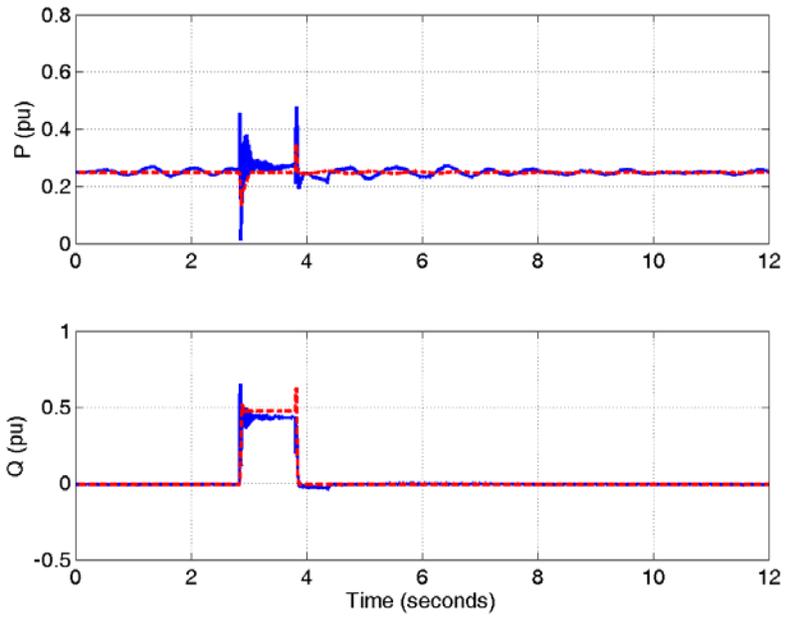


Figure 4-9: Validation result of simulation versus measured real and reactive power for vendor 2 (Vestas) – Case 16, the case is for a balanced 3-phase voltage dip of 30-40% at partial-load.

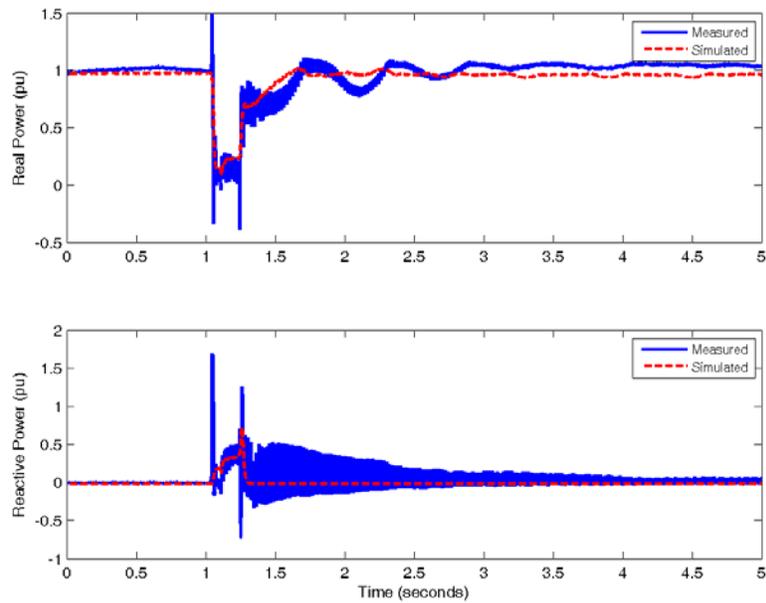


Figure 4-10: Validation result of simulation versus measured real and reactive power for a different type 3 machine design of vendor 2 (Vestas) – Case 1, the case is for a balanced 3-phase voltage dip of 70% at full-load.

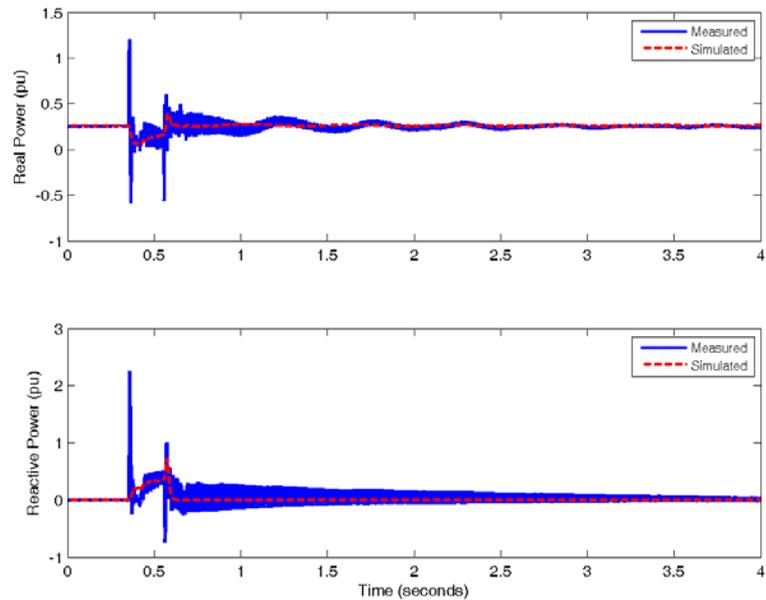


Figure 4-11: Validation result of simulation versus measured real and reactive power for a different type 3 machine design of vendor 2 (Vestas) – Case 1b, the case is for a balanced 3-phase voltage dip of 70% at partial-load.

