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Feasibility Study

An assessment of the westward transfer capability of various options for reinforcing the East-West Tie

1.0

A study to review the requirements for reinforcing the East-West Tie to provide a westward transfer capability of approximately 650MW

FINAL VERSION *18th August 2011*

FEASIBILITY STUDY:

TO ASSESS THE TRANSFER CAPABILITY OF VARIOUS OPTIONS FOR REINFORCING THE EAST-WEST TIE

EXECUTIVE SUMMARY

Feasibility Study: To assess the transfer capability of various options for reinforcing the East-West Tie

EXECUTIVE SUMMARY

1. Introduction

The OPA, in their report on the *Long-Term Electricity Outlook for the North-West*, has identified scope for additional load growth in the North-West and, from their assessment of the long-term supply needs for the area, *"finds that expansion of the E-W tie is the preferred alternative based on economic, flexibility, technical, operational and other considerations."*

"The OPA has assumed that the proposed expanded East-West Tie would be a new double-circuit 230kV overhead transmission line. The new line is to connect both Wawa TS and Lakehead TS.....and is to be switched at Marathon TS."

"The new line in conjunction with the existing tie is to provide total eastbound and westbound capabilities of the order of 650MW, while respecting all NERC, NPCC and IESO reliability standards."

Following the issue of FERC Order No. 743 on 18th November 2010, directing NERC to revise the definition of the Bulk Electric System (BES), it is expected that the 230kV transmission facilities west of Sudbury will be designated as BES.

This will require the East-West Tie to be designed to meet:

- the *Transmission System Planning Performance Requirements* specified in *NERC Standard TPL-001-2, &*
- the requirements for the *Design & Operation of the Bulk Power System* specified in *NPCC Directory No. 1*

This will mean that double-circuit contingencies will need to be respected at all times, rather than during high-risk periods when electrical storms are in the area, as is currently the practice.

It should be noted that although the standards specify other contingency conditions that must also be examined, including single-circuit contingencies with either a failure of their relay protection, or the failure of one of the breakers to operate, these conditions have been assumed to be less onerous for the system than double-circuit contingencies. However, to limit the adverse effects of breaker failure conditions, good station design will be critical.

Feasibility Study

This report summarises the results of analysis performed on two options for reinforcing the East-West Tie to achieve a transfer capability of approximately **650MW** westwards, measured at Wawa TS, while respecting double-circuit contingencies at all times:

Option 1 With a new 230kV double-circuit line installed between Wawa TS and Lakehead TS, as proposed by the OPA, and

Option 2 With a new 230kV high-capacity, single-circuit line installed between the same terminal stations.

East-West Tie

The present 'storm limit' on the East-West Tie, between Wawa TS and Mackenzie TS, under which double-circuit contingencies are respected, restricts transfers to approximately 175MW. As noted by the OPA in their report, should it become necessary to apply this limit at all times, it would severely affect the ability to supply the forecast load in the North-West, especially during periods of low rainfall when the output of the 780MW of hydroelectric facilities in the area would be restricted.

Sudbury Flow West Interface

The requirement to respect the loss of *'any two adjacent (vertically or horizontally) circuits on a common structure'* (NERC Standard TPL-001-2) would similarly have a significant effect on the transfer capability of the Sudbury Flow West Interface (SFW).
Following the loss of the 230kV double-circuit line between Algoma TS and Mississagi TS, all of the transfer across the SFW Interface would then appear on the 206km single-circuit 230kV line between Hanmer TS and Mississagi TS. The subsequent increase in the reactive losses would severely depress the voltages at Mississagi TS and Wawa TS; effectively limiting the maximum transfer across this Interface to approximately **350MW**.

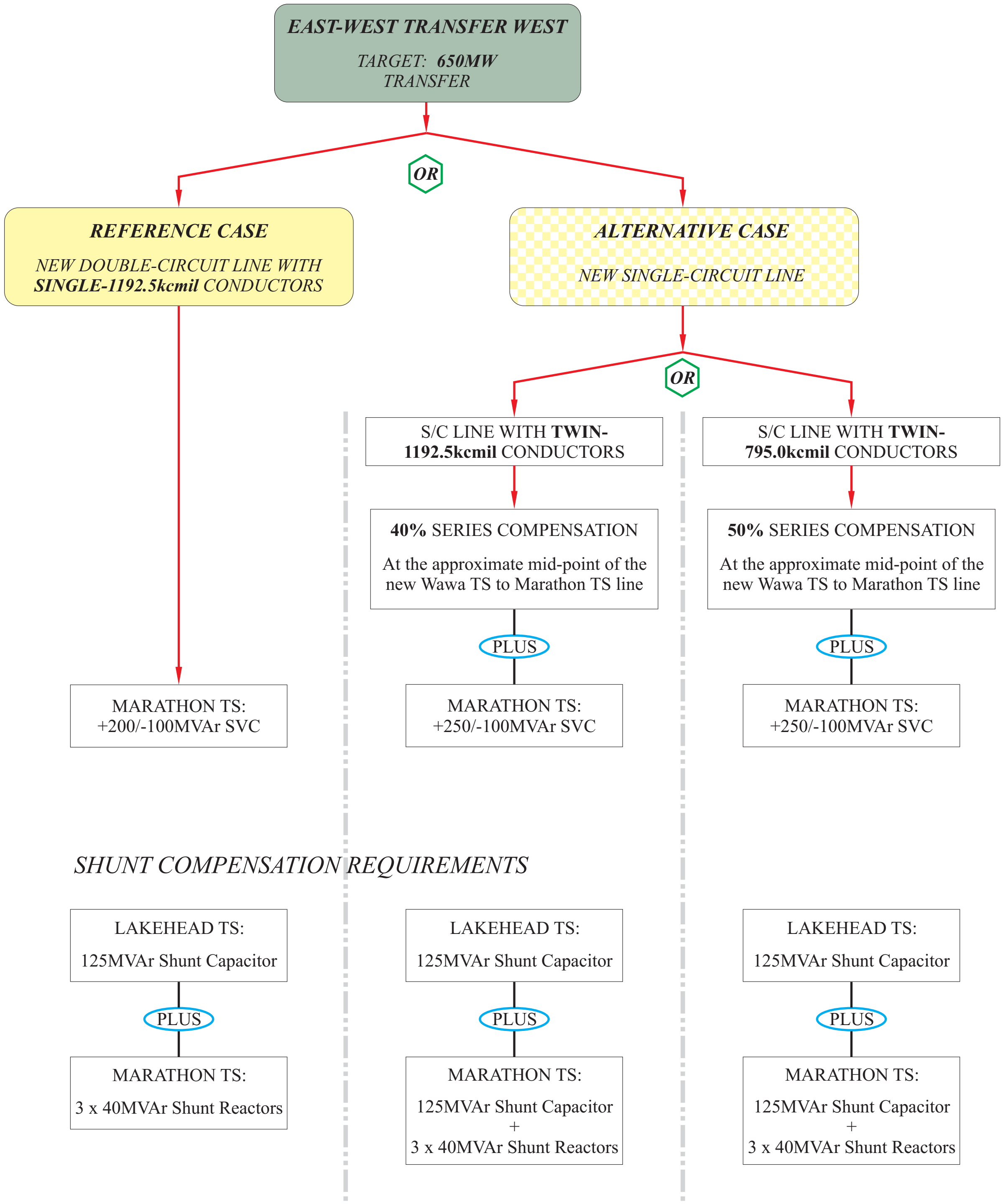
Transmission System between Mississagi TS & Wawa TS

The transmission system between Mississagi TS & Wawa TS consists of the facilities shown in the following Table:

Hydro One			*Circuits*	*Generation Connected*
Mississagi TS	to Wawa TS	230kV double-circuit line:	P25W & P26W	Aubrey Falls G1 & G2
Great Lakes Power				
Mississagi TS	to Third Line TS	Two 230kV circuits that occupy common structures for 11 spans	P21G & P22G	Wells G1 & G2
Third Line TS	to MacKay TS	230kV single-circuit line	K24G	-
MacKay TS	to Wawa TS	230kV single-circuit line	W23K	-

With the East-West Tie reinforced with a new double-circuit line between Wawa TS and Lakehead TS, double-circuit contingencies involving either the existing Hydro One owned line between Mississagi TS and Wawa TS, or the GLP owned line between Mississagi TS and Third Line, would restrict westward transfers across the East-West Tie Interface to a maximum of approximately **500MW**.

In their assessment, the OPA has identified a maximum transfer requirement across the East-West Tie of approximately *400MW* during the initial period of operation following its reinforcement. The 500MW E-W Tie Transfer West limit, for contingencies on that portion of the system between Mississagi TS and Wawa TS, would therefore be more than adequate for the expected transfers during this period.



SUMMARY OF THE REINFORCEMENT OPTIONS ***FIGURE 1***

SVC Static VAr Compensator

Reference Case for the Feasibility Study

The *Reference Case* that was used for this study assumed the construction of a new 230kV double-circuit line between Wawa TS and Lakehead TS, as proposed by the OPA, with intermediate terminations into Marathon TS. To minimise transmission losses, the new line was assumed to be equipped with single-1192.5kcmil conductors.

The following interface transfers were also assumed for the *Reference Case*, and these were achieved through adjustments to the load and generation patterns that were modelled:

- approximately **650MW** westwards, across the East-West Tie Interface, and
- approximately **350MW** across the Sudbury Flow West Interface

This report summarises the results of the analysis performed on the *Reference Case* and it also provides an assessment of an *Alternative Case* for reinforcing the East-West Tie based on the construction of a high-capacity, single-circuit 230kV line.

2. Conclusions

Figure 1 provides a summary of those facilities, identified through the analysis, which would be required to achieve the target transfer of **650MW** westwards across the East-West Tie, measured at Wawa TS, for both the *Reference Case* and the *Alternative Case,* with a coincident transfer of **350MW** across the Sudbury Flow West Interface.

2.1 Requirements for the Reference Case: With reinforcement consisting of a new 230kV double-circuit line equipped with single-1192.5kcmil conductors

For the *Reference Case*, an additional shunt capacitor bank with a nominal rating of 125MVAr (at 250kV) would be required at Lakehead TS to limit the pre-contingency reactive output from the two SVCs (Static VAr Compensators) at Lakehead TS.

Following a double-circuit contingency involving the new 230kV double-circuit line between Wawa TS and Marathon TS, all of the transfer on the East-West Tie would appear on the existing double-circuit line. To supply the immediate increase in the post-contingency reactive losses, a fast-acting source of reactive compensation would be required at Marathon TS. Further dynamic reactive compensation would also be needed to ensure that the IESO's criterion for voltage stability could be satisfied. This criterion requires the planned post-contingency transfer across the critical transmission Interface to have a margin of at least 5% from the transfer at which voltage instability is detected.

To supply both the increased post-contingency reactive losses and achieve a voltage stability limit that could accommodate a transfer of 650MW westwards across the East-West Tie, an SVC, or an equivalent source of dynamic reactive compensation, with a rating of **200MVAr,** would be required at Marathon TS.

The analysis also showed that the installation of the 200MVAr SVC, or its equivalent, at Marathon TS would be sufficient to respond to contingencies involving the new double-circuit line on the adjacent section of the East-West Tie between Marathon TS and Lakehead TS.

115kV Circuits T1M, A1B & A5A between Marathon TS and Alexander TS

Following a double-circuit contingency involving either the existing 230kV line between Marathon TS and Lakehead TS or the proposed new line, overloading of the parallel 115kV single-circuit connection between Marathon TS and Alexander TS would occur. To accommodate these increased transfers, the maximum continuous operating temperature for circuits T1M, A1B & A5A, that together form the parallel connection, would need to be increased to at least 93^{o}C to provide a continuous rating of approximately 620A.

Double-circuit Contingencies involving the section of the EW Tie between Lakehead TS & Mackenzie TS

To avoid overloading circuit B6M, which provides a parallel 115kV connection from Birch TS to Moose Lake TS, it was assumed that this circuit would be cross-tripped immediately following a double-circuit contingency involving circuits A21L & A22L between Lakehead TS and Mackenzie TS.

With the 230kV circuits A21L & A22L out-of-service, and with the 115kV circuit B6M cross-tripped, all of the load to the west of Mackenzie TS would then be isolated on to the Manitoba and Minnesota Interconnections.

To accommodate the immediate post-contingency reductions in both the transfers on the East-West Tie and in the associated reactive losses, while also maintaining voltages within acceptable limits, a reactive absorption capability of at least 100MVAr would be required at Marathon TS. This would be in addition to the absorption capability already assumed to be available from the two SVCs at Lakehead TS.

Reactive Compensation requirement for the lightly-loaded case

To maintain the pre-contingency voltages within the 250kV threshold and to limit the 'continuous' reactive absorption by the SVC at Marathon TS to a maximum of approximately 50MVAr , three 40MVAr shunt reactors would need to be installed at Marathon TS to augment the absorption capabilities of the SVCs at Lakehead TS and Marathon TS:

- Lakehead TS — a total of -80MVAr from both the existing SVC and the SVC that has been proposed to replace the existing synchronous condenser
- Marathon TS — -100MVAr as proposed to limit the post-contingency 'transient' voltages following the separation of the system west of Mackenzie TS in response to a contingency involving the 230kV line between Lakehead TS and Mackenzie TS

Restricting the maximum 'continuous' absorption by the SVC at Marathon TS to around 50MVAr was found necessary to ensure that the local voltages could be maintained below the 250kV threshold in the event of a contingency involving the SVC.

2.2 Requirements for the Alternative Case: With reinforcement consisting of a new 230kV single-circuit line

For the *Alternative Case*, the higher impedance of the new 230kV single-circuit line would result in an unbalanced flow distribution between the two lines, resulting in increased reactive losses. To compensate for these increased pre-contingency losses, a 125MVAr capacitor bank would be required at both Lakehead TS and Marathon TS.

For this Case, the loss of the existing double-circuit line would represent the more-critical contingency since all of the post-contingency transfer would then appear on the new single-circuit line.

With only the single-circuit line remaining in-service post-contingency, the reactive losses would be substantially higher than those arising from the *Reference Case*. To compensate for these increased post-contingency losses, the amount of dynamic reactive compensation available at Marathon TS would also need to increase.

For the version of the *Alternative Case* with twin-1192.5kcmil conductors, 'dynamic' compensation rated at 350MVAr would be required at Marathon TS to address the immediate post-contingency reactive requirements for a transfer of 650MW westwards across the East-West Tie.

However, a 350MVAr SVC would not be sufficient to provide a voltage stability limit that would satisfy the 5% margin required under the IESO's criteria. Since the voltage decline at Wawa TS would be the critical factor, further increases in the rating of the Marathon SVC would be far less effective than installing a second SVC at Wawa TS. Rather than pursuing this, the study concentrated on the benefits of installing series compensation on the new line.

Series Compensation on the new single-circuit line

The analysis for the *Reference Case* showed that a 200MVAr SVC would be required at Marathon TS to support the post-contingency flows through the existing double-circuit line following a contingency involving the new double-circuit line. For the *Alternative Case*, since a contingency involving the new single-circuit line would also leave only the existing double-circuit line in-service over the faulted section, an SVC rated at 200MVAr was considered to represent the *minimum* reactive requirement for achieving a transfer capability of 650MW with the *Alternative Case*.

The effect of installing different levels of series compensation on the section of the new single-circuit line between **Wawa TS and Marathon TS**, with the object of limiting the size of the SVC that would be required at Marathon TS to approximately **200MVAr**, was examined.

With the new single-circuit line equipped with either:

- ***twin-1192.5kcmil** conductors & with **40%** series compensation installed on the Wawa to Marathon section OR*
- ***twin-795.0kcmil** conductors & with **50%** series compensation installed on the Wawa to Marathon section*

For both versions of the *Alternative Case,* a **200MVAr** SVC at Marathon TS would be sufficient to provide a voltage stability limit with the necessary 5% margin to accommodate the post-contingency transfers following the loss of the existing double-circuit line between Wawa TS and Marathon TS.

For the loss of the existing double-circuit line on the adjacent section of the East-West Tie between Marathon TS and Lakehead TS, the SVCs at Lakehead TS would reach their maximum output, leaving insufficient reactive support available to allow for margin. To ensure that the requirement for a 5% margin could be satisfied, the rating of the SVC at Marathon TS would need to be increased to **250MVAr**.

115kV Circuits T1M, A1B & A5A between Marathon TS and Alexander TS

Following a double-circuit contingency involving the existing line between Marathon TS and Lakehead TS, the higher impedance of the new high-capacity, single-circuit line that would remain in-service over this section would result in higher transfers over the parallel 115kV connection than were recorded for the *Reference Case*. To accommodate this higher flow, the maximum continuous operating temperature for the circuits T1M, A1B & A5A that form this parallel connection would need to be increased to at least 105^{o}C to provide a long-term emergency rating of approximately 690A.

Double-circuit Contingencies involving the section of the East-West Tie between Lakehead TS and Mackenzie TS

For the Alternative Case, separation of that part of the system west of Mackenzie TS on to the Manitoba and Minnesota Interconnections and the subsequent reductions in the transfers on the East-West Tie, would require not only the full reactive absorption capability of the SVCs at Marathon TS and Lakehead TS, but also the cross-tripping of the new shunt capacitor bank at Marathon TS to ensure that voltages remained below the 250kV threshold.

Relative Merits of a new High-Capacity Single-Circuit line versus a new Double-Circuit line

One-plus-One Contingency

The NERC, NPCC & IESO criteria all refer to a requirement to respect a second single-element contingency after experiencing an initial single-element contingency or outage, with control actions being taken between the two events to adjust the flows.

With the East-West Tie reinforced with a new single-circuit line, it would therefore be necessary, immediately following a contingency or outage involving this new line, to re-prepare the system for the loss of one of the circuits on the remaining double-circuit line.

Since the loss of the new single-circuit line would leave only the existing double-circuit in-service over the affected section, the transfer capability of the East-West Tie would therefore be reduced to the present limit for a *single-circuit contingency* of 350MW.
Since the targeted transfer capability of the reinforced East-West Tie is 650MW, a reduction to 350MW following the loss of the new single-circuit line would therefore require either additional generating resources totalling at least 300MW to be dispatched, or if there were the capability to arm load rejection of up to 150MW in response to the second contingency, then this would allow a corresponding lesser amount of generation to be dispatched.

Increasing the transfers via the Interconnections with Manitoba and Minnesota would also allow the amount of generation capacity that would need to be dispatched to be reduced.

All of these control actions would comply with the IESO's criteria.

Reinforcing the East-West Tie with a new double-circuit line would require no similar actions following the loss of either of the double-circuit lines (a simultaneous One-plus-One contingency) or the loss of one circuit of one of the lines followed by the loss of one of the circuits of the companion line.

For the One-plus-One contingency condition, the installation of a new double-circuit line to reinforce the East-West Tie would therefore represent the superior option.

2.3 Transmission System Losses: For the two reinforcement options

The transmission losses recorded for each of the reinforcement options that were assessed have been summarised in the following Table:

Summary of Transmission Losses on the East-West Tie								
Diagram	*East-West Transfer West*	*Marathon to Wawa Section*			*Lakehead to Marathon Section*			*Total Losses for both Sections*
			Circuit losses	*Total Losses*		*Circuit losses*	*Total Losses*	
Reference Case: With double-circuit lines equipped with single-1192.5kcmil conductors								
5.	652.0MW	New line	8.6MW	20.6MW	New line	8.4MW	19.8MW	*40.4MW*
		Existing:	12.0MW		Existing:	11.4MW		
Alternative Case with: New single-circuit lines equipped with twin-1192.5kcmil conductors								
14.	664.2MW	New line	6.0MW	23.6MW	New line	5.6MW	21.4MW	*45.0MW*
		Existing:	17.6MW		Existing:	15.8MW		
Alternative Case with: New single-circuit lines equipped with twin-1192.5kcmil conductors & with 40% series compensation of the new Wawa x Marathon line								
18.	662.0MW	New line	10.0MW	20.8MW	New line	5.7MW	21.5MW	*42.3MW*
		Existing:	10.8MW		Existing:	15.8MW		
Alternative Case with: New single-circuit lines equipped with twin-795.0kcmil conductors & with 50% series compensation of the new Wawa x Marathon line								
28.	670.6MW	New line	17.9MW	27.5MW	New line	8.4MW	24.8MW	*52.3MW*
		Existing:	9.6MW		Existing:	16.4MW		

These results show the following:

- For the Reference Case (Diagram 5), the installation of the 1192.5kcmil conductors on the new double-circuit line would reduce the losses by approximately 6.4MW. (A reduction of approximately 27%)

  [3.4MW on the Wawa to Marathon section plus 3.0MW on the Marathon to Lakehead section.]

- For the Alternative Case with no series compensation installed on the new line (Diagram 14), the unbalanced flow distribution would increase the losses on the existing line by 10.0MW (~ 43%). The results also show that because of the much lower losses on the new line there would be little benefit from equipping it with a larger conductor.

- Installing series compensation on the new line of the Alternative Case would improve the flow distribution between the two lines, reducing the losses on the existing line.

  In Diagram 18, with 40% series compensation installed on the new line equipped with 1192.5kcmil conductors, the total losses for the two lines on the *Wawa to Marathon section* would be similar to those for the Reference Case.

  In Diagram 28, with 50% series compensation installed on the new line equipped with 795.0kcmil conductors, the total losses for the two lines on the *Wawa to Marathon section* would be approximately 7MW higher than those for the Reference Case. Although the higher level of compensation would contribute to these increased losses, the primary cause would be the smaller conductor size.

Series Compensation and Conductor Size: Effect on Transmission Losses

Although the primary objective of installing series compensation on the new single-circuit line for the *Alternative Case* was to achieve a reduction in the post-contingency reactive losses on the new line and to reduce the size of the SVC required at Marathon TS, the improved flow distribution that would occur between the two lines would be an added benefit.

Since the proportion of the East-West Tie transfer that would appear on the new line will depend on the level of compensation installed, this would present an opportunity to minimise the transmission losses through the selection of an appropriate conductor size in conjunction with the preferred level of series compensation.

3. Replacement SVC at Lakehead TS: Recommendation

In this study it was assumed that the replacement SVC for the existing synchronous condenser at Lakehead TS would be rated the same as the existing SVC; namely +60/-40MVAr.

The analysis has indicated that should the East-West Tie be reinforced and its transfer capability increased, that the Lakehead area would benefit from a higher rated unit.

It is therefore recommended that when a decision is made to replace the existing synchronous condenser that consideration should be given to acquiring an SVC with rating of at least ± 100MVAr.

4. Station Layout Diagrams

A second report detailing the proposed connection arrangements for the new facilities at Mississagi TS, Wawa TS, Marathon TS and Lakehead TS, paying particular attention to reducing any adverse effects from breaker-failure conditions, will be issued by end-September 2011.

FEASIBILITY STUDY:

TO ASSESS THE TRANSFER CAPABILITY OF VARIOUS OPTIONS FOR REINFORCING THE EAST-WEST TIE

STUDY REPORT

Feasibility Study: To assess the transfer capability of various options for reinforcing the East-West Tie

STUDY REPORT

This report summarises the results of analysis performed on different options for reinforcing the East-West Tie to achieve a transfer capability of approximately **650MW** westwards, measured at Wawa TS.

5. Reinforcement Options that were examined

i. The *Reference Case*, with the East-West Tie reinforced with a new 230kV double-circuit line, equipped with 1192.5kcmil conductors, installed between Wawa TS and Lakehead TS, with terminations into Marathon TS

ii. An *Alternative Case* with the reinforcement of the East-West Tie provided through the installation of a new single-circuit 230kV line between Wawa TS and Lakehead TS, with terminations into Marathon TS.

Two options were considered for the conductors to be installed on the proposed single-circuit line:

- Twin-795.0kcmil 26/7 conductors (two conductors per phase, separated by spacers), to give thermal ratings approximately the same as those provided by the existing double-circuit line.
- Twin-1192.5kcmil 54/19 conductors to provide similar thermal ratings to those proposed for the new double-circuit line.

Each of these cases will require different amounts of post-contingency reactive support to satisfy the IESO's voltage-stability requirements. Additional studies were also conducted to identify facilities that would permit the IESO's criteria to be met while minimising or eliminating the need for additional reactive compensation.

Assumed thermal ratings for the new line

Thermal Ratings for the new line *(assumed sheltered)*			*(MVA ratings at 240kV)*			
For an ambient temperature of 30^{o}C & a wind speed of 0-4km/hr			*Continuous at 93^{o}C*		*Long-term Emergency at 127^{o}C*	
1.	*Reference Case* For each circuit of the new double-circuit line	*equipped with **single**-1192.5kcmil 54/19 conductors*	1120A	466MVA	1440A	599MVA
2.	*Alternative Case* For the new circuit of the single-circuit line	*equipped with **twin**-795.0kcmil 26/7 conductors*	1750A	727MVA	2240A	931MVA
3.		*equipped with **twin**-1192.5kcmil 54/19 conductors*	2230A	927MVA	2880A	1197MVA

6. Generation Assumptions

North-West

For this study, the output from the existing hydroelectric facilities was set at 334MW, which would represent approximately 43% of the peak output of 780MW from these facilities. This would be similar to the expected output from the hydroelectric facilities during a dry year.

A further contribution of 56MW was also assumed to be available from the existing gas-fired facilities in the area, giving a total output of **390MW** from the generation facilities in the North-West.
The Atikokan and Thunder Bay facilities were assumed to be out-of-service, and the output from the wind-turbine facilities was assumed to be zero.

North-east

The output from the hydroelectric facilities owned by Great Lakes Power (GLP), within the area between Algoma TS and Wawa TS, was set at 560MW. This would represent approximately 70% of their peak output of 804MW.

The existing thermal generation in the area was assumed to contribute a further 142MW, primarily from the Lake Superior Power and the Algoma Steel facilities.

The total generation assumed for the GLP area was therefore **702MW**. For the entire north-east, of which the GLP area is part, the total generation output was assumed to be **1372MW**.

7. Load Assumptions

For this study, a peak load of 950MW was assumed for the North-West, which would give a peak demand of approximately1040MW once the transmission losses of approximately 90MW have been factored in. This demand would therefore correspond reasonably closely with the demand forecast contained in the OPA's report of 30th June 2011 entitled:

Long Term Electricity Outlook for the Northwest and Context for the East-West Tie Expansion

The base load for the North-West that had been modelled in the load flow case used for this study totalled approximately 675MW. To achieve the required load of 950MW, 215MW of new load was added in the Thunder Bay area, with a further 60MW of new load distributed throughout the Red Lake/Crow River/Musselwhite area.

To avoid possible overloading of the existing 115kV transmission facilities from Dryden TS as a result of adding the new loads in the Red Lake/Crow River/Musselwhite area, a new 115kV connection was assumed to be available between Valora Junction and Musselwhite SS.

8. Target Transfers on the East-West Tie and on the Sudbury Flow West Interface

With the output from the local generation facilities in the North-West set at 390MW, and with the total load in this area adjusted to 950MW, then after accounting for the estimated 90MW of transmission losses on the system west of Wawa TS, this would result in the targeted transfer of approximately **650MW** being required across the East-West Tie Interface.

For the area between Algoma TS and Wawa TS, the loads included in the model totalled approximately 370MW, while the transmission losses over this part of the system were shown to total approximately 30MW.

Analysis had also shown that the existing transmission facilities between Sudbury (Hanmer TS and Martindale TS) and Mississagi TS would be capable of supporting a maximum transfer of approximately **350MW**, following a double-circuit contingency involving the existing line between Algoma TS and Mississagi TS.

With a maximum transfer of **350MW** across the Sudbury Flow West Interface and with a total demand of approximately 400MW in the area between Algoma TS and Wawa TS, the output from the generating facilities in this area, all of it owned by GLP, had to be set at approximately 700MW to achieve the targeted transfer of **650MW** across the East-West Tie**.**

9. Planning Criteria

On 18th November 2010 FERC issued Order 743 and directed NERC to revise the definition of Bulk Electric System so that the definition encompasses all Elements and Facilities necessary for the reliable operation and planning of the interconnected bulk power system.

In response, NERC initiated Project 2010-17 SDT and proposed the following continent-wide definition of the Bulk Electric System:

Bulk Electric System:

All Transmission and Generation Elements and Facilities operated at voltages of 100kV or higher necessary to support bulk power system reliability. Elements and Facilities operated at voltages of 100kV or higher, including Radial Transmission systems, may be excluded and Elements and Facilities operated at voltages less than 100kV may be included if approved through the BES definition exemption process.

Should those 230kV transmission facilities west of Sudbury be designated as part of the Bulk Electric System, then the Standards that would need to be respected would be the following:

i. NERC Standard TPL-001-2 **Transmission System Planning Performance Requirements**

[This Standard scheduled to be submitted for regulatory approval during Q3 of 2011]

Extract from Table 1. Transmission System Standards - Normal and Emergency Conditions

Category	*Initial Condition*	*Event*	*Fault Type*	*Interruption of firm transmission service allowed*	*Non-consequential load loss*
P6 Multiple Contingency (Two overlapping singles)	Loss of one of the following followed by System adjustments: 1. Transmission Circuit 2. Transformer 3. Shunt Device	Loss of one of the following: 1. Transmission Circuit 2. Transformer 3. Shunt Device	3Ø	Yes	Yes
P7 Multiple Contingency (Common Structure)	Normal System	The loss of: Any two adjacent (vertically or horizontally) circuits on a common structure	SLG	Yes	Yes

ii. ***NPCC Directory No. 1*** dated 15th December 2009, which states:

5.4 Transmission Design Criteria

The portion of the **bulk power system** in each Planning Coordinator Area and in each Transmission Planning Area shall be designed with sufficient transmission capability to serve forecasted demand under the conditions noted in Sections 5.4.1 and 5.4.2. These criteria will also apply after any critical generator, transmission circuit, transformer, series or shunt compensating device or HVdc pole has already been lost, assuming that the Planning Coordinator Area generation and **power** flows are adjusted between outages by the use of the **ten-minute reserve** and where available, phase angle regulator control and HVdc control.

5.4.1 Stability Assessment

Stability of the **bulk power system** shall be maintained during and following the most severe of the **contingencies** stated below, with due regard to **reclosing.** For each of the **contingencies** stated below that involves a fault, **stability** shall be maintained when the simulation is based on **fault clearing** initiated by the **"system A" protection group**, and also shall be maintained when the simulation is based on **fault clearing** initiated by the **"system B" protection group**.

a. A permanent three-phase fault on any generator, transmission circuit, transformer or bus section, with **normal fault clearing**.

b. Simultaneous permanent phase to ground faults on different phases of each of two adjacent transmission circuits on a multiple circuit tower, with **normal fault clearing**.

iii. The IESO's Ontario Resource and Transmission Assessment Criteria (ORTAC)

From Section 2.7.1: ***The Bulk Power System Contingency Criteria***

In accordance with *NPCC* criteria A-02, the bulk power system portion of the *IESO-controlled grid* shall be designed with sufficient transmission capability to serve forecasted loads under the conditions noted in this section. These criteria will also apply after any critical generator, transmission circuit, transformer, series or shunt compensating device or HVdc pole has already been lost, assuming that generation and power flows are adjusted between *outages* by the use of *ten-minute operating reserve* and where available, phase angle regulator control and HVdc control.

Stability of the bulk power system shall be maintained during and following the most severe of the contingencies stated below, with due regard to reclosing. The following contingencies are evaluated for the bulk power system portion of the *IESO-controlled grid*:

a. A permanent three-phase fault on any generator, transmission circuit, transformer or bus section with normal fault clearing.

b. Simultaneous permanent phase-to-ground faults on different phases of each of two adjacent circuits of a multiple circuit tower, with normal fault clearing. If multiple circuit towers are used only for station entrance and exit purposes, and if they do not exceed five towers at each station, this condition is an acceptable risk and therefore can be excluded.

The analysis covered by this report therefore concentrated on the effects of double-circuit contingencies involving the following line sections:

i.	between Algoma TS and Mississagi TS	Circuits A23P & A24P	
ii.	between Wawa TS and Marathon TS	Circuits W21M & W22M,	or the new double-circuit line
iii.	between Marathon TS and Lakehead TS	Circuits M23L & M24L,	or the new double-circuit line
iv.	between Lakehead TS and Mackenzie TS.	Circuits A21L & A22L	

Analysis also examined the effect of double-circuit contingencies involving the line section between Mississagi TS and Wawa TS (circuits P25W & P26W) and the section of circuits P21G & P22G near GLP's Third Line Substation that uses double-circuit line construction, to provide an indication of the transfer capability of this portion of the system.

Both of these contingency conditions would result in the loss of generation capacity; for a P25W + P26W contingency - the loss of both Aubrey Falls units; and for a P21G + P22G contingency - the loss of both Wells units.

From Section 4.5.1 ***Power - Voltage (P-V) Curves***

With the loads modelled as constant MVA loads, the transfer across the critical interface is to be increased in small increments (usually 1% of the interface transfer), recording the power flow and busbar voltages until the knee-point of the P-V Curve is reached or the case does not solve.

For voltage stability, the interface transfer corresponding to the knee-point when multiplied by 0.95 (representing the required 5% margin) must be greater than the interface transfer recorded in the post-contingency study.

10. Transfers to Manitoba & Minnesota

For this study, pre-contingency transfers of approximately 0MW were assumed on the Interconnections with both Manitoba and Minnesota.

Operation of the Phase-Shifters

The current modes of operation for the phase-shifters on the Manitoba and Minnesota Interconnections are described below. For the purpose of this study it has been assumed that, following the reinforcement of the East-West Tie, the present modes of operation will continue.

Phase-shifters on the Manitoba Interconnections

Once a difference of more than 25.6MW from the scheduled transfer is detected across this Interconnection, the operation of the phase-shifters is initiated. Tap-changer operation will then continue until either the difference between the actual and the scheduled transfer is reduced below the 25.6MW threshold or until four tap-changer operations have been completed. Once four tap-changer operations have occurred within a two minute period, the controller is automatically switched to the manual mode.

Phase-shifters on the Minnesota Interconnection

For transfers across this Interconnection that increase by more than 55MW in 10 seconds, the two, series-connected phase-shifters will move a combined total of four taps before automatically switching to the manual mode.

For transfers that are greater than 10MW and less than 55MW, tap-changer operation will continue until the difference between the actual and the scheduled transfer is less than 10MW.

11. Contingency Conditions Examined

Sudbury Flow West Interface

- To establish the appropriate transfer level to use for the Sudbury Flow West Interface:

  A double-circuit contingency involving circuits A23P & A24P between Algoma TS and Mississagi TS

  This contingency would leave only circuit X74P between Hanmer TS and Mississagi TS to supply all of the system west of Mississagi TS

East West Tie Interface

- *For the Wawa - Marathon Section*

  i. For the *Reference Case* with a new double-circuit 230kV line, equipped with 1192.5kcmil conductors, installed between Wawa TS & Marathon TS

     A double-circuit contingency involving the *new* line would leave the existing line, with its lower-rated 795kcmil conductors, to carry the entire transfer on the East-West Tie.

  ii. For the *Alternative Case* with a new single-circuit 230kV line installed between Wawa TS & Marathon TS

     A double-circuit contingency involving the *existing* line would leave the new single-circuit line to carry the entire transfer on the East-West Tie.

- *For the Marathon - Lakehead Section*

  Depending on whether the reinforcement of the East-West Tie were to consist of either a new single- or a double-circuit line, the same contingency conditions that were identified for the previous section would also apply to this section.

  It should also be noted that for this section, there is a parallel, single-circuit 115kV connection, formed by circuits T1M, A1B & A5A between Marathon TS & Alexander TS. Since a portion of the post-contingency transfer would appear on this line, it could result in overloading.

- *For the Lakehead - Mackenzie Section*

  Since there are no plans to reinforce this section, a double-circuit contingency involving circuits A21L & A22L would require that the parallel 115kV circuit B6M be cross-tripped to avoid it being overloaded. Alternatively, this circuit could be operated normally-open.

  The net result of this contingency would be the separation of the system, with that part of the system west of Mackenzie TS remaining connected to the Manitoba & Minnesota systems via their respective Interconnections.

  Separation of this area from the East-West Tie and the transfer of its supply on to the Manitoba & Minnesota systems would therefore unload the connections between Hanmer TS and Lakehead TS, resulting in increased voltages.

12. *Study Results*

- For each of the reinforcement options, pre-contingency load-flows were performed and the results summarised in load-flow diagrams.

- For each contingency condition, two individual load-flows were performed for the following conditions and the results also summarised in separate load-flow diagrams:

  i. for the situation *prior to* the adjustment of the phase-shifters on the Manitoba & Minnesota Interconnects, and

  ii. for the situation *after* the phase-shifters had been adjusted.

  PV-analysis (Power versus Voltage) was then performed on the post-contingency case *after* the phase-shifter adjustments had been completed. The intent of this analysis was to confirm that the reactive resources available would be sufficient to provide the 5% margin on the critical transfer as required by the IESO's criteria.

Comments have only been provided on a selection of these studies.

However, the following commentary, for the initial study on the Reference Case, has been prepared to assist in the interpretation of these results.

12.1 Reference Case Commentary

With a new double-circuit 230kV line equipped with single-1192.5kcmil conductors

Diagram 5: Pre-contingency Load-Flow

For this case, the principal transfers and outputs from the SVCs were as follows:

Sudbury Flow West		353.1MW
East-West Transfer West		652.0MW
Manitoba Transfer	(positive into Ontario)	3.4MW
Minnesota Transfer	(positive into Ontario)	2.2MW
Marathon SVC	+ 200/- 100MVAr	13.6MVAr
Lakehead SVCs	+ 120/- 80MVAr	-53.4MVAr
NW Transmission Losses		83MW
NE Transmission Losses		70MW

Diagram 6: Post-contingency Load-Flow *prior to* the adjustment of the Manitoba & Minnesota phase-shifters
For a double-circuit contingency involving the Wawa to Marathon section of the new line

Sudbury Flow West		321.1MW	Δ	- 32.0MW	*Change compared to Diagram 5*
East-West Transfer West		622.8MW	Δ	- 29.2MW	
Manitoba Transfer	(positive into Ontario)	31.8MW	Δ	+ 28.4MW	
Minnesota Transfer	(positive into Ontario)	20.6MW	Δ	+ 18.4MW	
Marathon SVC	+ 200/- 100MVAr	152.5MVAr	Δ	+ 138.9MVAr	
Lakehead SVCs	+ 120/- 80MVAr	-61.4MVAr	Δ	- 8.0MVAr	
NW Transmission Losses		109MW	Δ	+ 26MW	
NE Transmission Losses		58MW	Δ	- 12MW	

Following the contingency, the transfers on the SFW & EW Tie-W Interfaces were reduced by 32MW and 29MW, respectively while the combined import via the Interconnections to Manitoba and Minnesota increased by approximately 47MW. The difference is due primarily to the increased losses on the system in the North-West

In response to the increased reactive losses on the existing line following the loss of the new line between Wawa TS and Marathon TS, the output from the SVC at Marathon is shown to increase by 139MVAr.

Diagram 7: Post-contingency Load-Flow *after* the adjustment of the Manitoba & Minnesota phase-shifters
For a double-circuit contingency involving the Wawa to Marathon section of the new line

Sudbury Flow West		373.0MW	Δ	+ 19.9MW	*Change compared to Diagram 5*
East-West Transfer West		668.6MW	Δ	+ 16.6MW	
Manitoba Transfer	(positive into Ontario)	18.0MW	Δ	+ 14.6MW	
Minnesota Transfer	(positive into Ontario)	2.5MW	Δ	+ 0.3MW	
Marathon SVC	+ 200/- 100MVAr	200.0MVAr	Δ	+ 186.4MVAr	
Lakehead SVCs	+ 120/- 80MVAr	-31.2MVAr	Δ	+ 22.2MVAr	
NW Transmission Losses		123MW	Δ	+ 40MW	
NE Transmission Losses		66MW	Δ	- 4MW	

Following the adjustment of the phase-shifters, the combined transfer from Manitoba and Minnesota would be reduced to 15MW, resulting in increased transfers over the SFW and E-W Tie-W Interfaces to supply the increased transmission losses in the North-West.

The increased transfer across the East-West Tie is shown to result in a further increase in the reactive losses on the remaining two circuits between Wawa TS and Marathon TS, causing the output of SVC at Marathon TS to reach its maximum of 200MVAr.

The combined reactive output from the two Wells units is shown as 19.5MVAr (leaving approximately 84MVAr of their capability remaining) while the combined reactive output from the two Aubrey Falls units is 20.6MVAr (leaving 45MVAr available).

Diagram 8: Results from the PV-analysis on the post-contingency case *after* phase-shifter action

A contingency involving the new double-circuit line between Wawa TS and Marathon TS would have a direct effect on the ability to transfer power westwards across the East-West Tie Interface. This study therefore examined the effect on the busbar voltages in the immediate area of increasing the transfers across this Interface. The purpose of this analysis was to confirm that adequate reactive resources would be available to provide a margin of at least 5% on the transfer that was recorded across the East-West Tie Interface in the post-contingency study.

From **Diagram 7**, the post-contingency transfer across the EW-W Interface was **668.6MW**.

The PV-analysis plots in **Diagram 8** start at this transfer level and show the effect of increasing the flow across the EW-W Interface until the load-flow fails to converge. This is shown to occur at an EW-W Transfer of **722MW**, when the voltages at Wawa TS and Marathon TS experienced excessive declines.

The final plot on **Diagram 8** shows the reactive capability remaining available from the monitored resources.

Since the SVC at Marathon TS was shown to have reached its maximum output of 200MVAr in **Diagram 7** it would no longer be able to contribute reactive support. Although the units at Wells GS are shown to provide some reactive support in response to the declining voltage at Mississagi TS, the decline at that location is not sufficient for these units to reach their maximum output. Similarly, for the units at Aubrey Falls GS. However, the greatest reactive contribution is shown to be provided by the SVCs at Lakehead TS and, from the upper plot on **Diagram 8**, they are shown to be successful in maintaining the voltage on the 230kV busbar at Lakehead TS at its set point of 243kV while they still have reactive capacity available.

Once the two SVCs at Lakehead reach their maximum combined output of 120MVAr, the load-flow fails to converge (since the output from these SVCs is shown as - 31.2MVAr in **Diagram 7**, they would therefore have 151.2MVAr remaining available for voltage support at the start of the PV-analysis.)

When the SVCs at Lakehead TS are no longer capable of maintaining the voltage at that busbar at its set point, the voltages at Wawa TS and Marathon TS will collapse, resulting in the load-flow failing to converge.

Applying a 5% margin on the limiting transfer of *722MW* at which the PV-analysis terminated would give a *voltage stability limit* of **686MW**. Since this would exceed the post-contingency transfer of 668.6MW, it would satisfy the IESO's voltage stability criterion.

The installation of a 200MVAr SVC at Marathon TS would therefore be sufficient to support the post-contingency transfer across the East-West Tie Interface of 668MW, or the equivalent pre-contingency transfer of 652MW.

In practice, this 'dynamic' reactive support could be provided by fast, mechanically-switched shunt devices with individual ratings selected to ensure that the IESO's criterion that the maximum incremental voltage change in response to their switching should be no greater than 4%, is respected. [Section 4.3.2 of ORTAC]

12.2 Summary of the results from the studies on the Sudbury Flow West Interface

To establish an appropriate value for the transfer across the Sudbury Flow West Interface to be included in the load flow model used for the analysis of the options for reinforcing the East-West Tie, an initial series of studies were completed. These studies examined the transfer capability of the existing transmission facilities between Sudbury and Mississagi TS, following the loss of the double-circuit line between Algoma TS and Mississagi TS. The results have been summarised in **Table 1**.

For these studies the proposed *Reference Case* reinforcement, involving a new 230kV double-circuit line between Wawa TS and Lakehead TS, via Marathon TS, was included in the model.

To achieve the targeted transfer of 650MW across the East-West Tie, a shunt capacitor rated at 125MVAr (at 250kV) was included at Lakehead TS on the 230kV busbar. For this analysis, no additional reactive support was included at Marathon TS.

The PV-analysis showed that with the two SVCs at Lakehead TS in-service, together with all four units at Wells GS and Aubrey Falls GS available to provide post-contingency reactive support, the voltage stability limit for the Sudbury Flow West Interface, after allowing for the required 5% margin, would be approximately 360MW.

For the transfers across Sudbury Flow West Interface, **350MW** was therefore adopted as the reference value in all of the subsequent analysis.

12.3 Summary of the results from the studies on the Reference Case

The results from the series of studies on the *Reference Case* with a new 230kV double-circuit line between Wawa TS and Lakehead TS, via Marathon TS, have been summarised in **Table 2**.

For contingencies involving the new double-circuit line between Wawa TS and Marathon TS, the PV-analysis shows that an SVC at Marathon TS with a rating of + 200MVAr would provide voltage stability limit that would be more than adequate to accommodate the targeted transfer of 650MW westwards across the East-West Tie.

However, for contingencies involving the new double-circuit line between Marathon TS and Lakehead TS, a 200MVAr SVC at Marathon would result in a voltage stability limit that would be marginally lower than the post-contingency transfer. This would mean that either a higher rated SVC would need to be installed at Marathon TS or that the replacement SVC for the existing synchronous condenser at Lakehead TS should have a higher rating than the +60/-40MVAr rating of the existing SVC.

For contingencies involving the existing double-circuit line between Lakehead TS and Mackenzie TS, that would require cross-tripping of the parallel 115kV circuit B6M and result in the separation of the system west of Mackenzie TS, the SVC at Marathon TS would need to have a reactive absorption capability of at least 100MVAr to ensure that voltages remain within the 250kV threshold.

In all of these studies the post-contingency flows on the remaining circuits were within their respective long-term emergency ratings except for those on the 115kV circuit T1M, between Marathon TS and Terrace Bay TS. Since the maximum conductor operating temperature of this circuit is only 70^{o}C, its rating is limited to just 96MVA. In **Diagram 8**, the post-contingency flow on this circuit is shown to be approximately 93MVA, but once the phase-shifters are adjusted this would increase to approximately 100MVA, as shown in **Diagram 9**.

TABLE 1:	***SFW Transfer***		***Study Results for the Reference Case*** ***With a new double-circuit line**, equipped with single-1192.5kcmil conductors*		
Diag.	*E-W Tie Transfer Westwards:* **650MW** *Sudbury Flow West (SFW) Transfer:* **350MW**			*EW Transfer W*	*SFW Transfer*
1.	Pre-contingency		*With a new 230kV double-circuit line between Wawa TS and Lakehead TS*	651MW	353MW
2.	D/C Contingency: Algoma x Mississagi circuits	No PS action	Manitoba: 38MW Minnesota: 25MW Lakehead SVCs: -80MVAr	580MW	273MW
3.		With PS action	Manitoba: 33MW Minnesota 2MW Lakehead SVCs: -45MVAr	615MW	312MW
4.		PV-analysis:	*Voltage Stability Limit for SFW Transfers:* *361MW*		

TABLE 2:	***EW Tie Transfer West***		***Study Results for the Reference Case*** ***With a new double-circuit line**, equipped with single-1192.5kcmil conductors*	
Diag.	*E-W Tie Transfer Westwards:* **650MW** *Sudbury Flow West (SFW) Transfer:* **350MW**			*EW Transfer W*
5.	Pre-contingency		*With a +200/-100MVAr SVC at Marathon TS*	652MW
6.	D/C Contingency: New Wawa x Marathon circuits	No PS action	Manitoba: 32MW Minnesota: 21MW Marathon SVC: 153MVAr Lakehead SVCs: -61MVAr	623MW
7.		With PS action	Manitoba: 18MW Minnesota: 3MW Mississagi SVC: **200MVAr** Marathon SVC: -31MVAr	669MW
8.		PV-analysis:	*Voltage Stability Limit for EW Tie-W Transfers:* *686MW*	
9.	D/C Contingency: New Marathon x Lakehead circuits	No PS action	Manitoba: 31MW Minnesota: 21MW Marathon SVC: 89MVAr Lakehead SVCs: 77MVA	624MW
10.		With PS action	Manitoba: 15MW Minnesota: 2MW Marathon SVC: 143MVAr Lakehead SVCs: 116MVAr	**673MW**
11.		PV-analysis:	*Voltage Stability Limit for EW Tie-W Transfers:* ***671MW***	
12.	D/C Contingency: Mackenzie x Lakehead circuits	No PS action	Manitoba: 119MW Minnesota: 75MW Marathon SVC: -100MVAr Lakehead SVCs: -69MVA	434MW
13.		With PS action	Manitoba: 130MW Minnesota: 64MW Marathon SVC: -100MVAr Lakehead SVCs: -69MVA	434MW

Notes on the Tables

PS	Phase-Shifters on the Interconnections to Manitoba and Michigan
PV-analysis	Power versus Voltage studies to confirm that the required 5% margin can be achieved on the post-contingency case
D/C Contingency	Double-circuit contingency involving adjacent circuits on a common line structure
S/C Contingency	Single-circuit contingency

As part of the project to reinforce the East-West Tie it is therefore recommended that the maximum operating temperature of circuits T1M, A1B & A5A that form the connection between Marathon TS and Alexandra SS be increased to at least 93^{O}C. This would provide a continuous rating for this connection of approximately 130MVA.

12.4 Summary of the results from the studies on the Alternative Case

The results from the series of studies on the *Alternative Case* with a new 230kV single-circuit line between Wawa TS and Lakehead TS, via Marathon TS, have been summarised in **Table 3**.

Following a double-circuit contingency involving the existing East-West Tie line, the higher reactance of the remaining single-circuit line would result in substantially higher reactive losses than would occur for the *Reference Case* that would leave a double-circuit line in-service. This would require greater amounts of reactive compensation to be installed to maintain an acceptable post-contingency voltage performance.

With the East-West Tie reinforced with a new single-circuit line equipped with twin-1192.5kcmil conductors, a 125MVAr (at 250kV) shunt capacitor would need to be installed at Marathon TS, in addition to a similarly rated bank at Lakehead TS, to compensate for the increased reactive losses.

The PV-analysis on the post-contingency case for the loss of the existing double-circuit line between Wawa TS and Marathon TS showed that an SVC at Marathon TS, rated at 350MVAr would be insufficient to achieve a voltage stability limit that would be high enough to accommodate the post-contingency transfer.

Series Compensation

Although the size of the SVC at Marathon TS could be increased, or a second SVC installed at Wawa TS to achieve the required voltage stability limit, this would not address the cause of the high reactive losses which arise as a result of the higher reactance of the single-circuit line.

Installing series compensation on the new line to reduce its effective reactance would reduce the reactive losses and hence the requirement for additional reactive compensation at Marathon TS.

Alternative Case with twin-1192.5kcmil conductors

The results from the studies for the *Alternative Case* with a new single-circuit line equipped with twin-1192.5kcmil conductors and with **40%** series compensation installed on the **Wawa TS to Marathon TS** section are summarised in **Diagrams 18 to 27** inclusive.

These show that, with 40% series compensation installed on the Wawa TS to Marathon TS section of the new line:

- for the loss of the existing double-circuit line between Wawa TS and Marathon TS, a 200MVAr SVC at Marathon TS, would be sufficient to provide a post-contingency voltage stability limit that would satisfy the IESO's criteria.

- for the loss of the existing double-circuit line between Marathon TS and Lakehead TS, the size of the SVC at Marathon TS would need to be increased to 250MVAr, to provide a post-contingency voltage stability limit that would satisfy the IESO's criteria.

TABLE 3: EW Tie Transfer West	Study Results for the Alternative Case — With a new single-circuit, high-capacity line			
Diag.	E-W Tie Transfer Westwards: **650MW** Sudbury Flow West (SFW) Transfer: **350MW**			
With a new single-circuit line, equipped with twin-1192.5kcmil conductors				*EW Transfer W*
14.	Pre-contingency		*With a **350MVAr** SVC at Marathon TS*	664MW
15.	D/C Contingency: Existing Wawa x Marathon circuits	No PS action	Manitoba: 45MW Minnesota: 28MW Marathon SVC: 128MVAr Lakehead SVCs: -60MVAr	589MW
16.		With PS action	Manitoba: 40MW Minnesota: 0MW Marathon SVC: 233MVAr Lakehead SVCs: -42MVAr	**636MW**
17.		PV-analysis:	*Voltage Stability Limit for EW Tie-W Transfers with a 350MVAr SVC at Marathon TS:* ***630MW***	
18.	Pre-contingency		*With a **200MVAr** SVC at Marathon TS & **40% series compensation** on the new Wawa x Marathon line*	662MW
19.	D/C Contingency: Existing Wawa x Marathon circuits	No PS action	Manitoba: 22MW Minnesota: 14MW Marathon SVC: 68MVAr Lakehead SVCs: -38MVAr	632MW
20.		With PS action	Manitoba: 2MW Minnesota: 1MW Marathon SVC: 123MVAr Lakehead SVCs: -16MVAr	676MW
21.		PV-analysis:	*Voltage Stability Limit for EW Tie-W Transfers:* *716MW*	
22.	D/C Contingency: Existing Marathon x Lakehead circuits	No PS action	Manitoba: 38MW Minnesota: 25MW Marathon SVC: 63MVAr Lakehead SVCs: 96MVAr	607MW
23.		With PS action	Manitoba: 27MW Minnesota: 0MW Marathon SVC: 142MVAr Lakehead SVCs: 120MVAr	**657MW**
24.		PV-analysis:	*Voltage Stability Limit for EW Tie-W Transfers with a 200MVAr SVC at Marathon TS:* ***646MW***	
25.		PV-analysis:	*Voltage Stability Limit for EW Tie-W Transfers with a **250MVAr** SVC at Marathon TS:* ***662MW***	
26.	D/C Contingency: Mackenzie x Lakehead circuits.	No PS action	Manitoba: 120MW Minnesota: 75MW Marathon SVC: -95MVAr Lakehead SVCs: -28MVA	433MW
27.		With PS action	Manitoba: 131MW Minnesota: 64MW Marathon SVC: -95MVAr Lakehead SVCs: -28MVA	433MW
With a new single-circuit line, equipped with twin-795.0kcmil conductors				*EW Transfer W*
28.	Pre-contingency		*With a **200MVAr** SVC at Marathon TS & **50% series compensation** on the new Wawa x Marathon line*	671MW
29.	D/C Contingency: Existing Wawa x Marathon circuits	No PS action	Manitoba: 22MW Minnesota: 15MW Marathon SVC: 93MVAr Lakehead SVCs: -26MVAr	656MW
30.		With PS action	Manitoba: 4MW Minnesota: 3MW Marathon SVC: 146MVAr Lakehead SVCs: -3MVAr	700MW
31.		PV-analysis:	*Voltage Stability Limit for EW Tie-W Transfers:* *735MW*	
32.	D/C Contingency: Existing Marathon x Lakehead circuits	No PS action	Manitoba: 45MW Minnesota: 29MW Marathon SVC: 70MVAr Lakehead SVCs: 120MVAr	616MW
33.		With PS action	Manitoba: 40MW Minnesota: 1MW Marathon SVC: 164MVAr Lakehead SVCs: 120MVAr	**667MW**
34.		PV-analysis:	*Voltage Stability Limit for EW Tie-W Transfers with a 200MVAr SVC at Marathon TS:* ***649MW***	
35.		PV-analysis:	*Voltage Stability Limit for EW Tie-W Transfers with a **250MVAr** SVC at Marathon TS:* ***665MW***	

Alternatively, as indicated by the bottom plot on **Diagram 25**, where the SVCs at Lakehead are shown to have exhausted their reactive capability before the transfer margin is applied, the availability of *additional* reactive capability at Lakehead TS would avoid the need to increase the rating of the SVC at Marathon TS to 250MVAr to achieve the required voltage stability limit.

- for the loss of the existing double-circuit line between Mackenzie TS and Lakehead TS which would unload the East-West Tie following the isolation of the loads west of Mackenzie TS on to the Manitoba and Minnesota Interconnections, the new 125MVAr shunt capacitor bank at Marathon TS would need to be cross-tripped. This would be in addition to having a 100MVAr absorption capability from the SVC at Marathon TS to ensure that the post-contingency voltages are maintained below the 250kV threshold.

Alternative Case with twin-795.0kcmil conductors

The results from the studies for the *Alternative Case,* with a new single-circuit line equipped with twin-795.0kcmil conductors and with the level of series compensation installed on the **Wawa TS to Marathon TS** section increased to **50%**, are summarised in **Diagrams 28 to 35** inclusive.

These show that with the new line equipped with the smaller conductors but with the level of series compensation on the Wawa TS to Marathon TS section increased to **50%,** there would be no change in the rating required for the SVC at Marathon TS for the following double-circuit contingencies:

- for a contingency involving circuits W21M & W22M, from Wawa to Marathon: an SVC rated at **200MVAr**
- for a contingency involving circuits M21L & M22L, from Marathon to Lakehead: an SVC rated at **250MVAr**

As before, the analysis indicates that if the reactive capability of the SVCs at Lakehead TS were to be increased (by installing a higher rated SVC to replace the existing synchronous condenser) it would result in a lower rated SVC being required at Marathon TS to respond to contingencies involving the existing line between Marathon TS and Lakehead TS.

12.5 115kV Circuits T1M, A1B and A5A

In **Diagram 33**, in which the results for a contingency involving the existing double-circuit line between Marathon TS and Lakehead TS have been summarised, a post-contingency flow of 136MW is shown on circuit T1M. This would require the maximum conductor operating temperature of this circuit, as well as that for circuits A1B & A5A, to be increased from their present values (70^{o}C for T1M; 84^{o}C for A5A; and 66^{o}C for A5A) to at least 105^{o}C to provide a long-term emergency rating that could accommodate this transfer.

Should a new single-circuit line be installed to reinforce the East-West Tie, then it is recommended that the maximum operating temperature of circuits T1M, A1B & A5A that form the connection between Marathon TS and Alexandra SS be increased to at least 105^{o}C. This would provide a long-term emergency rating for this connection of approximately 144MVA.

13. Transmission Losses

Table 4 summarises the losses on the principal 230kV circuits for the various transmission reinforcement options that were assessed.

TABLE 4	***Summary of Transmission Losses on the East-West Tie***							
	East-West Transfer West	*Marathon to Wawa Section*			*Lakehead to Marathon Section*			*Total Losses for both Sections*
			Circuit Losses	*Total Losses*		*Circuit Losses*	*Total Losses*	
Reference Case: With double-circuit lines equipped with single-1192.5kcmil conductors								
Diagram 5.	652.0MW	New line	8.6MW	20.6MW	New line	8.4MW	19.8MW	40.4MW
		Existing: W21M & W22M	12.0MW		Existing: M23L & M24L	11.4MW		
Case with: New single-circuit lines equipped with twin-1192.5kcmil conductors								
Diagram 14.	664.2MW	New line	6.0MW	23.6MW	New line	5.6MW	21.4MW	45.0MW
		Existing: W21M & W22M	17.6MW		Existing: M23L & M24L	15.8MW		
*Case with: New single-circuit lines equipped with twin-1192.5kcmil conductors with **40%** series compensation of the new Wawa to Marathon line*								
Diagram 18.	662.0MW	New line	10.0MW	20.8MW	New line	5.7MW	21.5MW	42.3MW
		Existing: W21M & W22M	10.8MW		Existing: M23L & M24L	15.8MW		
*Case with: New single-circuit lines equipped with twin-795.0kcmil conductors with **50%** series compensation of the new Wawa to Marathon line*								
Diagram 28.	670.6MW	New line	17.9MW	27.5MW	New line	8.4MW	24.8MW	52.3MW
		Existing: W21M & W22M	9.6MW		Existing: M23L & M24L	16.4MW		

Table 5 shows the corresponding flow distribution between the new and the existing circuits for each of the transmission reinforcement options.

TABLE 5	***Flow Distribution for each of the Transmission Reinforcement Options***			*Combined Flows*	
				Wawa x Marathon Section	Marathon x Lakehead Section
Reinforcement Option					
Reference Case	New double-circuit line with single-1192.5kcmil conductors	Diagram 5	New	325MW	276MW
			Existing	327MW	273MW
				Compensated Section	*Uncompensated Section*
Alternative Case	New single-circuit line with twin-1192.5kcmil conductors	Diagram 14	New	270MW *41%*	225MW *41%*
			Existing	394MW *59%*	325MW *59%*
	New single-circuit line with twin-1192.5kcmil conductors *plus* 40% series compensation on the WxM section	Diagram 18	New	353MW *53%*	226MW *41%*
			Existing	309MW *47%*	325MW *59%*
	New single-circuit line with twin-795.0kcmil conductors *plus* 50% series compensation on the WxM section	Diagram 28	New	375MW *56%*	219MW *40%*
			Existing	296MW *44%*	333MW *60%*

Table 5 shows that for the *Reference Case*, the flow distribution between the two lines is reasonably balanced even though the new line has been assumed to be equipped with larger conductors.

For the *Alternative Case* with no series compensation installed on the new single-circuit line, approximately 40% of the flow is distributed on the new line and 60% on the existing line. Although the size of the conductor installed on the new line is shown to have an effect on the flow distribution between the two lines, it is relatively small (~ 1%).

The effect that the installation of series compensation would have on the flow distribution between the two lines is summarised below:

	Effect on the flow distribution of installing Series Compensation on the new line			
Conductors on new line	Twin-1192.5kcmil Conductors		Twin-795.0kcmil Conductors	
	Uncompensated	With **40%** Series Compensation	Uncompensated	With **50%** Series Compensation
New Line	41%	53%	40%	56%
Existing Line	59%	47%	60%	44%

The transmission losses that have been summarised in **Table 4** show the following:

- For the *Reference Case* (**Diagram 5**), since the flow distribution between the new and the existing line are virtually the same, the difference in the losses of approximately 6.4MW (a reduction of approximately 27%) would represent the reduction that would result from using the larger conductor on the new line.

  [3.4MW on the Wawa to Marathon section plus 3.0MW on the Marathon to Lakehead section.]

- For the *Alternative Case* with no series compensation installed on the new line (**Diagram 14**), the unbalanced flow distribution would increase the losses on the existing line by 10.0MW (~ 43%). The results also show that because of the much lower losses on the new line there would be little benefit from equipping it with a larger conductor.
- Installing series compensation on the Wawa TS to Marathon TS section of the new line of the *Alternative Case* would increase the flow over this section of the new line, resulting in reduced losses on the existing line.

  In **Diagram 18**, for the case with the new line equipped with 1192.5kcmil conductors, installing 40% series compensation would result in combined losses for the two lines on the Wawa to Marathon section, which would be similar to those for the Reference Case.

  In **Diagram 28**, for the case with the new line equipped with 795.0kcmil conductors, increasing the level of series compensation to 50% would result in a higher proportion of the flow over the Wawa to Marathon section appearing on the new line. The combined losses on the two lines over this section are shown to be approximately 7MW higher than those for either the *Reference Case* or the version of the *Alternative Case* with the larger 1192.5kcmil conductors.

14. Reactive Compensation requirements for the lightly loaded case

To represent a typical ‘lightly loaded case’, the load in the North-West was reduced to 428MW and the generation was adjusted to 460MW. Since the transmission losses for the North-West totalled approximately 22MW, this was intended to result in a transfer across the East-West Tie Interface of approximately 0MW.

Diagrams 36 & 38 show the results of the studies with the same load and generation patterns but with the East-West Tie reinforced with a new double-circuit line and a new single-circuit line, respectively.

For both studies, the shunt compensation remained the same, with the following reactors assumed to be in-service:

- Wawa TS — Two 36MVAr tertiary-connected reactors (existing)
- Marathon TS — Two 40MVAr tertiary-connected reactors (NEW)
- Mackenzie TS — One 40MVAr tertiary-connected reactor (existing)

In addition, the following reactive absorption capabilities were assumed to be available:

- At Marathon a new 230kV-connected SVC with an absorption capability of 100MVAr
- At Lakehead TS, it was assumed that the existing synchronous condenser would be replaced with an SVC having the same +60/-40MVAr rating as the existing SVC.

For the two studies, the reactive absorption by these dynamic resources was as follows:

Reactive Absorption for the lightly-loaded case		
	Diagram 36 *With a new double-circuit line*	*Diagram 38* *With a new single-circuit line*
Marathon SVC	- 97.2MVAr	- 67.0MVAr
Lakehead SVCs (combined contribution)	- 67.0MVAr	- 60.8MVAr

TABLE 6:	**EW Tie Transfer West**	**Study Results for the light-load condition with transfers of ~ 0MW on the EW Tie**	
Diag.	*E-W Tie Transfer Westwards:* Approximately **0MW**	*Sudbury Flow West (SFW) Transfer:* Approximately **0MW**	*EW Transfer W*
With a new double-circuit line, equipped with single-1192.5kcmil conductors *With a +200/-100MVAr SVC & two 40MVAr reactors at Marathon*			
36.	Pre-contingency	*Marathon SVC: -97.2MVAr Lakehead SVCs: -76MVAr Lakehead: 242kV Marathon: 241kV Wawa: 245kV*	-6.4MW
37.	*Post-contingency: SVC tripped*	*Marathon SVC: 0MVAr Lakehead SVCs: -80MVAr Lakehead: 250kV Marathon: 255kV Wawa: 254kV*	-7.2MW
With a new single-circuit line, equipped with twin-1192.5kcmil conductors & with 40% series compensation of the Wawa to Marathon section *With a +200/-100MVAr SVC & two 40MVAr reactors at Marathon*			
38.	Pre-contingency	*Marathon SVC: -67.0MVAr Lakehead SVCs: -61MVAr Lakehead: 242kV Marathon: 241kV Wawa: 245kV*	-6.3MW
39.	*Post-contingency: SVC tripped*	*Marathon SVC: 0MVAr Lakehead SVCs: -80MVAr Lakehead: 245kV Marathon: 249kV Wawa: 250kV*	-6.6MW

TABLE 7:	**EW Tie Transfer West**		**Study Results for Contingencies on the 230kV system between Mississagi TS and Wawa TS**	
Diag.	*E-W Tie Transfer Westwards:* **500MW**		*Sudbury Flow West (SFW) Transfer:* **350MW**	*EW Transfer W*
With a new double-circuit line, equipped with single-1192.5kcmil conductor *With a +200/-100MVAr SVC & two 40MVAr reactors at Marathon*			*With a single generating unit in-service at Wells GS and Aubrey Falls GS*	
40.	Pre-contingency		*With a **200MVAr** SVC at Marathon TS & with one unit in-service at Wells GS & one at Aubrey GS*	520MW
41.	D/C Contingency: Existing Mississagi to Wawa circuits *P25W + P26W*	No PS action	Manitoba: 44MW Minnesota: 28MW Marathon SVC: -25MVAr Lakehead SVCs: -3MVAr	427MW
42.		With PS action	Manitoba: 42MW Minnesota: -3MW Marathon SVC: 16MVAr Lakehead SVCs: 9MVAr	**465MW**
43.		PV-analysis:	*Voltage Stability Limit for EW Tie-W Transfers:* ***500MW***	
44.	D/C Contingency: Existing Mississagi to Third Line circuits *P21G + P22G*	No PS action	Manitoba: 28MW Minnesota: 18MW Marathon SVC: -15MVAr Lakehead SVCs: 6MVAr	456MW
45.		With PS action	Manitoba: 22MW Minnesota: -3MW Marathon SVC: 19MVAr Lakehead SVCs: 18MVAr	***488MW***
46.		PV-analysis:	*Voltage Stability Limit for EW Tie-W Transfers:* ***562MW***	
47.	S/C Contingency: Existing Wawa to MacKay circuit *W23K*	No PS action	Manitoba: 10MW Minnesota: 7MW Marathon SVC: -14MVAr Lakehead SVCs: 19MVAr	490MW
48.		With PS action	Manitoba: -3MW Minnesota: -3MW Marathon SVC: 12MVAr Lakehead SVCs: 31MVAr	**517MW**
49.		PV-analysis:	*Voltage Stability Limit for EW Tie-W Transfers:* ***569MW***	

Studies were performed to examine the effect on the local voltages of tripping the SVC at Marathon TS at these levels of reactive absorption.

The results are summarised in **Diagrams 37 & 39** for the *Reference* and *Alternative Case*, respectively.

For the Reference Case, with the Marathon SVC absorbing 97MVAr pre-contingency, the loss of the SVC would result in voltages of 255kV at Marathon TS and 254kV at Wawa TS, which would exceed the permitted maximum of 250kV.

For the Alternative Case, with the Marathon SVC absorbing 67MVAr pre-contingency, the voltages at Wawa TS and Marathon TS would increase to 249.7kV and 249.1kV, respectively, in response to the loss of the SVC. The voltage at Marathon would therefore be only marginally within the 250kV limit.

The results from these studies, which are summarised in **Table 6,** show the following:

- A minimum of *three* new 40MVAr shunt reactors would need to be installed at Marathon TS regardless of whether the proposed reinforcement consists of a new 230kV double-circuit line or a new 230kV single-circuit line.

  Installation of the third reactor would be required to limit the reactive absorption by the SVC at Marathon TS to less than about 50MVAr so that in the event that the SVC should trip, the voltages would remain within the agreed 250kV threshold.

- Although the SVC proposed for Marathon TS would not be permitted to operate continuously at an absorption level in excess of 50MVAr because of the consequences of it tripping when loaded above this level, it would still need to have a 'dynamic' capability of at least -100MVAr.

  This requirement was identified in Section 12.3 to ensure that the post-contingency voltages would remain below the 250kV threshold following the loss of the double-circuit line between Lakehead TS and Mackenzie TS and the subsequent separation of that part of the system west of Mackenzie TS on to the Interconnections.

- The rating of the replacement SVC for the existing synchronous condenser at Lakehead TS would need to be at least the same as the existing unit so that the combined absorption capability of the two units would be at least 80MVAr to ensure that the Lakehead voltage would remain within acceptable limits.

15. Transfer Capability of the Existing Transmission Facilities between Mississagi TS and Wawa TS

Although the enhanced East-West Tie is required to have a transfer capability of at least **650MW** westwards, the OPA's assessment of the Long-Term Electricity Outlook for the North-West has identified a maximum transfer requirement during the initial period of operation of the enhanced facility, of approximately 400MW westwards.

Studies were conducted to confirm that the transfer capability of the existing transmission facilities between Mississagi TS and Wawa TS, while respecting the loss of either of the double-circuit lines in this part of the system, would be sufficient to support a transfer of at least 400MW westwards across the East-West Tie.

The results are summarised in **Table 7** and also in **Diagrams 40 to 49**, inclusive.

For these studies, the East-West Tie was assumed to be reinforced with a new double-circuit line as proposed under the *Reference Case.* A +200/-100MVAr SVC was also assumed to be installed at Marathon TS, in addition to three 40MVAr reactors, of which only two were required to be in-service for these studies.

Only a single generating unit was assumed to be in-service, pre-contingency, at Wells GS and at Aubrey Falls GS, for the following reasons:

- to limit the amount of post-contingency reactive support that could be provided from these facilities, and
- to increase the post-contingency transfer across the East-West Tie Interface.

A contingency involving circuits P25W & P26W would result in the operational units at Aubrey Falls being isolated, while a contingency involving circuits P21G & P22G would similarly result in the isolation of the operational units at Wells GS. In response to the resulting resource deficiency from the loss of these units, there would be a significant increase in the transfers on the Manitoba and Minnesota Interconnections. Although these increased transfers would be reduced through automatic adjustments to the phase-shifters on the Interconnections, they would not be reduced to zero, particularly on the Manitoba Interconnection which allows only four tap-changer operations before locking out.

With two units automatically isolated at either Wells GS or Aubrey Falls, the combined post-contingency transfers via the Manitoba and Minnesota Interconnections would be substantially higher following the adjustment of the phase-shifters.

Since any *increase* in the post-contingency transfers across the Interconnections would result in a corresponding *decrease* in the transfer across the East-West Tie, the studies therefore examined the loss of only a single unit at either Wells GS or Aubrey Falls GS to minimise the reduction in the latter transfer.

In addition to examining the double-circuit contingencies involving circuits P25W & P26W; and P21G & P22G, the effect of a single-circuit contingency involving circuit W23K between Wawa TS and MacKay TS was also examined. For this contingency, since there would be no associated loss of generation capacity, the post-contingency transfer across the East-West Tie Interface would not be similarly affected.

For all three contingencies, the analysis showed that, with the new double-circuit line between Wawa TS and Lakehead and the addition of a 200MVAr SVC at Marathon, the existing transmission facilities between Mississagi TS and Wawa TS would be able to support a westward transfer of approximately **500MW** across the East-West Tie.

16. Reinforcement of the East-West Tie with a new 230kV single-circuit line rather than a double-circuit line

All of the criteria produced by NERC, NPCC & the IESO refer to a requirement to respect a second single-element contingency after experiencing an initial single-element contingency or outage, with control actions taken between the two events to adjust the flows.

The IESO's planning criteria require any control actions to re-prepare the system for a subsequent contingency be implemented within the 30 minute period following an initial contingency.

The IESO's criteria for determining the adequacy of any plans to reinforce the transmission system also limit the maximum loss to two elements, either simultaneously or with one loss following another.

With the East-West Tie reinforced with a single-circuit line, the criteria require that, following the loss of the new single-circuit line, control actions be implemented to prepare the system for the loss of one of the circuits on the remaining double-circuit line.

Following the loss of the new single-circuit line, the system configuration for the section affected by the fault would revert to the present arrangement, for which the transfer capability is approximately 350MW, when respecting the loss of only a single circuit.

Since the targeted transfer capability of the reinforced East-West Tie is 650MW, a reduction to 350MW following the loss of the new single-circuit line would therefore require, as a control action, either the dispatch of additional generating resources totalling at least 300MW, or a lesser amount if there were also the capability to arm load rejection of up to 150MW in response to the second contingency. An increase in the transfers via the Interconnections with Manitoba and Minnesota would also allow the amount of generation capacity that would need to be dispatched to be reduced.

Reinforcing the East-West Tie with a new double-circuit line would therefore offer a higher level of security since, from the planning perspective, the initial loss of the two elements of the double-circuit line would provide acceptable performance, in accordance with the prevailing standards, while requiring no control actions to be taken following the initial loss of either of the double-circuit lines.

17. Replacement SVC at Lakehead TS: Recommendation

In this study it has been assumed that the replacement SVC for the existing synchronous condenser at Lakehead TS would be rated the same as the existing SVC; namely +60/-40MVAr.

The analysis has indicated that should the East-West Tie be reinforced and its transfer capability increased, that the Lakehead area would benefit from a higher rated unit.

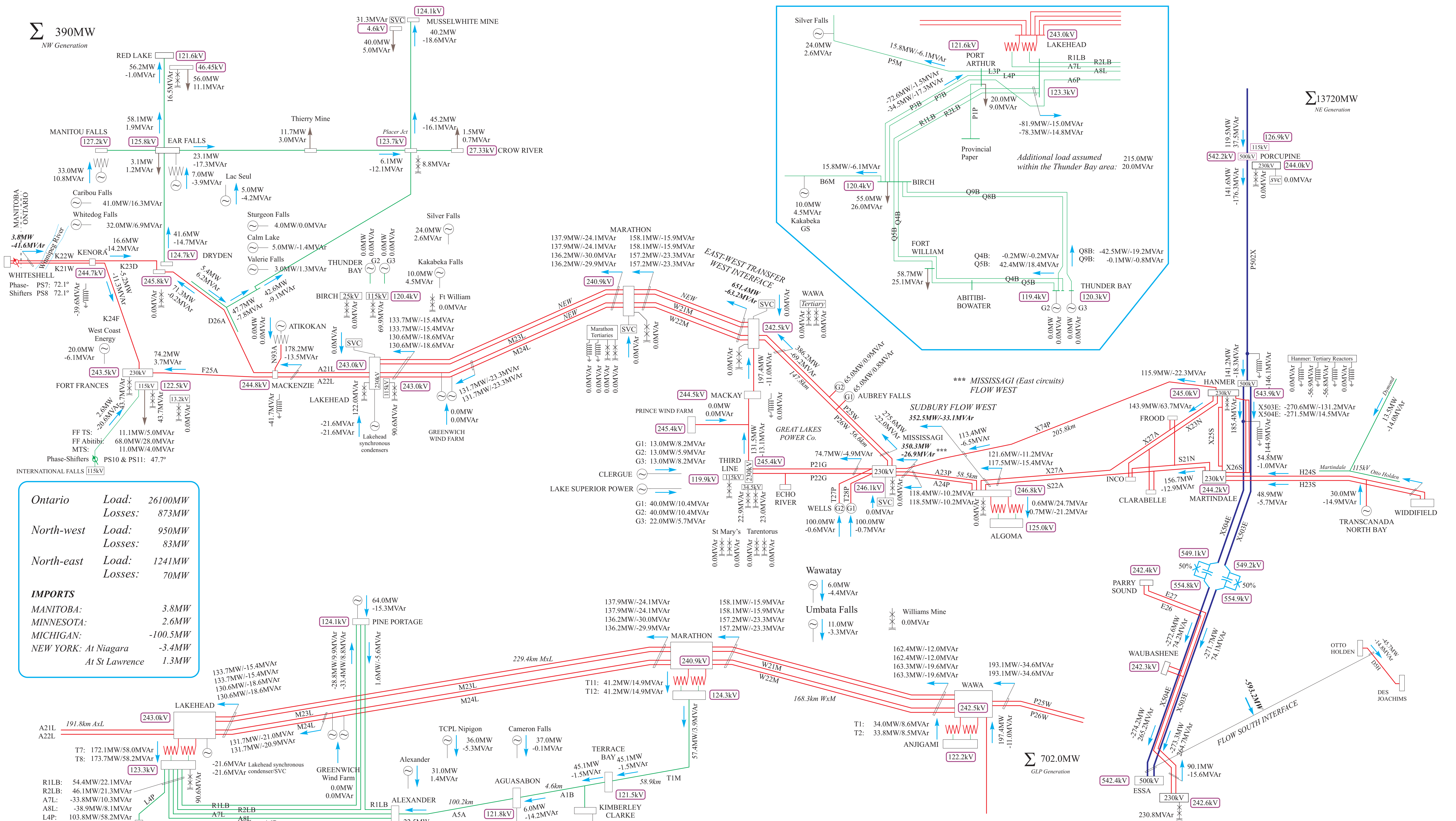
It is therefore recommended that when a decision is made to replace the existing synchronous condenser that consideration should be given to acquiring an SVC with rating of at least ± 100MVAr.

APPENDIX A Line Ratings										
230kV Line Ratings				*Ratings at 30^{o}C Ambient: 4km/hr wind: MVA at 240kV*						
Circuit	*Conductor (Limiting Section)*		*Sag Temp*	*Continuous at 93^{o}C or Sag Temperature, if lower*		*Long-Term 'Emergency' at 127^{o}C or Sag Temperature, if lower*		*15-min LTR at Sag Temperature*		
X74P ***Hanmer TS to Mississagi TS***										
Hanmer TS to Mississagi TS	1192.5kcmil	54/19	127^{o}C	1120A	465MVA	1440A	598MVA	1650A	686MVA	*Pre-load of 1120A*
S22A: ***Martindale TS to Algoma TS*** ***150.1km*** *(Martindale - Clarabelle 11.9km + Clarabelle - Algoma 138.1km)*										
Martindale-Clarabelle Jct	1924kcmil	69/19	127^{o}C	1500A	623MVA	1940A	806MVA	2400A	997MVA	*Pre-load of 1500A*
Clarabelle Jct to Algoma TS	1924kcmil	69/19	127^{o}C	1500A	623MVA	1940A	806MVA	2400A	997MVA	*Pre-load of 1500A*
	1307.4kcmil	28/19	127^{o}C	1160A	482MVA	1500A	623MVA	1800A	748MVA	*Pre-load of 1160A*
X27A: ***Hanmer TS to Algoma TS*** ***155.6km***										
Hanmer TS to Junction Point	1843.2kcmil	72/7	93^{o}C/116^{o}C	1420A	590MVA	1720A	715MVA	1990A	827MVA	*Pre-load of 1420A*
Junction Point to Algoma	1307.4kcmil	28/19	127^{o}C	1160A	482MVA	1500A	623MVA	1800A	748MVA	*Pre-load of 1160A*
A23P & A24P: ***Mississagi TS to Algoma TS*** ***58.5km***										
Mississagi to Algoma	795kcmil	26/7	150^{o}C	880A	366MVA	1120A	466MVA	1430A	594MVA	*Pre-load of 880A*
P25W & P26W: ***Mississagi TS to Wawa TS*** ***204.4km*** *(Mississagi - Aubrey Falls 56.6km + Aubrey Falls - Wawa 147.8km)*										
Mississagi TS to Aubrey Falls Jct	795kcmil	26/7	110^{o}C	880A	366MVA	1010A	420MVA	1070A	445MVA	*Pre-load of 880A*
Aubrey Falls Jct to Wawa TS	795kcmil	26/7	93^{o}C	880A	366MVA	880A	366MVA	880A	366MVA	*Pre-load of 880A*
W21M & W22M: ***Wawa TS to Marathon TS*** ***168.3km***										
W21M	795kcmil	26/7	93^{o}C	880A	366MVA	880A	366MVA	880A	366MVA	*Pre-load of 880A*
W22M			111^{o}C	880A	366MVA	1020A	424MVA	1080A	449MVA	*Pre-load of 880A*

230kV Line Ratings (Continued)				*Ratings at 30°C Ambient: 4km/hr wind: MVA at 240kV*						
Circuit	*Conductor (Limiting Section)*		*Sag Temp*	*Continuous at 93°C or Sag Temperature, if lower*		*Long-Term 'Emergency' at 127°C or Sag Temperature, if lower*		*15-min LTR at Sag Temperature*		
M23L & M24L: Marathon TS to Lakehead TS			***229.4km***							
M23L	795kcmil	26/7	95°C	880A	366MVA	890A	370MVA	900A	374MVA	*Pre-load of 880A*
M24L										

Ratings for Proposed 230kV Lines			*Ratings at 30°C Ambient: 4km/hr wind: MVA at 240kV*						
Conductor		*Sag Temp*	*Continuous at 93°C*		*Long-Term 'Emergency' at 127°C*		*15-min LTR at 150°C Temperature*		
Double-circuit line with ***single****-1192.5kcmil*	54/19	127°C	1120A	465MVA	1440A	598MVA	1650A	686MVA	*Pre-load of 1120A*
Single-circuit line with ***twin****-1192.5kcmil*	54/19	127°C	2230A	927MVA	2880A	1197MVA	3310A	1376MVA	*Pre-load of 2230A*
Single-circuit line with ***twin****-795.0kcmil*	26/7	127°C	1750A	727MVA	2240A	931MVA	2480A	1031MVA	*Pre-load of 1750A*

115kV Line Ratings				*Ratings at 30°C Ambient: 4km/hr wind: MVA at 121kV*						
Circuit	*Conductor (Limiting Section)*		*Sag Temp*	*Continuous at 93°C or Sag Temperature, if lower*		*Long-Term 'Emergency' at 127°C or Sag Temperature, if lower*		*15-min LTR at Sag Temperature*		
T1M: Marathon TS to Terrace Bay SS										
Marathon TS to Terrace Bay	477.0kcmil	26/7	70°C	460A	96MVA	460A	96MVA	460A	96MVA	*Pre-load of 460A*
A1B: Terrace Bay SS to Aguasabon SS										
Terrace Bay SS to Aguasabon	477.0kcmil	26/7	84°C	570A	119MVA	570A	119MVA	570A	119MVA	*Pre-load of 570A*
A5A: Aguasabon SS to Alexandra SS										
Aguasabon SS to Alexandra SS	477.0kcmil	26/7	66°C	430A	90MVA	430A	90MVA	430A	90MVA	*Pre-load of 570A*

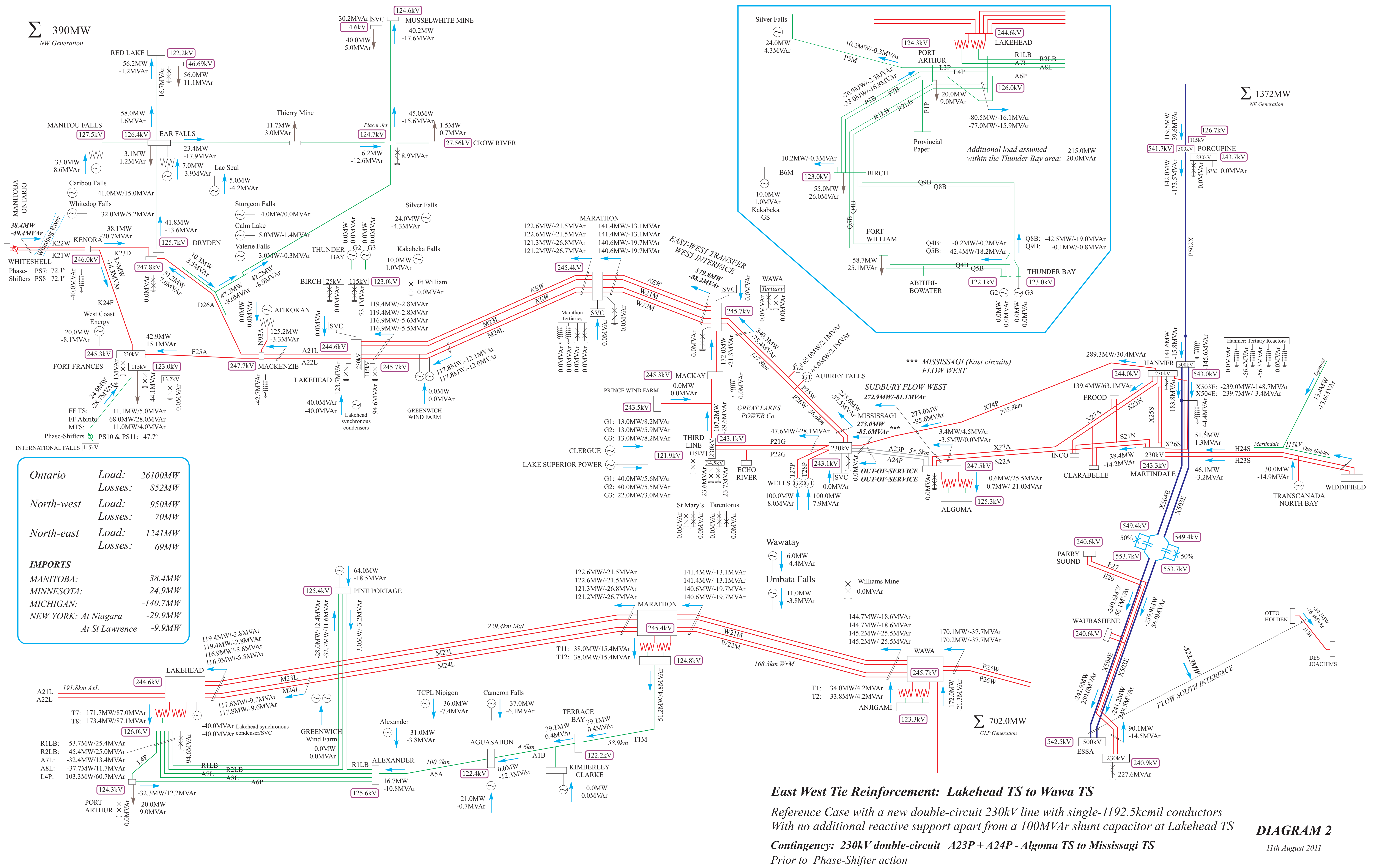


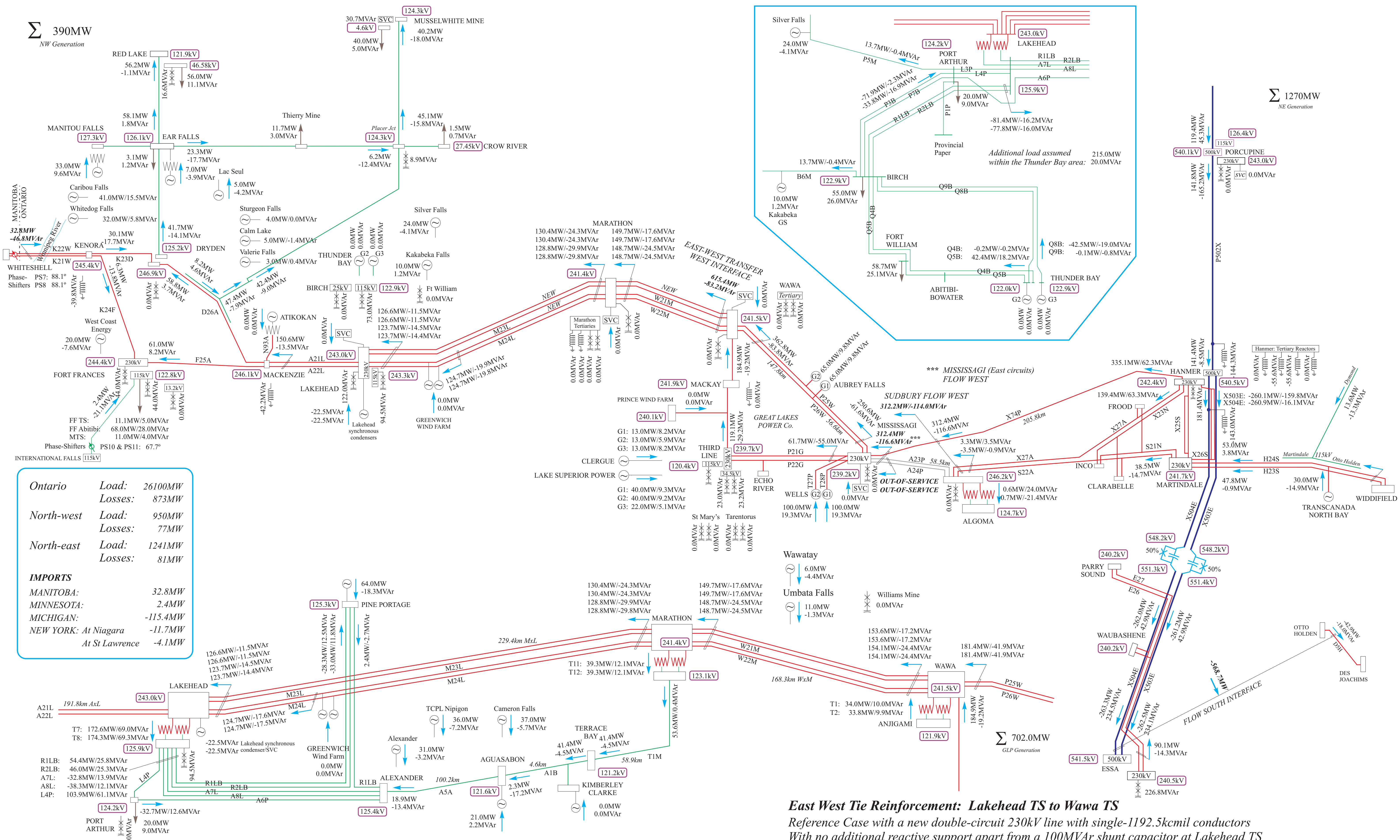
East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
With no additional reactive support apart from a 100MVAr shunt capacitor at Lakehead TS

DIAGRAM 1

11th August 2011


Σ 390MW
NW Generation
Σ 1372MW
NE Generation
Σ 702.0MW
GLP Generation
RED LAKE
EAR FALLS
MANITOU FALLS
Thierry Mine
MUSSELWHITE MINE
CROW RIVER
Lac Seul
Caribou Falls
Whitedog Falls
Sturgeon Falls
Calm Lake
Valerie Falls
Silver Falls
Kakabeka Falls
Ft William
KENORA
DRYDEN
WHITESHELL
MANITOBA
ONTARIO
Winnipeg River
West Coast Energy
FORT FRANCES
INTERNATIONAL FALLS
ATIKOKAN
MACKENZIE
THUNDER BAY
BIRCH
LAKEHEAD
GREENWICH WIND FARM
MARATHON
EAST-WEST TRANSFER WEST INTERFACE
WAWA
MACKAY
AUBREY FALLS
PRINCE WIND FARM
GREAT LAKES POWER Co.
MISSISSAGI
THIRD LINE
CLERGUE
LAKE SUPERIOR POWER
ECHO RIVER
WELLS
St Mary's
Tarentorus
ALGOMA
SUDBURY FLOW WEST
*** MISSISSAGI (East circuits) FLOW WEST
OUT-OF-SERVICE
HANMER
PORCUPINE
FROOD
INCO
CLARABELLE
MARTINDALE
TRANSCANADA NORTH BAY
WIDDIFIELD
PARRY SOUND
WAUBASHENE
ESSA
OTTO HOLDEN
DES JOACHIMS
FLOW SOUTH INTERFACE
Silver Falls
LAKEHEAD
PORT ARTHUR
Provincial Paper
Additional load assumed within the Thunder Bay area: 215.0MW 20.0MVAr
BIRCH
Kakabeka GS
FORT WILLIAM
ABITIBI-BOWATER
THUNDER BAY
Ontario Load: 26100MW
Losses: 852MW
North-west Load: 950MW
Losses: 70MW
North-east Load: 1241MW
Losses: 69MW
IMPORTS
MANITOBA: 38.4MW
MINNESOTA: 24.9MW
MICHIGAN: -140.7MW
NEW YORK: At Niagara -29.9MW
At St Lawrence -9.9MW
PINE PORTAGE
Wawatay
Umbata Falls
Williams Mine
TCPL Nipigon
Cameron Falls
Alexander
AGUASABON
TERRACE BAY
KIMBERLEY CLARKE
ALEXANDER
ANJIGAMI
GREENWICH Wind Farm
East West Tie Reinforcement: Lakehead TS to Wawa TS
Reference Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
With no additional reactive support apart from a 100MVAr shunt capacitor at Lakehead TS
Contingency: 230kV double-circuit A23P + A24P - Algoma TS to Mississagi TS
Prior to Phase-Shifter action
DIAGRAM 2
11th August 2011



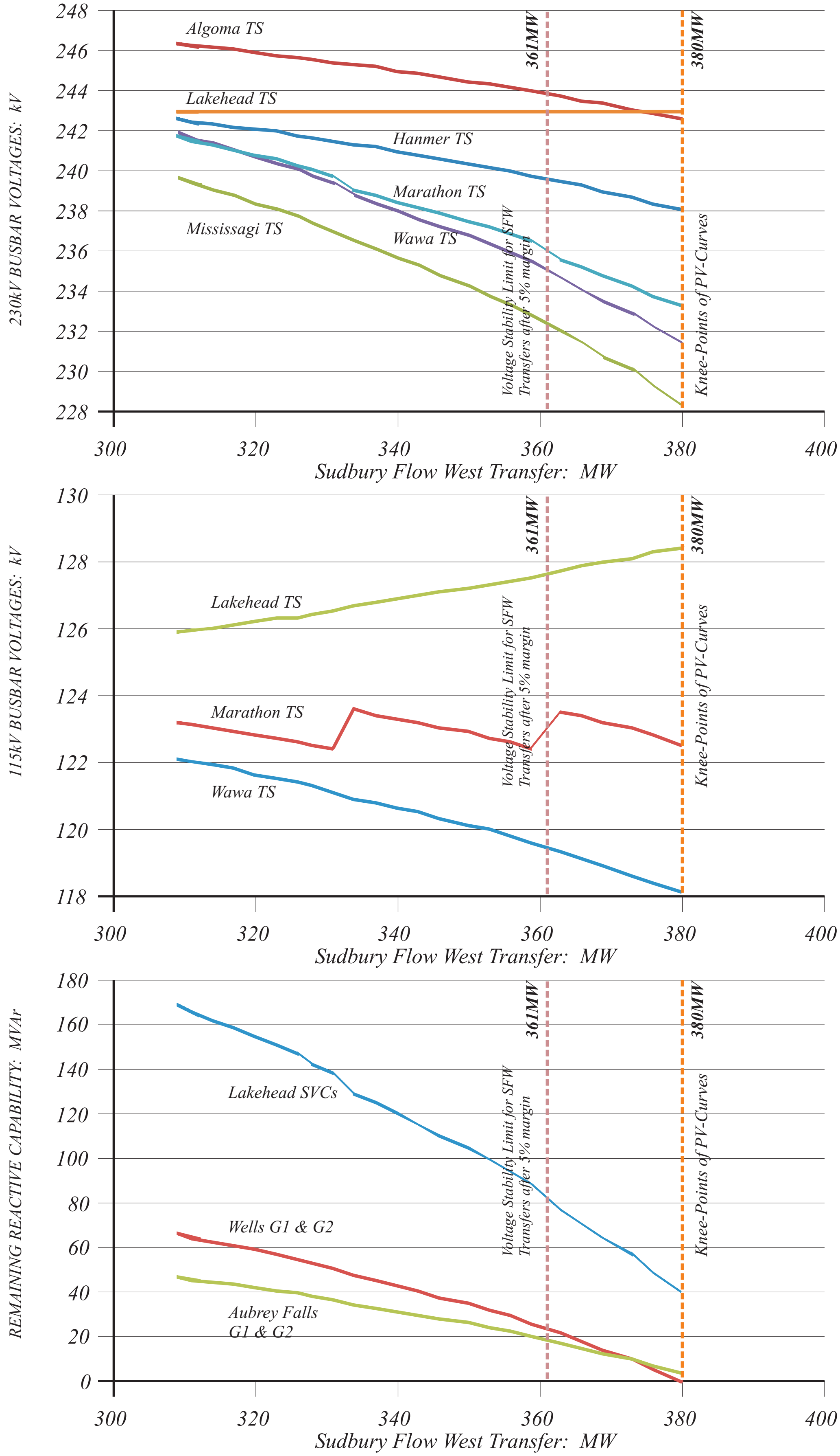
East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
With no additional reactive support apart from a 100MVAr shunt capacitor at Lakehead TS

Contingency: 230kV double-circuit A23P + A24P - Algoma TS to Mississagi TS
After Phase-Shifter action

DIAGRAM 3

11th August 2011



PV-analysis
No additional SVCs

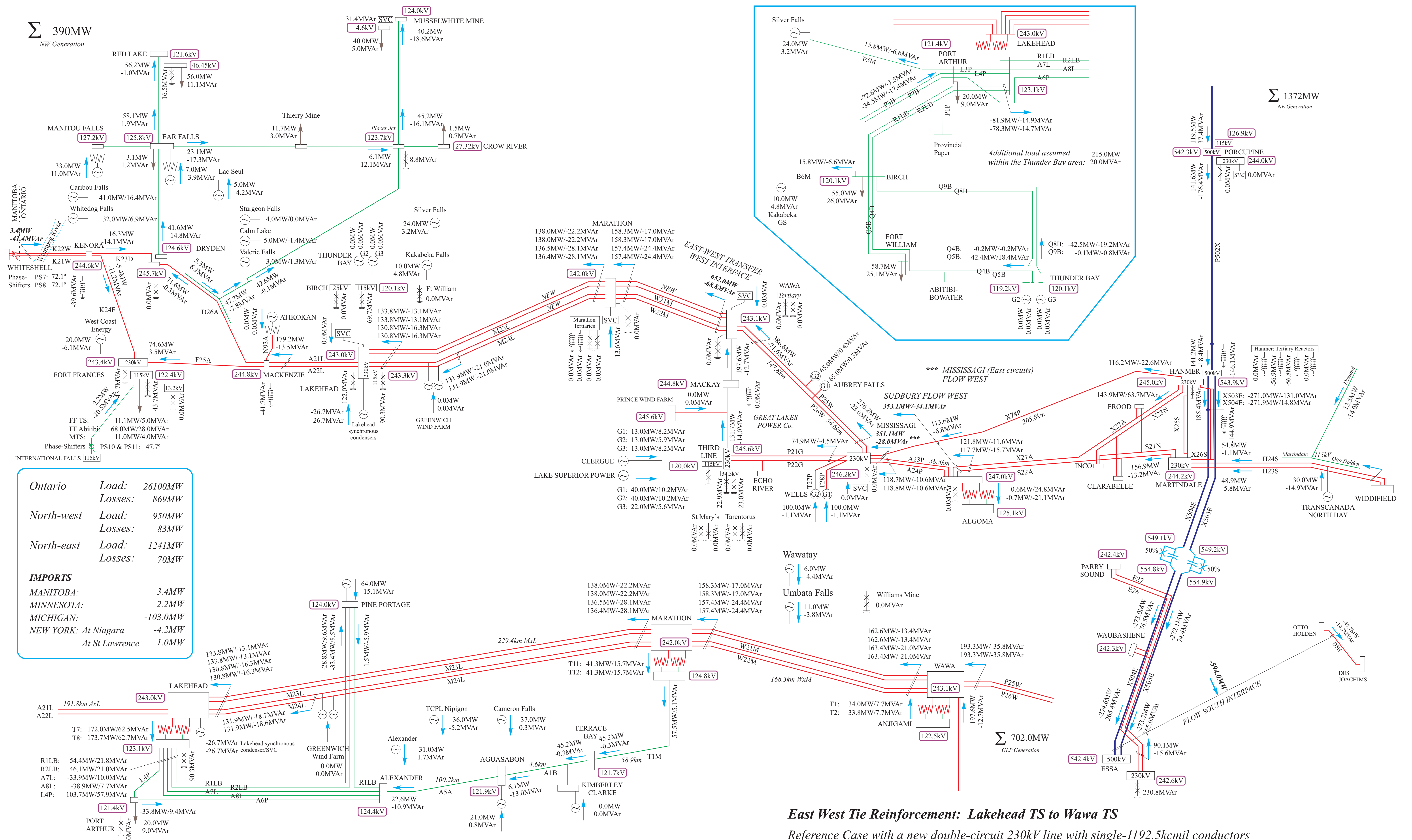
East West Tie Reinforcement: Lakehead TS to Wawa TS

Case with a new double-circuit 230kV line with 1192.5kcmil conductors

Contingency: 230kV double-circuit A23P & A24P
After Phase-Shifter action

DIAGRAM 4

26th July 2011

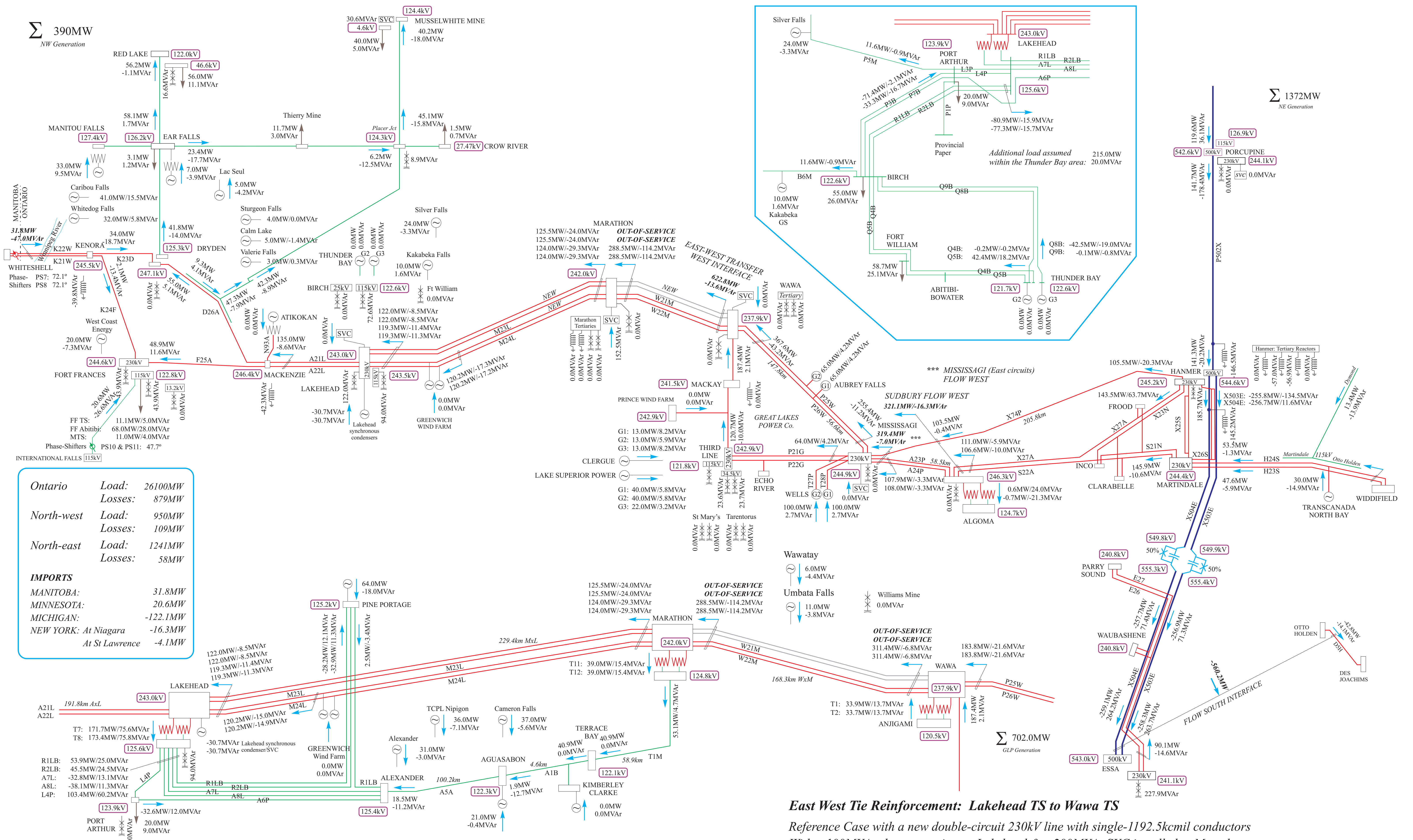


East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
With a 100MVAr shunt capacitor at Lakehead & a 200MVAr SVC installed at Marathon

DIAGRAM 5

11th August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with single-1192.5kcmil conductors

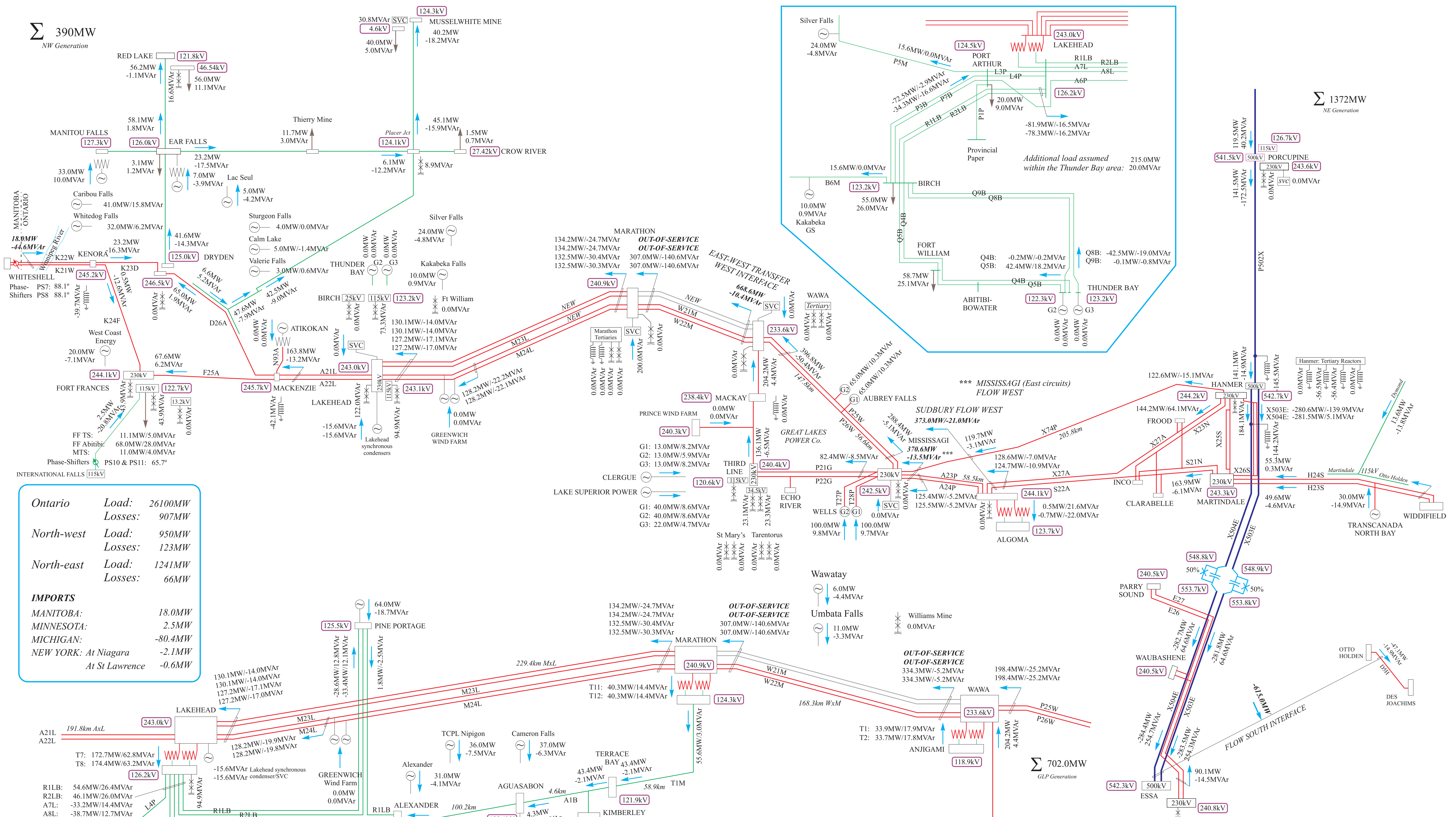
With a 100MVAr shunt capacitor at Lakehead & a 200MVAr SVC installed at Marathon

Contingency: 230kV double-circuit involving the new Wawa TS to Marathon TS line

Prior to Phase-Shifter action

DIAGRAM 6

11th August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with single-1192.5kcmil conductors

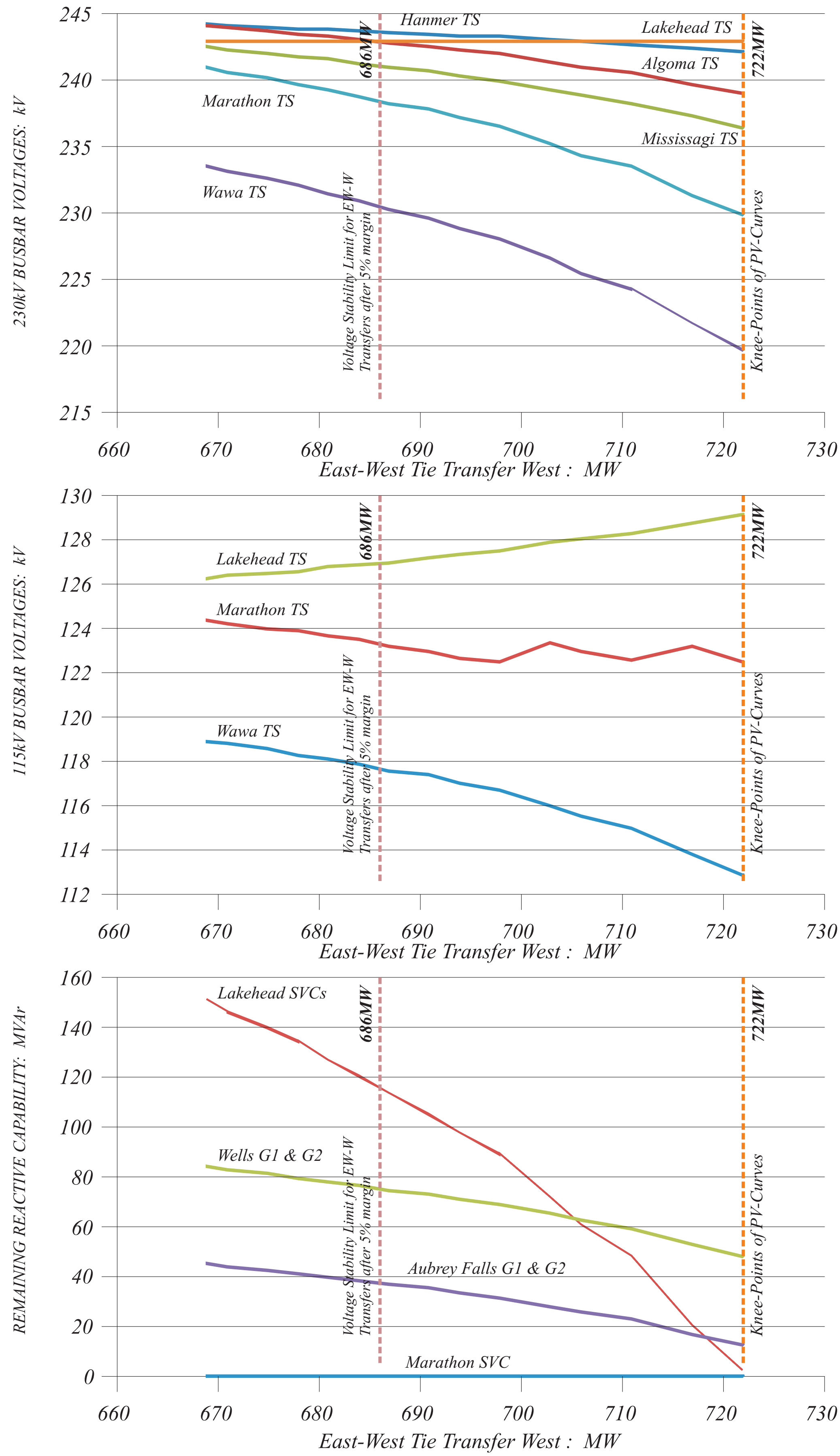
With a 100MVAr shunt capacitor at Lakehead & a 200MVAr SVC installed at Marathon

Contingency: 230kV double-circuit involving the new Wawa TS to Marathon TS line

After Phase-Shifter action

DIAGRAM 7

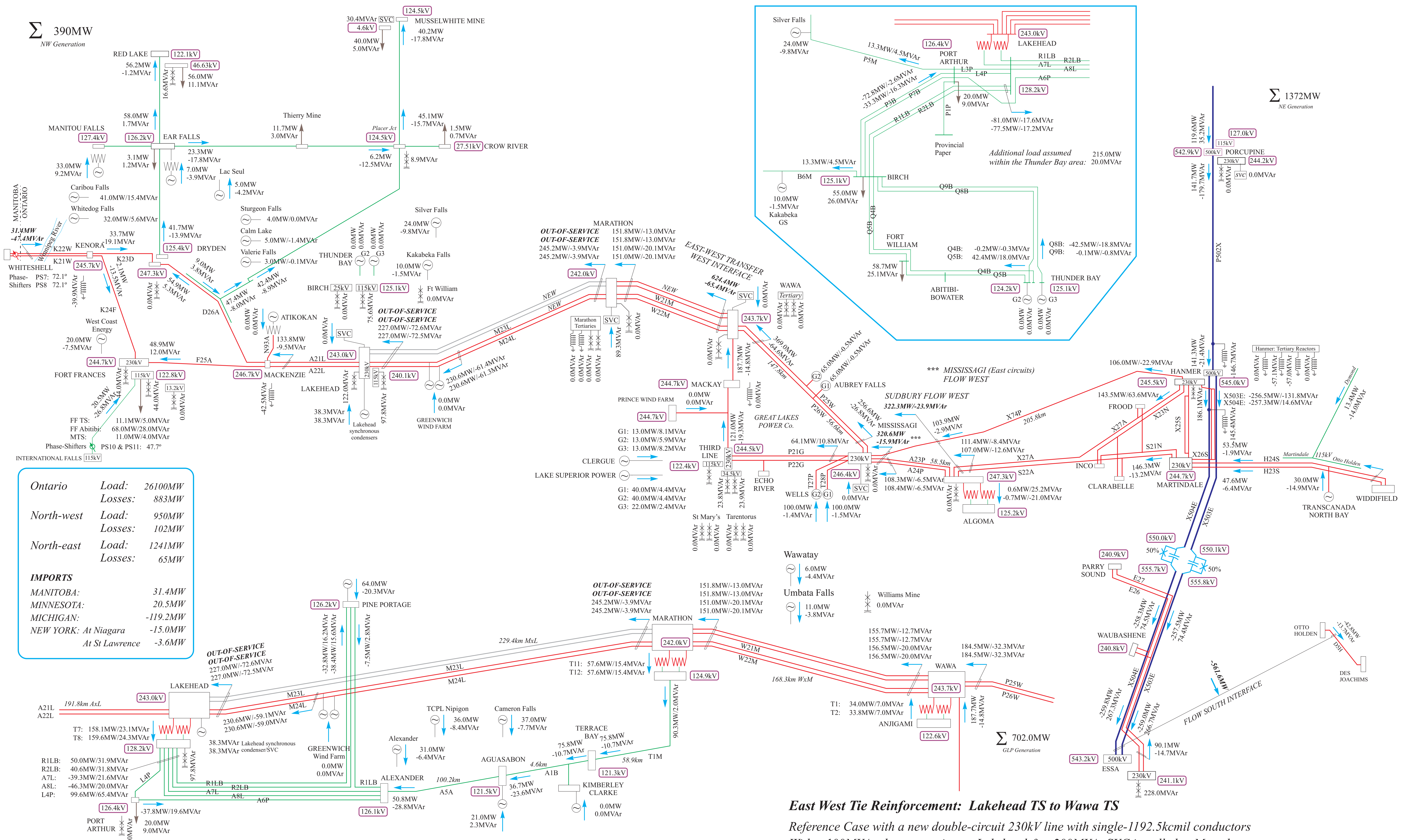
11th August 2011



PV-analysis
Marathon 200MVAr SVC

East West Tie Reinforcement: Lakehead TS to Wawa TS
Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
Contingency: new 230kV double-circuit Wawa TS to Marathon TS
After Phase-Shifter action

DIAGRAM 8
30th July 2011

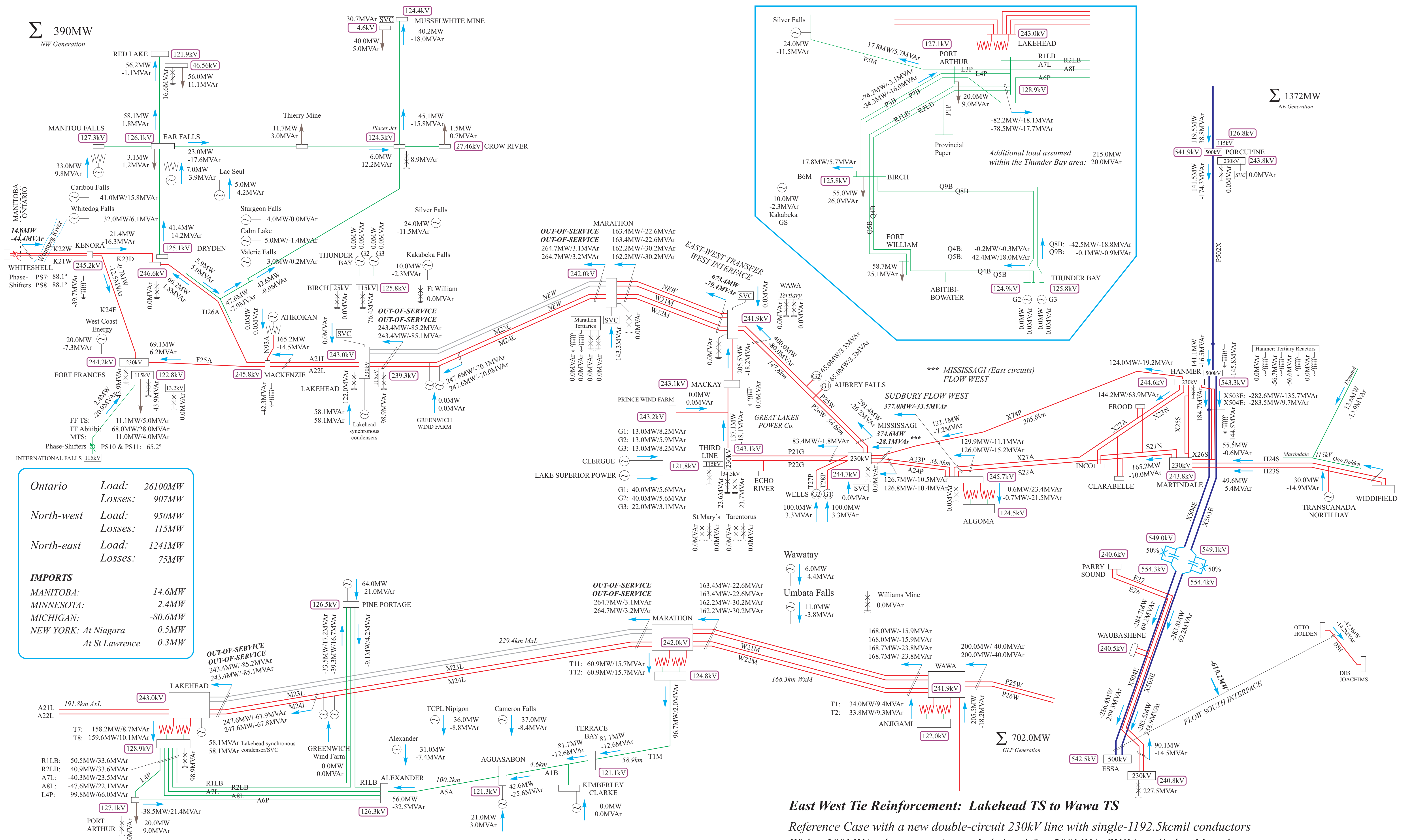


East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
With a 100MVAr shunt capacitor at Lakehead & a 200MVAr SVC installed at Marathon
Contingency: 230kV double-circuit involving the new Marathon TS to Lakehead TS line
Prior to Phase-Shifter action

DIAGRAM 9

11th August 2011



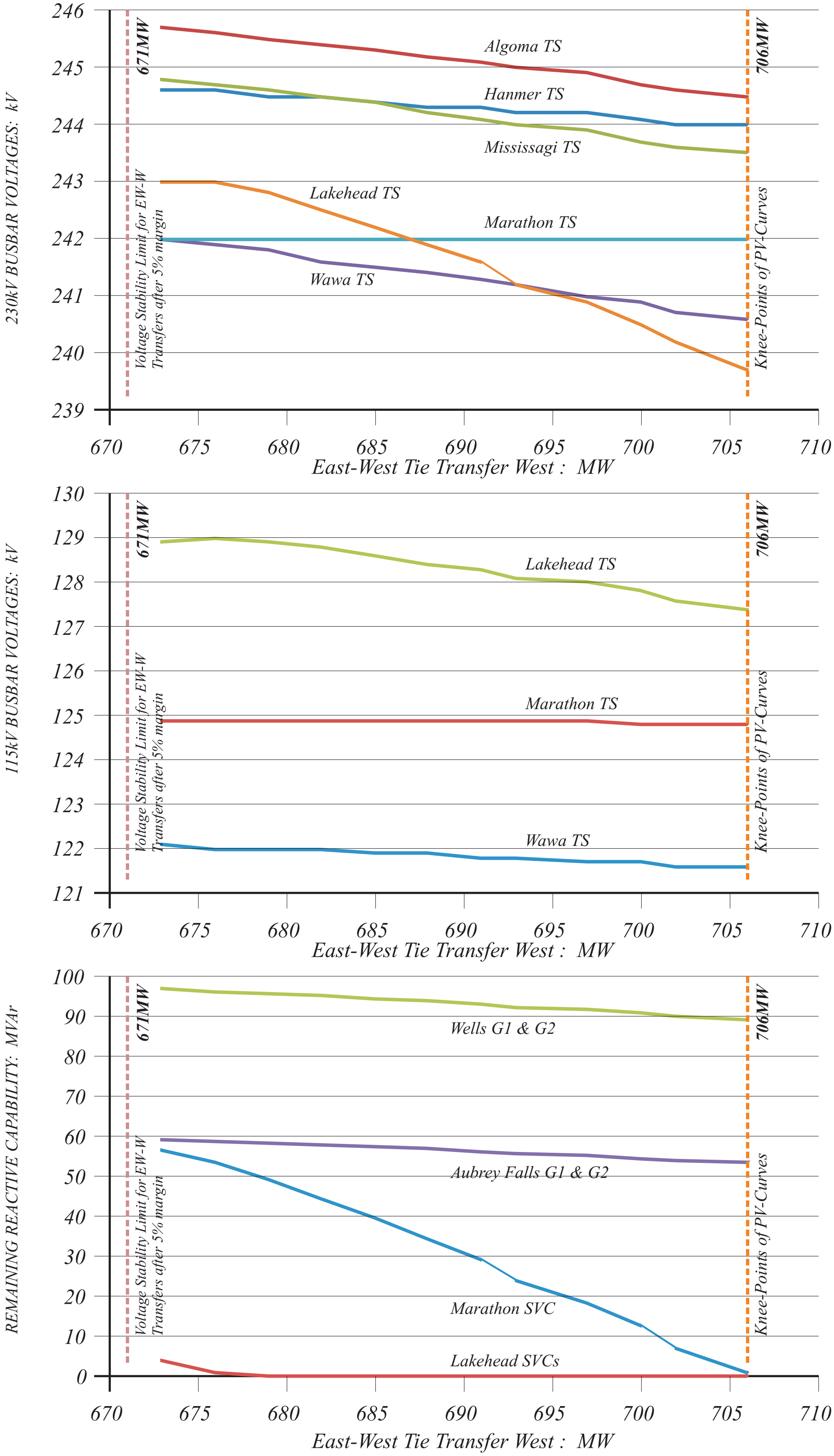
East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
With a 100MVAr shunt capacitor at Lakehead & a 200MVAr SVC installed at Marathon

Contingency: 230kV double-circuit involving the new Marathon TS to Lakehead TS line
After Phase-Shifter action

DIAGRAM 10

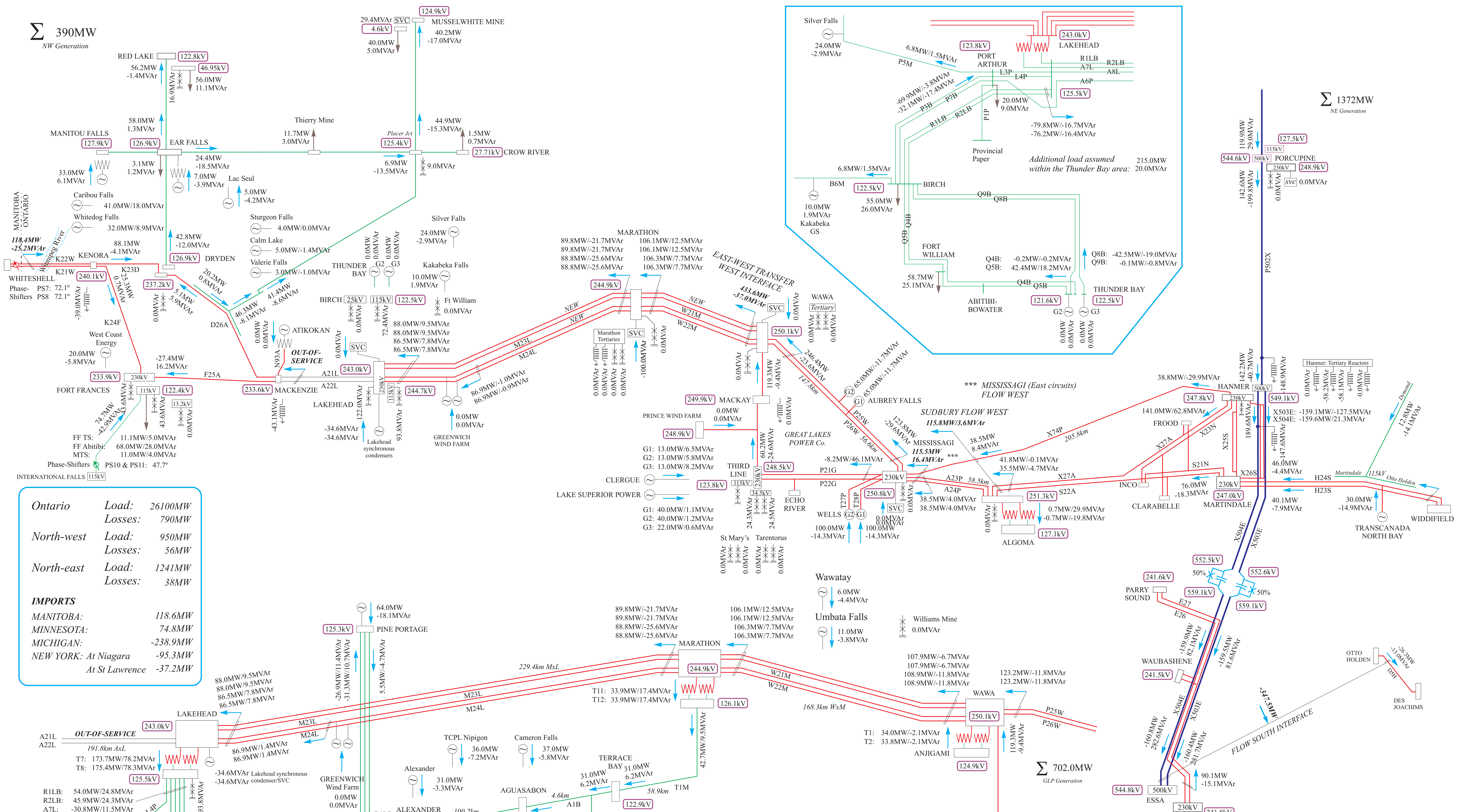
11th August 2011



PV-analysis
Marathon 200MVAr SVC

East West Tie Reinforcement: Lakehead TS to Wawa TS
Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
Contingency: new 230kV double-circuit Marathon TS to Lakehead TS
After Phase-Shifter action

DIAGRAM 11
26th July 2011



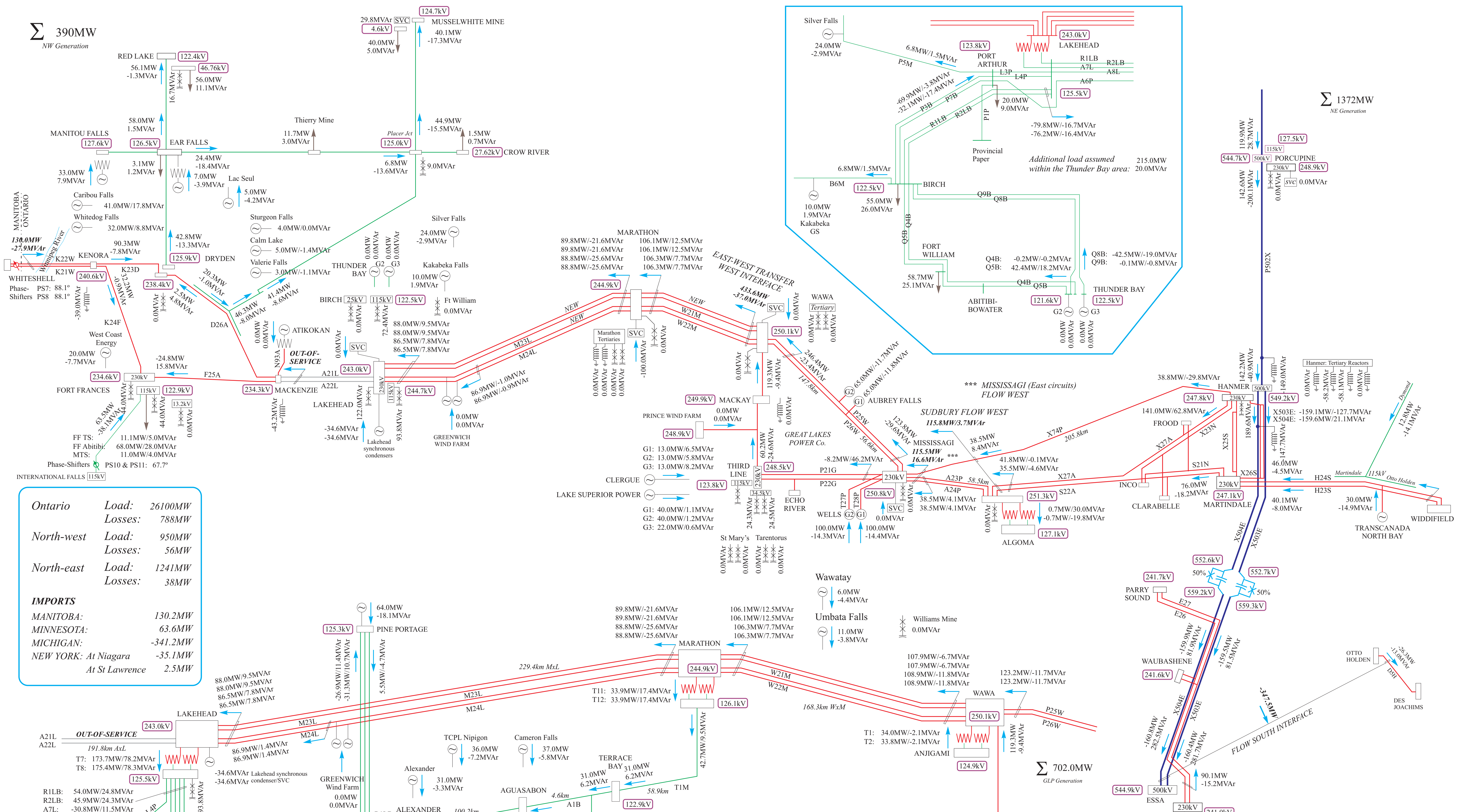
Ontario	Load:	26100MW
	Losses:	790MW
North-west	Load:	950MW
	Losses:	56MW
North-east	Load:	1241MW
	Losses:	38MW
IMPORTS		
MANITOBA:		118.6MW
MINNESOTA:		74.8MW
MICHIGAN:		-238.9MW
NEW YORK:	At Niagara	-95.3MW
	At St Lawrence	-37.2MW

East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
With a 100MVAr shunt capacitor at Lakehead & a 200MVAr SVC installed at Marathon
Contingency: 230kV double-circuit A21L + A22L Lakehead TS to Mackenzie TS
115kV Circuit B6M - Moose Lake TS to Birch TS cross-tripped
Prior to Phase-Shifter action

DIAGRAM 12

11th August 2011

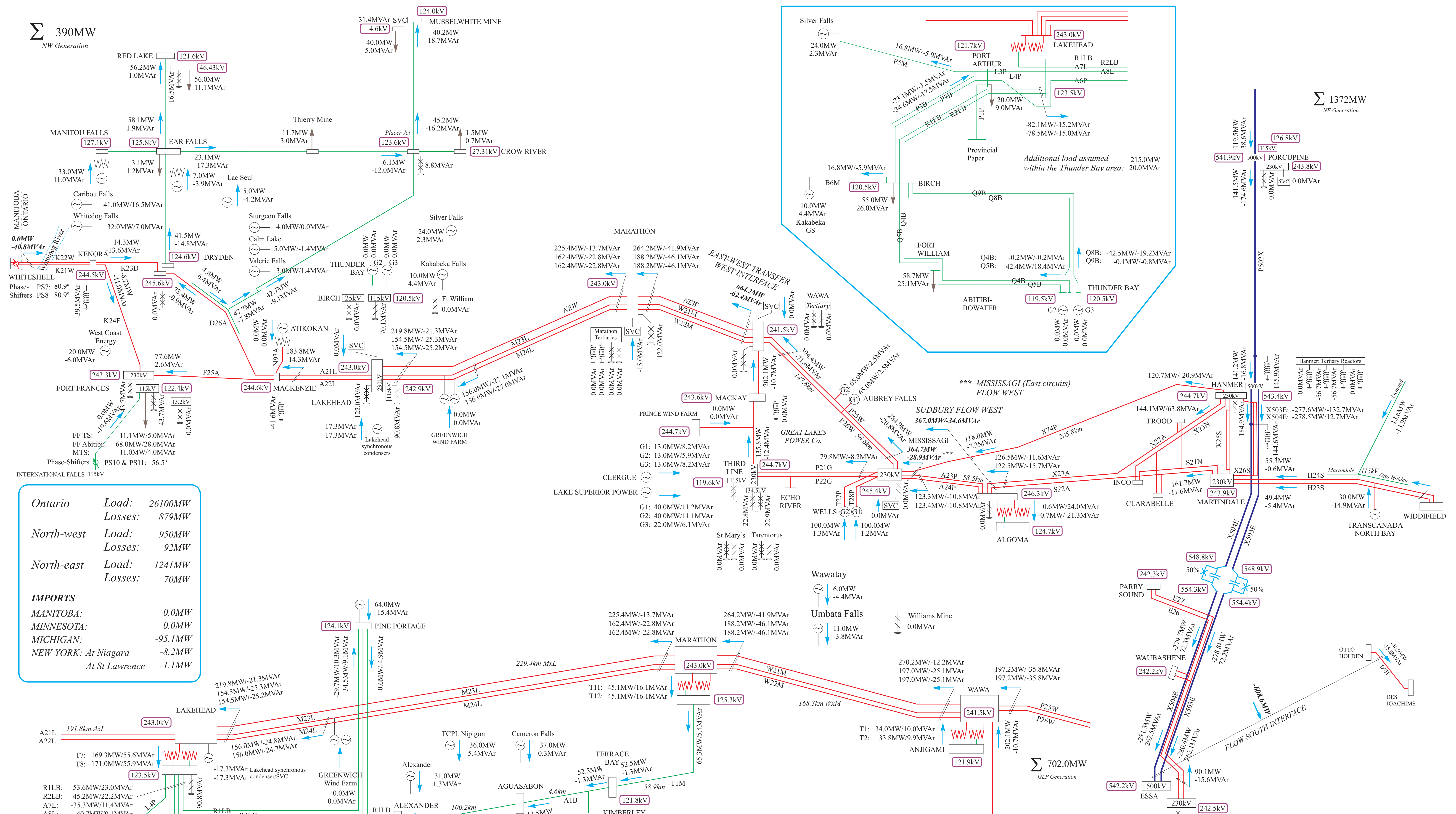


East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
With a 100MVAr shunt capacitor at Lakehead & a 200MVAr SVC installed at Marathon
Contingency: 230kV double-circuit A21L + A22L Lakehead TS to Mackenzie TS
115kV Circuit B6M - Moose Lake TS to Birch TS cross-tripped
After Phase-Shifter action

DIAGRAM 13

11th August 2011

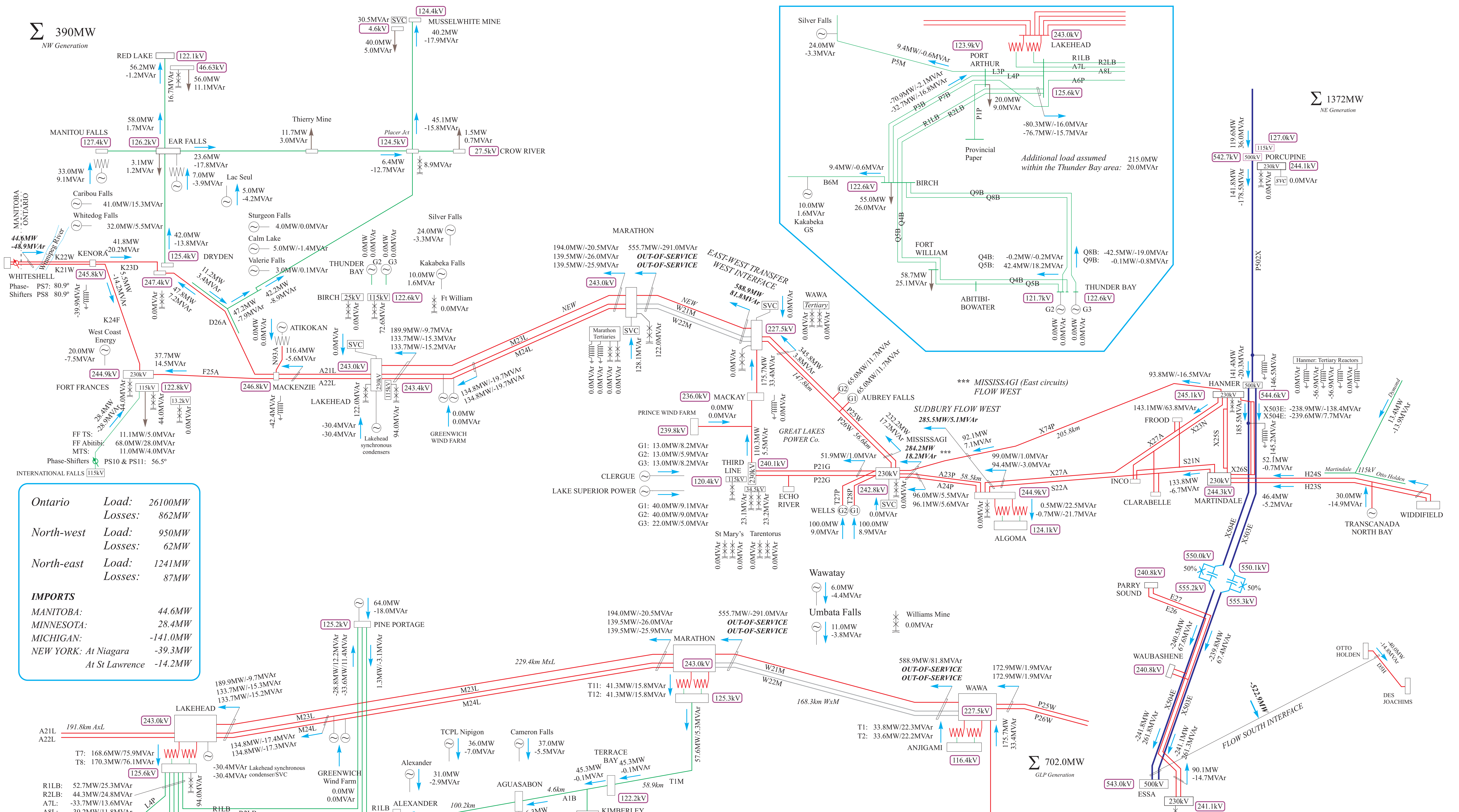


East West Tie Reinforcement: Lakehead TS to Wawa TS

Alternative Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors
With a 100MVAr capacitor at Lakehead & Marathon and a 350MVAr SVC at Marathon

DIAGRAM 14

11th August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

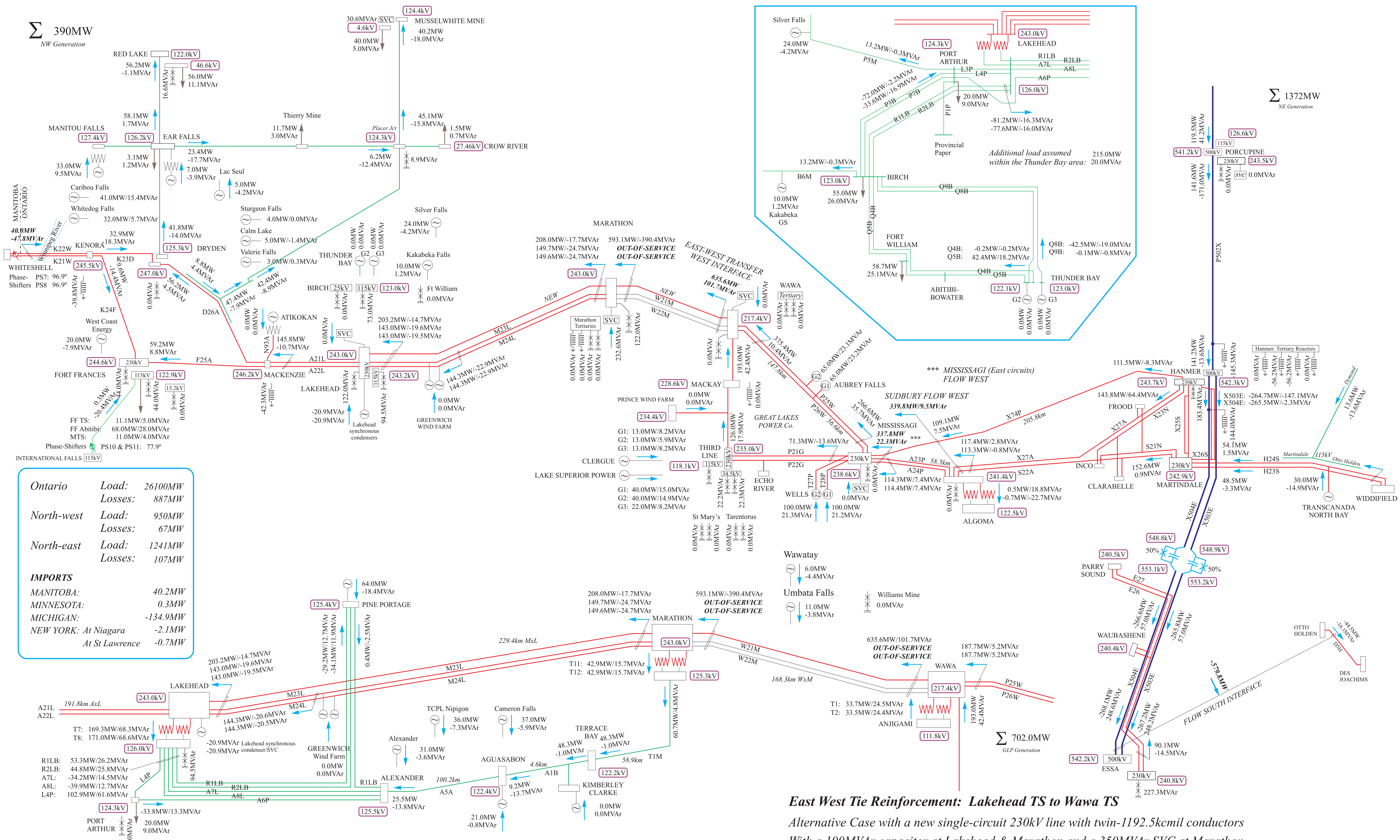
Alternative Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors
With a 100MVAr capacitor at Lakehead & Marathon and a 350MVAr SVC at Marathon

Contingency: 230kV double-circuit W21M + W22M Wawa TS to Marathon TS

Prior to Phase-Shifter action

DIAGRAM 15

11th August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

Alternative Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors

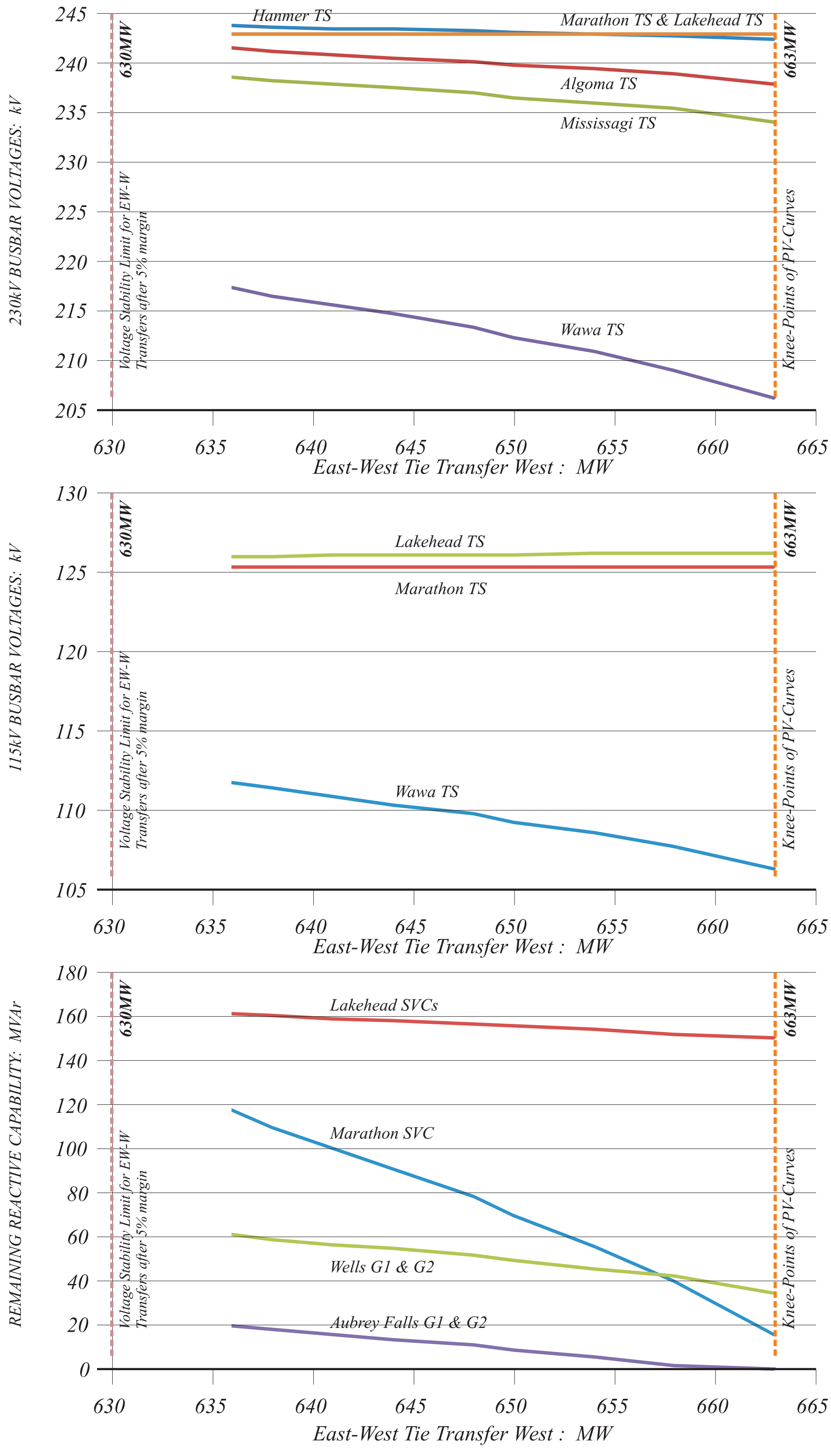
With a 100MVAr capacitor at Lakehead & Marathon and a 350MVAr SVC at Marathon

Contingency: 230kV double-circuit W21M + W22M Wawa TS to Marathon TS

After Phase-Shifter action

DIAGRAM 16

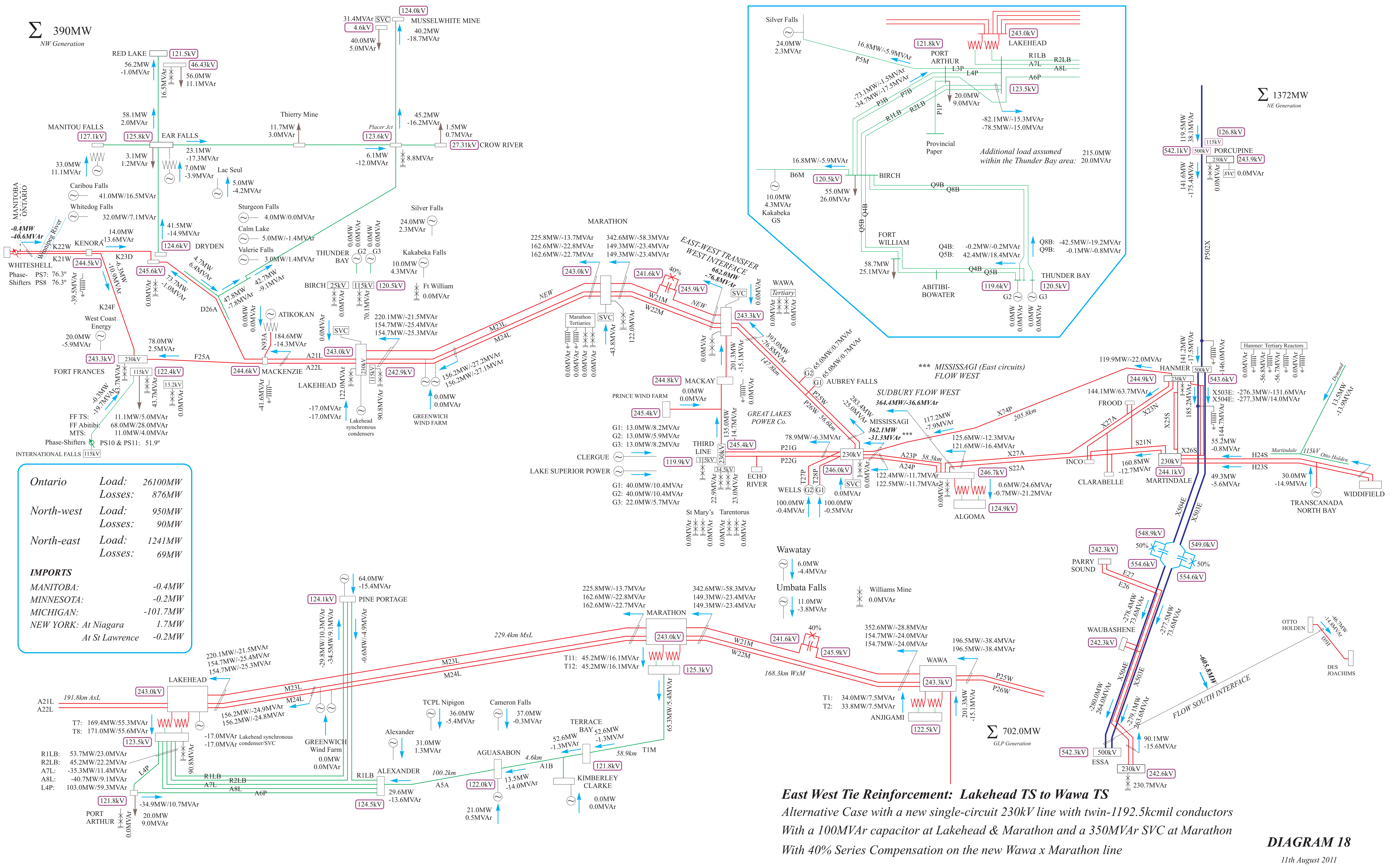
11th August 2011



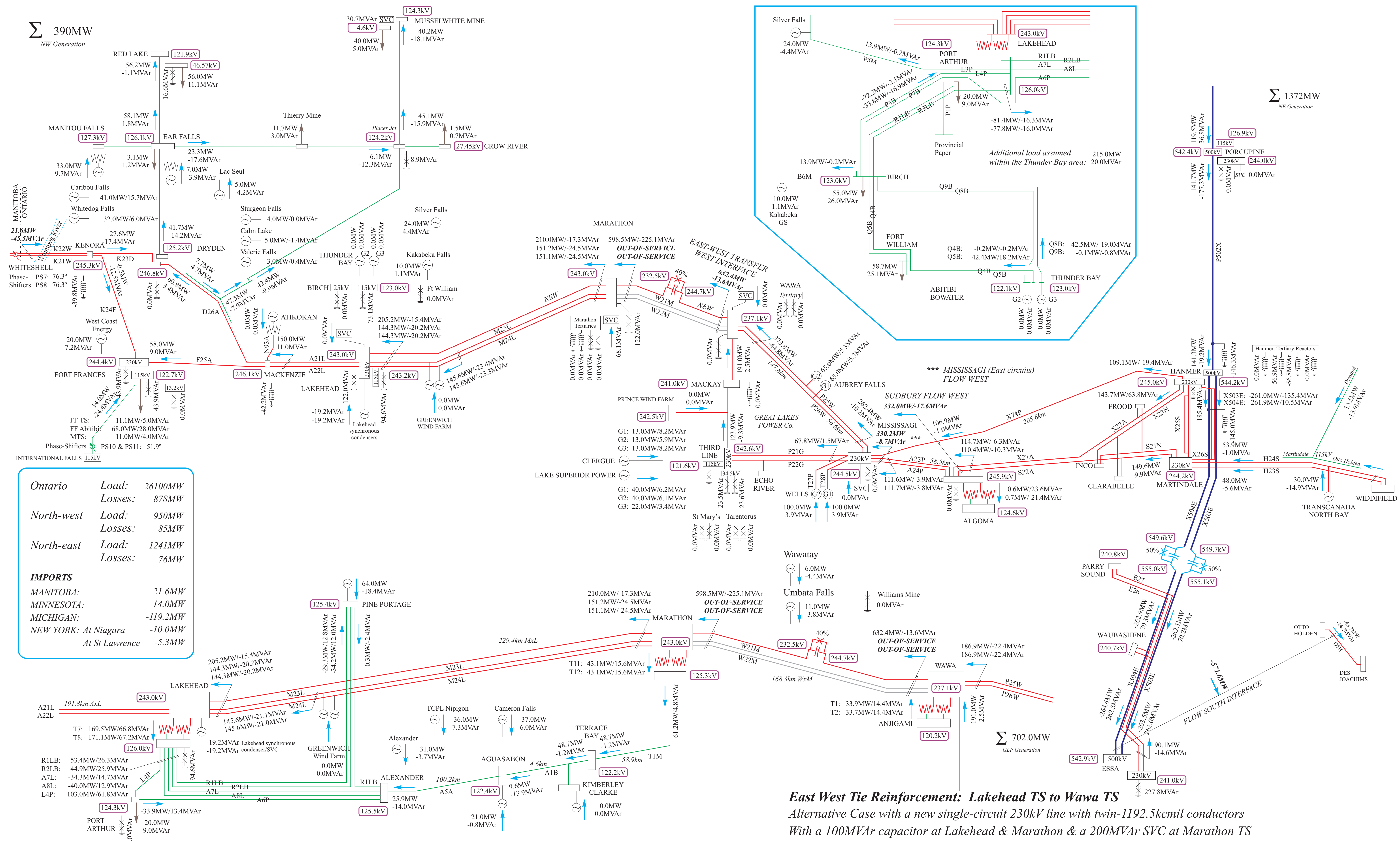
PV-analysis
Marathon
350MVAr SVC

East West Tie Reinforcement: Lakehead TS to Wawa TS
Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors
Contingency: new 230kV double-circuit Wawa TS to Marathon TS
After Phase-Shifter action

DIAGRAM 17
28th July 2011



Σ 390MW
NW Generation
Σ 1372MW
NE Generation
Σ 702.0MW
GLP Generation
RED LAKE
EAR FALLS
MANITOU FALLS
Thierry Mine
MUSSELWHITE MINE
Placer Jct
CROW RIVER
Lac Seul
Caribou Falls
Whitedog Falls
MANITOBA
ONTARIO
Winnipeg River
KENORA
WHITESHELL
Phase-Shifters PS7: 76.3° PS8 76.3°
DRYDEN
Sturgeon Falls
Calm Lake
Valerie Falls
Silver Falls
Kakabeka Falls
Ft William
THUNDER BAY
BIRCH
ATIKOKAN
West Coast Energy
FORT FRANCES
MACKENZIE
LAKEHEAD
Lakehead synchronous condensers
GREENWICH WIND FARM
INTERNATIONAL FALLS
FF TS: 11.1MW/5.0MVAr
FF Abitibi: 68.0MW/28.0MVAr
MTS: 11.0MW/4.0MVAr
Phase-Shifters PS10 & PS11: 51.9°
MARATHON
Marathon Tertiaries
EAST-WEST TRANSFER WEST INTERFACE 662.0MW -76.8MVAr
WAWA
MACKAY
PRINCE WIND FARM
THIRD LINE
CLERGUE
LAKE SUPERIOR POWER
GREAT LAKES POWER Co.
AUBREY FALLS
MISSISSAGI
*** MISSISSAGI (East circuits) FLOW WEST
SUDBURY FLOW WEST 364.4MW/-36.6MVAr
WELLS
ECHO RIVER
St Mary's
Tarentorus
ALGOMA
INCO
CLARABELLE
FROOD
MARTINDALE
HANMER
Hanmer: Tertiary Reactors
PORCUPINE
TRANSCANADA NORTH BAY
WIDDIFIELD
Martindale
Otto Holden
PARRY SOUND
WAUBASHENE
ESSA
OTTO HOLDEN
DES JOACHIMS
FLOW SOUTH INTERFACE
Silver Falls
PORT ARTHUR
LAKEHEAD
Provincial Paper
Additional load assumed within the Thunder Bay area: 215.0MW 20.0MVAr
Kakabeka GS
FORT WILLIAM
ABITIBI-BOWATER
THUNDER BAY
Ontario Load: 26100MW Losses: 876MW
North-west Load: 950MW Losses: 90MW
North-east Load: 1241MW Losses: 69MW
IMPORTS
MANITOBA: -0.4MW
MINNESOTA: -0.2MW
MICHIGAN: -101.7MW
NEW YORK: At Niagara 1.7MW
At St Lawrence -0.2MW
PINE PORTAGE
229.4km MxL
191.8km AxL
168.3km WxM
T7: 169.4MW/55.3MVAr
T8: 171.0MW/55.6MVAr
R1LB: 53.7MW/23.0MVAr
R2LB: 45.2MW/22.2MVAr
A7L: -35.3MW/11.4MVAr
A8L: -40.7MW/9.1MVAr
L4P: 103.0MW/59.3MVAr
PORT ARTHUR
Lakehead synchronous condenser/SVC
GREENWICH Wind Farm
Wawatay
Umbata Falls
Williams Mine
TCPL Nipigon
Cameron Falls
Alexander
ALEXANDER
AGUASABON
TERRACE BAY
KIMBERLEY CLARKE
ANJIGAMI
T1: 34.0MW/7.5MVAr
T2: 33.8MW/7.5MVAr
T11: 45.2MW/16.1MVAr
T12: 45.2MW/16.1MVAr
East West Tie Reinforcement: Lakehead TS to Wawa TS
Alternative Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors
With a 100MVAr capacitor at Lakehead & Marathon and a 350MVAr SVC at Marathon
With 40% Series Compensation on the new Wawa x Marathon line
DIAGRAM 18
11th August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

Alternative Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors

With a 100MVAr capacitor at Lakehead & Marathon & a 200MVAr SVC at Marathon TS

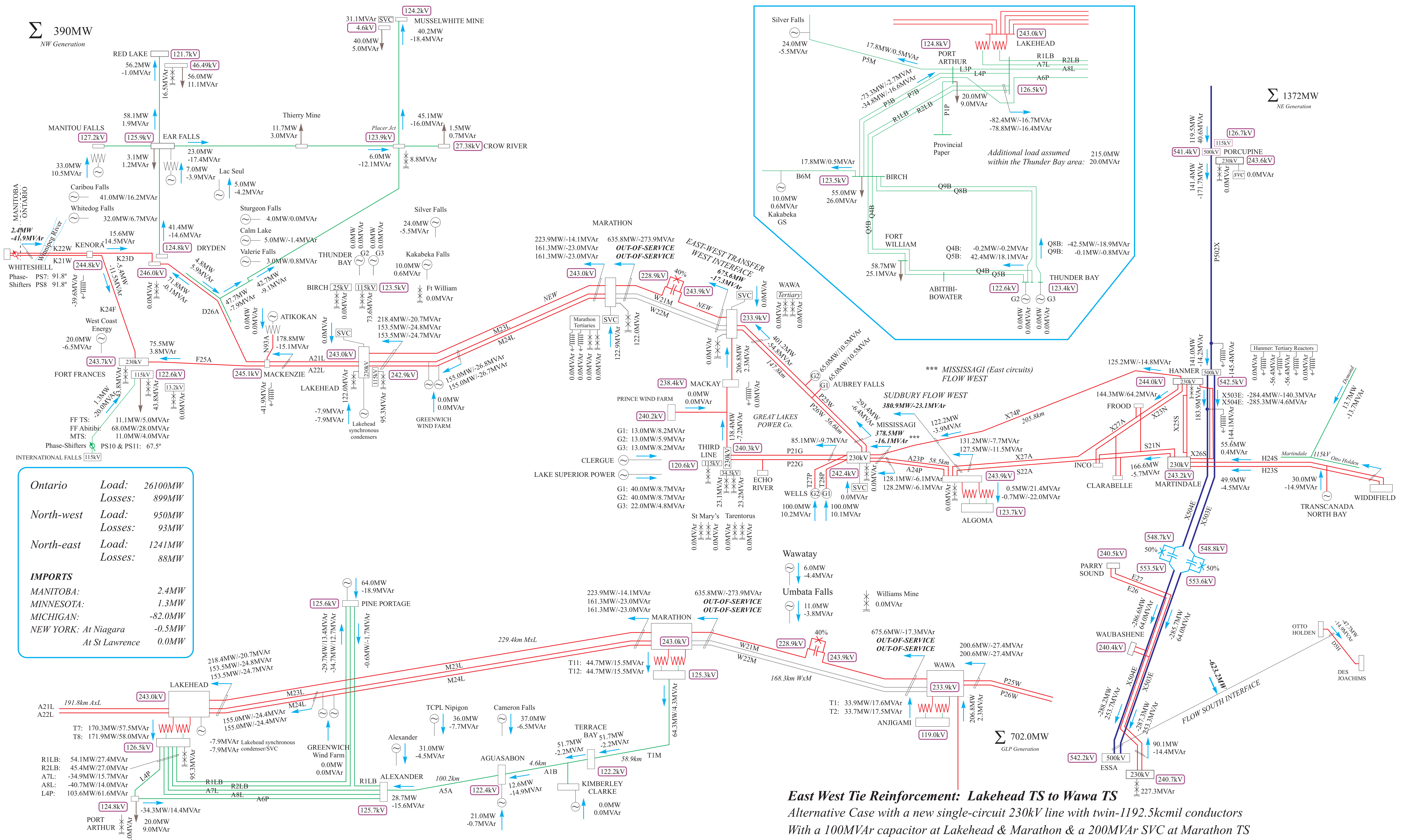
With 40% Series Compensation on the new Wawa x Marathon line

