PINE PORTAGE UPGRADE STAGES 2 & 3
IESO EXPEDITED SYSTEM IMPACT ASSESSMENT

Executive Summary

Ontario Power Generation Inc. (OPG, the "connection applicant") has proposed to upgrade major equipment in multiple stages at Pine Portage GS. The first stage, upgrading the runner of G4, was completed in May, 2013. The report assesses the second and third stages of the upgrade, which primarily includes upgrading the runner of G3, replacing the generator winding of G3, and replacing the generator step-up transformers T1 and T2.

This assessment concluded that the proposed changes are expected to have no material adverse impact on the reliability of the IESO-controlled grid. Therefore, the IESO recommends that a *Notification of Conditional Approval for Connection* be issued for Pine Portage Stages 2 & 3 upgrade, subject to implementation of the requirements outlined in this report.

Requirements

(1) The generation facility shall regulate speed with an average droop based on maximum active power adjustable between 3 - 7% and set at 4%. Regulation deadband shall not be wider than ± 0.06%. Speed shall be controlled in a stable fashion in both interconnected and island operation. A sustained 10% change of rated active power after 10 s in response to a constant rate of change of speed of 0.1%/s during interconnected operation shall be achievable.

(2) The generation facility is required to have the capability to inject or withdraw reactive power continuously (i.e. dynamically) at its connection point up to 33% of its rated active power at all levels of active power output. A conventional synchronous unit with a power factor range of 0.90 lagging and 0.95 leading at rated active power connected via a main output transformer impedance not greater than 13% based on generator rated apparent power is acceptable.

(3) The connection applicant shall ensure that the connected equipment is designed to be fully operational in all reasonably foreseeable ambient temperature conditions. The connected equipment must also be designed so that the adverse effects of its failure on the IESO-controlled grid are mitigated.

(4) The connection applicant shall ensure that the generation facility has the capability to provide short-time capabilities specified in IEEE/ANSI 50.13 and continuous capability determined by either field current, armature current, or core-end heating. More restrictive limiting functions, such as steady state stability limiters, shall not be enabled without IESO approval.

(5) According to Section 7.3 of Chapter 4 of the Market Rules, the connection applicant shall provide to the IESO the applicable telemetry data listed in Appendix 4.15 of the Market Rules on a continual basis. For this proposed project, the IESO will continue to require the operating quantities associated with the new equipment.

(6) The connection applicant shall ensure that the new protection systems at Pine Portage GS are designed to satisfy all the requirements of the Transmission System Code and any additional requirements identified by the transmitter.

The protection systems within the generation facility must only trip the appropriate equipment required to isolate the fault.

Any modifications made to protection relays by the generator after this SIA is finalized must be submitted to the IESO as soon as possible or at least six (6) months before any modifications are to be implemented on the existing protection systems.

(7) The connection applicant must complete the IESO Facility Registration/Market Entry process for the project in a timely manner before the IESO final approval for connection is granted.

The connection applicant is required to ensure that the performance of the governor installed on G3 at Pine Portage GS matches or exceeds the predicted performance in this assessment. As soon as the commissioning tests are completed and the actual data is available, the connection applicant is required to provide updated parameters and models for Pine Portage G3. If the actual data differ materially from the data that is used in the report, then further analysis of the project will need to be performed by the IESO.

1 Project Description

OPG has proposed to upgrade major equipment at Pine Portage GS. The first stage, upgrading the runner of G4, was completed in May, 2013. The report assesses the second and third stages of the upgrade which primarily includes upgrading the G3 runner and replacing G3 generator windings, the step-up transformers T1 and T2, LV breakers, and protective relays of T1 and T2. Details of each stage are described as follows.

Second stage:

- Upgrade the runner at G3, increasing the maximum continuous rating (MCR) from 34.9 MW to 37.25 MW.
- Replace G3 windings, like for like.
- Replace G3T2 and G4T2 generator breakers, like for like.
- Replace main output transformer T2 with capacity increasing from 3x25.66 MVA to 3x30 MVA.
- Upgrade T2 protection system from existing Main and Backup scheme to a duplicated A and B protection groups as detailed below:
  - Multifunctional relays, SEL-387E and Beckwith M-3311, are selected for implementing A and B protection groups respectively.
  - Each of the upgraded T2 protection groups will add LV over voltage (59) and over excitation (24) protective functions.
  - The protective zone of the upgraded T2 protections will be extended to cover the AT2 bus. As a result, the existing AT2 bus protection will be eliminated.

  The upgrade of T2 protections consists of the following two phases:
  - Phase 1 - Before the replacement of T2, G4T2 and G3T2, the existing T2 protective relays will be replaced with multifunctional relays with no change to protective zone and functions.
  - Phase 2 - After the replacement of T2, G4T2 and G3T2, CT inputs to the multifunctional relays will be duplicated, AT2 bus protection will be eliminated, and new protective functions 59 and 24 will be added.