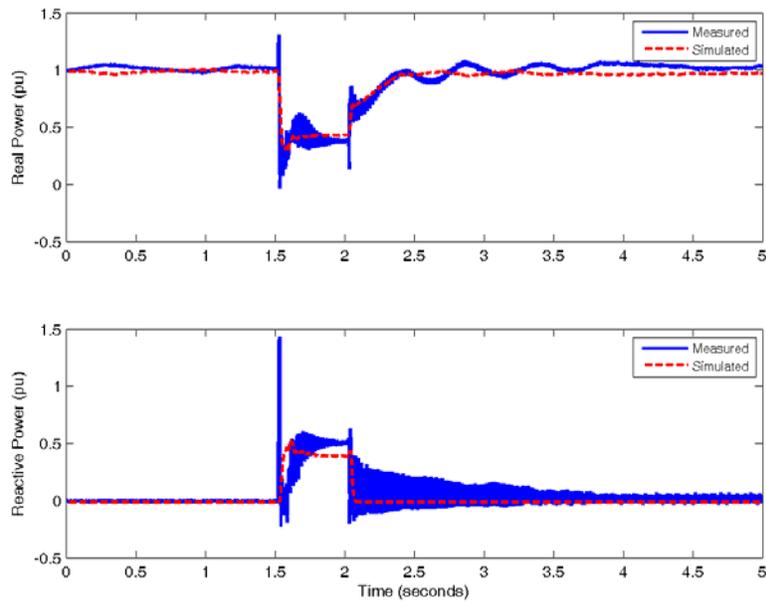


Figure 4-12: Validation result of simulation versus measured real and reactive power for a different type 3 machine design of vendor 2 (Vestas) – Case 2, the case is for a balanced 3-phase voltage dip of 40% at full-load.

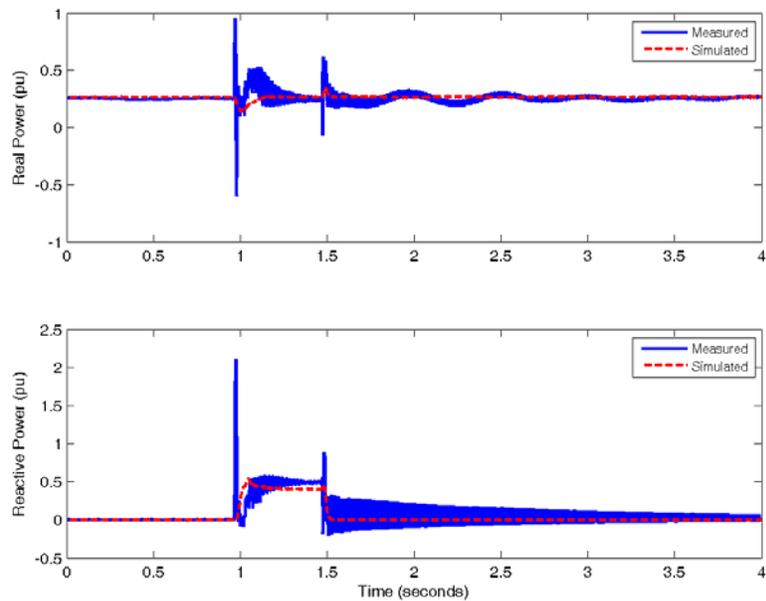


Figure 4-13: Validation result of simulation versus measured real and reactive power for a different type 3 machine design of vendor 2 (Vestas) – Case 2, the case is for a balanced 3-phase voltage dip of 40% at partial-load.

5

SOME ADDITIONAL PROPOSED CHANGES FOR CONSIDERATION FOR FUTURE IMPLEMENTATION

Recently, Gamesa issued some additional proposed changes to the IEC model [9]. These were reviewed and commented on in detail in [4], with the feedback presented to both IEC and WECC REMTF. Here for the sake of completeness will briefly review these proposals. The proposed changes are as follows:

1. The addition of a rudimentary representation of the active crow-bar action for designs that incorporate such protection (e.g. Gamesa's WTG). The proposal in [9] is based on [10], with some modifications. What we will present here is based on Gamesa's proposal, but we have further modified it in order to make it more applicable to various designs.
2. Modifying the current limits to allow for representation of a stator only current limit, as opposed to a total current limit. This would be an option.
3. The addition of a simple representation of the active drive train damper. This has actually been discussed several times before.
4. The addition of a filter in the speed measurement for feedback to the torque controller.
5. The addition of a simpler (as compared to [11]) representation of stator flux dynamics. This is in lieu of the original proposal from REPower [11] that suggested the use of a PI loop in the generator/converter model.

