aeso
ALBERTA ELECTRIC SYSTEM OPERATOR

AB-BC Export Capability

Winter Export TTC Levels based on Calgary Area Generation

Final Report

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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. Consequently, a study was conducted in July of 2005 to review the summer export limits. The new limits, which consider Calgary area generation (CAG), have been implemented as of August 31, 2005. This study will review the winter limits and analyze the effect of CAG on winter export limits.

2 Study Objective

The objectives of this study were:

- to review and revise, where necessary, export limits for the winter 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 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 winter timeframe were online in the base case. However, all Calgary area

generation was left off line in the base case, as it was considered in sensitivity studies and will be added to base export TTC as an adder.

- 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.
- Analysis was performed on study cases with load blocks ranging from 6600 MW – 8300 MW (6600MW, and 6900 MW and up in 200 MW increments). Export was varied for each scenario until a suitable level, based on voltage stability and thermal overloading, was found.

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).

Area 6 was scaled independently of the other areas; this was done in order to capture the fact that Calgary area load grows faster than AIES load (for example as AIES goes from 6000 – 7000 MW, the *percentage* of Calgary area load will grow). In order to set a study case to a given AIES load level, first the Calgary area load was scaled to a level that represents a high percentage of AIES load for the given load level (according to historical data), and then the remainder of the areas mentioned above were scaled in order to reach the desired load level.

As per the most recent Summer Export Capability study, Calgary Area Generation (CAG) will be considered to be able to provide increased export capability, over and above the base level. Additionally, changes to the assumptions regarding the base loaded generation at Nova Joffre suggest that generation from Joffre should be considered as an adder (an increase over base export TTC), rather than as a base loaded machine. This will be reviewed for future export capability studies.

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 single and double 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 in order to confirm the cumulative effect of MWs supplied by the various CAG units, as well as Joffre generation.

6 Scenarios Studied

The load-flow base case used was the winter 2004/2005 medium load case. The generation dispatch pattern of the cases was similar to that used in the March 2005 study, except that all CAG and Joffre generation was off-line in the base case (regardless of the typical level for each unit) because both CAG and Joffre were dispatched up in sensitivity analysis.

Additional scenarios were studied to reconcile the differences between the export and TMR study assumptions. These studies mainly consisted of interchanging Calgary load and export and analyzing the effect on system stability.

All capacitor banks in southern Alberta were online in the base case in order to increase voltage stability. In real-time, cap bank switching would be done manually as load increased, or as system conditions required.

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	Winter
AIES	0.939
Calgary area	0.957

6.2 Southern Generation

Southern generation 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 approximately 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 Big Horn plant outputs was increased from that used in the March 2005 Export Capability Study in order to better represent a 95% duration. Table 2 lists the base generation levels used in the study.

Table 2. Southern Generation Levels

Generation Plant	Winter
Sheerness NTG	555 MW
Battle River NTG	589 MW
South Hydro (Irrigation)	0 MW
South Wind	Disconnected
Med Hat (Negative number means load)	-32 MW
Joffre	Disconnected[1]
Brazeau	Disconnected
Balzac	Disconnected[1]
Bow Hydro	Disconnected[1]
Calpine	Disconnected[1]
Carseland	Disconnected[1]
Cavalier	Disconnected[1]

1 Cumulative effect of CAG considered in sensitivity studies

6.3 Contingencies

The contingencies studied include the loss of double circuit lines, select 240 kV lines sharing a common breaker (assuming breaker failure after single line trip), a Calgary area cap bank, the SVC, and major southern area generation units. The complete list of contingencies studied is shown in Table 3.

Table 3. Contingency List

Contingencies Studied
928L & 906L
925L & 929L
922L & 926L
190L & 903L
910L & 914L
927L & 924L
933L & 931L
925L & 901L
918L & 190L
928L & 903L
Janet 74S 138 kV Cap Bank
Langdon SVC
Sheerness 1 & 2

7 Sensitivity Studies

As the results of the August 2005 Summer Export Capability Study indicated that Calgary area generation could be grouped in order to calculate export capacity increases, this study only considered sensitivities with multiple CAG units online, ranging from 0 – 790 MW online (Bow Hydro's maximum MW output was considered to be 220 MW for the winter, based on historical data). The MW range tested for each CAG unit is shown in Table 4.

