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Toronto, ON
M5W 4E5

IESO Expedited System Impact Assessment

ATIKOKAN G1 CONTROL UPGRADE

2013-EX668

FINAL REPORT

Executive Summary

Conditional Approval for Connection

Ontario Power Generation (the "connection applicant") is proposing to replace the excitation system, power system stabilizer and governor controls of Atikokan G1 as part of the facility's conversion from coal to biomass.

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 the replacement of the excitation system, power system stabilizer and governor controls of Atikokan G1, subject to implementation of the requirements outlined in this report.

The connection applicant shall satisfy all applicable requirements and standards specified in the Market Rules and the Transmission System Code. The following requirements highlight some of the general requirements that are applicable to the proposed project.

Requirements

1. The connection applicant shall ensure that the facility has the capability to supply continuously all levels of active power output for 5% deviations in terminal voltage. The proposed facility shall 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.

   The proposed facility shall have the capability to regulate automatically voltage within ±0.5% of any set point within ±5% of rated voltage at a point whose impedance (based on rated apparent power and rated voltage) is not more than 13% from the highest voltage terminal. If the AVR target voltage is a function of reactive output, the slope $\Delta V/\Delta Q_{max}$ shall be adjustable to 0.5%. The equivalent time constants shall not be longer than 20 ms for voltage sensing and 10 ms for the forward path to the exciter

2. The excitation system shall have (a) positive and negative ceilings not less than 200% and 140% of rated field voltage at rated terminal voltage and rated field current; (b) a positive ceiling not less than 170% of rated field voltage at rated terminal voltage and 160% of rated field current; (c) a voltage response time to either ceiling not more than 50 ms for a 5% step change from rated voltage under open-circuit conditions; and (d) a linear response between ceilings. Rated field current is defined at rated voltage, rated active power and required maximum continuous reactive power.

3. The Power System Stabilizer (PSS) shall have (a) a change of power and speed input configuration; (b) positive and negative output limits not less than ±5% of rated AVR voltage; (c) phase compensation adjustable to limit angle error to within 30° between 0.2 Hz and 2.0 Hz under conditions specified by the IESO, and (d) gain adjustable up to an amount that either increases damping ratio above 0.1 or elicits exciter modes of oscillation at maximum active output unless otherwise specified by the IESO.
4. The connection applicant shall ensure that the 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. The connection applicant shall ensure that the facility has the capability to operate continuously between 59.4Hz and 60.6Hz and for a limited period of time in the region above straight lines on a log-linear scale defined by the points (0.0s, 57.0Hz), (3.3s, 57.0Hz), and (300s, 59.0Hz). The facility shall regulate speed with an average droop based on maximum active power adjustable between 3% and 7% and set at 4%. Regulation dead band 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. Due consideration will be given to inherent limitations such as mill points and gate limits when evaluating active power changes. Control systems that inhibit governor response shall not be enabled without IESO approval.
6. The connection applicant must complete the IESO Facility Registration/Market Entry process in a timely manner before IESO final approval for connection is granted.

   As part of the IESO Facility Registration/Market Entry process, the connection applicant must provide evidence to the IESO confirming that the equipment installed meets the Market Rules requirements and matches or exceeds the performance predicted in this assessment. This evidence shall be either type tests done in a controlled environment or commissioning tests done on-site. In either case, the testing must be done not only in accordance with widely recognized standards, but also to the satisfaction of the IESO. Until this evidence is provided and found acceptable to the IESO, the Facility Registration/Market Entry process will not be considered complete and the connection applicant must accept any restrictions the IESO may impose upon this project's participation in the IESO-administered markets or connection to the IESO-controlled grid. The evidence must be supplied to the IESO within 30 days after completion of commissioning tests. Failure to provide evidence may result in disconnection from the IESO-controlled grid.

   If the submitted models and data differ materially from the ones used in this assessment, then further analysis of the project will need to be done by the IESO.

   At the sole discretion of the IESO, performance tests may be required at generation and transmission facilities. The objectives of these tests are to demonstrate that equipment performance meets the IESO requirements, and to confirm models and data are suitable for IESO purposes. The transmitter may also have its own testing requirements. The IESO and the transmitter will coordinate their tests, share measurements and cooperate on analysis to the extent possible.

1 Project Description

Ontario Power Generation (OPG) is planning to replace the excitation system, power system stabilizer and governor controls at Atikokan GS as part of the facility's conversion from coal to biomass. The existing Brown Boveri Company (BBC) analog electronic static excitation system will be replaced with the Emerson digital static excitation system with an integrated power system stabilizer. The existing BBC governor control system will be replaced with the Emerson turbine control system. The existing generator and turbine will be retained and there will be no change in the registered maximum capability (MW) of Atikokan G1. The unit's ratings after the upgrade are shown in Table 1.

Table 1: Atikokan G1 Unit Ratings

Description	Value
Nameplate Rating	270 MVA
Maximum Continuous Rating (MCR)	227 MW
Rated Voltage	18 kV
Rated Active Power (RAP)	227 MW
Rated power factor	0.85

The scheduled in-service date after the upgrades is Q1 2014.

OPG provided the following dynamic models for the excitation system, power system stabilizer, governor and generator of Atikokan G1.

1.1 Excitation System Model for Atikokan G1

The Emerson digital static excitation system is represented by the PSS/E ESST4B model. The block diagram of the PSS/E ESST4B model is shown in Figure 1 and the parameters of the excitation system are shown in Table 2.

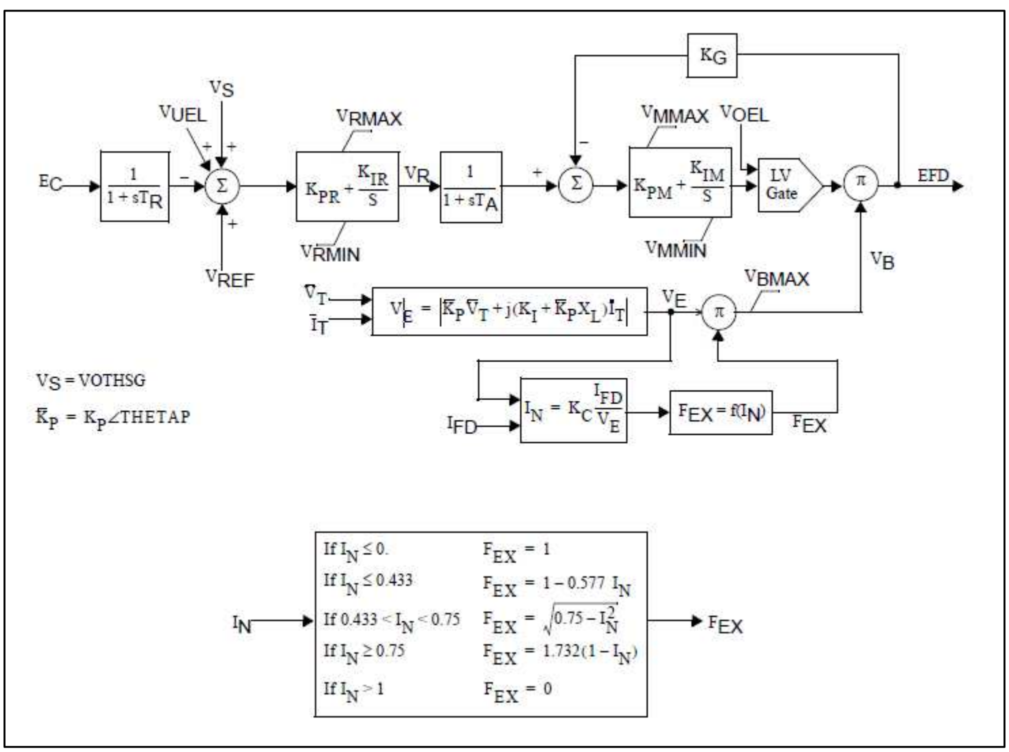

Figure 1: ESST4B Block Diagram

Table 2: Atikokan G1 Excitation System Model ESST4B

T_R	K_{PR}	K_{IR}	V_{RMAX}	V_{RMIN}	T_A	K_{PM}	K_{IM}	V_{MMAX}
0.02	180	18	6.68	-5.99	0.01	1	0	6.68
V_{MMIN}	K_G	K_P	K_I	V_{BMAX}	K_C	X_L	Thetap	
-5.99	0	1	0	1.2	0.097	0	0	

1.2 Power System Stabilizer Model for Atikokan G1

The power system stabilizer is represented by the PSS/E PSS2A model. The block diagram of the PSS/E PSS2A model is shown in Figure 2 and the parameters of the stabilizer are shown in Table 3.