Active Crow-Bar Model & Stator Transients:

Like the ABB design, Gamesa also uses an active-crow bar on their WT3 turbine design. Therefore, they are suggesting the addition of a simple emulation of the active crow-bar in the generic model. We have adapted, and slightly changed, the original proposal here to the existing WECC WT3 proposal discussed in the previous section of this report. Note in the IEC current draft the current limits are in the generator/converter model and the active crow-bar acts on these limits to make them zero when the crow-bar is active and release them to their original values afterwards. In the WECC proposed implementation here, in order to keep the same modular approach for all the WTG models, the current limits are in the P/Q control model and we are suggesting adding the active crow-bar emulation to the generator/converter model. Here it will force the currents to zero when the crow-bar is active and release them again afterwards. The net effect is identical. Gamesa has since agreed and incorporated this suggestion into their latest memorandum.

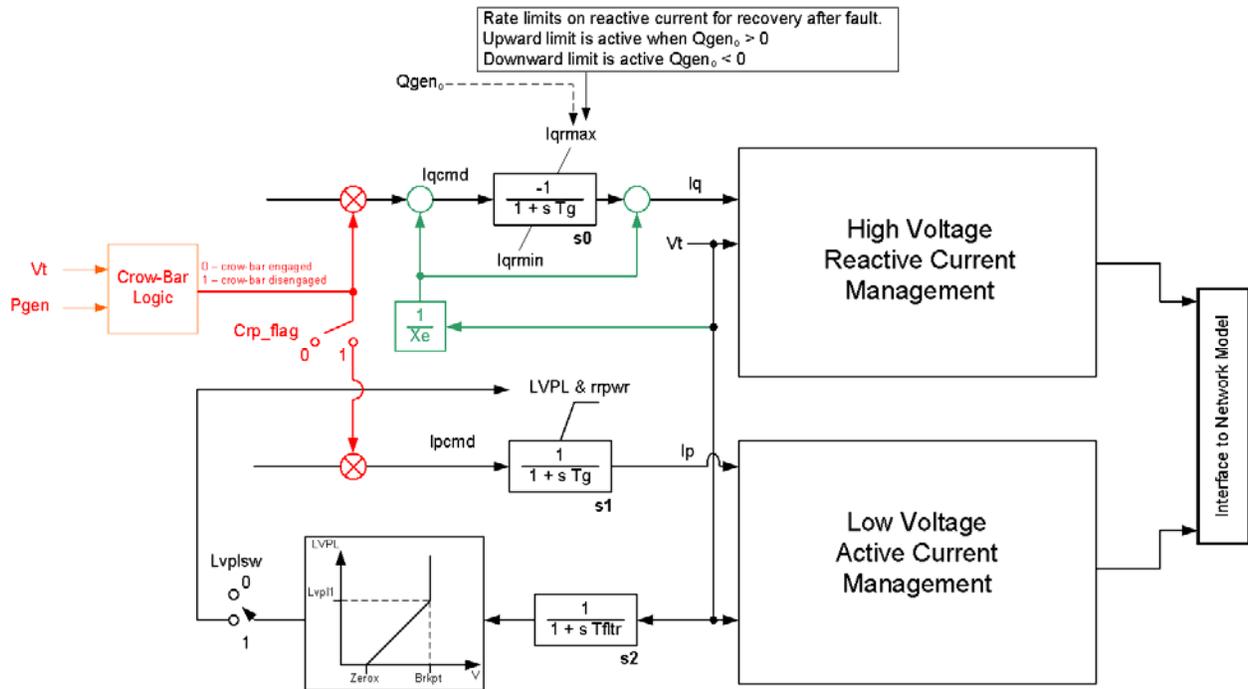


Figure 5-1: Modified generator/converter model (*regc_b*) to include crow-bar emulation and $1/X_e$ impedance to effect a rudimentary emulation of stator current transients in the reactive power. Changes shown in red and green, respectively.

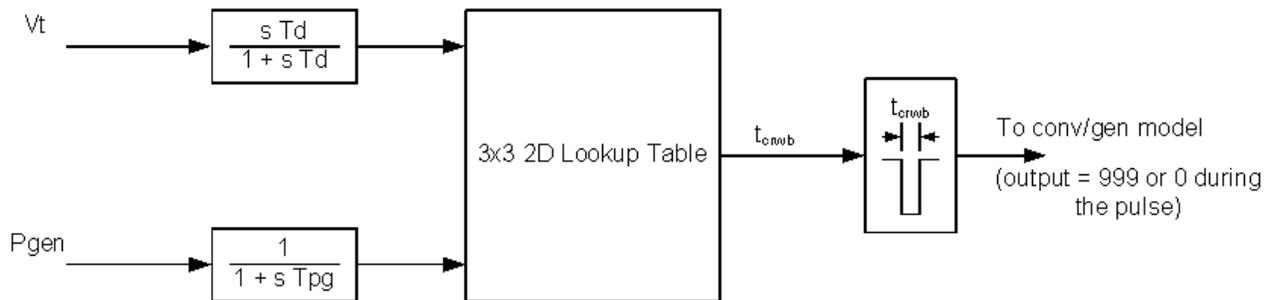


Figure 5-2: The crow-bar logic.