Third stage:

- Replace G1T1 and G2T1 generator breakers, like for like.
- Replace main output transformer T1 with capacity increasing from 3x25.66 MVA to 3x30 MVA.
- Upgrade T1 protection system from existing Main and Backup scheme to a duplicated A and B protection groups as detailed below:
  - Multifunctional relays, SEL-387E and Beckwith M-3311, are selected for implementing A and B protection groups respectively.
  - Each of the upgraded T1 protection groups will add LV over voltage (59) and over excitation (24) protective functions.
  - The protective zone of the upgraded T1 protections will be extended to cover the AT1 bus. As a result, the existing AT1 bus protection will be eliminated.

The work above is scheduled to be completed as follows:

- Phase 1 T2 protection upgrade – Sep 1 to 7, 2013
- Upgrade of G3 runner – April, 2014
- Replacement of T2, G3T2, G4T2, and Phase 2 T2 protection – June 23 to August 5, 2014
- Replacement of T1, G1T1, G2T1, and T1 protection – August 11 to September 18, 2014

2 Equipment Data Verification

2.1 Generator Step-Up Transformers

The new transformer data for Pine Portage T1 and T2 is given in Table 1.

Table 1: Generator Step-Up Transformer data

	New T1 & T2
Configuration	single phase x 3
Transformation (kV)	126.5/13.8/13.8
Winding Configuration	Y-g/Delta/Delta
Continuous Thermal Rating (summer 30°C)	3 x 30 MVA = 90 MVA (ONAN)
10 Day Thermal Rating (summer 30°C)	N/A
Positive Sequence Impedance	HX = 11.72% based on 45 MVA base HY = 11.72% based on 45 MVA base XY = 22.38% based on 45 MVA base
Off-load tap-changer (OLTC)	Taps (1-6): 136.0, 132.8, 129.7, 126.5, 123.3, 120.2 kV
In service off-load tap position	Tap 4: 126.5 kV

2.2 Generator

The proposed new generator ratings of Pine Portage G3 are given in Table 2.

Table 2: Generator Data

Generator data	
MVA	44.3 MVA
Maximum continuous Summer rating	37.25 MW
Rated voltage	13.8 kV
Rated power factor	0.9

The proposed generator and governor models of Pine Portage G3 are given in Table 3 and Table 4, respectively. The block diagram of this governor model is shown in Figure 1.

Table 3: Generator Model Parameters of Pine Portage G3

MODEL : GENSAE – Generator Parameters			
Description	**CON's**	**Parameter**	**Value**
d-axis OC Transient Time Constant	J	T’do (>0)	6
d-axis OC sub-transient Time Constant	J+1	T’’do (>0)	0.03

q-axis OC sub-transient Time Constant	J+2	T"qo (>0)	0.05
Inertia	J+3	H	2.703
Damping	J+4	D	0
d-axis Synchronous Reactance	J+5	Xd	1.13
q-axis Synchronous Reactance	J+6	Xq	0.97
d-axis Transient Reactance	J+7	X'd	0.43
Subtransient Reactance	J+8	X"d=X"q	0.28
Leakage Reactance	J+9	Xl	0.12
Saturation Factor at 1.0 pu Et	J+10	S(1.0)	0.16
Saturation Factor at 1.2 pu Et	J+11	S(1.2)	0.46

Table 4: Governor Model Parameters of Pine Portage G3

MODEL : HYGOV – Governor Parameters			
Description	**CON's**	**Parameter**	**Value**
Permanent Droop	J	R	0.04
Temporary Droop	J+1	r	0.4
Governor Time Constant	J+2	Tr (>0)	0.05 (Note 1)
Filter Time Constant	J+3	TF (>0)	0.2
Servomotor Time Constant	J+4	Tg (>0)	0.794
Gate Velocity Limit	J+5	VELM	0.1
Maximum Gate Limit	J+6	GMAX	1
Minimum Gate Limit	J+7	GMIN	0
Water Time Constant	J+8	TW (>0)	1
Turbine Gain	J+9	At	1.26
Turbine Damping	J+10	Dturb	0
No-Load Flow	J+11	qNL	0.045

