Memo

Date: 6/21/2004

To: Fred Ritter and John Kehler, AESO

From: Pouyan Pourbeik, ABB Inc.

Cc: Wille Wong, ABB Inc.

RE: Sensitivity Analysis on Low-Voltage Ride-Through Requirements

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A question that has been presented to AESO is "What is the minimum requirements on low-voltage ride-through?". Since the release of the ABB study reports on 5th May 2004, both the GE PSLF and PTI PSS/E software programs have significantly changed the wind turbine generator models available, particularly for the doubly-fed induction-generator. As such, it seemed prudent to revisit the key simulation previously performed.

In the voltage regulation study report [1], it was shown that without low-voltage ride-through there exists a potential for all of the wind generation on the system to trip off-line for a fault on the 240 kV transmission system. This was shown to be the case with all of the wind turbine generators being doubly-fed induction-generators. One of the critical cases was with a fault at Peigan 240 kV and subsequent clearing of the Peigan to Dewinton 240 kV line. This case has been simulated again with the latest available GE PSLF and PTI PSS/E models for the GE 1.5 MW wind turbine generator (which we would expect should be indicative of doubly-fed induction-generators from other manufacturers). The results are shown in Figures 1 through 4.

Figure 1 shows a comparison between the terminal-voltage at the Waterton equivalent wind turbine generator for this fault using the GE PSLF model versus the PTI PSS/E model. As can be seen there is still some difference between the two models, however, the minimum terminal voltage during the fault in both cases is very close. Some comments are pertinent:

1) For the GE PSLF model we see an initial immediate drop in voltage once the fault incepts followed by an exponential decay. This is what one would typically expect to see at the terminals of a rotating machine directly connected to the grid.
2) In the PTI PSS/E model we see that the voltage immediately drops to its minimum value and then perturbs (oscillates) around this value. In the previous version of the PSS/E model (the only version available at the time of the study) these perturbations in the

terminal voltage during the fault were even more pronounced. It is our belief that these perturbations are an artifice of the model.

The differences in the models are due to what must be slightly different approaches taken in developing the models by the two software vendors. What is perhaps reassuring is that the minimum voltage reached by both models during the fault is of similar magnitude. This after all is what determines the required low-voltage ride-through capability. According to GE's latest report on their model [2], their latest model has been benchmarked against other results and so is the best model presently available. As shown in Figure 1, the latest PSS/E model (version 1.5) shows better agreement with the latest PSLF model.

Figure 2 shows the terminal-voltage of the equivalent wind turbine generator (WTG) for all eleven new proposed wind farms between 2004 and 2007 (see Table 1-1 of [1]). This simulation was done using the new PSS/E model of the GE WTG (version 1.5, a preliminary release made available to ABB on 6/10/04 as a user of PSS/E). Figure 3 shows the same case as was simulated with the version of the model released in January 2004, which was the latest version available at the time of the study. It can be seen that there is considerable difference in the minimum terminal voltage of the unit during a fault, between the two models. Based on the earlier model a low-voltage ride-through system would need to ensure ride-through down to and below 15% voltage. However, based on the latest model ride-through below 15% voltage is probably not required. The voltage recovery at the WTG for the DFIG model is also markedly different with the newer PSS/E model, this is due to significant changes made in the model to more closely represent the machine voltage regulation control loops.

Figure 4 shows the same simulation with all the WTGs modeled as conventional induction generators with the appropriate amount of dynamic VArs (SVC) at the machine terminals. This is the simulation of contingency 1 in Table 2-6 of [1]. As can be seen, in this case the terminal voltage of the WTGs does not go below 15% for this regional 240 kV fault either.

In summary, based on the latest available models, for the critical 240 kV faults the WTGs need only be able to ride-through down to 15% voltage. That is, the quoted ride-through capability of 0 to15% for 200 ms in [1] may not be necessary. This assumes that the latest models are more representative of the actual machine behavior. **Note:** the dominant factors in determining the terminal voltage of the units are (i) the reactance of machines stator winding (sub-transient/transient reactance), (ii) the impedance between the machine and the fault location, (iii) the machines transient time constant. In the final standard to be developed by AESO, it may be easier to specific a suggested ride-through capability but to state that in the final analysis what is required is that the majority of the WTGs in a wind farm should ride-through a normally cleared transmission fault on the138 kV and above transmission system. This of course would assume that the protection system on the transmission lines are appropriate to clear line faults in a reasonable time frame – i.e. one cannot have protection that takes 500 ms or more to clear a 138 kV transmission fault and expect generation to ride-through (see recommendation 5 in the executive summary of [1]).