A few comments are pertinent for this proposal:

1. In [9] it is said that the block acting on V_t is a "derivative" and that the 3x3 2D lookup table is based on the derivative of voltage and the initial real power output of the generator. Based on these values a time duration for the engagement of the active crow-bar is calculated. Strictly speaking this block does not calculate the derivative of V_t . The block in front of V_t is a "washout" filter. A derivative would be $s/(1+sT_d)$. This is explained further in [4]. The distinction is that a washout filter will give an output equal to the absolute value of the change in the input signal and then washout the steady-state change quickly. Therefore, it is a means of determining the "magnitude" of the change in the input; in our case the size of the voltage dip. Therefore we believe that the lookup table should be based on the "magnitude of the voltage dip" and not the derivative of voltage. This is an important point.

2. The proposal in [9] suggests that both real and reactive power be forced to zero during the period that the active crow-bar is effective. We have some significant concerns with this. The concerns are as follows:
 - a. It is not possible with such a simple model to predict exactly what the effective real and reactive current will be during the action of the crow-bar circuit. The reason is that depending on the initial operating condition of the generator (whether it is running at super-synchronous speed, near synchronous speed or sub-synchronous speed) the unit effectively becomes an induction machine when the rotor circuit is shorted and so may momentarily absorb a small amount of real and reactive power, or momentarily generate some real power and be near zero reactive power or absorbing some reactive power, etc. – see [12] for a detailed explanation.
 - b. The data needed for the lookup table will be quite specific to each turbine and is not necessarily standard vendor data. It will probably need to be determined through some simulation trial and error.
 - c. It should be fully appreciated that this is a very rudimentary approximation. It has many limitations such as the one mentioned above in (a) as well as the fact that it will not properly be able to emulate situations where the fault is an unbalanced fault – many planning studies look at single-line to ground faults.

The proposal of adding $1/X_e$ as a simpler approximation to what was originally proposed in [11] (and several times discussed at the IEC, WECC and IEEE meetings) is actually a welcome addition. This is much simpler than the proposed PI loops and only adds one more parameter to the model. Also, if one wishes to neglect this effect X_e can be set to a very large number.

Based on the above comments, we believe the crow-bar emulation should be modified to what is shown in Figure 5-1. That is, the output of the crow-bar logic is either 1 or 0. It is always 1, and changes to zero for the duration (T_{crwb}) during which the crow-bar engages. The output is then simply multiplied by real and reactive current. Also, a flag is made available in order to disconnect the crow-bar emulation from the real current. The reason for this is illustrated in the example below. Gamesa appears to now agree with these proposed changes and has accordingly revised their memo.

One of the cases in the previous section utilized an active crow-bar technology – see Figure 4-3 and Figure 4-4. Note the design (as with others such as Gamesa) that incorporate active crow-bars do meet various grid codes. The discussion here is solely on the subject of modeling. So if we re-simulate the cases in those figures but with the addition of the proposed changes discussed above (i.e. active crow-bar emulation and addition of the $1/X_e$ term) we get the results in Figure 5-3 and Figure 5-4.

Note: we have set $crp_flag = 0$ – i.e. no crow-baring of the real power.

The results clearly show some improvement in the model performance. The question, however, is does the improvement justify the added complication in the model? Also, the cautions provided above under bullet point 2., should also be considered.

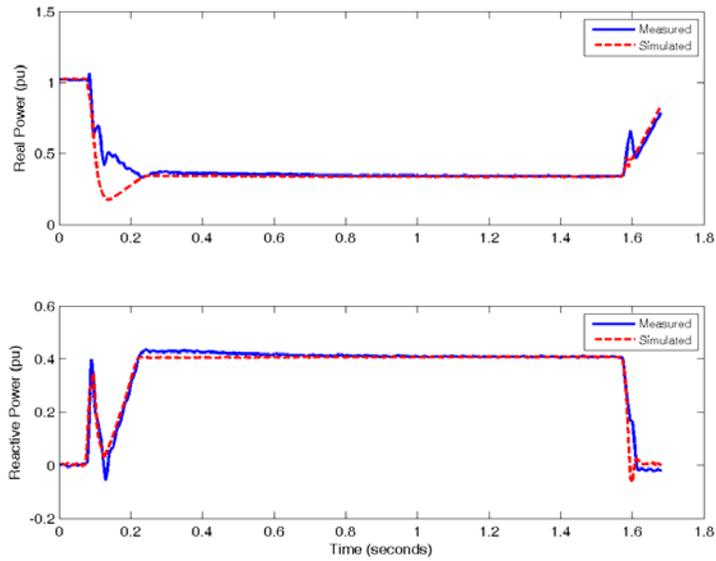


Figure 5-3: Validation result of simulation versus measured real and reactive power for vendor 1 (ABB). The case is for a balanced 3-phase voltage dip of 40% at full-load. This case includes the emulation of active crow-bar as shown in Figure 5-1.