Table 4. Plant and Element Sensitivities Studied

Plant or Element	Winter (MW)
Carseland	0 to 80
Calpine	0 to 290
Balzac	0 to 100
Cavalier	0 to 100
Bow Hydro	0 to 220
Calgary Area Generation (Combination of Units – Incl. Bow)	0 to 790
Nova Joffre	0 to 450

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 CAG/Export Sensitivity

The results indicate that the sensitivity of CAG export capacity increases is based on AIES load and the corresponding base export limit. Therefore, the CAG export TTC factor found for each load block is listed in Table 5. The export TTC increase factors are basically increases in the amount of export that the AIES can support for a given load level and remain stable. Also, since the effect of CAG decreases as load decreases, it would be most conservative to use the lowest load level in a load block to determine the effectiveness. However, the highest load in a load block was used, with the assumption that the increased margin at the lower end of a load block would more than compensate for the increased effectiveness.

Also, the results indicate that the increase factor decreases as more CAG is online. Therefore, in order to safely maximize the factor values, the factor found for the amount of CAG that would increase TTC to 800 MW was used. For example:

- Base TTC = 500 MW

- 400 MW of excess CAG resulted in a 320 MW export increase = 0.8 increase factor
- 360 MW of excess CAG resulted in a 300 MW export increase = 0.8333 increase factor

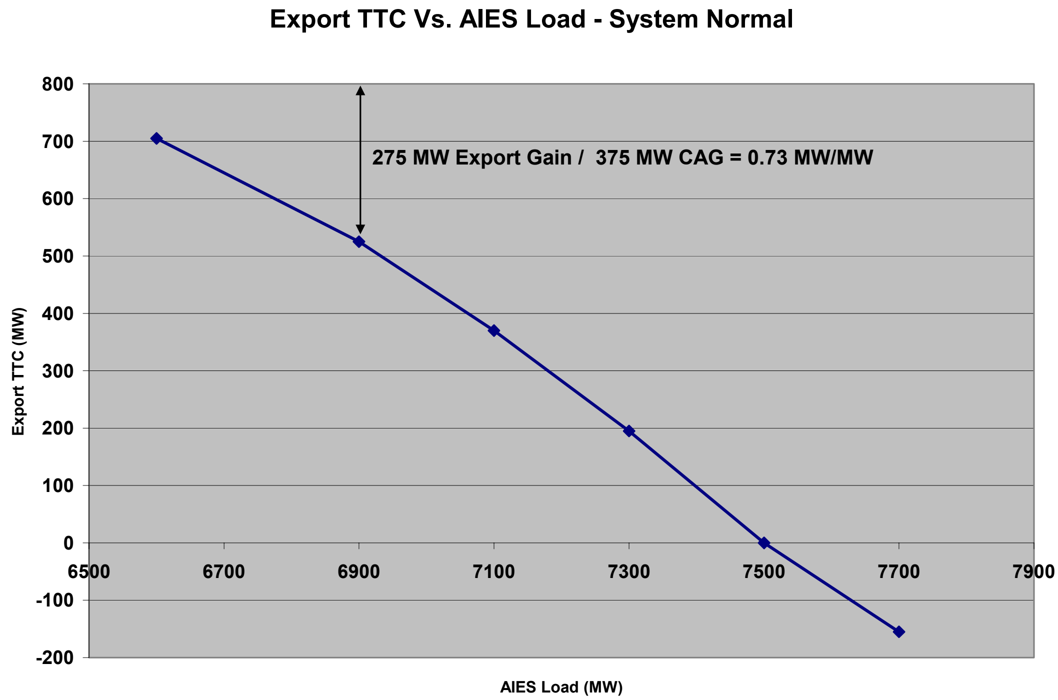
The factor of 0.833 would be used because the maximum increase for this base TTC level is 300 MW (maximum export TTC is 800 MW), so it is unnecessary to use the smaller value found for 400 MW of excess CAG (it would unnecessarily reduce the available export increase for less CAG).

Table 5. Export Increase Factors

AIES Load Level (MW)	Export Increase Factor
8300 to 9999	0.95
8100 to 8299	0.95
7900 to 8099	0.95
7700 to 7899	0.95
7500 to 7699	0.95
7300 to 7499	0.95
7100 to 7299	0.87
6900 to 7099	0.80
6600 to 6899	0.73
< 6600 MW	0.68

An example of how the export increase factor was found is shown in Figure 1. It was found that 375 MW of CAG was needed to increase the 6600-6900 MW load block to 800 MW export TTC. Therefore, the export increase factor for this load block was found to be 275 MW Export TTC Increase / 375 MW CAG = 0.73 MW / MW.