Note (1) Tr = 0.05 s for normal online operation; Tr = 5 s for island operation

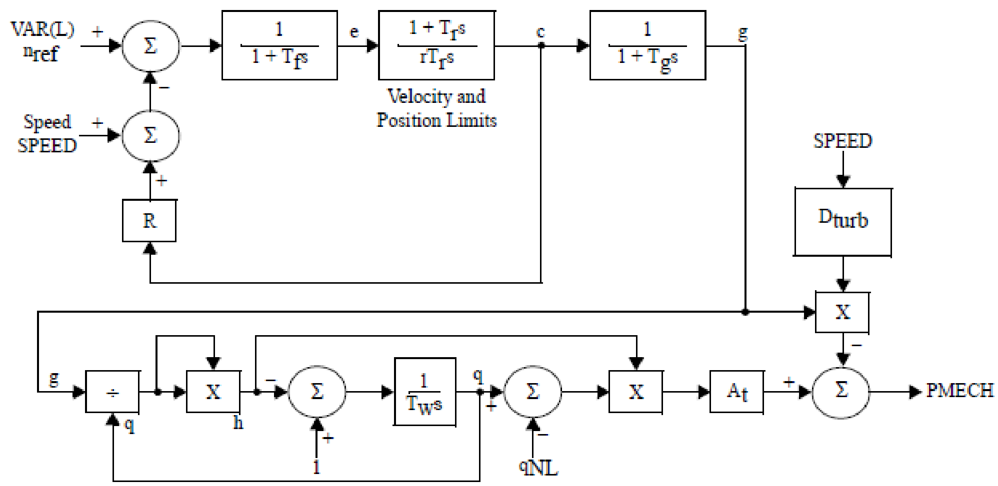

Figure 1: Governor Model Block Diagram (HYGOV)

3 Assessments

3.1 Study Assumptions

For this assessment, the 2014 summer peak load base case was used with the following assumptions:

(1) **Transmission facilities**: All existing and committed major transmission facilities with 2014 in-service dates or earlier were assumed in-service.

(2) **Generation facilities:** All existing and committed major generation facilities with 2014 in-service dates or earlier were assumed in-service. Major local generation dispatch includes:

- Maximum generation output at Pine Portage GS, Alexander GS, and Cameron GS;
- Thunder Bay and Atikokan units out of service.

(3) **Import/Export:** No import or export was assumed between Manitoba and Ontario.

The system demand, demand and generation in Northwest, and primary interface flow after the Pine Portage G3 runner upgrade are summarized in Table 5. Load demands used are based on extreme weather summer peak conditions.

Table 5: Demands and Primary Interface Flow for Base Case (MW)

System Demand	NW Demand	NW Generation	East West Transfer East (EWTE)
27,320	560	910	326

3.2 Reactive Power Evaluation

As per Appendix 4.2 of the Market Rules, a generator connected to the IESO-controlled grid must have the capability to inject or withdraw reactive power continuously (i.e. dynamically) at a connection point up to 33% of its rated active power at all levels of active power output except where a lesser continually available capability is permitted by the IESO. A conventional synchronous unit with a power factor range of 0.90 lagging and 0.95 leading at rated active power connected via main output transformer impedance not greater than 13% based on generator rated apparent power is acceptable.

Table 6: Generator Data

Generator	MVA	Rated PF	MCR MW	Qmax at 0.9 lag PF	Qmax Actual	Qmin Required	Qmin at 0.95 lead PF
G3	44.3	0.9	37.25	18.04	22	-12.24	-24

Table 6 shows the generator reactive power requirement and the actual reactive power ratings obtained based on the power capability curves.

Simulations were conducted to verify whether Pine Portage GS can achieve the reactive capability range at the HV side of the transformers at a typical system voltage of 125 kV using the proposed parameters for the new step-up transformers. The tap positions of both transformers were set to 126.5 kV. Table 7 shows that the plant is able to inject and withdraw the entire required range of reactive power at the HV side of the transformers, thus meeting the Market Rules’ requirements.

Table 7: Reactive Power Capability at the HV side of Pine Portage GS

P (MW)	HV bus Voltage (kV)	T1/T2 Tap Position (kV)	Generator Terminal Voltage G1/G2 (pu)	Generator Terminal Voltage G3/G4 (pu)	Injection Qrequired (Mvar)	Injection Qactual (Mvar)
133.5	125	126.5	1.0233	1.0308	44.63	50.2
133.5	125	126.5	0.9568	0.95	-44.63	-57.3
0	125	126.5	1.026	1.0355	44.63	64.8
0	125	126.5	0.9605	0.9539	-44.63	-45.1

3.3 LV Generator Breaker Requirements

The replacement of the LV generator breakers is covered in the existing expedited connection assessment CAA 2013-EX660.

3.4 Protection Upgrade

The proposed plans of protection upgrade at Pine Portage T1 and T2 had been reviewed. In phase 1 of the Pine Portage T2 upgrade, the existing transformer protective relays will be replaced with multifunctional relays with no changes to protective zones, functions and settings. Phase 1 of the Pine Portage T2 upgrade is covered in the previous connection assessment CAA 2013-EX679.

During the Pine Portage T1 protection upgrade, the existing transformer protective relays will be replaced with multifunctional relays with additional protective functions: LV overvoltage (59) and over excitation (24).

In phase 2 of the Pine Portage T2 protection upgrade, the multifunctional relays will also have additional protective functions: LV overvoltage (59) and over excitation (24).

The above proposed changes will not result in material adverse impact on the reliability of the integrated power system.

The connection applicant shall ensure that the new protection systems at Pine Portage GS are designed to satisfy all the requirements of the Transmission System Code and any additional requirements identified by the transmitter. The protection systems within the generation facility must only trip the appropriate equipment required to isolate the fault.