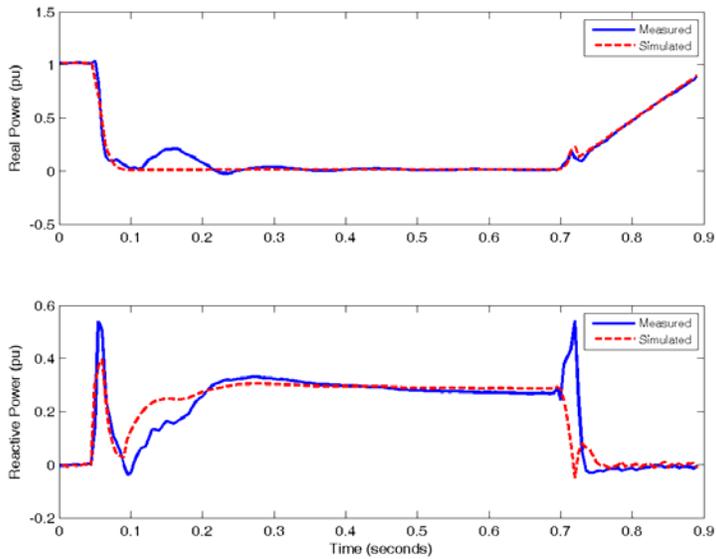


Figure 5-4: Validation result of simulation versus measured real and reactive power for vendor 1 (ABB). The case is for a balanced 3-phase voltage dip of 75% at full-load. This case includes the emulation of active crow-bar as shown in Figure 5-1.

Addition of the Active Damping Control, Stator-Current Limit and Speed Measurement Time Constant:

The second set of proposed changes is shown in Figure 5-5. The implementation of the stator current limit is not shown. This is a simple change. The addition is to have an option for which we multiply I_{pmax} by the generator speed in the equations in Appendix B, for Q-priority.

These changes are pertinent of the second example in section 4, the Vestas unit. Let us first look at two examples for that case, duplicated from above Figure 4-5 and Figure 4-7. If we now add the newly proposed changes and instead impose the active damping control (as opposed to the fixed passive shaft damping constant), we get the results in Figure 5-6 and Figure 5-7. As can be seen the results look very similar. With the addition of the stator current limit, we do see some oscillations in the real power during the fault, which more closely emulates the actual turbine behavior.

We acknowledge that Gamesa has shown a significantly larger difference in their results [9].

It is expected that it will be quite difficult at best to identify a single set of optimized parameters for either the passive or active damping model that will yield a good match of the torsional oscillations over a wide range of operating conditions. The reasons for this are many, including the complexity of the actual controls and the complex nature of the actual physics of the phenomena, both of which cannot be captured by simplified generic performance models as presented here.

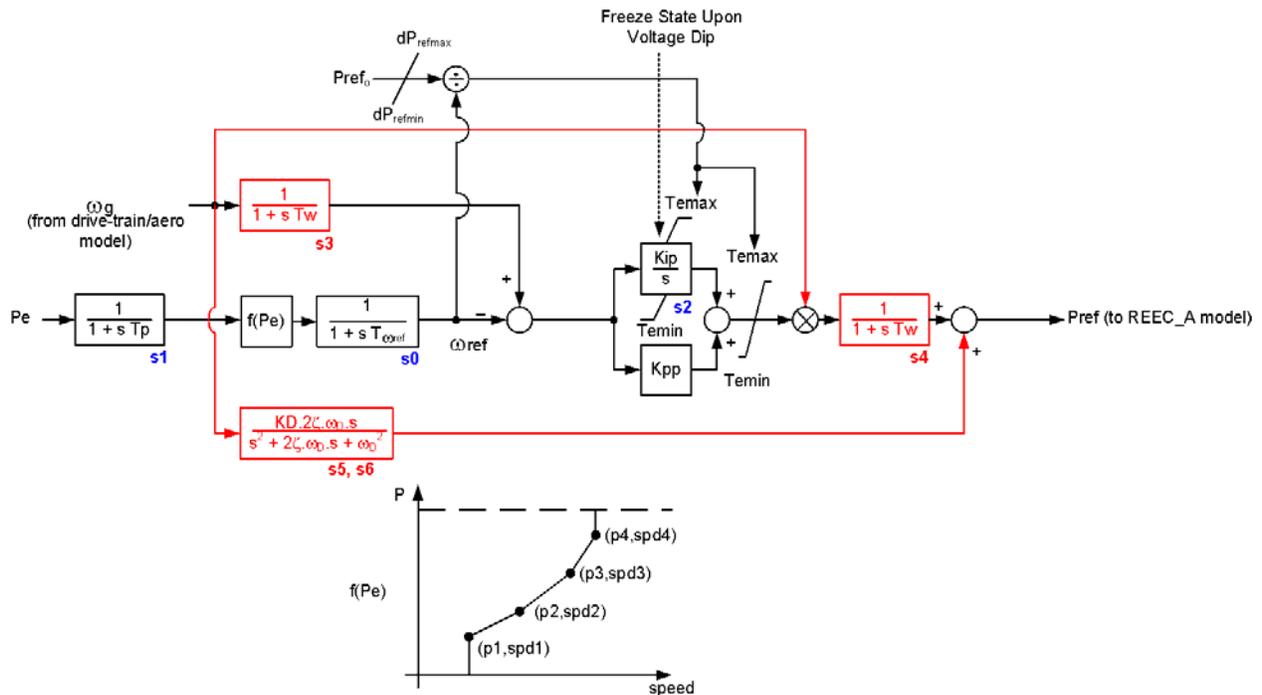


Figure 5-5: Addition of an active damper model and a few extra time constants to the torque controller – [wtgtrq_b](#).