One last consideration is to what level might the terminal voltage of the WTGs fall for a fault in the immediate electrical vicinity of the high-side of the wind farm substation transformer (**Note:** for a fault either on the substation transformer or anywhere on the collector system one would expect the WTGs in the farm to trip.). To test this case, a sensitivity case was simulated with a normally cleared 3-phase fault at the Pincher Creek 138 kV bus. This was assumed to emulate a fault on one of the 240/138 kV Pincher Creek transformers and thus the transformer is tripped to clear the fault. This fault is then in essence right on the high-side of the Pincher Creek 100 MW wind farm. For this case Figure 5 shows the terminal voltage on the Pincher Creek WTG. We see that in this case, again with the latest GE 1.5 MW DFIG model in PSS/E, the terminal voltage of the WTG does not drop below 15%.

References:

[1] "Integration of Wind Energy into the Alberta Electric System – Stage 1: Voltage Regulation Study", Report number 2004-10803-2.R02.4, issued by ABB Electric Systems Consulting, May 5th, 2004.
[2] "Modeling of GE Wind Turbine-Generators for Grid Studies", version 3.2, May 4th, 2004 – provided as part of the GE PSLF users manual.

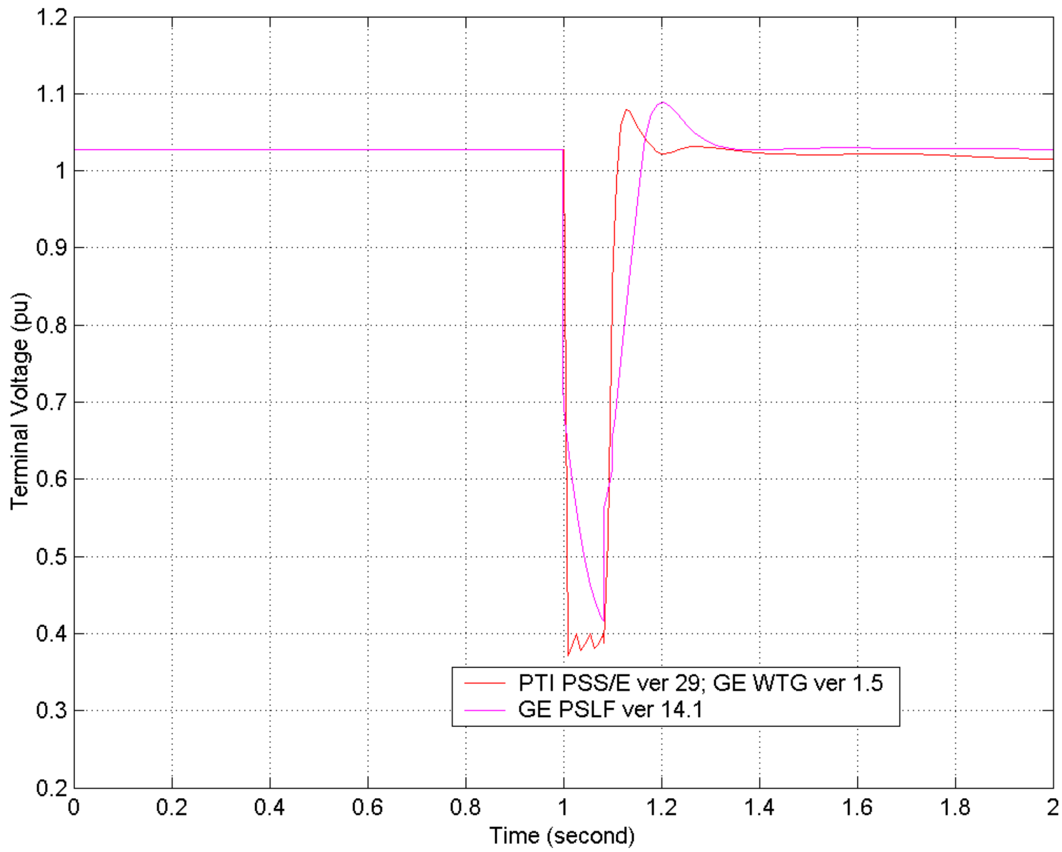
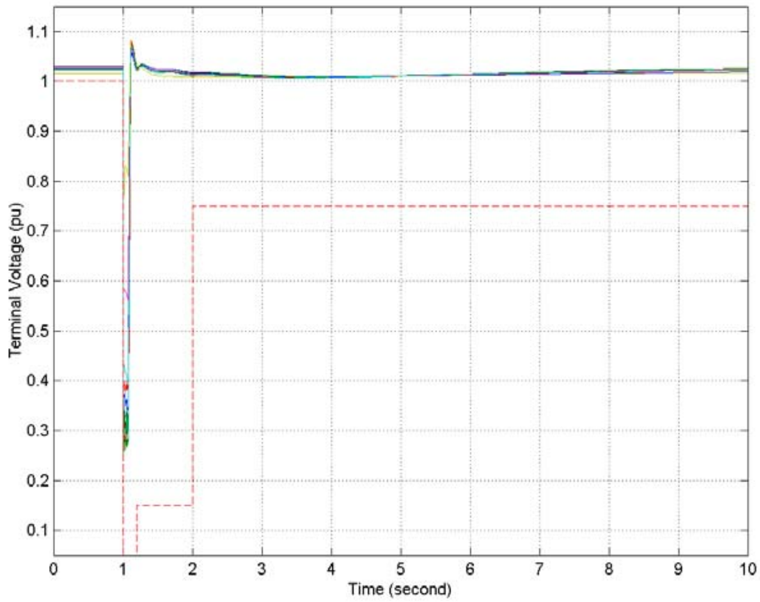
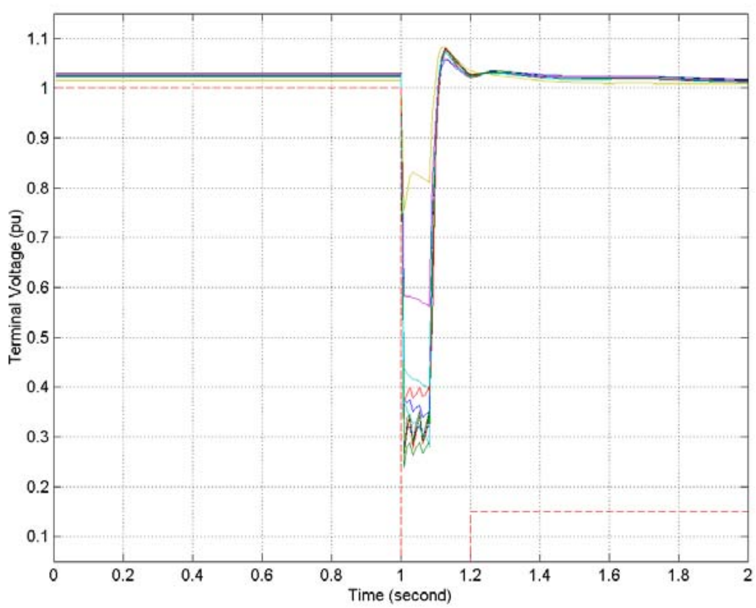


Figure 1: Terminal voltage of Waterton for a fault at Peigan 240 kV followed by clearing the Peigan - Dewinton 240 kV line. Simulations performed in both PSLT and PSS/E.

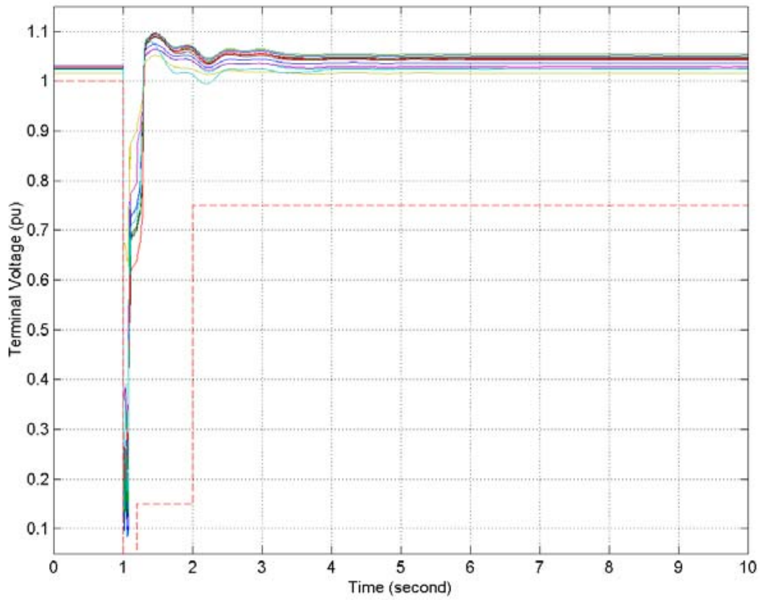


a) Zero to ten seconds.



b) Zero to two seconds.

Figure 2: Terminal voltage of all eleven new wind farms for a fault at Peigan 240 kV followed by clearing the Peigan - Dewinton 240 kV line. Simulations performed in PSS/E using latest DFIG model.



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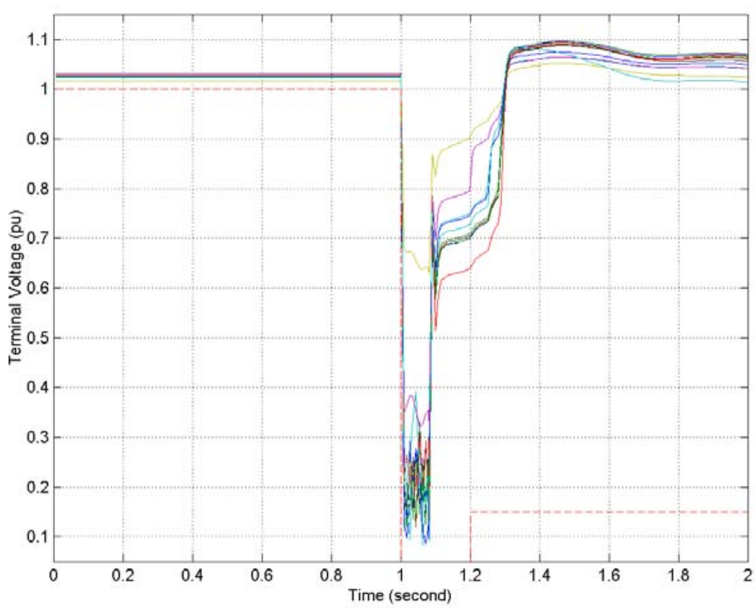
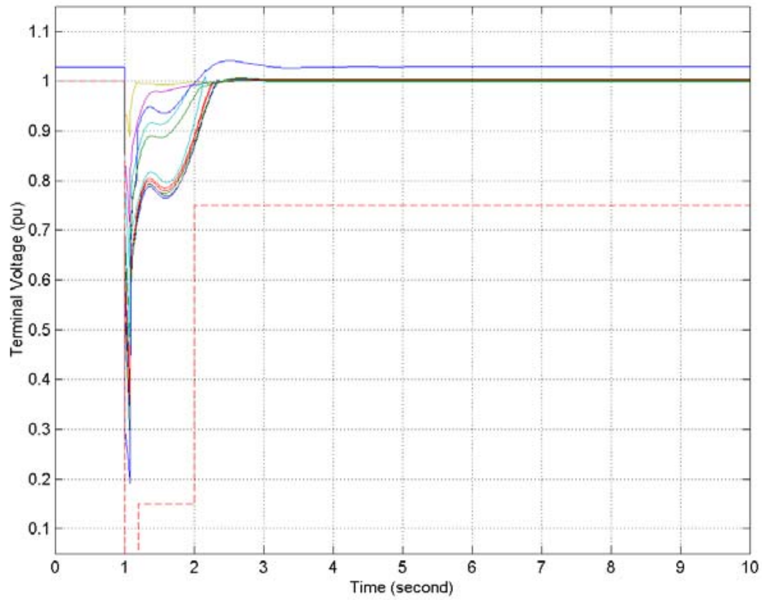
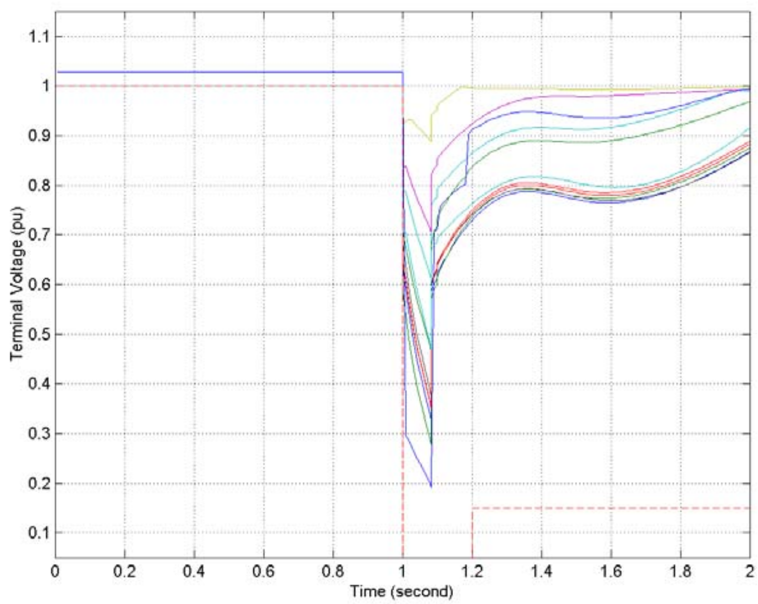


b) Zero to two seconds.

Figure 3: Terminal voltage of all eleven new wind farms for a fault at Peigan 240 kV followed by clearing the Peigan - Dewinton 240 kV line. Simulations performed and reported in the study report using PSS/E's older version of DFIG model.



a) Zero to ten seconds.



b) Zero to two seconds.

Figure 4: Terminal voltage of all eleven new wind farms for a fault at Peigan 240 kV followed by clearing the Peigan - Dewinton 240 kV line. Simulations performed and reported in the study report with conventional induction generators in PSS/E.

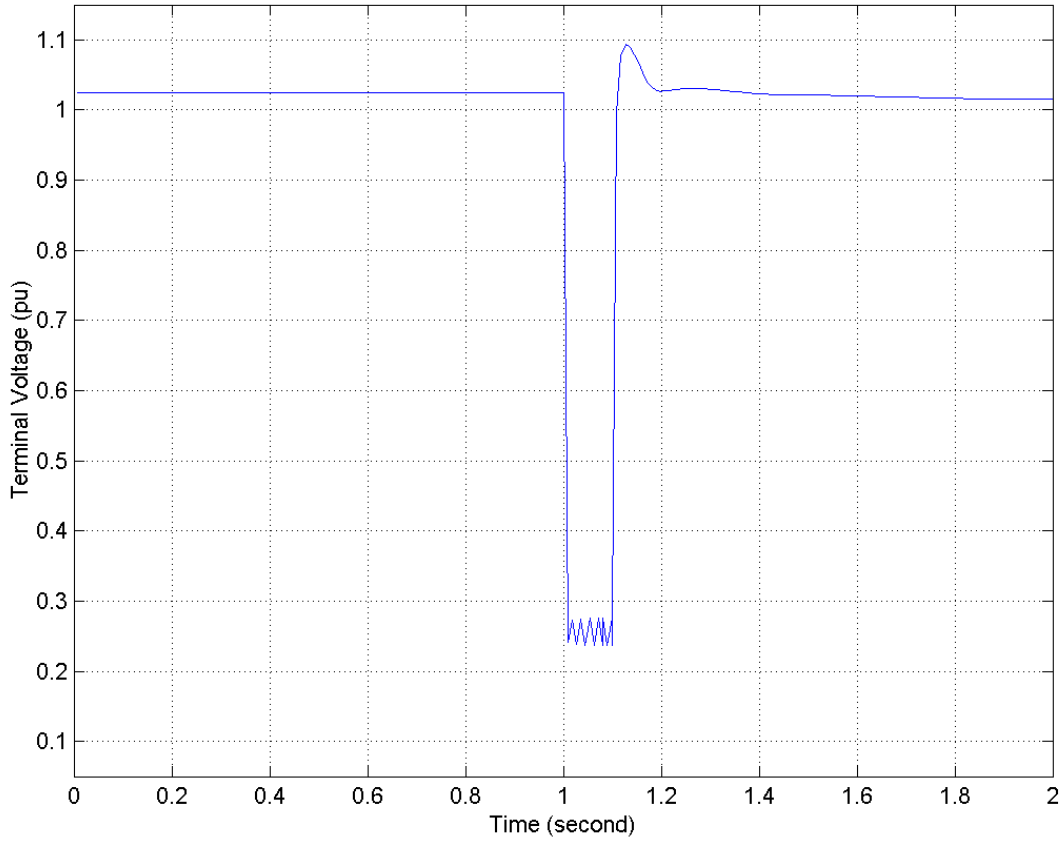


Figure 5: Terminal voltage of Pincher Creek WTG for a fault at Pincher Creek 138 kV followed by clearing one of the Pincher Creek 240/138 kV transformers. Simulations performed in PSS/E using the latest DFIG model.