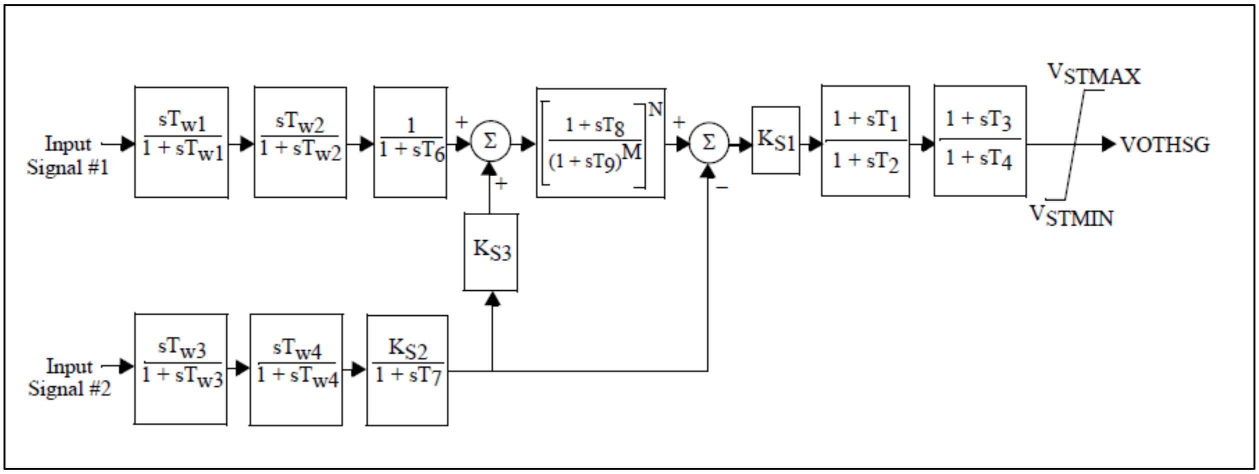

Figure 2: PSS2A Block Diagram

Table 3: Atikokan G1 Power System Stabilizer Model PSS2A

ICS1	REMBUS1	ICS2	REMBUS2	M	N	T_{W1}	T_{W2}
1	0	3	0	5	1	7	7
T_6	T_{W3}	T_{W4}	T_7	K_{S2}	K_{S3}	T_8	T_9
0	7	0	7	0.596	1	0.5	0.1
K_{S1}	T_1	T_2	T_3	T_4	V_{STMAX}	V_{STMIN}	
15	0.1	0.03	0.06	0.02	0.05	-0.05	

1.3 Governor Model for Atikokan G1

The governor is represented by the PSS/E WSIEG1 model. The block diagram of the PSS/E WSIEG1 model is shown in Figure 3 and the parameters of the governor are shown in Table 4.

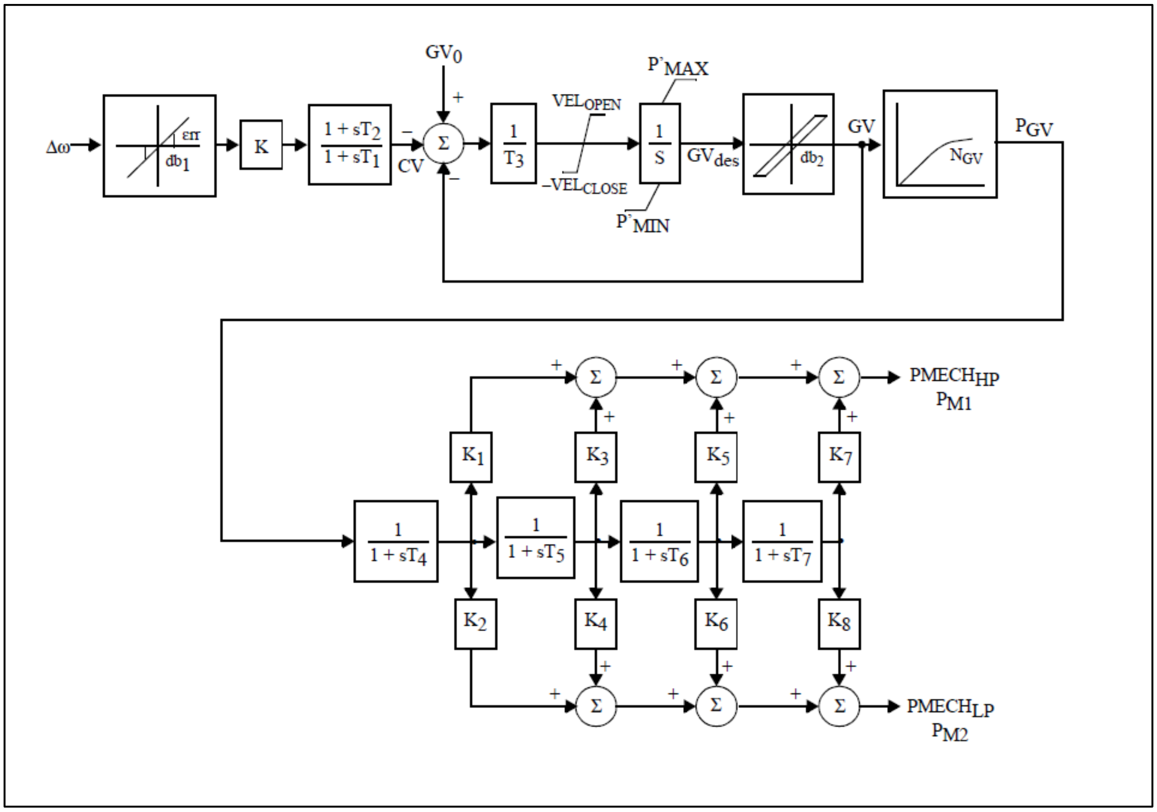

Figure 3: WSIEG1 Block Diagram

Table 4: Atikokan G1 Governor Model WSIEG1

K	T_1	T_2	T_3	U_{OPEN}	U_{CLOSE}	P_{MAX}	P_{MIN}	T_4
25	0.149	0	0.25	0.33	-0.33	1	0	0.42
K_1	K_2	T_5	K_3	K_4	T_6	K_5	K_6	T_7
0.25	0	4.24	0.25	0	0.72	0.5	0	0
K_7	K_8	db_1	err	db_2	GV_1	$P(GV_1)$	GV_2	$P(GV_2)$
0	0	0.0003	0	0	0	0	1	0.841
GV_3	$P(GV_3)$	GV_4	$P(GV_4)$	GV_5	$P(GV_5)$	IBLOCK		
0	0	0	0	0	0	0		

1.4 Generator Model for Atikokan G1

OPG has provided an updated generator model for Atikokan G1 with a slightly different saturation coefficient at 1.2 pu terminal voltage. The original and updated generator models for Atikokan G1 are shown in Table 5.