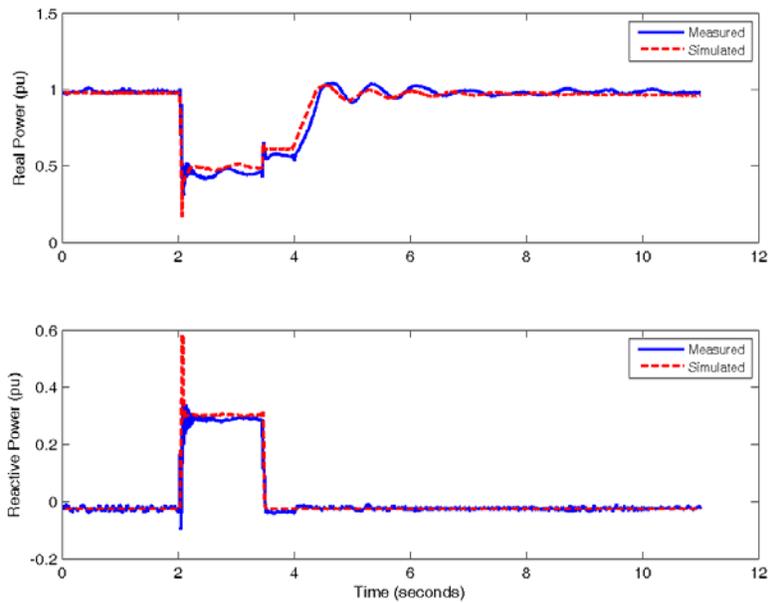


Figure 5-6: Validation result of simulation versus measured real and reactive power for vendor 2 (Vestas) – Case 34, the case is for a balanced 3-phase voltage dip of 20-30% at full-load. This includes the active-damping controller and stator-current limit additions.

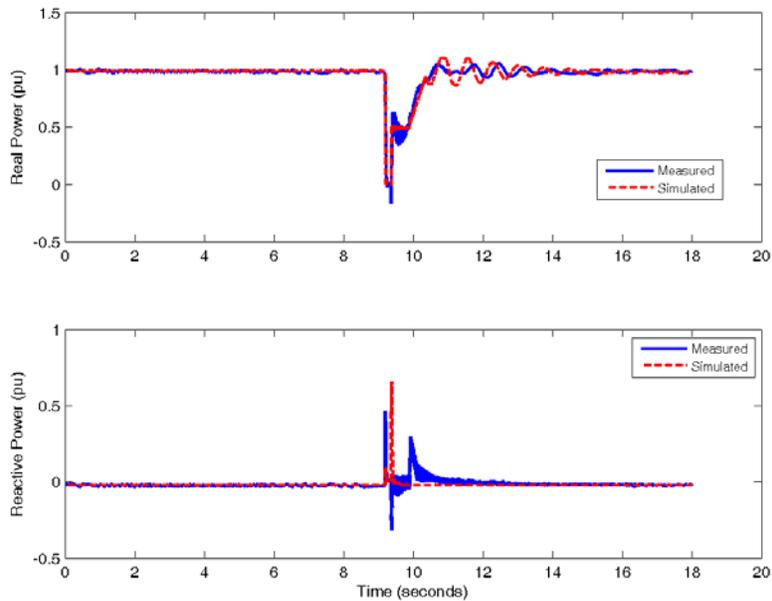


Figure 5-7: Validation result of simulation versus measured real and reactive power for vendor 2 (Vestas) – Case 5, the case is for a balanced 3-phase voltage dip of >95% at full-load. This includes the active-damping controller and stator-current limit additions.

Summary and Conclusions:

In summary, the proposals by Gamesa, after some minor modifications discussed here, do provide some improvement in the simulation results. However, there are two concerns:

1. They add significant additional parameters and complexity to the model.
2. In particular, the proposed simple active crow-bar model introduces a significant additional number of parameters, while it has limited applicability. As discussed above, it may give a false impression of greater accuracy while it is a very rough representation of the actual physics of the active crow-bar action.

All these results and suggestions have been presented to both the IEC TC88 W27 modeling working group (on 6/15/12 by webcast) and to the WECC REMTF at the 6/18/12 meeting in Salt Lake City.

The IEC group is likely to adopt these changes or some modified version of them – we are refereeing here to the changes in this section only (i. active crow-bar emulations, ii. active damping controller, etc.). The WECC REMTF decided on 6/18/12, through a unanimous vote, that these additions add more complication and do not yield necessarily greater fidelity for the intended purpose and use of these generic models – i.e. system wide, positive-sequence, stability studies. As such, in the next release of the models for use in North America the version described in section 4, without these further additions, is being pursued. These additions can of course be added in the future given the modular approach to modeling the wind turbine generators that has now been established.