Figure 1. Export TTC Increase Factor Calculation



8.2 Calgary Load/Export Relationship

Analysis was conducted on several operating scenarios to determine the relationship between export and Calgary load. The tests consisted of finding the voltage stability limit for a scenario, and then scaling down Calgary load by a given amount and increasing export by the same amount (or more), and ensuring that the scenario was still stable. There were no situations found in which replacing Calgary load with export worsened system stability.

Note that the TMR study results suggesting that a given amount of MW of CAG could support a given amount of Calgary area load was not always found, it was dependent on the generation dispatched in the study cases, as well as the load distribution pattern. However, it was found that export is not harder on the system than Calgary load, so a given amount of CAG MW should always be able to support at least as much export as excess Calgary area load.

8.3 Overall CAG 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 the generation dispatch methodology used in the two studies. Modifications to Calgary area TMR will be made in Q4 2005 in order to capture current system conditions.

The results suggest that Calgary area generation is an effective source for increasing export limits because this generation does not increase overloads on the North-South 240 kV lines and it provides a significant increase per MW in PV margin.

8.4 Joffre / Export Sensitivity

It was found that Joffre generation provides some additional export capability, but is dependent on AIES load and the status of several lines near Joffre. Table 6 lists the Joffre Export Increase Factors for each AIES load range, assuming system normal conditions.

Table 6. Joffre Export Increase Factors

AIES Load Level (MW)	Export Increase Factor
8300 to 9999	0.6
8100 to 8299	0.6
7900 to 8099	0.6
7700 to 7899	0.6
7500 to 7699	0.6
7300 to 7499	0.6
7100 to 7299	0.58
6900 to 7099	0.52
6600 to 6899	0.43
< 6600 MW	0.35

Preliminary studies show that the status of several lines greatly affect the amount of export support that the Joffre plant can provide. Time constraints have prevented further engineering analysis of these contingencies; therefore the Joffre Export Increase Factor should be set to zero during times when any of the lines or segments of the lines, listed in Table 7 are out of service.

Table 7. Line Outages Affecting Joffre Adder

Line Out of Service
755L (Joffre – Piper-Red Deer)
753L (Joffre – Gaetz)
796L (Joffre – Gaetz)
900L
901L
925L
929L

9 Recommendations

9.1 OPP Changes and Additions

9.1.1 Calgary Area Generation "Adder"

Study results indicate that replacing Calgary area load with export does not worsen system stability. Therefore if, according to the TMR tables, there is enough generation to support more Calgary load than currently on-line, then every additional MW of Calgary load that can be supported can alternatively be an additional MW of export that can be supported. 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. **Export TTC Increase Factor * (Effective CAG online)**
2. **Export TTC Increase Factor * (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, which account for line outages and low generation levels.

The Export TTC Increase Factor is the relationship between CAG and export capacity for a given load block.

Equation 1 no longer includes a MW subtraction to account for CAG online in the base case, because all CAG was disconnected in the base case.

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
- AIES Load 7600 MW
- 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 W-1 in OPP 510, there is enough generation online to support 1,450 MW of load. The minimum of the following would be chosen for increasing TTC:

1. 0.96 * (205) = 196.8 MW
2. 0.96 * (350) = 336 MW

The TTC increase would then be 196.8MW.

The TMR tables from OPP 510 that will be referenced to calculate the CAG adder for each system condition are shown in Table 8. 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 8. CAG Adder Reference Tables

System Condition	OPP 510 Table
System Normal	W-1
1201L Out of Service	W-2
SVC Out of Service	W-2
936L or 937L Out of Service	W-3
928L or 906L Out of Service	W-4
Other 240 kV Line Out of Service	W-2
One Sheerness Unit Out of Service	W-5
Both Sheerness Units Out of Service	W-5
Calgary Area Cap Bank Out of Service	W-1A

9.1.2 Joffre Export Adder

As mentioned in section 8.4, Joffre generation has a positive effect on export capability. It is suggested that a second adder be used to account for the amount of online Joffre generation. The equation for the adder is shown below:

1. Joffre Export Increase Factor * (Joffre Generation)

The Joffre Export Increase Factor is related to the AIES load and the status of lines in the Joffre area surrounding the Joffre plant, and is listed in Table 6 and Table 7 of Section 8.4.

The Joffre Export Increase Factor should be added to the base TTC factor (along with the addition of the CAG adder) to calculate the "enhanced" TTC value.

9.1.3 Export TTC Changes

After further analysis, it is suggested that revisions be made to some of the export limits in Table 4 of OPP 304. These revisions are due to the more accurate method of simulating load growth in Calgary relative to the rest of the AIES, and the removal of CAG and Joffre generation from the base TTC limits (the effect of both CAG and Joffre will be considered due to the TTC adders). Table A2 lists the current winter export limits and Table A3 lists the new recommended limits. Along with the changes to the limits, the following changes have been made to the table itself:

- The "<6300 MW" load block has been removed from Table A3, as there are no hours forecast to be below this level. The next block has been changed from "6300 – 6600 MW" to "<6600 MW".
- An additional load block has been added for the range of 8100 MW to 8300 MW. This is suggested because although the value for the 8100 MW – 8300 MW block in is well below zero,

there is still potential for export during periods of very high CAG output (during system normal conditions).

- The column for "Either One North-South 240 kV Line OOS[2]" has been renamed "One 240 kV Backbone Line Out of Service", and should included 900L in the list of lines satisfy this condition.

Real-time concerns regarding voltage control have highlighted the need for specifying minimum operating voltages when exporting. Table 9 lists the minimum operating voltages that must be maintained at Sundance, Keephills, Genesee, Ellerslie, Benalto, Sarcee, and Janet in order for export limits to apply. Export should be curtailed in order to maintain these voltages if all other voltage regulation resources have been exhausted.

Table 9. Minimum Operating Voltage

Substation	Minimum Voltage (kV)
Sundance 240 kV	257
Keephills 240 kV	249
Genesee 240 kV	250
Ellerslie 240 kV	247
Benalto 240 kV	244
Gaetz 240 kV	243
Sarcee 240 kV	243
Janet 240 kV	248

9.1.4 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 in order 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. And since ATC cannot be negative, TTC cannot be less than 65 MW.

The recommended export limit calculation table is shown in Table A4. The values listed were found by conducting studies to determine the amount of effective CAG and Joffre generation that would be needed to increase export to 0 MW (assuming export increase factors mentioned in Table 5). 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 on A3.

The study results indicate that there is not enough CAG or Joffre generation to raise TTC above 65 MW if the AIES load is greater than 8300 MW.

Table 10 lists the maximum export allowed for a given system condition, regardless of AIES load. This will allow for export to increase above the limit that is in the "<6600 MW" block, but not above 800 MW, for most conditions. Export must still be limited to the level listed in the "< 6600 MW" block when 1201L, 936L, 937L, or the SVC is out of service due to pre-contingency overloading (1201L, 936L, and 937L) and post-contingency stability concerns (SVC).

Table 10. Maximum Export Limits

System Condition	Maximum Export Limit (MW)
System Normal	800
1201L Out of Service	115
SVC Out of Service	465
936L or 937L Out of Service	465
928L or 906L Out of Service	800
Other 240 kV Line Out of Service	800
One Sheerness Unit Out of Service	800
Both Sheerness Units Out of Service	800
Calgary Area Cap Bank Out of Service	800

The dramatic decrease in export capability when one North-South 240 kV line is out of service is due to the fact that additional thermal constraints were found (i.e. the loss of 928 & 906L when 918L out of service). The March 2005 limits were based on the assumption that voltage stability was the limiting factor (the system has much higher voltage stability limits than thermal limits in this condition). The new method of modeling Calgary area load growth and the removal of CAG and Joffre generation from the study base cases also affect the base limits. However, the change mentioned above that recommends that export be allowed to increase above the value in the "< 6600 MW" block using the adders should mitigate this somewhat.

The studies indicated that there could be overloading of the Benalto 17S 240 kV / 138 kV transformer and on 717L between Benalto and Red Deer 63S when 900L is out of service and 928L and 906L trip. However, the overloads can be mitigated by opening 717L. The loss of 900L was analyzed but not considered when setting export limits because of this mitigating factor.

9.2 Future Considerations

The loss of the double circuit 914L and 910L may result in overloads on 874L (East Edmonton – Bretonal - Cooking Lake – Bardo), and/or 780L from East Edmonton to Nisku, and/or 80L (Red Deer – South Red Deer – North Red Deer), depending on which segment of 914L trips. This contingency and the subsequent overloads were deemed to be a system issue independent of export, and therefore were not considered when determining export limits. Additional studies should be conducted in order to determine how to mitigate this contingency appropriately, including the possible addition of transmission equipment.

The loss of 933L & 931L may cause overloads on 760L and the Empress 163S 240kv/138kV transformer. There is currently a RAS in place to trip one Sheerness unit if the plant is generating more than 550 MW NTG and the two lines trip. This RAS was implemented for dynamic stability reasons; however, the trigger value of 550 MW should be lowered to 420 MW in order to prevent overloads in the Empress area during times of high southern demand, and low south Generation.

Appendix A

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

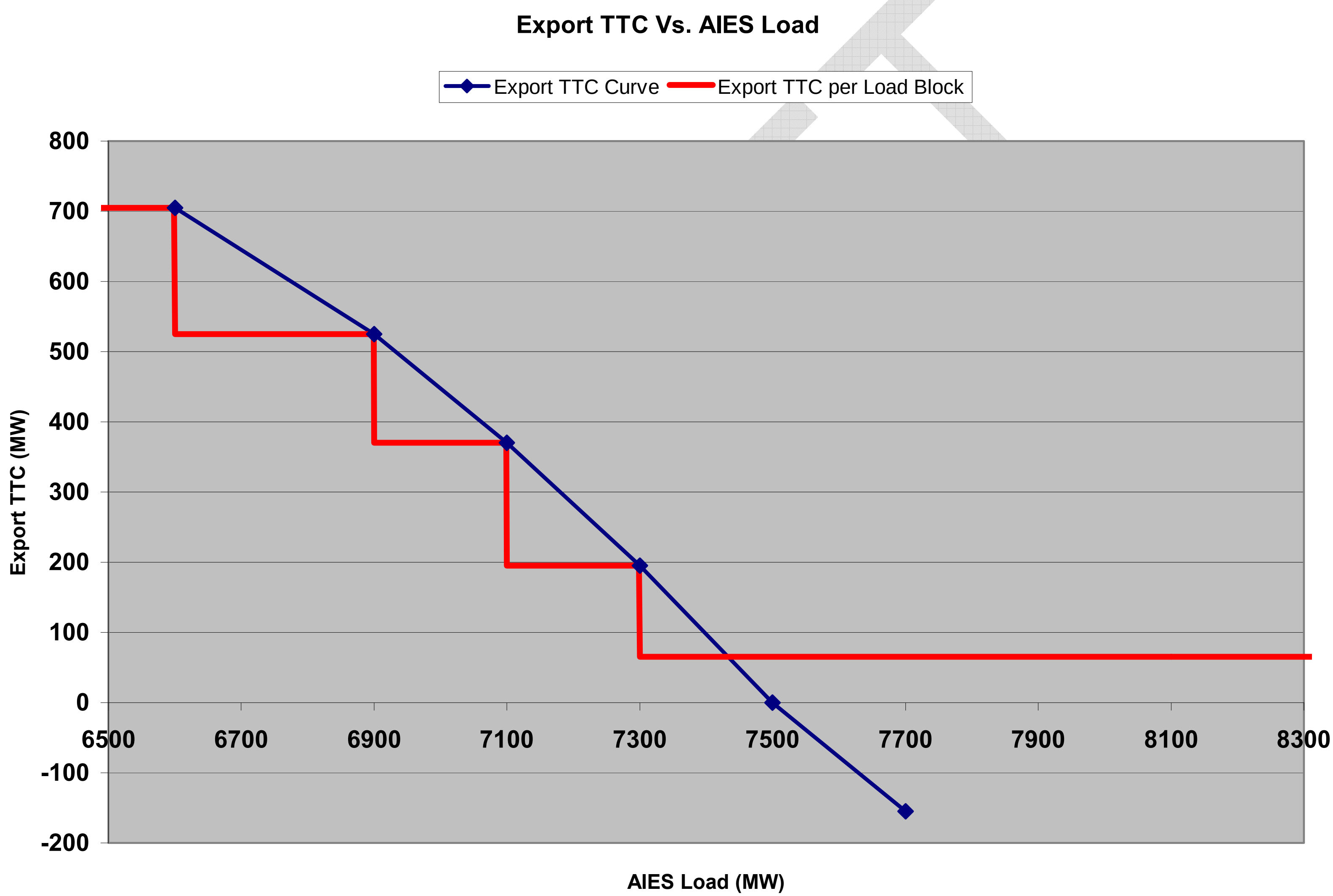


Table A1. System Normal TMR Requirements – (Table W-1 in OPP 510)