Table 5: Original and Updated Atikokan G1 Generator Models

Generator Model	T'_{do}	T''_{do}	T'_{qo}	T''_{qo}	H	D	X_d	X_q	X'_d	X'_q	X''_d	Xl	S(1.0)	S(1.2)
Original GENROU	6.2	0.033	1.5	0.5	5.87	0	2.052	1.944	0.27	0.67	0.19	0.1674	0.1	**0.4347**
Updated GENROE	6.2	0.033	1.5	0.5	5.87	0	2.052	1.944	0.27	0.67	0.19	0.1674	0.1	**0.45**

2 Assessments

2.1 Excitation System Performance

The performance of the proposed excitation system was assessed to verify that the field voltage positive and negative ceilings and voltage response time meet the Market Rules' requirements.

2.1.1 Field Voltage Ceiling Test

Appendix 4.2 of the Market Rules requires the excitation system for a generation facility directly connected to the IESO-controlled grid to have positive and negative ceilings not less than 200% and 140% of rated field voltage, respectively, at rated terminal voltage and rated field current, and a positive ceiling not less than 170% of rated field voltage at rated terminal voltage and 160% of rated field current.

2.1.1.1 Positive Ceiling

The response ratio test was performed to evaluate the positive ceiling voltage of the proposed excitation system. The generator was initialized to its rated active power at 0.9 lagging power factor and rated terminal voltage. At t=1s, the voltage set point was raised suddenly in order to drive the field voltage to its positive ceiling as quickly as possible.

Figure 4 shows the response ratio results of the proposed excitation system at Atikokan G1. It shows that both rated field voltage and rated field current are about 2.705 pu. The positive ceiling of the field voltage is about 5.579 pu, which exceeds 200% of the rated field voltage. When the field current rises above 4.328 pu, 160% of rated field current, the field voltage reaches 5.163 pu, which exceeds 170% of the rated field voltage. These test results meet the Market Rules' requirements.

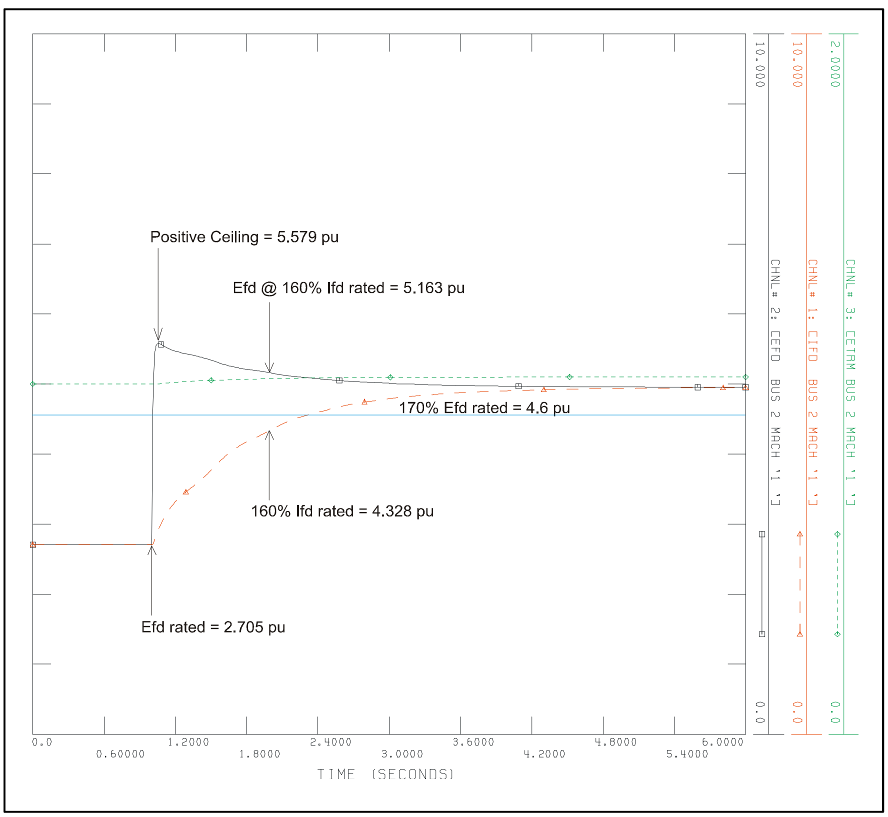

Figure 4: Atikokan G1 Excitation System Positive Ceiling Test

2.1.1.2 Negative Ceiling

The response ratio test was repeated to evaluate the negative ceiling voltage of the proposed excitation system. The generator was initialized to its rated active power at 0.9 lagging power factor and rated terminal voltage. At t=1s, the voltage set point was dropped suddenly in order to drive the field voltage to its negative ceiling as quickly as possible.

The results shown in Figure 5 indicate that the negative ceiling voltage is about -4.495 pu which exceeds 140% of the rated field voltage. Therefore, the negative ceiling voltage of the proposed excitation system meets the Market Rules' requirement.

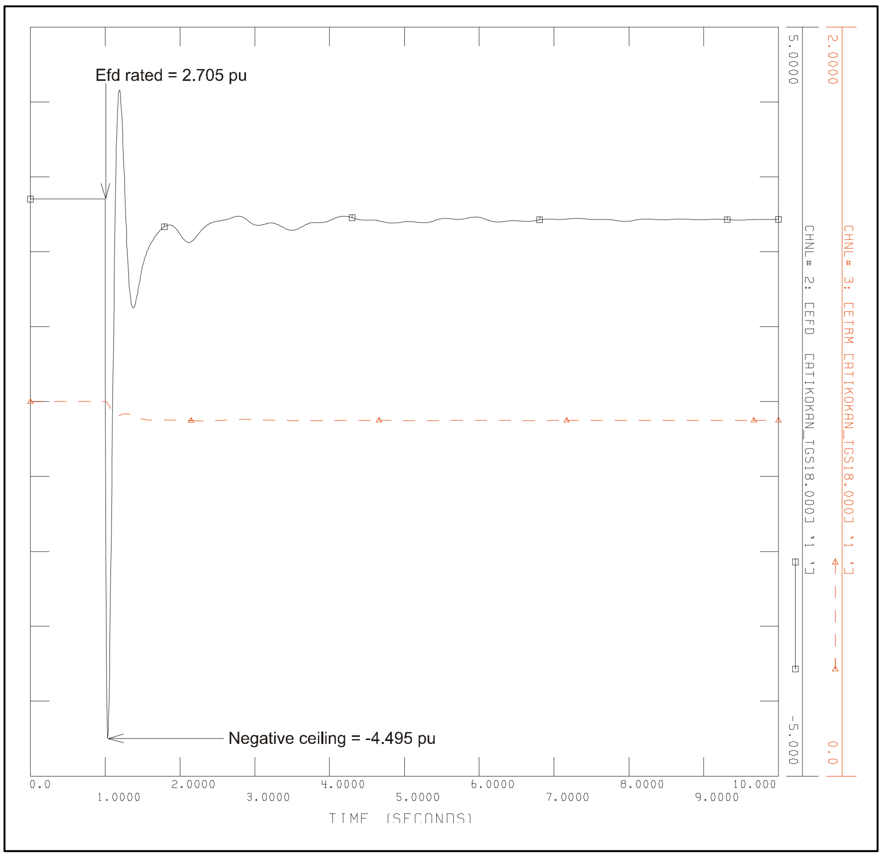

Figure 5: Atikokan G1 Excitation System Negative Ceiling Test

2.1.2 Open Circuit Test

Appendix 4.2 of the Market Rules requires the excitation system for a generation facility directly connected to the IESO-controlled grid to have a voltage response time to either ceiling not more than 50 ms for a 5% step change from rated voltage under open-circuit conditions and a linear response between ceilings.