6

CONCLUSION AND SUMMARY

At this point, with the gracious input of the various equipment vendors for type 3 wind turbine generators, a proposed model is on the table that appears to cater to at least three designs tested so far.

A key feature of the proposed type 3 model is that it is modularized. That is, it is made of seven (7) modules several of which are identical to the type 4 model.

All the cases presented here, and in the previous work [3], are for balanced disturbances. For unbalanced conditions positive sequence models will likely not be suitable. This is particularly true for the type 3 machines [7]. This requires further investigation.

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.

The WECC REMTF decided on 6/18/12 that in the next release of the models for use in North America the version described in section 4 will be pursued. The additional changes in section 5, and future modifications yet to be discussed (e.g. emulated inertia), can of course be added in the future given the modular approach to modeling the wind turbine generators that has now been established.

7

REFERENCES

- [1] NERC IVGTF 1-1, Standard Models for Variable Generation, May 18, 2010, [http://www.nerc.com/docs/pc/ivgtf/IVGTF_Report_PhaseII_Task1-1_Final\(5.24\).pdf](http://www.nerc.com/docs/pc/ivgtf/IVGTF_Report_PhaseII_Task1-1_Final(5.24).pdf)
- [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)
- [3] P. Pourbeik, “Proposed Changes to the WECC WT4 Generic Model for Type 4 Wind Turbine Generators”, Prepared under Subcontract No. NFT-1-11342-01 with NREL, Issued to WECC REMTF and IEC TC88 WG27 12/16/11; (last revised 8/17/12).
- [4] P. Pourbeik, “Model Validations Attempts for the Type 3 Generic Model Structure – Review of Proposed Changes by Gamesa”, Memorandum to WECC REMTF, IEC TC88 WG27 and P173, 5/22/12.
- [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] W. W. Price and J. J. Sanchez-Gasca, “Simplified Wind Turbine Generator Aerodynamic Models for Transient Stability Studies”, Proceedings of the IEEE PSCE 2006.
- [7] S. Seman, “Examples of Model Validation for Wind Generation – ABB Work”, September 22, 2010, EPRI Workshop on Variable Generation Modeling and Model Validation, Charlotte, NC.
- [8] P. Pourbeik, “Proposed Model for PV1”, Memorandum sent to WECC REMTF on 4/14/12.
- [9] Francisco Jiménez, “IEC Type 3 model correlation report”, Memo Issued on 5/17/12 to IEC group. Memo from Gamesa.
- [10] A. Timbus, P. Korba, A. Vilhunen, G. Pepe, S. Seman and J. Niiranen, “Simplified Model of Wind Turbines with Doubly-Fed Induction Generator”, 10th Large-Scale Integration of WPP into Power Systems 2011
- [11] Jens Fortmann, Stephan Engelhardt, Jörg Kretschmann, Christian Feltes, Martin Janßen, Tobias Neumann, Istvan Erlich “Generic Simulation Model for DFIG and Full Size Converter based Wind Turbines”, 9th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants, Quebec City, 2010
- [12] CIGRE Technical Brochure 328, *Modeling and Dynamic Behavior of Wind Generation as it Relates to Power system Control and Dynamic Performance*, August 2007, CIGRE WG C4.601. (www.e-cigre.org)

A

CURRENT LIMITS AS PRESENTLY IMPLEMENTED IN THE WECC MODLE

ImaxTD, Iphl, Iqhl and pqflag are user input values

If ($V_t \geq 1$)