3.5 Thermal Assessment

The Ontario Resource and Transmission Assessment Criteria (ORTAC) requires that all line and equipment loading be within their continuous ratings with all elements in service, and within their long-term emergency ratings (LTE) with any element out of service. Immediately following contingencies, lines may be loaded up to their short-term emergency ratings (STE) where control actions such as re-dispatch, switching, etc. are available to reduce the loading to the long-term emergency ratings.

Existing generation congestion in the Northwest area due to post-contingency thermal limitation of the Marathon and Lakehead 115 kV local circuits has been identified in the previous SIA report (CAA 2007-284). The limiting circuits are T1M, A1B and A5A for high Flow East conditions, and circuits A6P, A7L and A8L for high Flow West conditions. The generation increment arising from the Pine Portage G3 runner upgrade tends to slightly increase the loading on the identified 115 kV circuits. Therefore, at times, the connection applicant may be required to curtail slightly more generation within its facility for reliability purposes. These congested scenarios were not repeated in this report.

This thermal assessment primarily examines the impact that the proposed G3 runner upgrade would have on the thermal loading of the 115 kV circuits emanating from Pine Portage SS. All units at Pine Portage GS were operated at full output to maximize the flows on the circuits emanating from Pine Portage SS (i.e. R1LB, R2LB and R9A). Recognized contingencies involving these circuits were investigated to determine if the remaining circuits will be overloaded post-contingency after the Pine Portage G3 runner upgrade.

Table 8 shows the thermal analysis results after the Pine Portage G3 runner upgrade. With all elements in-service, the flows on all monitored line sections are within their continuous ratings pre-contingency. The post-contingency flows on all monitored line sections are within their LTE ratings.

Table 8: Thermal Loading Results for 115 kV Circuits emanating from Pine Portage SS

Circuit	From Bus	To Bus	Cont	LTE	All I/S		Loss of R1LB		Loss of R2LB		Loss of R9A	
			Amps	Amps	Amps	%Cont	Amps	%LTE	Amps	%LTE	Amps	%LTE
R1LB	Pine Portage SS	Lakehead TS	330	330	204	61.8	0	0	267.5	81.1	292.4	88.6
R1LB	Lakehead TS	Birtch TS	620	790	158	25.5	0	0	205.7	26	158.9	20.1
R2LB	Pine Portage SS	Lakehead TS	420	420	232.2	55.3	293.3	69.8	0	0	333.7	79.5
R2LB	Lakehead TS	Birch TS	620	790	151.2	24.4	200	25.3	0	0	152.2	19.3
R9A	Pine Portage SS	Alexander JCT	420	420	191.6	45.6	330.5	78.7	357.7	85.2	0	0
R9A	Alexander SS	Alexander JCT	420	420	246.7	58.7	386.6	92	413.6	98.5	0	0

3.6 Voltage Assessment

The ORTAC states that with all elements in-service pre-contingency, the following criteria shall be satisfied:

- The pre-contingency voltage on 115 kV buses must not be less than 113 kV;
- The post-contingency voltage on 115 kV buses must not be less than 108 kV;
- The voltage change following a contingency must not exceed 10% pre-ULTC and 10% post-ULTC on both 115 kV buses.

As the average operating voltage at Pine Portage 115 kV bus is typically high, the voltage assessment was carried out under maximum reactive power absorption at Pine Portage GS to determine the worst impact on system voltages following the loss of the Pine Portage T2 transformer, which removes both Pine Portage G3 and G4. Table 9 shows that the voltage levels are within the criteria under both pre- and post-contingency conditions, and post-contingency voltage changes are within acceptable ranges after the Pine Portage upgrade stages 2 & 3.

Table 9: Voltage Assessment Results for the Loss of Pine Portage T2

Bus Name	Pre-Cont.	Loss of Pine Portage T2			
		Pre-ULTC		Post-ULTC	
	kV	kV	%	kV	%
Pine Portage 115 kV	122.2	124.9	2.2	125.4	2.6
Lakehead 115 kV	124.1	125.6	1.2	126.7	2.1
Birch 115 kV	122.2	123.6	1.1	124.4	1.8
Alexander SS 115 kV	123.4	125	1.3	125.3	1.5

3.7 Governor Response

Appendix 4.2 of the Market Rules requires that the governors must regulate speed with an average droop based on maximum active power adjustable between 3 - 7% and set at 4% unless otherwise specified by the IESO. Regulation deadband shall not be wider than +/- 0.06%. Speed shall be controlled in a stable fashion in both interconnected and island operation. A sustained 10% change of rated active power after 10s in response to a change of speed of 0.1%/s during interconnected operation shall be achievable.

3.7.1 Governor Stability Test during Islanding Operation

Governor response test was performed in an islanding operation for a step change to the generator output set point to assess the governor stability as well as the droop characteristic. The generator was initialized to 50% of rated generator output. At t=0, the generator output set point was increased by 1% of the full load. To demonstrate a governor droop of 4%, a speed change of 0.04% is expected.

Figure 2 gives the governor response and shows that the governor response is stable in an islanding operation and the droop for this governor system is approximately 3%.

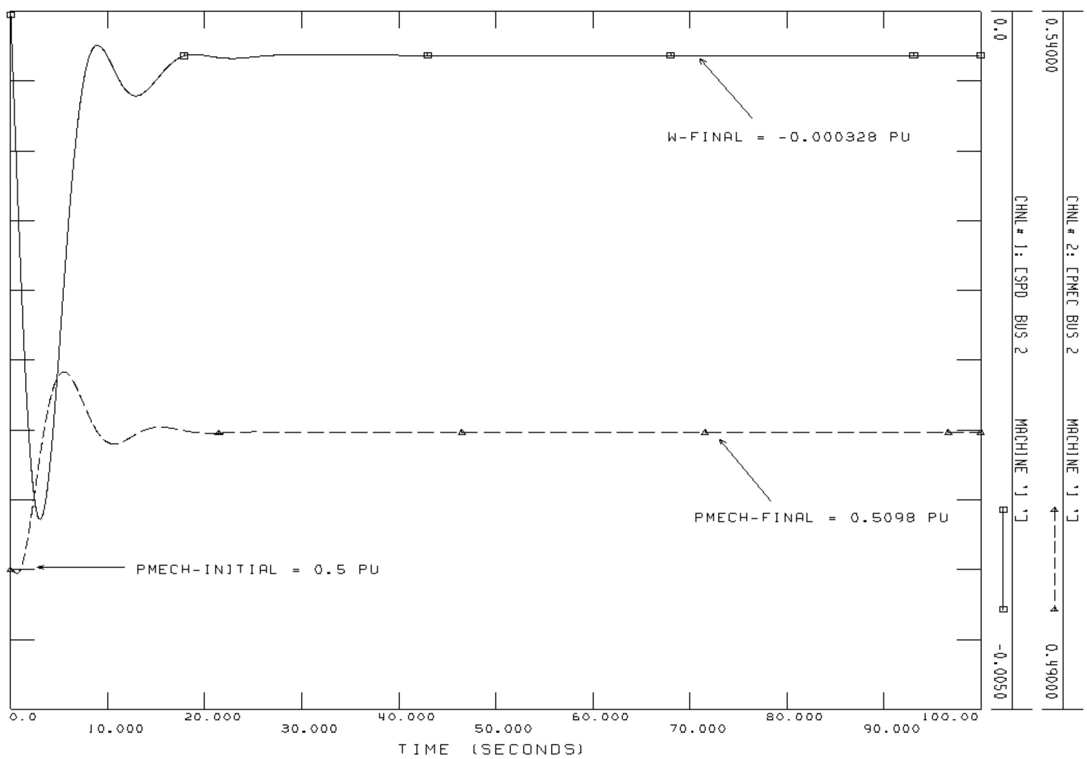

Figure 2: Governor Response in Islanding Operation

3.7.2 Governor Stability Test during Interconnected Operation

Governor response test was then performed in an interconnected operation for a step change of system frequency. The generator was initialized to 50% of rated generator output. At t =10s, the system frequency was stepped down by 0.1%. To demonstrate a governor droop of 4%, a mechanical output change of 2.5% of the full load is expected.

Figure 3 shows the response of the proposed governor system which indicates that governor response is stable in the interconnected operation and the droop for this governor system is approximately 3%.

No intentional speed dead band of this governor is set based on the governor model provided.

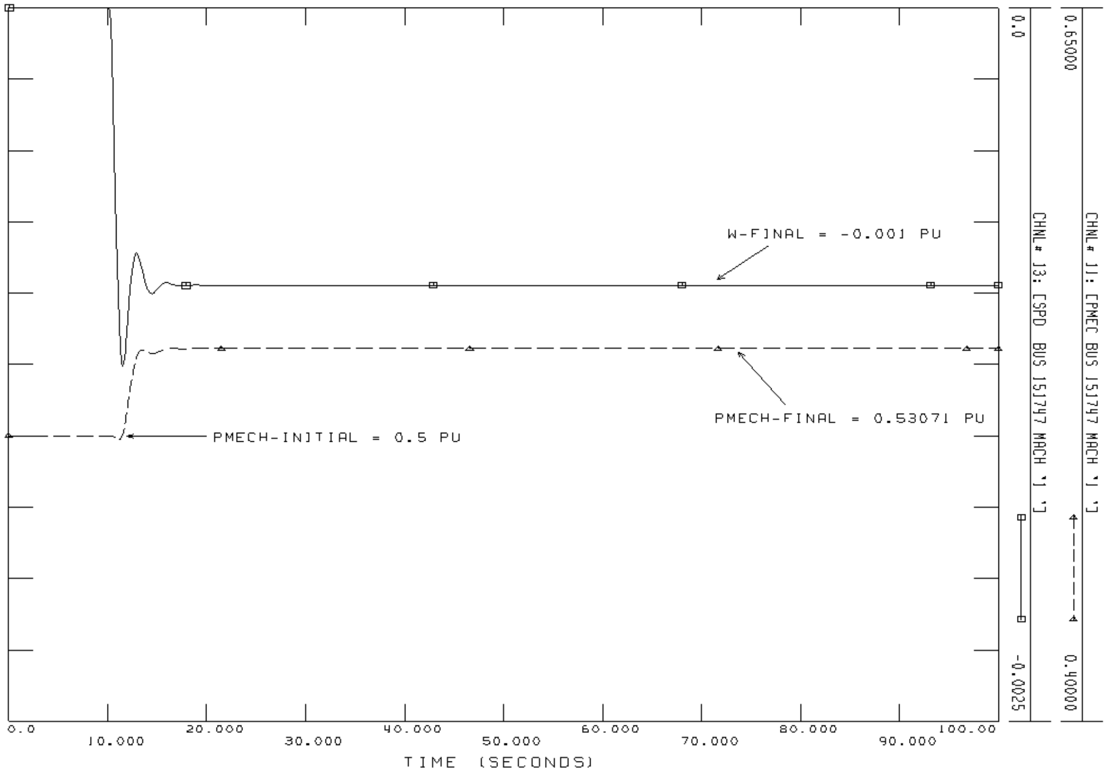

Figure 3: Governor Response in Interconnected Operation

3.7.3 Change of Speed of 0.1%/s during Interconnected Operation

Governor response tests were also performed in interconnected operation with a 0.1%/s change in system frequency to assess the speed and magnitude of governor responses. The generator power output was initialized to 50% of its rated generator output. At t=1s, the system frequency was ramped down or up at a speed of 0.1%/s for 10s.

Figure 4 and Figure 5 show the generator mechanical power response in response to system frequency decline and rise, respectively. The simulation results indicate that after the system frequency ramps down or up for 10 s, the proposed governor is capable of providing a sustained 10% change of rated active power. Therefore, the governor response rate meets the Market Rules' requirements.

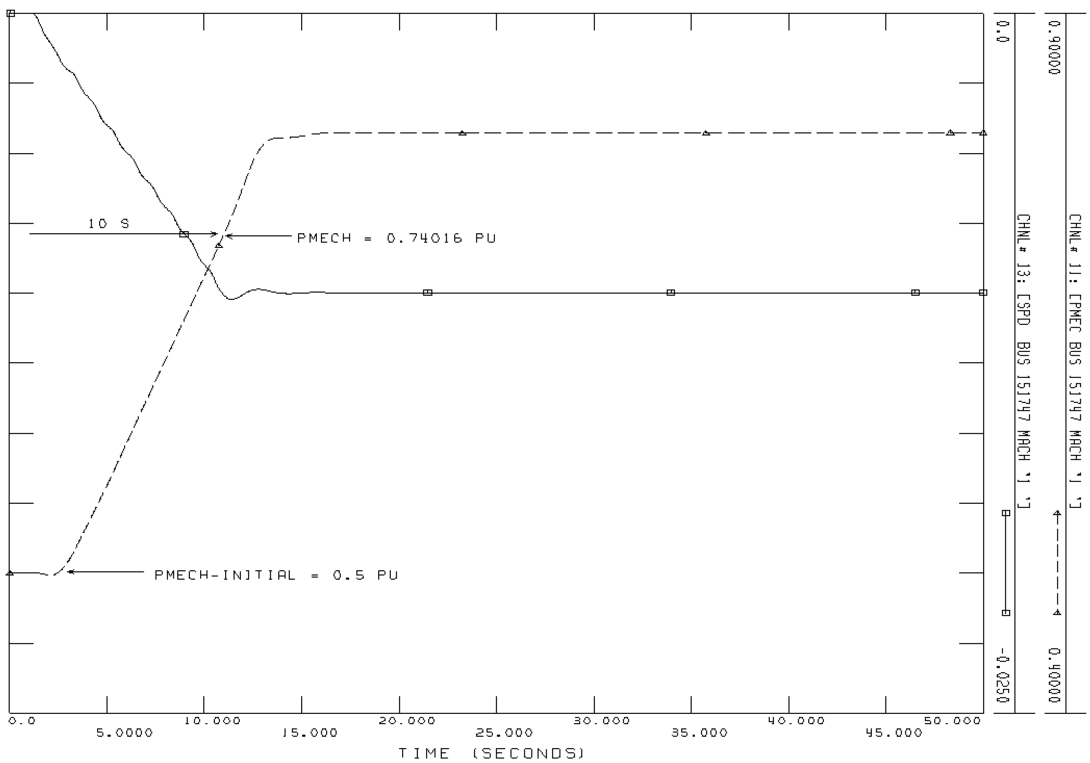

Figure 4: Generator Mechanical Power in response to System Frequency Decline

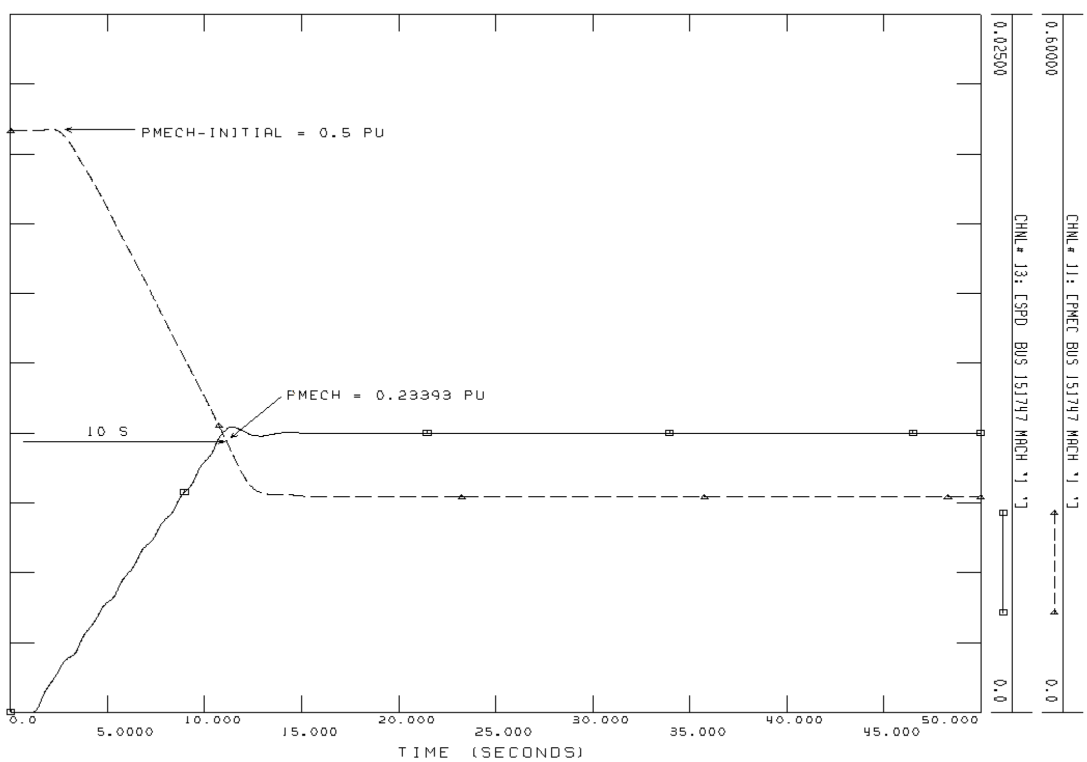

Figure 5: Generator Mechanical Power in response to System Frequency Rise

3.8 Transient Stability Analysis

Transient stability analysis was performed for both systems before and after the Pine Portage upgrade stages 2 & 3. Simulation results were compared to identify if the transient stability of the local system close to Pine Portage will be adversely impacted by the proposed upgrade. The rotor angles of Pine Portage units were monitored for a recognized fault close to Pine Portage SS, as shown in Table 10.

Table 10: Studied Contingency for Transient Stability

Fault location	Type of fault	Fault clearing time	
R1LB near Pine Portage SS	3-phase*	At Pine Portage SS	116 ms
		At Lakehead TS	149 ms
		At Birch TS	188 ms

(*) A 3-phase fault was simulated in place of a line-to-line-to-ground (LLG) fault as this represents a more conservative and more severe fault than recognized by the IESO.

Figure 6 and Figure 7 compare the monitored variables before and after the Pine Portage upgrade stages 2 & 3 and indicate the transient response of the Pine Portage units remain almost identical after the upgrade. No material adverse impact will be expected on the system transient stability after the proposed upgrade at Pine Portage GS.

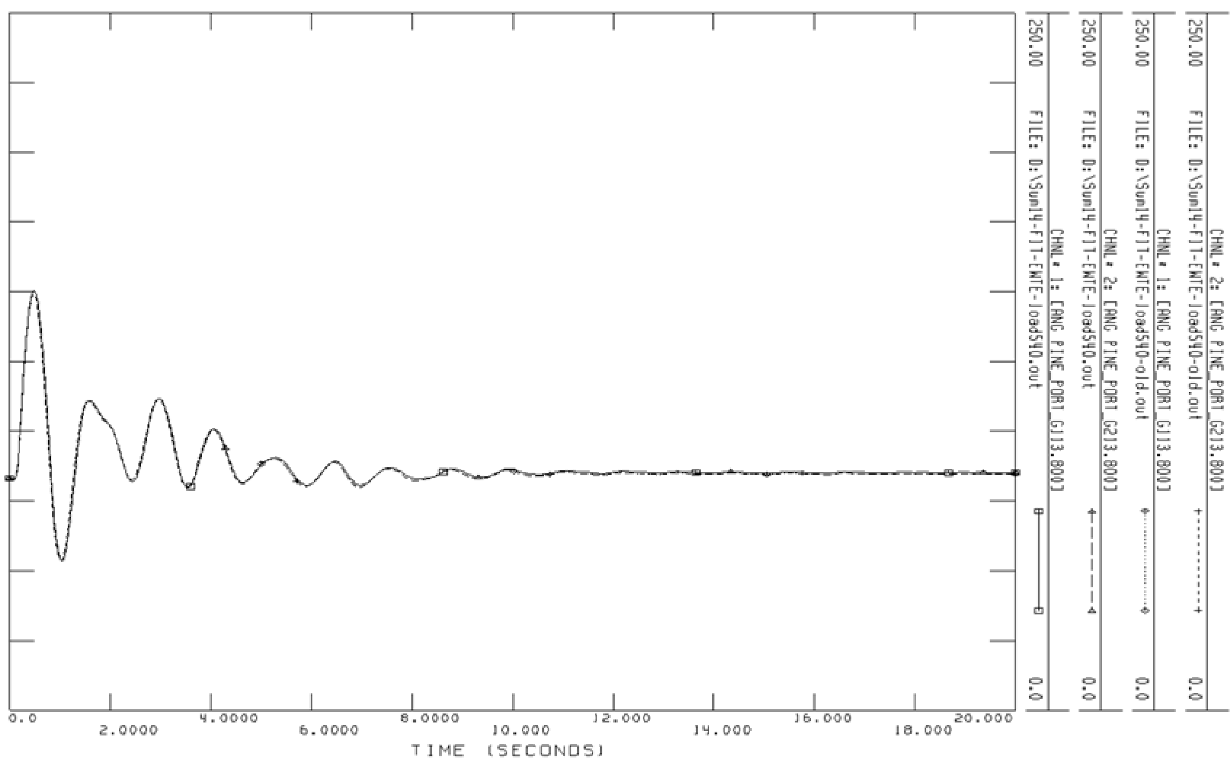

Figure 6: Rotor Angle Response of Pine Portage G1 and G2 following a 3-phase Fault on Circuit R1LB at Pine Portage SS before and after the Proposed Upgrade at Pine Portage GS

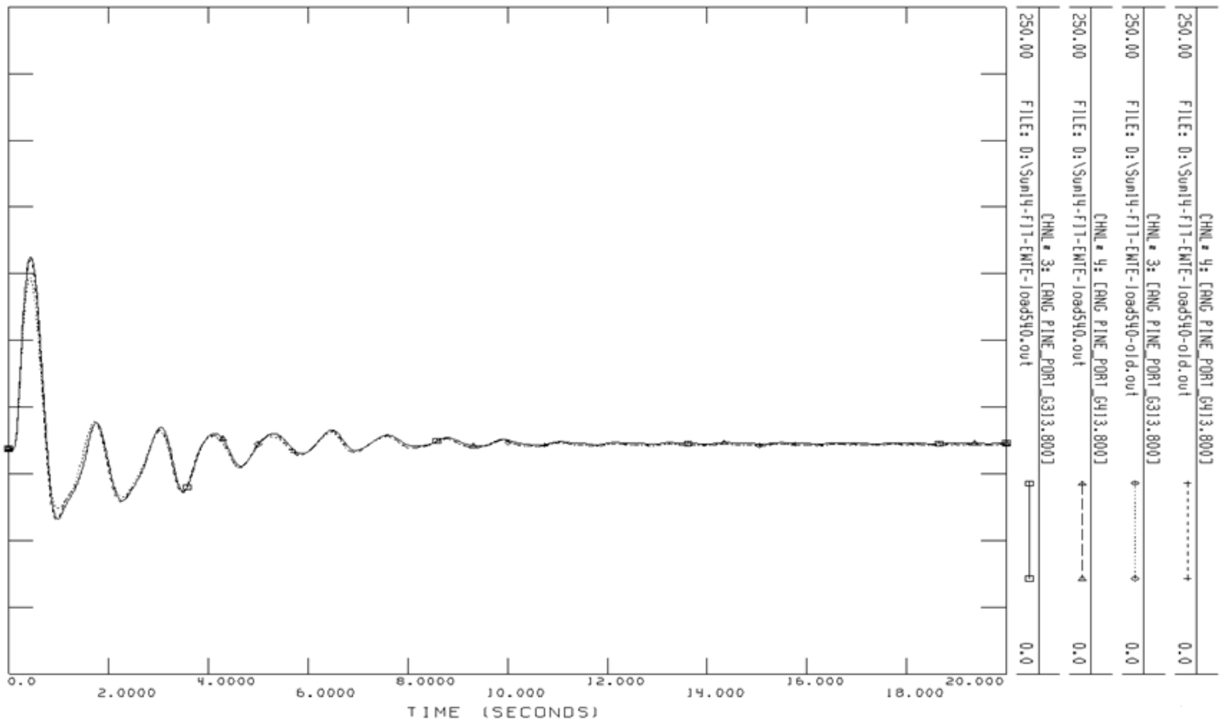

Figure 7: Rotor Angle Response of Pine Portage G3 and G4 units following a 3-phase fault on Circuit R1LB at Pine Portage SS before and after the Proposed Upgrade at Pine Portage GS