2.1.2.1 Positive Ceiling Voltage Response Time

Open circuit test was performed to evaluate the positive ceiling voltage response time for the proposed excitation system. The generator was initialized to its rated terminal voltage under open circuit conditions. At t=0, the voltage set point was increased by 5%.

Figure 6 shows the response of the positive ceiling open circuit test for Atikokan G1. The initial open circuit voltage (E_{fdoc}) is 1.1 pu and the rated field voltage ($E_{fdrated}$) is 2.705 pu.

Based on the Market Rules' requirement, for a +5% step change, the field voltage is required to reach 195% of rated field voltage within:

$$RT_{OCPOS} = 50^* (1.95\ E_{fdrated} - E_{fdoc})/ (1.95\ E_{fdrated} - E_{fdrated}) = 81.23\ ms$$

Figure 6 shows that the field voltage reaches 5.47 pu, which exceeds 195% of rated field voltage, within 16.7 ms, thus meeting the Market Rules' requirement.

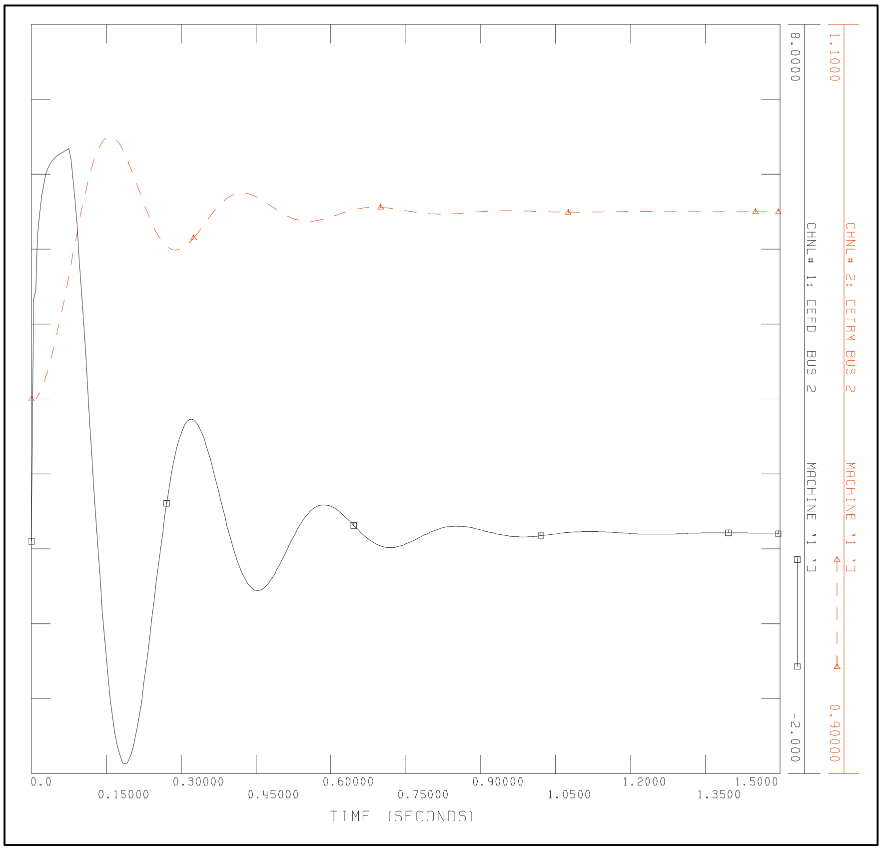

Figure 6: Atikokan G1 Excitation System Positive Ceiling Open Circuit Test

2.1.2.2 Negative Ceiling Voltage Response Time

Open circuit test was performed to evaluate the negative ceiling voltage response time for the proposed excitation system. The generator was initialized to its rated terminal voltage under open circuit conditions. At t=0, the voltage set point was decreased by 5%.

Figure 7 shows the response of the negative ceiling open circuit test for Atikokan G1. Based on the Market Rules' requirement, for a -5% step change, the field voltage is required to reach 128% of rated field voltage within:

$$RT_{OCNEG} = 50^* (1.28\ E_{fdrated} + E_{fdoc})/ (1.28\ E_{fdrated} + E_{fdrated}) = 36.99\ ms$$

Figure 7 shows that the field voltage reaches -4.23 pu, which exceeds 128% of rated field voltage, within 12.5 ms, thus meeting the Market Rules' requirement.

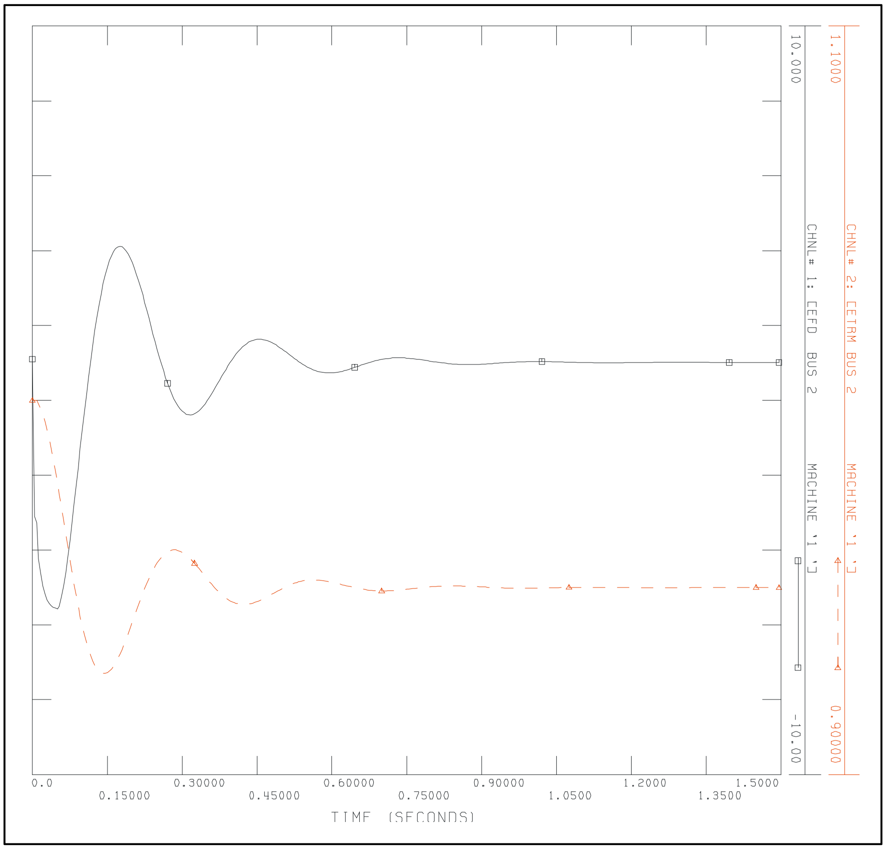

Figure 7: Atikokan G1 Negative Ceiling Open Circuit Test

2.2 Governor System Performance

Appendix 4.2 of the Market Rules requires that the facility shall regulate speed with an average droop based on maximum active power adjustable between 3% and 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 constant rate of change of speed of 0.1%/s during interconnected operation shall be achievable.