 Iqmxv = qmax

Else

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

Endif

If (pqflag = 0) % Q - priority

 Iqmax = min {Iqmxv, Iqhl, ImaxTD}

 Iqmin = -1 × Iqmax

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

 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), (vq3,Iq3), (vq4,Iq4),}

VDL2 is a piecewise linear curve define by four pairs of numbers:
{(vp1,Ip1), (vp2,Ip2), (vp3,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
```

C

PARAMETER LIST FOR THE MODEL

C.1 REGC_A Model – Generator/Converter

This model is identical to that described in [3]. See Appendix C of [3] for the parameter list.

C.2 REEC_A Model – Electrical Controls

This model is identical to that described in [3]. See Appendix C of [3] for the parameter list.

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 WTGAR_A Model – Aero-Dynamics

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

Parameter	Description	Typical Range of Values	Units
Ka	Aero-dynamic gain factor	0.007	pu/degrees
θ_0	Initial pitch angle	0	degrees

C.5 WTGPT_A Model – Pitch-Controller

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

Parameter	Description	Typical Range of Values	Units
Kiw	Pitch-control integral gain	N/A	pu/pu
Kpw	Pitch-control proportional gain	N/A	pu/pu
Kic	Pitch-compensation integral gain	N/A	pu/pu
Kpc	Pitch-compensation proportional gain	N/A	pu/pu
Kcc	Proportional gain	N/A	pu/pu
T θ	Pitch time constant	0.3	s
θ_{max}	Maximum pitch angle	27 – 30	degrees
θ_{min}	Minimum pitch angle	0	degrees
d θ_{max}	Maximum pitch angle rate	5 to 10	degrees/s
d θ_{min}	Minimum pitch angle rate	-10 to -5	degrees/s

C.6 WTGTRQ_A Model – Torque-Controller

The table below is a list of all the parameters of the *wtgtrq_a* model (Figure 3-7).

Parameter	Description	Typical Range of Values	Units
Kip	Integral gain	N/A	pu/pu
Kpp	Proportional gain	N/A	pu/pu
Tp	Power measurement lag time constant	0.05 to 0.1	s
Twref	Speed reference time constant	30 to 60	s
Temax	Maximum torque	1.1 to 1.2	pu
Temin	Minimum torque	0	pu
Tw	Time constat	0	s
dPrefmax	Maximum Pref change rate	N/A	pu/s
dPrefmin	Minimum Pref change rate	N/A	pu/s
ω_{offset}	Speed offset; typically = 0 – if this parameter is none zero then the torque controller will initialize at its non-windup limit; this parameter CANNOT be negative.	0	pu
s2reset	This is the value to which the torque controller integrator state is reset to upon a voltage dip; if it is a negative number then the state is not reset and is only frozen upon a voltage dip.	-99	pu
p1	User-define pairs of points	0.2	pu
spd1		0.58	pu
p2		0.4	pu

Parameter	Description	Typical Range of Values	Units
spd2		0.72	pu
p3		0.6	pu
spd3		0.86	pu
p4		0.8	pu
spd4		1.0	pu

C.7 REPC_A Model – Power Plant Controller

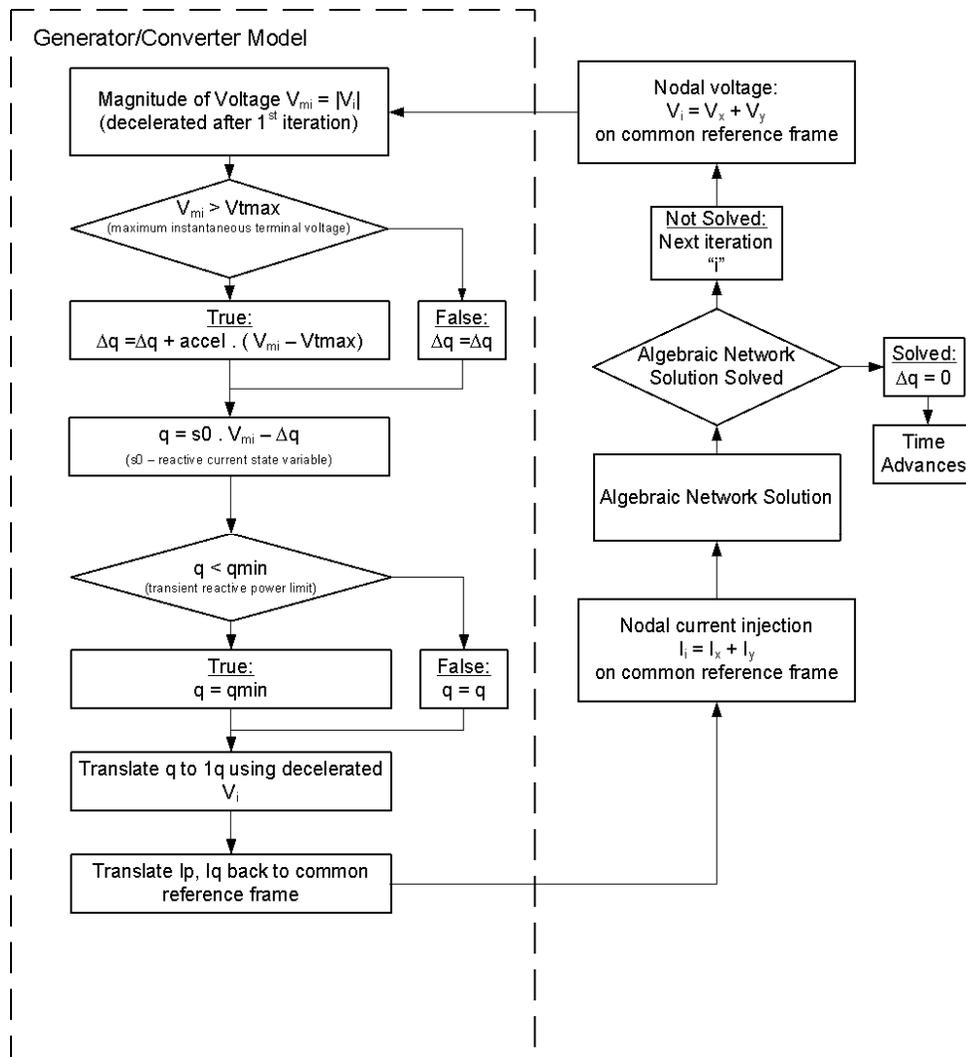
This model is identical to that described in [3]. See Appendix C of [3] for the parameter list.

D

CONVERTER MODEL GRID INTERFACE

In the generator/converter model block diagram (see Figure 2-4 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:

