AB-BC Export Capability

Summer Export TTC Levels based on Calgary Area Generation

Final Report

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Approved:			

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1 Background

The AESO initiated a study to examine the transfer limits on the Alberta-BC intertie in late 2003. The study, titled Alberta–BC Interconnection Studies, was completed in May 2004. The study results were primarily used to develop operating procedures related to BC import levels combined with single and multiple contingencies in the KEG area with Genesee #3 in service.

A second study, Transmission Study of KEG Region, was undertaken during September 2004 to determine if the increased flows on the Edmonton to Calgary corridor due to Genesee #3 operation should be considered in defining transfer limits on the Alberta-BC intertie. The study concluded that no changes to operating procedures were required for the period 2004 to winter 2005/06.

Previous studies performed in 2002 by the Transmission Administrator identified that Alberta to BC transfer limits were a function of both Alberta demand and southern Alberta generation. The studies completed in 2004 confirmed the results of the previous studies. The studies also indicated that southern Alberta is subject to voltage collapse for contingencies during conditions of high demand, high exports, and low southern generation.

In the last quarter of 2004, the AESO performed a detailed study to determine the impact of southern generation on export capability. The initial export limits resulting from this study were based on conditions with low southern generation. Further stakeholder discussions have emphasized the need for increasing export TTC during times with higher southern generation.

2 Study Objective

The objectives of this study were:

- to review and revise, where necessary, export limits for the summer season considering online generation levels in the Calgary area. The export limitation findings of this study will continue to apply until the 240 kV backbone and associated network topology is significantly modified.
- to determine the sensitivity of export capability on various generation and transmission conditions, and to determine if Calgary area generation (CAG) online and in excess of current TMR requirements can be used to support export.

3 Study Scope

- Power-voltage (PV) analysis was performed on the AIES to determine the voltage stability load limit (VSLL) in base conditions.
- A deterministic methodology was used to reduce the reliance on assumptions about online southern generation.
- The AESO generation stacking order was not used for this study.
- To determine the base southern area generation levels, generators that are online greater than 95% of all hours of the summer timeframe were online in the base case.
- PV analysis was used to monitor various contingencies and was repeated for 0 to 800 MW of export, in increments of 100 MW. Additional contingencies on the 240 kV backbone were

analyzed to ensure that any transmission line overloads of greater than 120% would be considered in setting export TTC values.

- Steady state voltage checks were conducted in order to ensure that voltage levels within the AIES were within acceptable levels.

4 Study Assumptions

Constant MVA load models were used. This is in alignment with the WECC paper "Voltage Stability Criteria, Undervoltage Load shedding Strategy, and reactive Power Reserve Monitoring Methodology" dated May 1998

Area loads were scaled using a constant power factor.

Only areas of the province that are not largely made up of industrial load were scaled during PV analysis. This is because areas with large industrial loads are generally base loaded, and do not vary in the same uniform manner as non-industrial loads. The areas scaled include: 6, 13, 20 to 24, 26, 27, 29 to 32, 34 to 39, 42 to 47, 49, 50, 52 to 57, and 60 (according to the AESO map).

Each southern generator's ability to support export was the same for all system conditions listed in Table 5 of OPP 304. This was checked for select cases and proved to be accurate. For example, the megawatt increase in export capability per additional CAG megawatt is the same in the system normal case and any other system condition.

Export levels for each system condition can only be increased up to the value listed in the "<6300" MW block. This is to avoid pre-contingency overloads (as in the case of 1201L, 936L, or 937L out of service), post-contingency overloads (one 240 kV North-South line, one Sheerness unit, or both Sheerness units out of service), potential instability (SVC out of service), or over-frequency (system normal, Calgary area Cap Bank, or one Carseland unit out of service).

5 Methodology

Selected single and double transmission contingencies were examined for PV stability. These contingencies include the loss of major generation units in southern Alberta, as well as single circuit and double circuit contingencies. Single contingencies require a 5% load margin, while double contingencies require a 2.5% load margin.

Additional contingencies were examined to determine the export capability of the AIES during times when a major system element (generator, transmission line, or cap bank) is out of service. Double contingencies (over an original outage) were taken into consideration in these scenarios.

Selected sensitivities were studied together to confirm the cumulative effect of various units.

6 Scenarios Studied

The load-flow base case used was the summer 2005 medium load case. The generation dispatch was the same as that of the March 2005 export study, but was modified so that Sheerness output was raised to 580 MW NTG (its 95% duration value). The new output level better represents the typical summer minimum Sheerness generation.

Additional southern generation was dispatched in sensitivity studies to determine the capability of each unit to support export.

Additional scenarios were studied to reconcile the differences between the export and TMR study assumptions. These studies mainly consisted of increasing the Southern generation, as well as shifting a higher percentage of load to the Calgary area (to approximately 15% of AIES from 12.5%).

All capacitor banks in southern Alberta were online in the base case. This resulted in very high voltage levels in light load conditions, but allowed the system to be scaled up to a higher load level. In real-time, cap bank switching would be done manually as load increased.

6.1 Pre-Conditions

Table 1 lists the power factor in the base case and all subsequent cases. These values correspond to other cases used in previous studies, and represent the historical power factors determined for each season.

Table 1. Base Case Power Factors

Area	Summer
AIES	0.931
Calgary area	0.923
South	0.930

6.2 Southern Generation

Southern generation (Table 2) was adjusted in the study to levels that represent the lowest generation level that could typically be expected from each plant. A unit would have to be on about 95% of all hours (in the recent year) for it to be considered online in this study. This analysis was based on seasonal duration curves from each plant. The Sheerness output differs from that in the March 2005 export study because the individual unit durations were examined separately rather than looking at the plant output as a whole.

Table 2. Southern Generation Levels

Generation Plant	Summer
Sheerness NTG	580 MW
Battle River NTG	582 MW
South Hydro (Irrigation)	36 MW*
South Wind	Disconnected
Med Hat (Negative number means load)	-32 MW
Joffre	125 MW
Brazeau	Disconnected
Bow Hydro	24 MW
Carseland	32 MW

* Old Man = 20 MW, Raymond Reservoir = 9 MW, Taylor = 4.5 MW, Chin Chute = 2.5 MW

6.3 Contingencies

Contingencies studied to determine generator effectiveness were limited to those found to be the most severe in the export study for each system condition listed in Table 5 of OPP 304. These contingencies are listed in Table 3. Additional contingencies, such as the loss of 928L and 906L, were studied to monitor for possible overloads.

Table 3. Contingency List

Precondition	Contingencies Studied
System Normal	The loss of SH1 & 2 or the loss of 936L & 937L
1201L OOS	No further study
SVC OOS	Sheerness 1 & 2
936L or 937L OOS	Sheerness 1 & 2
One North-South Line OOS	Sheerness 1 & 2
One Sheerness unit OOS	Loss of second SH unit as well as the SVC
Both Sheerness units OOS	936L & 937L
Calgary area cap bank OOS	Sheerness 1 & 2
One Carseland OOS	Sheerness 1 & 2

7 Sensitivity Studies

The sensitivities listed in Table 4 were studied by setting the generation units to the output levels listed, and then analyzing the increase in export capacity that each plant provided.

Table 4. Plant and Element Sensitivities Studied

Plant or Element	Summer (MW)
Carseland	0 to 80
Calpine	0 to 290
Balzac	0 to 100
Cavalier	0 to 100
Bow Hydro	0 to 200
Calgary Area Generation (Combination of Units – Incl. Bow)	0 to 770
Brazeau	0 to 390
Joffre	0 to 200
Medicine Hat[1]	-30 to 30

1 Net interchange of the City of Medicine Hat

8 Summary of Results

This summary is divided into two sections, one outlining the increase in export capability relative to Alberta load, and the other discussing export capability relative to Calgary area load.

8.1 Alberta Load/Export Sensitivity

Table 5 lists the effect of each generator on export capacity. The unit effect on the voltage stability load limit (VSLL) is also included for comparison with the March 2005 export report. An increase in VSLL can be viewed as the increase in AIES load level that can support the same amount of export. The March 2005 export report stated increases in VSLL due to additional Calgary area generation as the sum of a constant VSLL increase and an additional MW VSLL increase per MW online (i.e., 35 MW + 1 MW VSLL / MW generation for the Carseland plant). This was replaced with one value, a MW increase in VSLL for every MW online (i.e., 1.43 MW VSLL / MW generation for Carseland). Note that some values have changed due to additional studies and slight changes in study scenarios.

Table 5. Generator Sensitivities

Sensitivity	Load Increase: VSLL Increase Found in March '05 Export Study	Load Increase: Load Increase Factor Found in Current Study[1]	Export Increase: Increase in Export Capacity per Generation? Level
Carseland Plant	35 + MW Gen	1.43	0.91 MW / MW
Calpine Plant	95 MW + MW Gen	1.33	0.84 MW / MW
Balzac Plant	85 MW + 1.05 MW Gen	1.5	0.95 MW / MW
Cavalier Plant	MW Gen	1.18	0.75 MW / MW
Bow Hydro	20 MW + 1.35 * MW Gen	1.32	0.84 MW / MW
Calgary Area Generation (Combination of Units)	Additive as listed above.	1.28	0.81 MW / MW
Sheerness	-25 MW for 0-200 MW, 0 MW for 300-700 MW[2]	No Effect	No Effect
Medicine Hat	1.75 * MW Export	1.75	1.1 MW / MW
Brazeau[3]	35 + 0.25 * MW Gen	0.31	0.20 MW / MW
Joffre	62.5 MW + 0.425 * MW Gen	0.425	0.27 MW / MW

1 Approximately equal to: (Max MW output of plant + MW support of plant due to MVAr available) / (Max MW output of plant)

2 This worst contingency for this switched from the loss of 936L & 937L to Sheerness 1 and 2 at 300 MW export (only because the tie would trip if 936L & 937L were to trip for ≥ 300 MW of Export).