2.2.1 Governor Response in Island Operation

Governor response test was performed in island operation to evaluate the droop characteristic of the proposed governor. The generator power output was initialized to 50% of its rated MVA value and at t=0, the generator output set point was increased by 10% of its rated MVA value.

Figure 8 shows the governor response for Atikokan G1 in island operation. The governor response is stable and the droop is approximately 4% which meets the Market Rules' requirement.

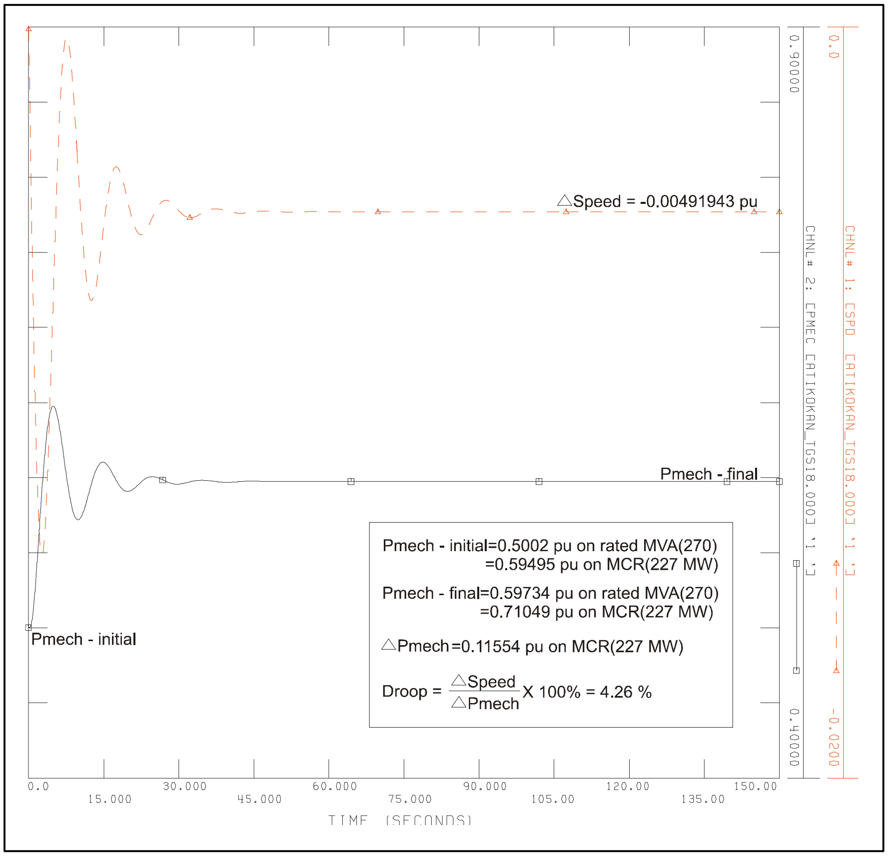

Figure 8: Atikokan G1 Governor Response in Island Operation

2.2.2 Governor Response in Interconnected Operation

Governor response test was performed in interconnected operation to evaluate the droop characteristic of the proposed governor. The generator power output was initialized to 50% of its rated MVA value and at t=10s, the system frequency was decreased by 1%.

Figure 9 shows the governor response for Atikokan G1 in interconnected operation. The governor response is stable and the droop is approximately 4% which meets the Market Rules' requirement.

Also, the speed deadband of the proposed governor is set to 0.0003 pu or 0.03% as per the governor model data which meets the regulation deadband requirement as specified in the Market Rules.

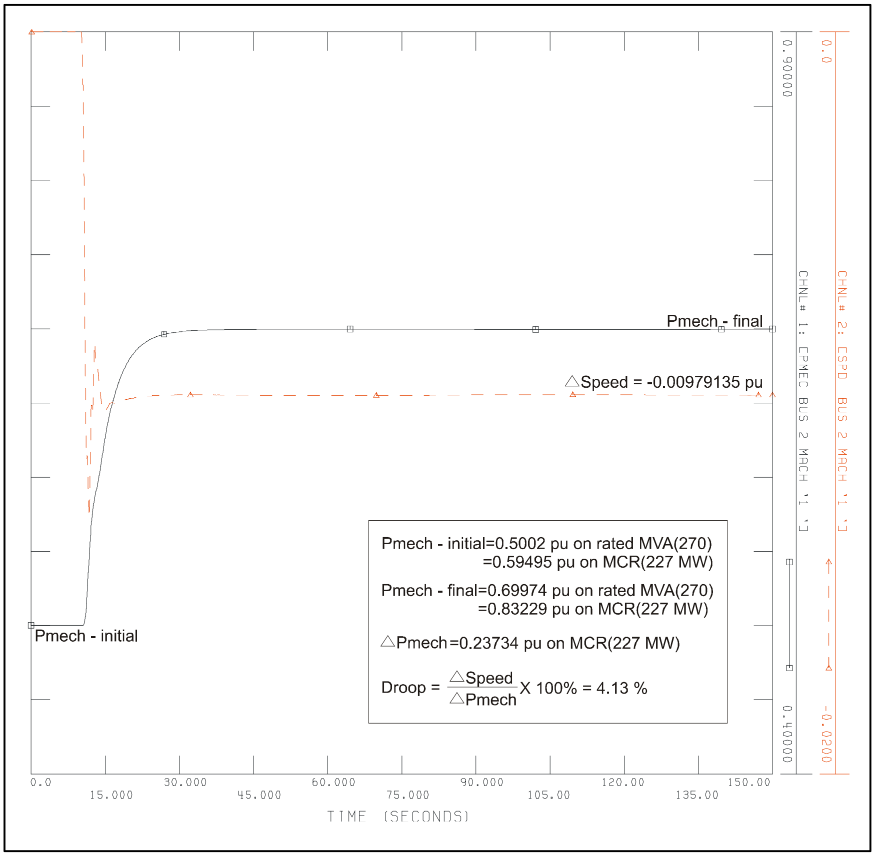

Figure 9: Atikokan G1 Governor Response in Interconnected Operation

2.2.3 Governor Response Rate in Interconnected Operation

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

Figure 10 and Figure 11 show Atikokan G1's mechanical output power 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 14% change of rated active power which is greater than 10% of rated active power (0.841 pu based on its rated MVA). Hence, the governor response rate meets the Market Rules' requirements.