Calgary Area Load (MW)	Minimum MW Generation (MW)	Minimum Generator Reactive Reserve (MVAr)	Correlated Alberta Internal Load (MW)
1,401 to 1,450	190	125	>9,000
1,351 to 1,400	100	100	8,901 to 9,000
1,301 to 1,350	70	35	8,751 to 8,900
<1,301	0	0	<8,751

Table A2. Current Winter Export Limits (Table 4 in OPP 304)

Export TTC (winter season – from November 1 to April 30)

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	95	65	65	85	65	65	65	65	65	65	65
7700 to 7899	215	115	95	205	115	95	65	140	115	65	130
7500 to 7699	345	115	215	315	240	225	90	265	240	205	255
7300 to 7499	465	115	340	445	365	345	155	390	365	335	385
7100 to 7299	605	115	465	465	485	465	215	515	490	455	505
6900 to 7099	725	115	465	465	605	590	265	640	615	585	635
6600 to 6899	800	115	465	465	715	705	335	765	740	705	755
6300 to 6599	800	115	465	465	800	800	365	800	800	800	800
< 6300	800	115	465	465	800	800	365	800	800	800	800

Table A3. Recommended Winter Export Limits (Table 4 in OPP 304)

Export TTC (winter season – from November 1 to April 30)

All units in MW

Min Alberta Internal Load (MW)	Max Alberta Internal Load (MW)	System Normal	1201L Out of Service	SVC Out of Service	937L or 936L Out of Service	One 240 kV Backbone Line Out of Service	One Sheerness Unit Off Line	Two Sheerness Units Off Line	0 to 54 MVAR Calgary Area cap bank Unavailable	56 to 81 MVAR Calgary Area cap bank Unavailable	82 to 108 MVAR Calgary Area cap bank Unavailable
8300	9999	65	65	65	65	65	65	65	65	65	65
8100	8299	65	65	65	65	65	65	65	65	65	65
7900	8099	65	65	65	65	65	65	65	65	65	65
7700	7899	65	65	65	65	65	65	65	65	65	65
7500	7699	65	65	65	65	65	65	65	65	65	65
7300	7499	65	65	65	65	65	65	65	65	65	65
7100	7299	65	65	65	65	65	65	65	65	65	65
6900	7099	180	115	65	140	65	65	65	135	115	90
6600	6899	405	115	230	365	65	140	65	350	325	300
0	6599	605	115	335	465	65	310	65	550	525	500

Table A4. Recommended Winter Export Limit Calculation Table

Min Alberta Internal Load (MW)	Max Alberta Internal Load (MW)	System Normal	1201L Out of Service	SVC Out of Service	937L or 936L Out of Service	One 240 kV Backbone Line Out of Service	One Sheerness Unit Off Line	Two Sheerness Units Off Line	0 to 54 MVAR Calgary Area cap bank Unavailable	56 to 81 MVAR Calgary Area cap bank Unavailable	82 to 108 MVAR Calgary Area cap bank Unavailable
8300	9999	-2000	-2000	-2500	-2000	-2500	-2000	-2000	-2000	-2000	-2000
8100	8299	-825	-900	-1175	-900	-1600	-950	-1250	-875	-900	-925
7900	8099	-650	-715	-960	-700	-1400	-800	-1100	-705	-725	-750
7700	7899	-425	-500	-795	-475	-1200	-650	-975	-475	-500	-525
7500	7699	-300	-375	-600	-350	-1000	-475	-775	-355	-375	-400
7300	7499	-155	-225	-405	-200	-825	-300	-625	-210	-240	-270
7100	7299	15	-50	-190	-25	-650	-150	-475	-40	-65	-90
6900	7099	180	115	40	140	-480	0	-325	135	115	90
6600	6899	405	115	230	365	-345	140	-190	350	325	300
0	6599	605	115	335	465	-185	310	25	550	525	500