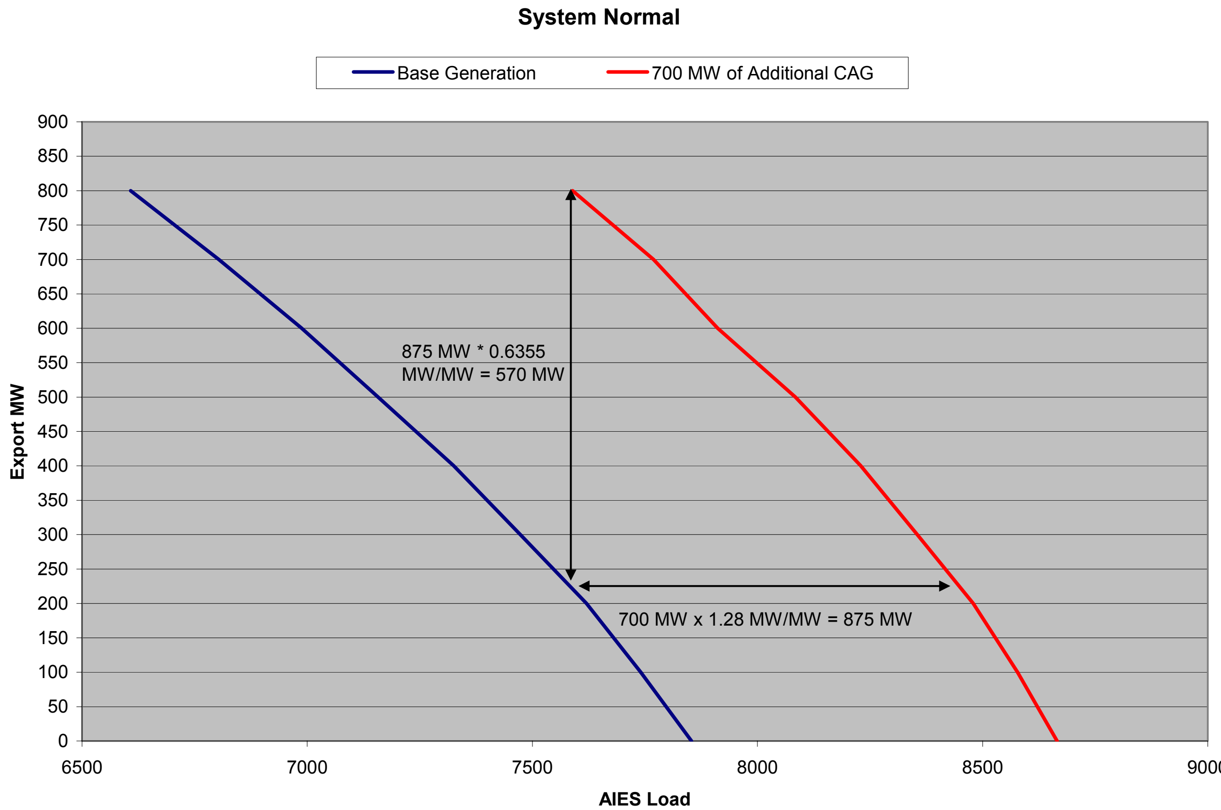
3 Should not be considered due to other factors mentioned below

The ability of each generator to support export (defined as the % effectiveness) was determined by varying each generator MW output and determining the change in VSLL. An increase in VSLL can be thought of in this case as an increase in the amount of AIES load that can support a given export level (i.e., moving the Base Generation line in Figure 1 to the right). This effectiveness was further refined to be presented as a multiplier by taking the increase in VSLL caused by the generation increase and dividing this by the MW increase in generation output.

Most units provided a linear increase in VSLL per MW increase in generation. The change in VSLL could then be converted to a change in potential export limits by using the slope of the export/AIES load line. This was found to be approximately 0.6355 MW of export for every 1 MW increase in VSLL (as shown in Figure A1 in Appendix A).

As an example, the combination of all of the Calgary area generation units produces a VSLL increase of 1.28 MW/MW CAG. To convert this to an export factor, the 1.28 MW/CAG MW was multiplied by 0.6355 export MW/VSLL MW increase. This resulted in a value of 0.81 MW/MW. An example of this can is shown in Figure 1, with 700 MW of CAG. Additional sensitivity results are presented in Figure A2.

Figure 1. Export TTC Increase Factor Calculation



8.1.1 Brazeau

Brazeau had a small positive effect on the export capacity when considering voltage stability alone. However, in severe conditions, overloading of 900L during a 928L and 906L double contingency became a limiting factor, and such an increase in Brazeau generation would worsen the overload. Therefore, Brazeau should not be considered for use in increasing export levels.

8.1.2 Sheerness

Increasing Sheerness does not increase the amount of export that can be supported because the loss of the Sheerness plant was typically the worst contingency. Therefore, an increase in Sheerness generation does not increase export capability. However, generation from the plant was effective at off-loading 900L in the event of a 928L and 906L outage. The Sheerness units should be considered fully operational if output is greater than 290 MW. This is the threshold level that offloads 900L so that it remains within its emergency thermal ratings during a 928L and 906L contingency and with the recommended export limits.

8.2 Calgary Load/Export Relationship

Several operating scenarios were analyzed to determine the relationship between export and Calgary load. There were no situations found in which export was harder on the system than Calgary area load. Note that the TMR study results suggesting that X MW of CAG could support Y MW of Calgary area load was not always found. It depended on the generation dispatched in the study cases as well as the load distribution pattern. However, it was found that export is easier on the system than Calgary load, so a given amount of CAG MW could always support more export than Calgary area load.

The results of this analysis are shown in Figure A3. The analysis was performed using cases 508 and 518 from the original TMR study (0 MW export, SVC +/- 250 MVAr, 0 MW of CAG). The load values do not fully align with the previous TMR study values, because some load-correction offsets for the Calgary versus AIES load were added to the original case (to align the load value found in the study with the system load as seen by the controllers). However, the relative positions of the lines are accurate and suggest that export can be more easily supported by CAG than Calgary area load.

8.3 Overall Results

The differences between the scenarios analyzed in the March 2005 export study and the TMR study made it a challenge to reconcile the two sets of findings. This is mainly due to the difference in load distribution within the province. Modifications to Calgary area TMR will be made in Q4 2005 to capture current system conditions.

The results suggest that Calgary area generation and Medicine Hat output are the only truly effective generation sources for increasing export limits because they assist in reducing overloads on the North-South 240 kV lines, as well as providing PV margin. Given the current SC tool, and the fact that Medicine Hat has rarely been exporting energy during spring/summer 2005, it would be most efficient to consider only Calgary area generation. Also, all Calgary generation should be considered to be one source (i.e., only use the effectiveness listed for a combination of units in Table 5).

9 Recommendations

9.1 OPP Changes and Additions

9.1.1 Calgary Area Generation "Adder"

Study results indicate that export is easier on the system than Calgary load. Therefore if, according to the TMR tables, there is enough generation to support more Calgary load than is currently on-line, then every additional MW of Calgary load that could be supported could be considered as one more MW of export. However, additional studies also show that export is harder on the system compared to AIES load as a whole. To reconcile the two findings, it is recommended that the minimum of the two calculations be used when increasing export:

1. 0.81 * (Effective CAG online - 56 MW on in the base case)
2. 0.81 * (Excess Calgary Load that can be supported according to effective generation levels and TMR requirements stated in OPP 510)

"Effective" refers to the CAG online after taking into account the effectiveness factors listed in Appendix C and Appendix D of OPP 510. The factor of 0.81 is the relationship between AIES load and export capacity mentioned earlier. The 56 MW online in the base case is subtracted because the current export limits were calculated with the assumption that 56 MW of CAG was online, so this must be subtracted when calculating the *excess* CAG.

Note that when one Carseland unit is out of service, the 56 MW that is subtracted from equation 1 should be reduced to 40 MW, as the 16 MW off line is already accounted for in the export TTC table.

It is expected that equation 1 will be the limiting factor during times of low Calgary area load, and equation 2 will become more dominant as Calgary area load increases. For example, consider the following system conditions:

- System Normal
- Calgary Load = 1100 MW
- Effective CAG online = 205 MW & 100 MVAr

In this case, the TMR requirement would be 0 MW (see Table A1), but according to Table S-1 in OPP 510, there is enough generation online to support 1,400 MW of load. The minimum of the following would be chosen for increasing TTC:

1. 0.81 * (205-56) = 120.7 MW
2. 0.81 * (300) = 243 MW

The TTC increase would then be 120.7 MW.

The TMR tables from OPP 510 that will be referenced to calculate the CAG adder for each system condition are shown in Table 6. Equation 2 above will reference the amount of Calgary area load that can be supported for the current system condition and amount of CAG.

Table 6. CAG Adder Reference Tables

System Condition	OPP 510 Table
System Normal	S-1
1201L Out of Service	S-2
SVC Out of Service	S-2
936L or 937L Out of Service	S-3
One North-South Line Out of Service	S-2
One Sheerness Unit Out of Service	S-2
Both Sheerness Units Out of Service	S-2
Calgary Area Cap Bank Out of Service	S-1A
One Carseland Out of Service	S-1

9.1.2 Export TTC Changes

After further analysis of potential overloads, it is suggested that revisions be made to some of the export limits in Table 5 of OPP 304. These revisions include conditions when one or both Sheerness units are out of service, when one North-South 240 kV transmission line is out of service, and when 1201L is out of service. The current summer export TTC limits are shown in Table A2, and the new recommended limits are shown in Table A3.

Table 7. Recommended Changes to Export TTC Limits

AIES Load Level	1201L Out of Service	One 240 kV NS Line Out of Service	One SH Unit Out of Service	Two SH Units Out of Service
8,100 to 9,999	65	65	65	65
7,900 to 8,099	65	65	65	65
7,700 to 7,899	65	65	65	65
7,500 to 7,699	115	65	65	65
7,300 to 7,499	115	65	65	65
7,100 to 7,299	115	65	65	65
6,900 to 7,099	115	65	150	65
6,600 to 6,899	115	100	270	100
6,300 to 6,599	115	300	450	275
6,300	115	450	650	365

9.1.3 Additional Comments Regarding OPP 304 Policies

Figure A1 shows the actual curve from the study results and the step-line that was derived from the curve to generate the TTC values listed in Table 5 of OPP 304. Note that the TTC values in OPP 304 are limited to a minimum of 65 MW. TTC is held to a minimum of 65 MW because with a TRM of 65 MW, ATC would be zero when TTC is 65 MW. ATC cannot be negative, and so TTC cannot be less than 65 MW.

The recommended export limit calculation is shown in Table A4. The values listed were found by extrapolating the curve in Figure A1 and creating a corresponding step-line. Any additional export that is available due to excess CAG must be added to the values in Table A4, rather than summed with the values in Table A3.

The study results indicate that there is not enough CAG to raise TTC above 65 MW if the AIES load is greater than 8,100 MW.

The maximum export level for each system condition should not exceed the value listed in the "<6300" row of Table 5 (OPP 304) for the given condition. For example, the maximum export during either a 936L or 937L outage should not be increased above 465 MW, even if the additional CAG would indicate that it can be increased above this limit. These limits have been put in place to avoid pre- and post-contingency overloads, instability and/or over-frequency (as listed in Study Assumptions).

9.2 Future Considerations

As overloads on the 240 kV backbone become a limiting factor on export, additional studies should be conducted to study the possibility of using a Remedial Action Scheme (RAS) that will trip 1201L in the event of certain N-1 and N-2 contingencies on the backbone. For example, a trip of 928L & 906L (double circuit) can cause overloads on 900L depending on load, export, and generation conditions in the south. A RAS to trip 1201L or Alberta source generation in this event would mitigate the overload during low load/high export conditions, and would remove the loss of 928L and 906L as the limiting contingency in export capability. This study could be included in future export and Generator Remedial Action Scheme (GRAS) studies.

Appendix A

Figure A1. System Normal – Base Export Vs. AIES Load Line And Current Export Limit Blocks

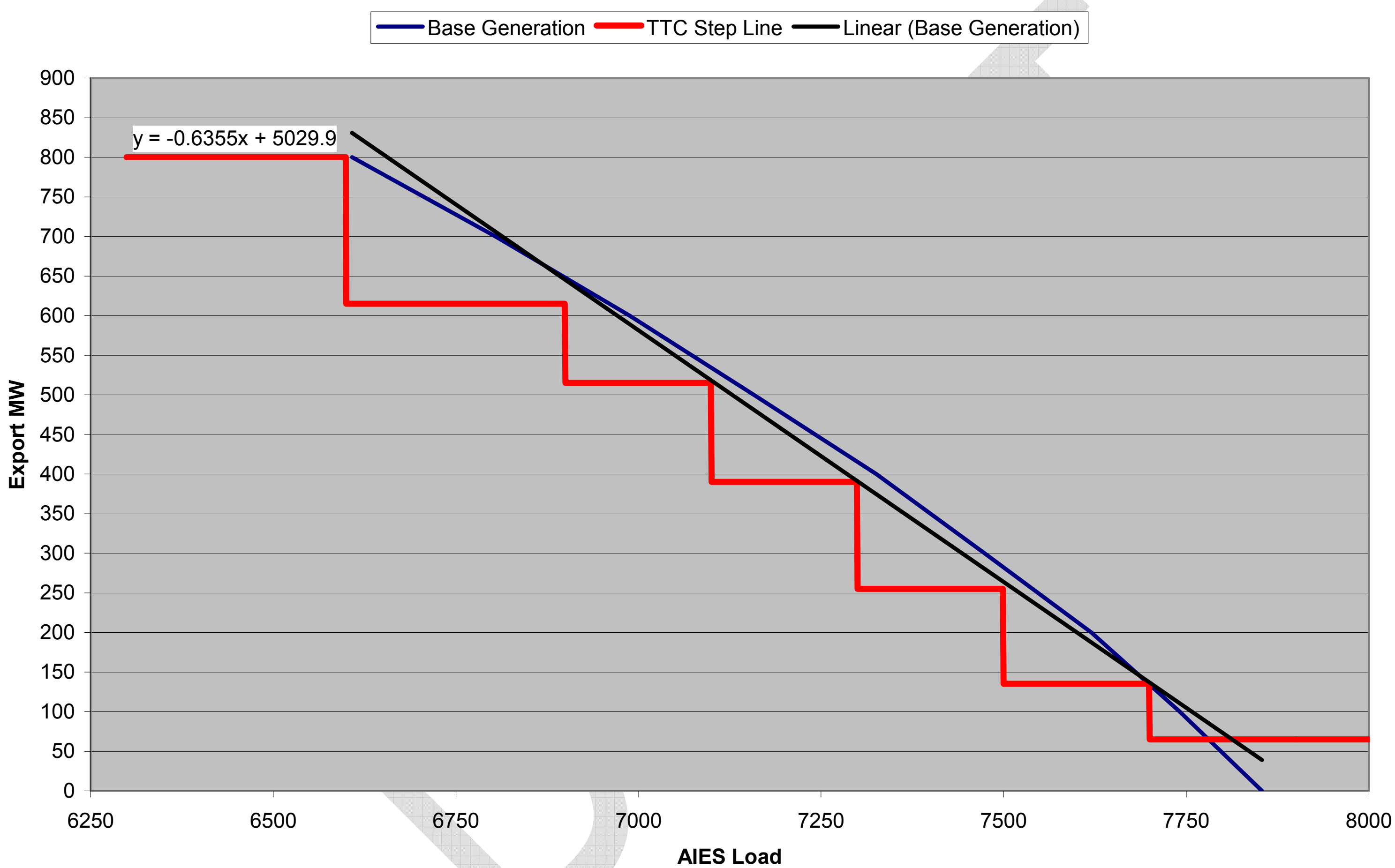


Figure A2. System Normal – Export vs. AIES Load For Various CAG Levels

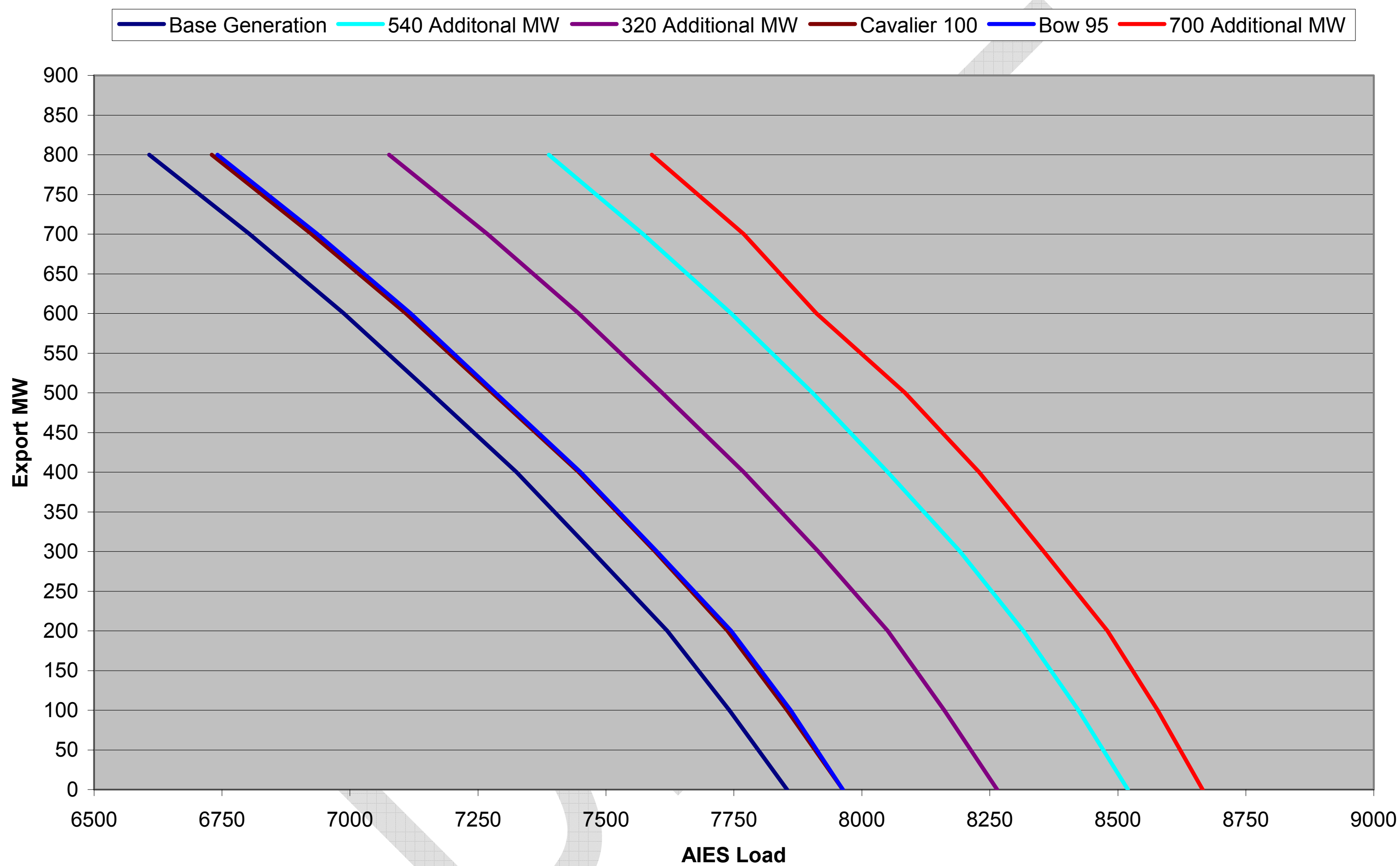


Figure A3. PV Curves – AIES Load with Stated Export and Generation

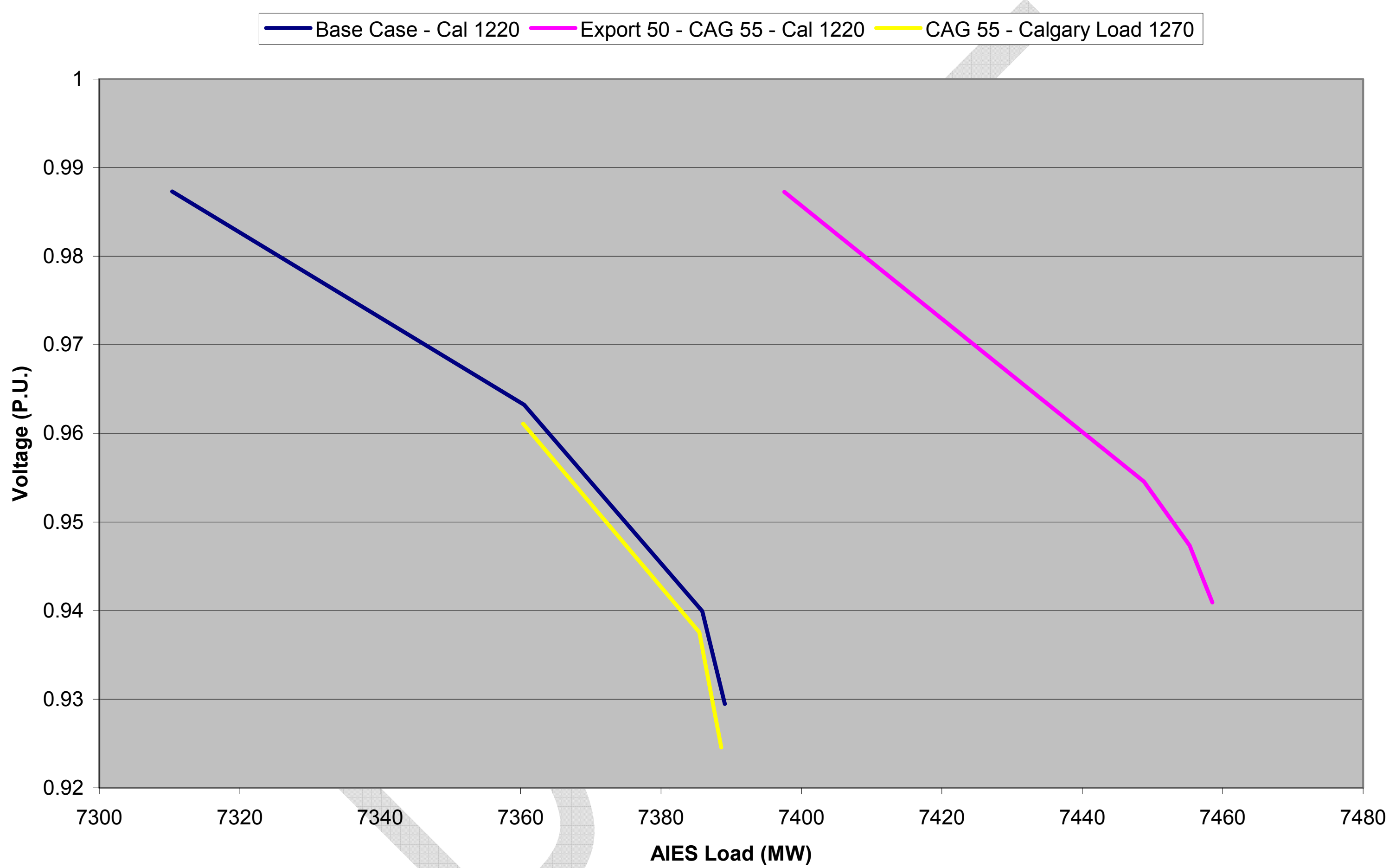


Table A1. System Normal TMR Requirements – (Table S-1 in OPP 510)

Calgary Area Load (MW)	Minimum MW Generation (MW)	Minimum Generator Reactive Reserve (MVAr)	Correlated Alberta Internal Load (MW)
1,401 to 1,450	350	160	>8,600
1,351 to 1,400	200	100	8,451 to 8,600
1,301 to 1,350	100	100	8,351 to 8,450
1,251 to 1,300	55	40	8,201 to 8,350
<1,251	0	0	<8,201

Table A2. Current Summer Export Limits (Table 5 in OPP 304)

Export TTC (summer season – from May 1 to October 31)

All units in MW

Alberta Internal Load (AIL)[1]	System Normal	1201L OOS	SVC OOS	936L or 937L OOS	Either One North-South 240 kV Line OOS[2]	One Sheerness Unit Off Line[3]	Two Sheerness Units Off Line[3]	Accumulated loss of MVAr capability from Calgary area Capacitor Banks[4]			Either one Carseland Unit Off Line
								≤ 54	> 55 & ≤ 81	>81 & ≤108	
8100 to 9999	65	65	65	65	65	65	65	65	65	65	65
7900 to 8099	65	65	65	65	65	65	65	65	65	65	65
7700 to 7899	65	115	65	65	65	65	65	65	65	65	65
7500 to 7699	135	115	65	115	65	65	65	90	65	65	85
7300 to 7499	255	115	130	240	165	130	65	215	190	175	205
7100 to 7299	390	115	255	365	285	255	90	340	315	305	340
6900 to 7099	515	115	385	465	405	385	165	465	455	425	465
6600 to 6899	615	115	465	465	515	510	240	590	580	555	590
6300 to 6599	800	115	465	465	715	690	365	795	765	740	790
< 6300	800	115	465	465	800	800	365	800	800	800	800

Table A3. Recommended Summer Export Limits (Table 5 in OPP 304)

Export TTC (summer season – from May 1 to October 31)

All units in MW

Alberta Internal Load (AIL)[1]	System Normal	1201L OOS	SVC OOS	936L or 937L OOS	Either One North-South 240 kV Line OOS[2]	One Sheerness Unit Off Line[3]	Two Sheerness Units Off Line[3]	Accumulated loss of MVAr capability from Calgary area Capacitor Banks[4]			Either one Carseland Unit Off Line
								≤ 54	> 55 & ≤ 81	>81 & ≤108	
8100 to 9999	65	65	65	65	65	65	65	65	65	65	65
7900 to 8099	65	65	65	65	65	65	65	65	65	65	65
7700 to 7899	65	65	65	65	65	65	65	65	65	65	65
7500 to 7699	135	115	65	115	65	65	65	90	65	65	85
7300 to 7499	255	115	130	240	65	65	65	215	190	175	205
7100 to 7299	390	115	255	365	65	65	65	340	315	305	340
6900 to 7099	515	115	385	465	65	150	65	465	455	425	465
6600 to 6899	615	115	465	465	100	270	100	590	580	555	590
6300 to 6599	800	115	465	465	300	450	275	795	765	740	790
< 6300	800	115	465	465	450	650	365	800	800	800	800

Table A4. Recommended Summer Export Limit Calculation Table

Alberta Internal Load (MW)	Alberta Internal Load (MW)	System Normal	1201L Out of Service	SVC Out of Service	937L or 936L Out of Service	North South 240kV Line Out of Service	One Sheerness Unit Off Line	Two Sheerness Units Off Line	0 to 54 MVAR Calgary Area cap bank MVAr unavailable	55 to 81 MVAR Calgary Area cap bank MVAr unavailable	82 to 108 MVAR Calgary Area cap bank Unavailable	Carseland Generation Off Line
8100	9999	-1374	-1400	-1494	-1400	-2600	-2500	-3000	-1424	-1454	-1500	-1440
7900	8099	-167	-250	-294	-225	-1200	-800	-1150	-217	-247	-300	-220
7700	7899	-40	-100	-168	-80	-1000	-600	-950	-90	-120	-175	-92
7500	7699	135	115	-42	115	-750	-400	-750	90	50	-50	85
7300	7499	255	115	130	240	-550	-200	-550	215	190	175	205
7100	7299	390	115	255	365	-300	50	-350	340	315	305	340
6900	7099	515	115	385	465	65	150	-100	465	455	425	465
6600	6899	615	115	465	465	100	270	100	590	580	555	590
6300	6599	800	115	465	465	300	450	275	795	765	740	790
0	6299	800	115	465	465	450	650	365	800	800	800	800