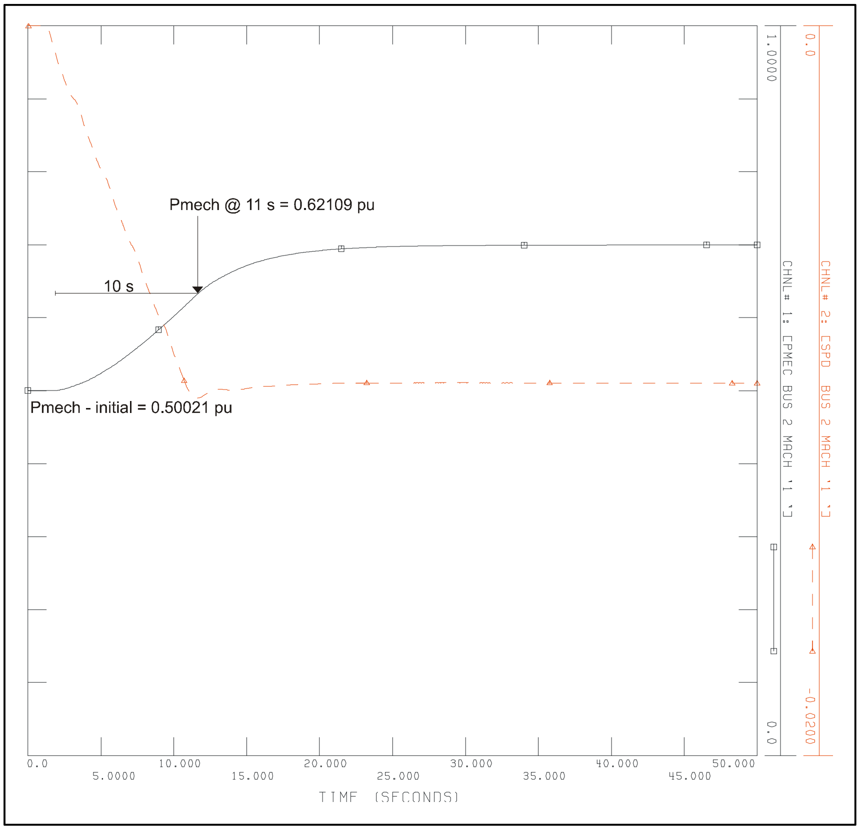

Figure 10: Atikokan G1 Governor Response Rate to System Frequency Decline

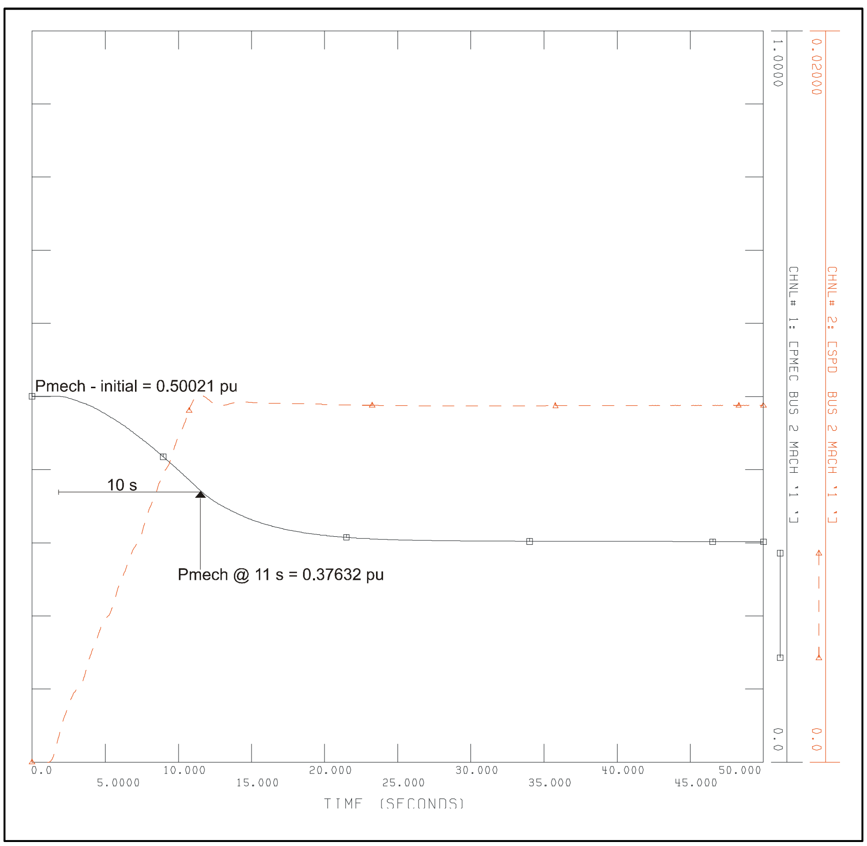

Figure 11: Atikokan G1 Governor Response Rate to System Frequency Rise

2.3 Transient Stability Performance

Transient stability analysis was performed to determine if the power system will be transiently stable for recognized fault conditions after the replacement of the excitation system, PSS, and governor controls at Atikokan G1 as well as the proposed PSS will be able to increase the damping for system oscillations. In particular, rotor angle stability of generators in the Northwest area including Atikokan G1 was monitored.

The 2013 summer peak load base case was used for the study. Three scenarios were developed to achieve highest transfers through the East and West of Mackenzie interfaces, as well as high East-West transfers East and West based on various generation dispatches and interchanges. Major system assumptions for the defined scenarios are shown in Table 6. Basically, scenario S1 and S2 represent highest transfer east and west on the Mackenzie interface, respectively, under current operating limits. Scenario S3 represents highest transfer east on the Mackenzie interface under storm conditions where loss of towers are respected under current operating limits.

Table 6: Scenarios for Transient Stability Assessment

Scenario	Transfer East/West of Mackenzie (TEM/TWM)	East West Transfer East (EWTE)	Ontario to Manitoba Transfer	Ontario to Minnesota Transfer	Northwest Generation	Northwest Load
S1	TEM=475 MW	354 MW	-160 MW	0 MW	868 MW	560 MW
S2	TWM=350 MW	-350 MW	172 MW	0 MW	453 MW	560 MW
S3	TEM=160 MW	190 MW	0 MW	0 MW	799 MW	560 MW

The recognized contingencies close to Atikokan GS which do not result in the loss of Atikokan G1 by configuration were considered. All contingencies involving 230 kV circuit(s) out of Mackenzie were tested and only the contingency that resulted in the largest rotor angle swing of Atikokan G1 under each scenario is presented in this report. Table 7 lists the most critical contingency in terms of transient stability of Atikokan G1 for each study scenario defined in Table 6.

Table 7: Simulated Contingencies for Transient Stability

ID	Scenario Used	Contingency	Location	Fault Type	Fault Clearing Time (ms)	
					Local	Remote
SC1	S1	A21L	Mackenzie	3 phase*	83	116
SC2	S2	D26A	Mackenzie	3 phase*	98	131
SC3	S3	A21L + A22L	Mackenzie	LLG fault	83	116

(*) 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 in the Northwest.

The rotor angle responses of generators in the Northwest following the simulated contingencies are shown in Figure 12 to Figure 14. The simulation results show that Atikokan G1 and other generators in the Northwest zone have a stable performance and the oscillations are well damped. Therefore, it can be concluded that the proposed changes to Atikokan G1 will not adversely impact the reliability of the IESO-controlled grid.

An additional simulation for SC1 was performed with the PSS at Atikokan G1 out of service. The rotor angle responses of Atikokan G1 with and without the PSS in-service are compared in Figure 15. The comparison indicates that the proposed PSS tends to increase damping of the oscillations in the rotor angle response of the generator.

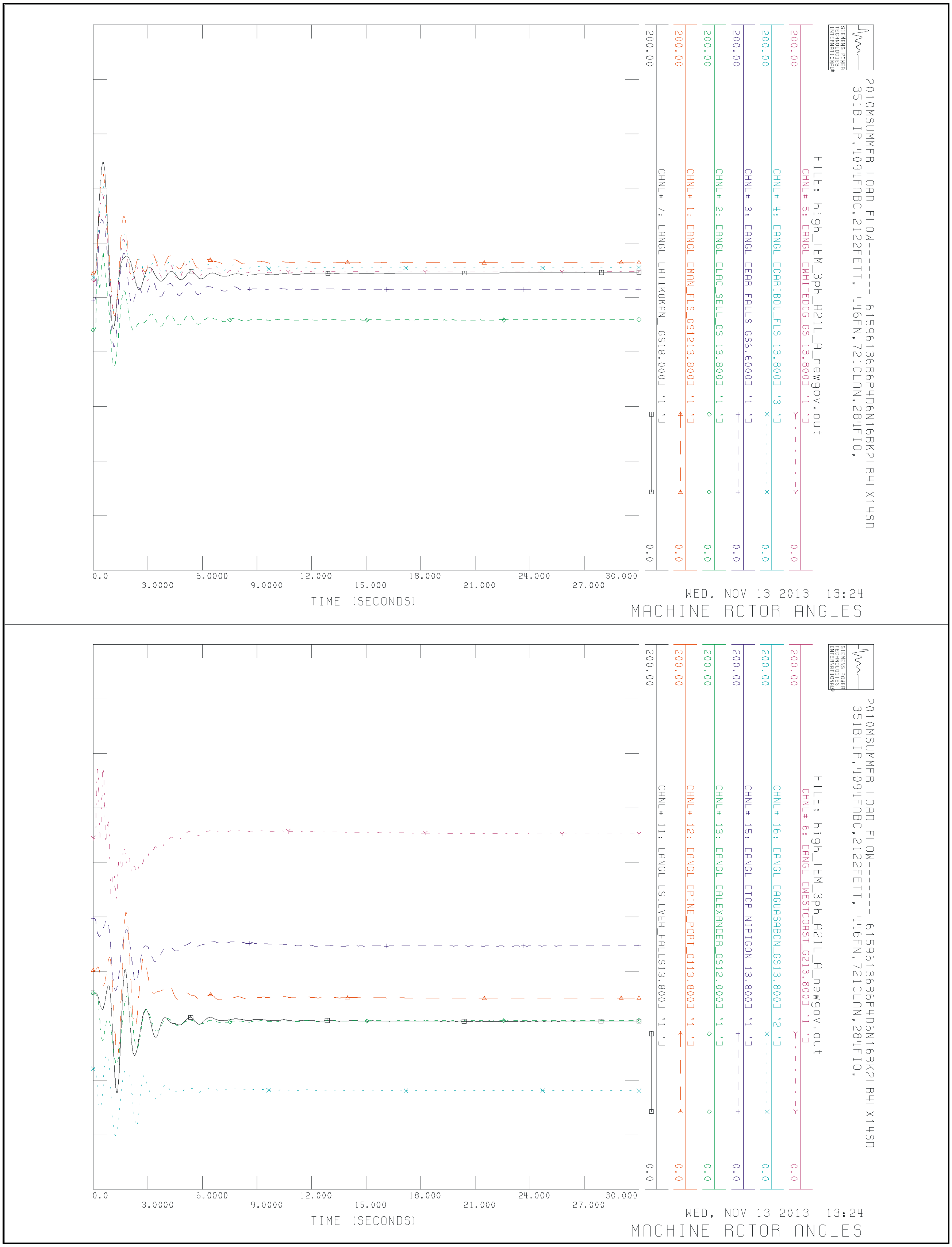

Figure 12: Rotor Angle Responses of Generators in Northwest Following a 3ph Fault on A21L at Mackenzie under Scenario S1

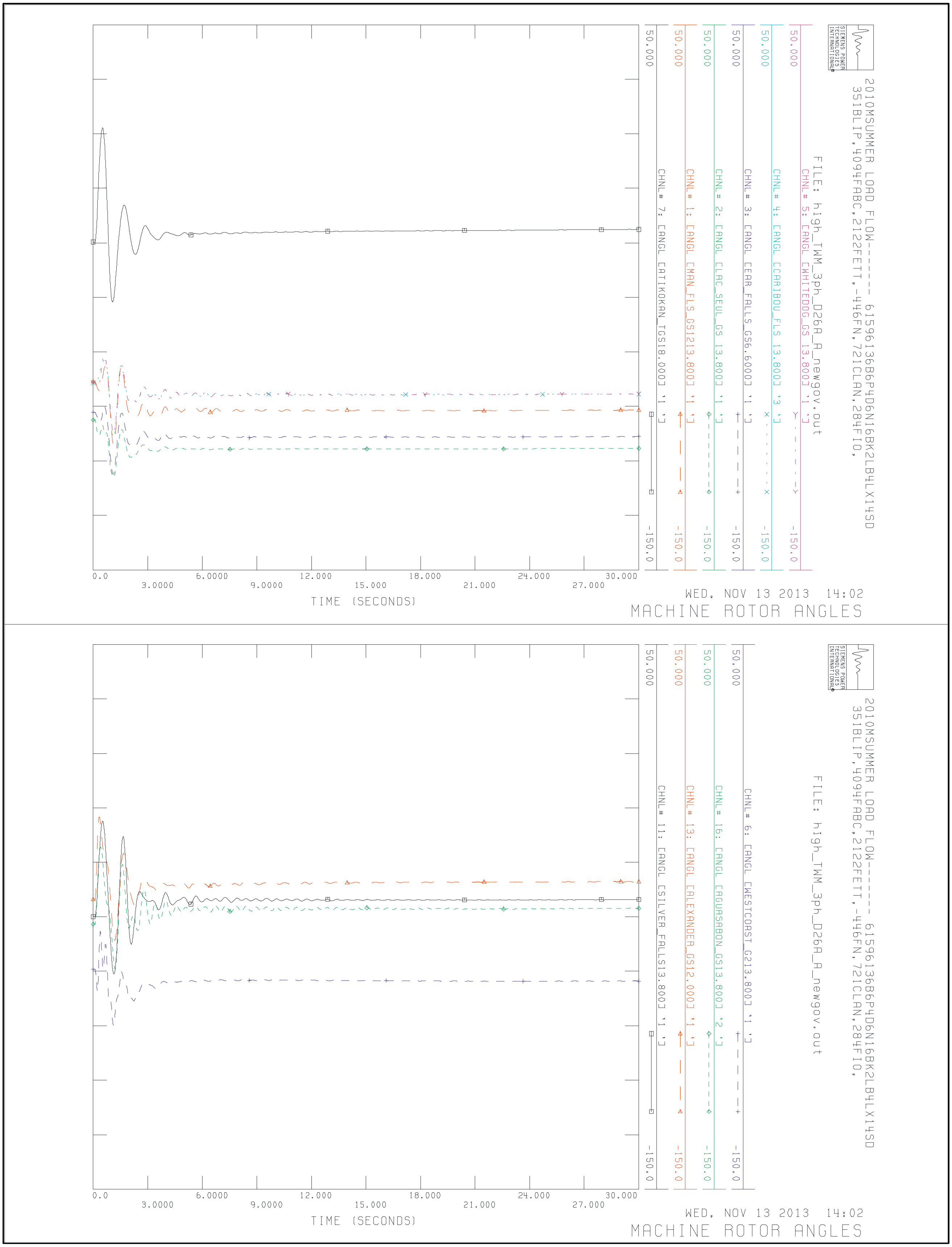

Figure 13: Rotor Angle Responses of Generators in Northwest Following a 3ph Fault on D26A at Mackenzie under Scenario S2

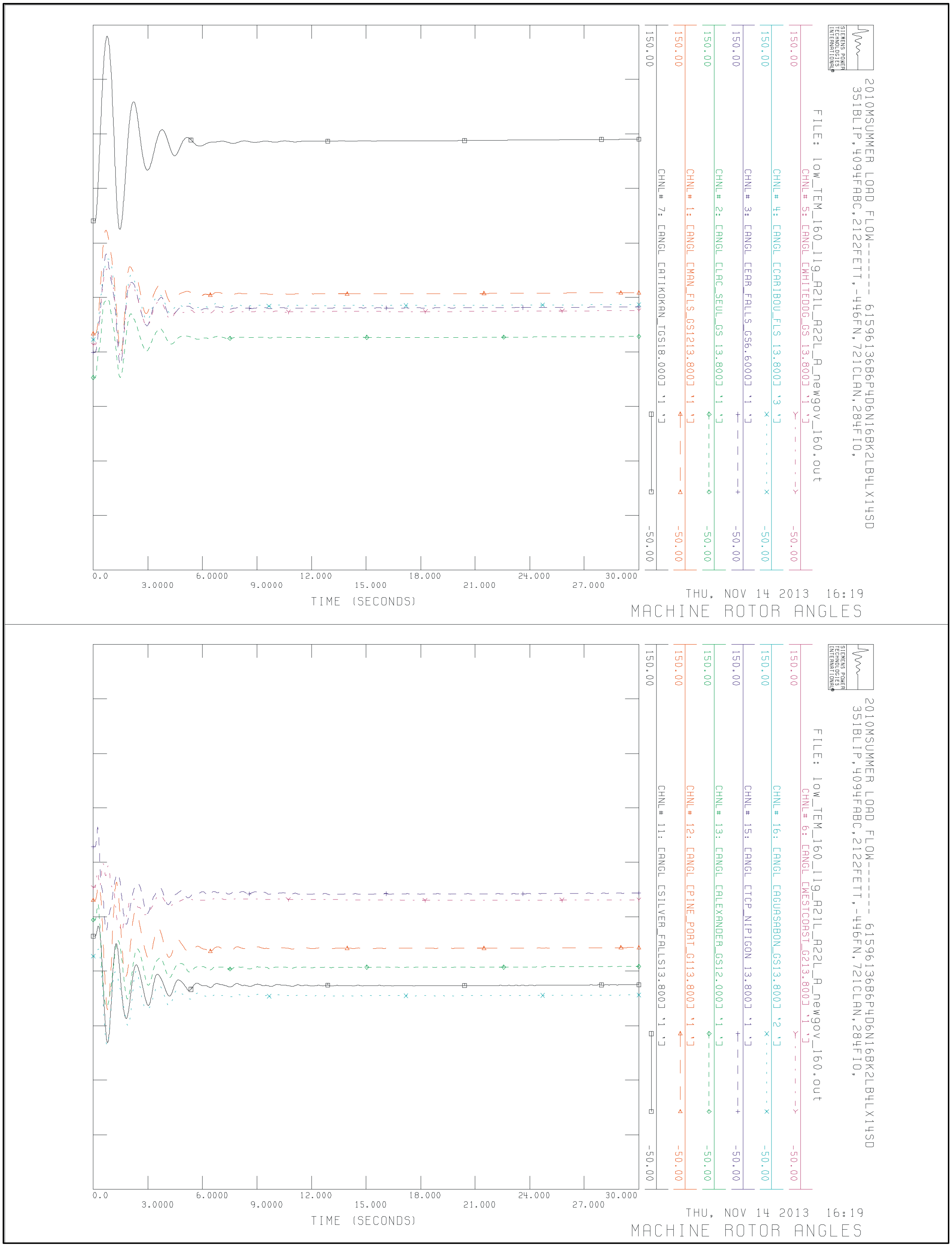

Figure 14: Rotor Angle Responses of Generators in Northwest Following a LLG Fault on A21L&A22L at Mackenzie under Scenario S3

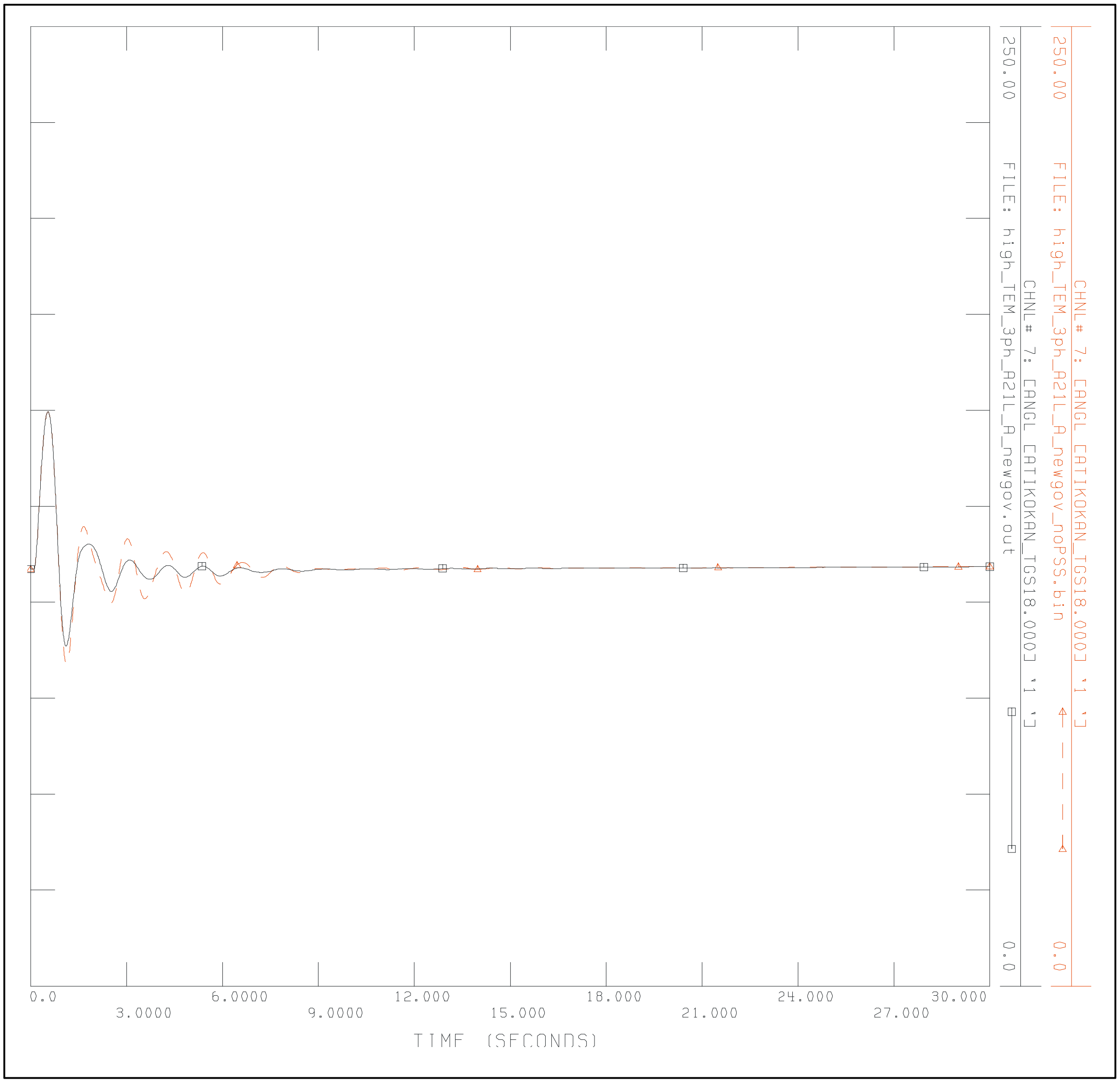

Figure 15: Comparison of Atikokan G1 Rotor Angle With and Without the PSS Following a 3ph Fault on A21L at Mackenzie under Scenario S1