Contingency: 230kV double-circuit W21M + W22M Wawa TS to Marathon TS

Prior to Phase-Shifter action

DIAGRAM 19

11th August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

Alternative Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors

With a 100MVAr capacitor at Lakehead & Marathon & a 200MVAr SVC at Marathon TS

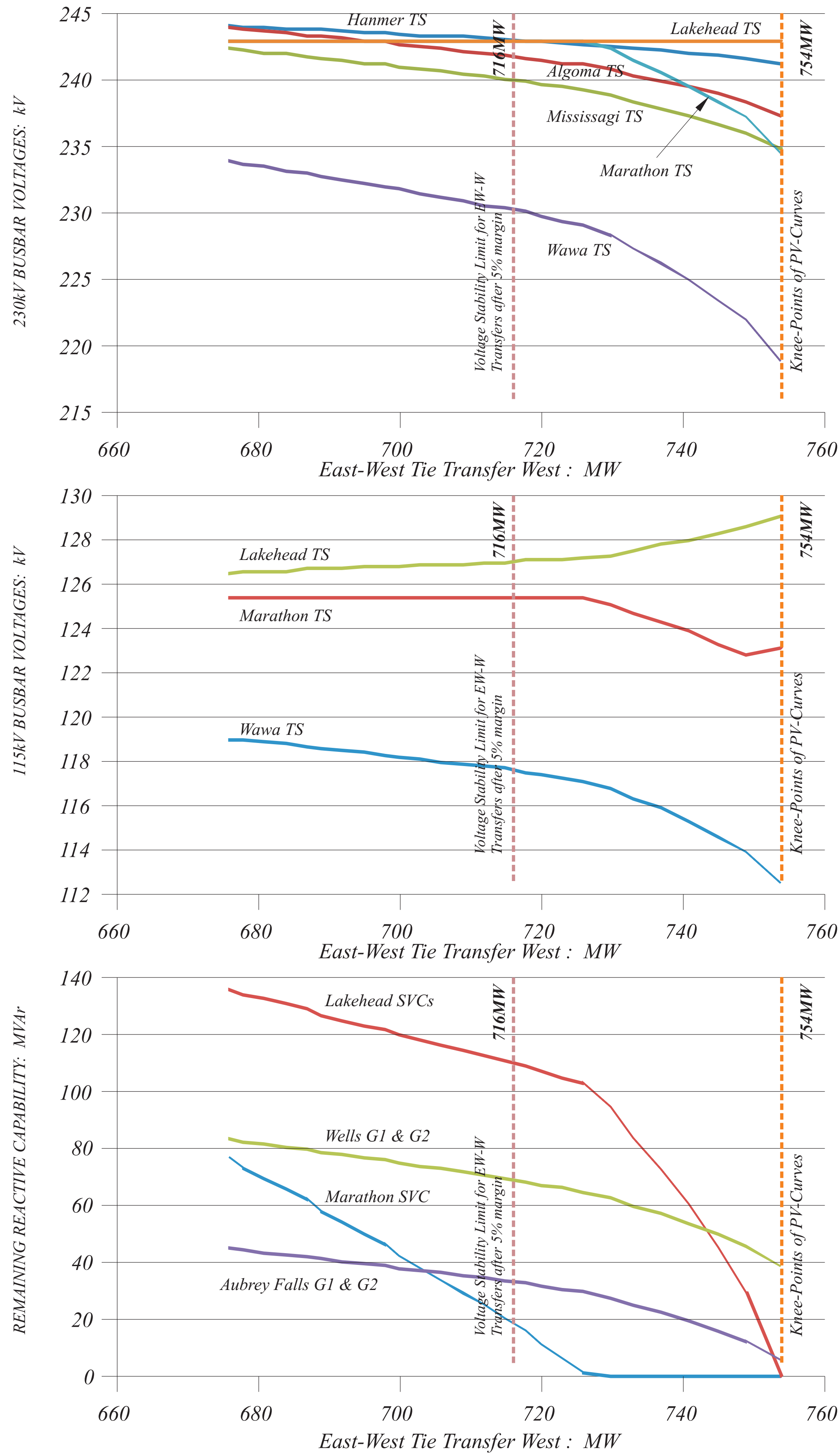
With 40% Series Compensation on the new Wawa x Marathon line

Contingency: 230kV double-circuit W21M + W22M Wawa TS to Marathon TS

After Phase-Shifter action

DIAGRAM 20

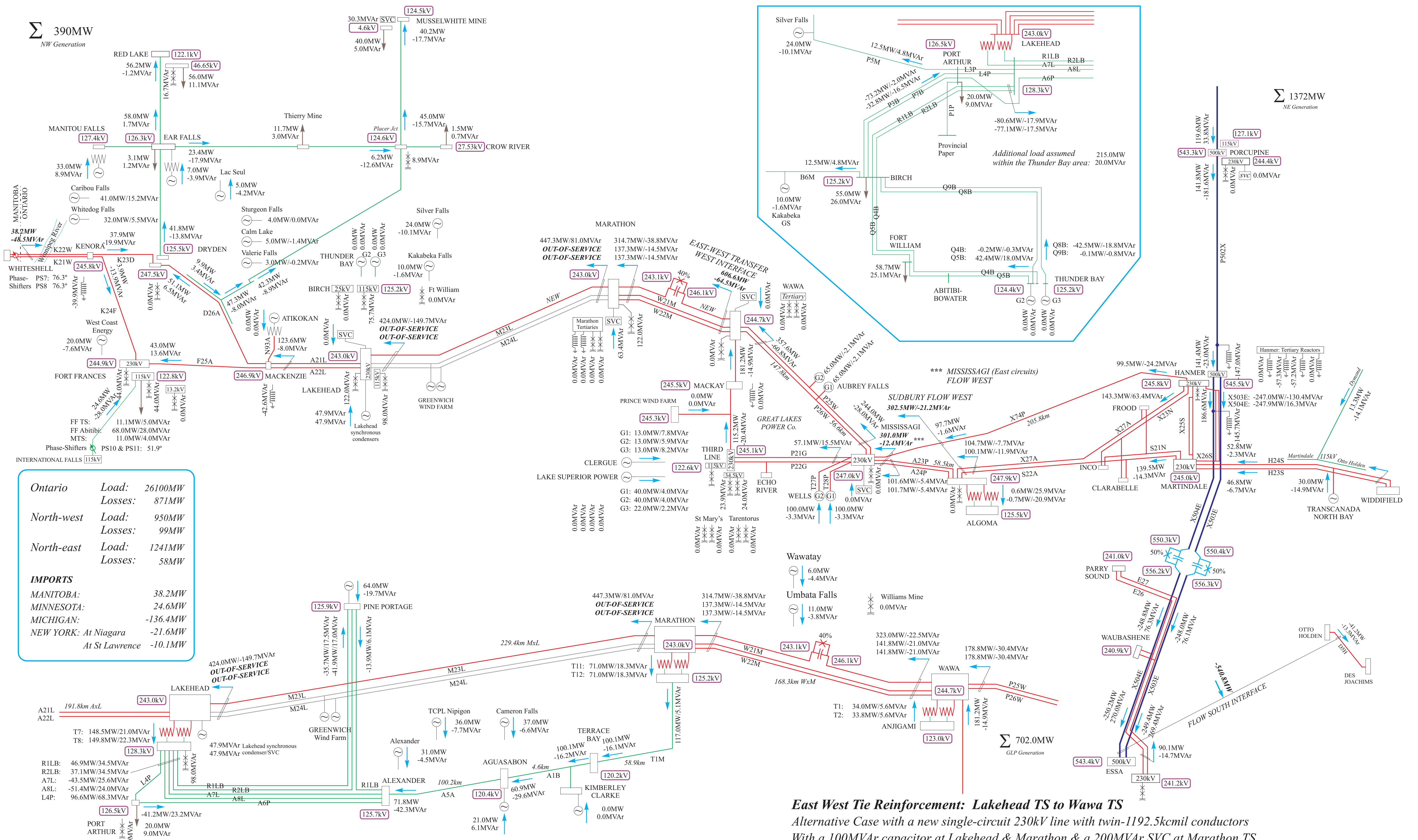
11th August 2011



PV-analysis
Marathon 200MVAr SVC + series caps on new WxM line

East West Tie Reinforcement: Lakehead TS to Wawa TS
Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors
Contingency: existing 230kV double-circuit Wawa TS to Marathon TS
After Phase-Shifter action

DIAGRAM 21
28th July 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

Alternative Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors

With a 100MVAr capacitor at Lakehead & Marathon & a 200MVAr SVC at Marathon TS

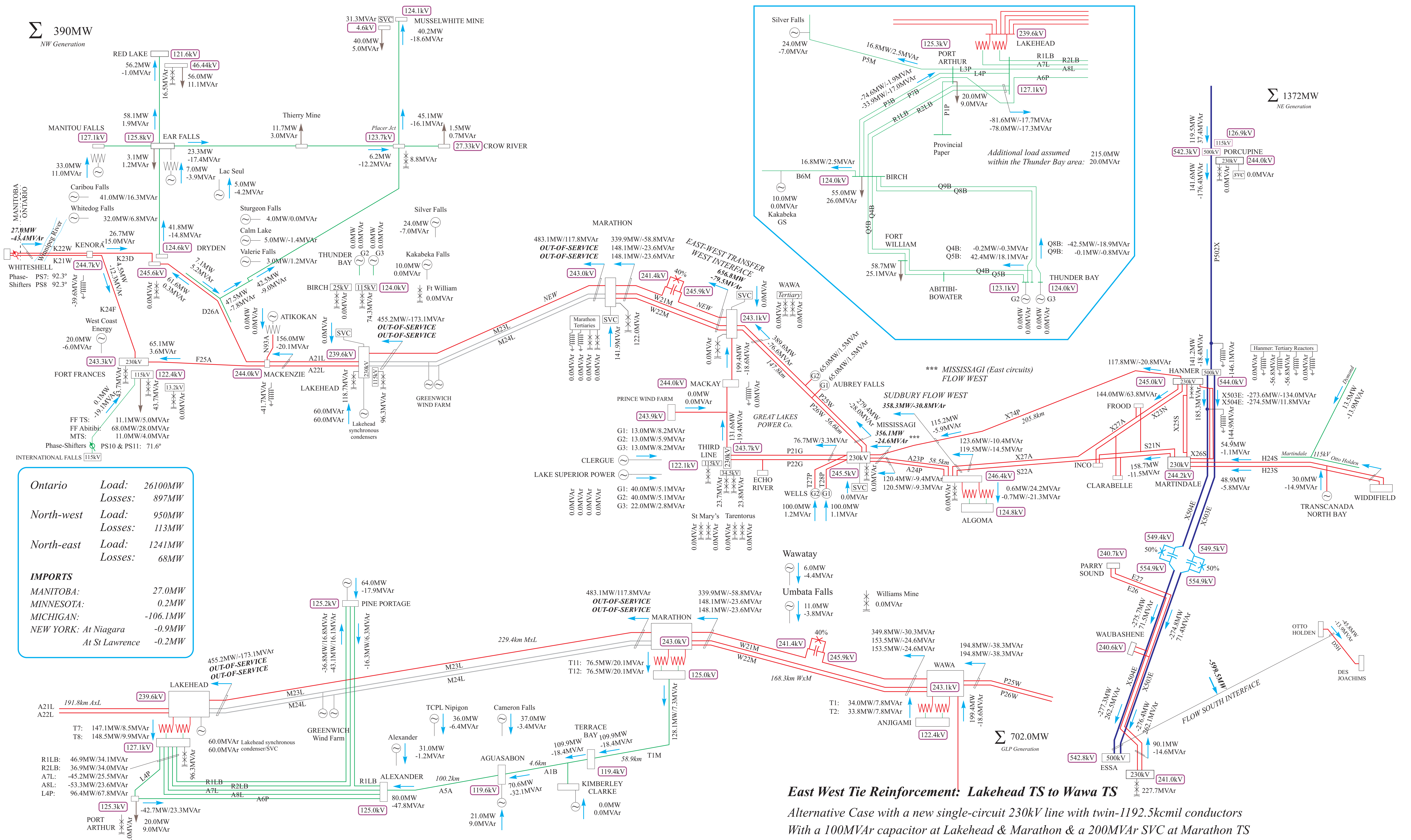
With 40% Series Compensation on the new Wawa x Marathon line

Contingency: 230kV double-circuit M23L + M24L Marathon TS to Lakehead TS

Prior to Phase-Shifter action

DIAGRAM 22

11th August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

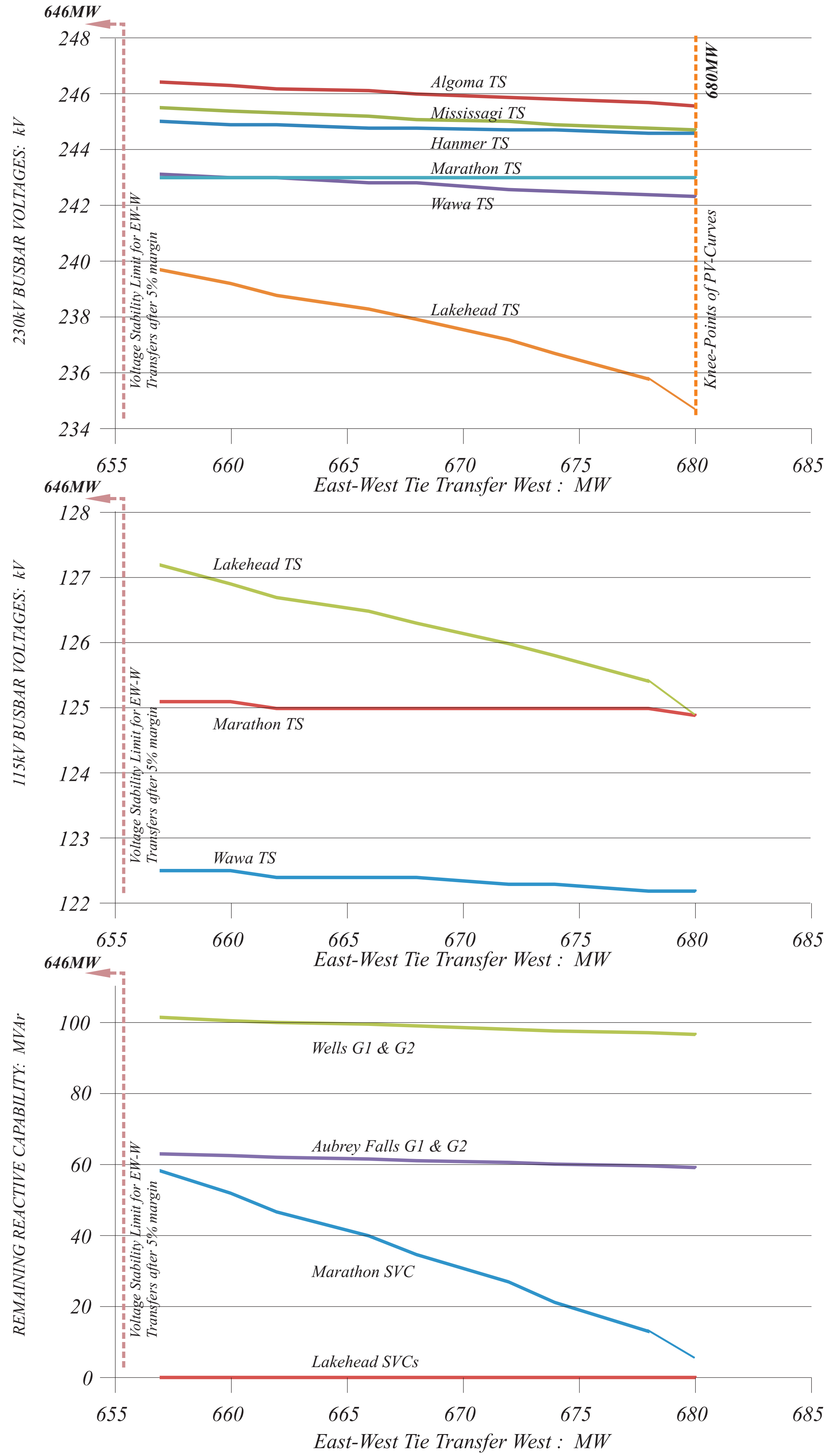
Alternative Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors
With a 100MVAr capacitor at Lakehead & Marathon & a 200MVAr SVC at Marathon TS
With 40% Series Compensation on the new Wawa x Marathon line

Contingency: 230kV double-circuit M23L + M24L Marathon TS to Lakehead TS

After Phase-Shifter action

DIAGRAM 23

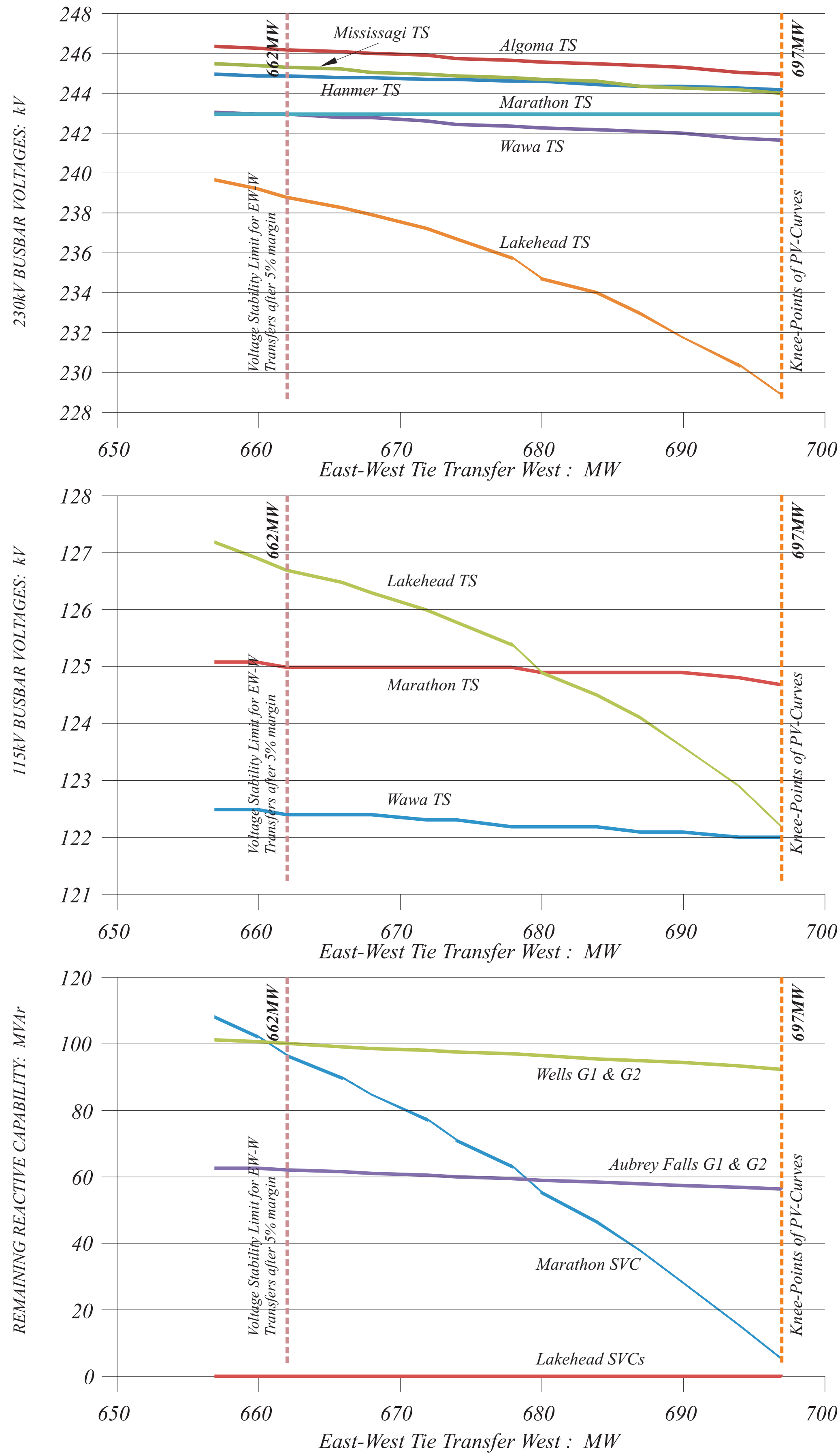
11th August 2011



PV-analysis
Marathon 200MVAr
SVC + series caps
on new WxM line

East West Tie Reinforcement: Lakehead TS to Wawa TS
Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors
Contingency: existing 230kV double-circuit Marathon TS to Lakehead TS
After Phase-Shifter action

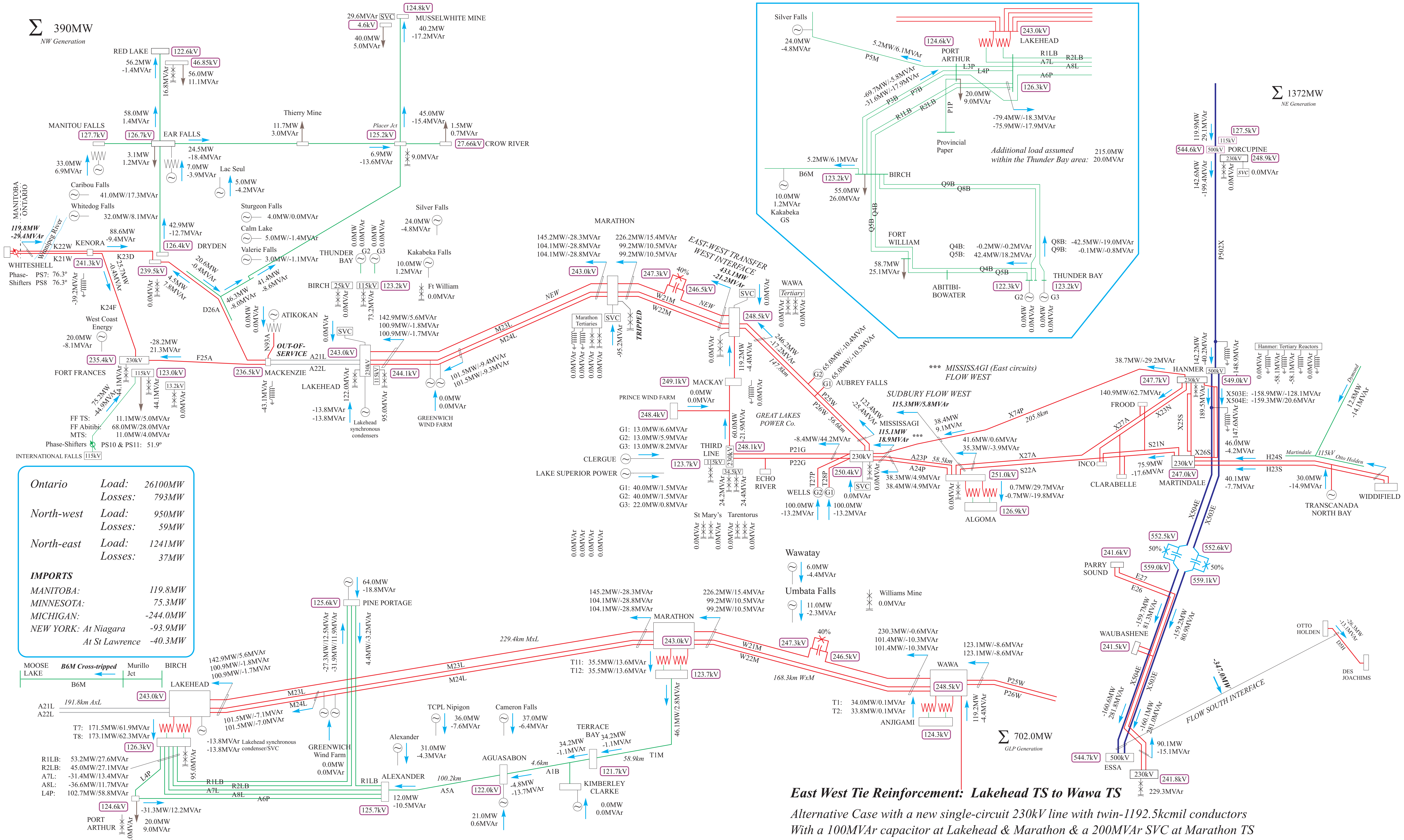
DIAGRAM 24
29th July 2011



PV-analysis
Marathon ***250MVAr***
SVC + series caps
on new WxM line

East West Tie Reinforcement: Lakehead TS to Wawa TS
Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors
Contingency: existing 230kV double-circuit Marathon TS to Lakehead TS
After Phase-Shifter action

DIAGRAM 25
29th July 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

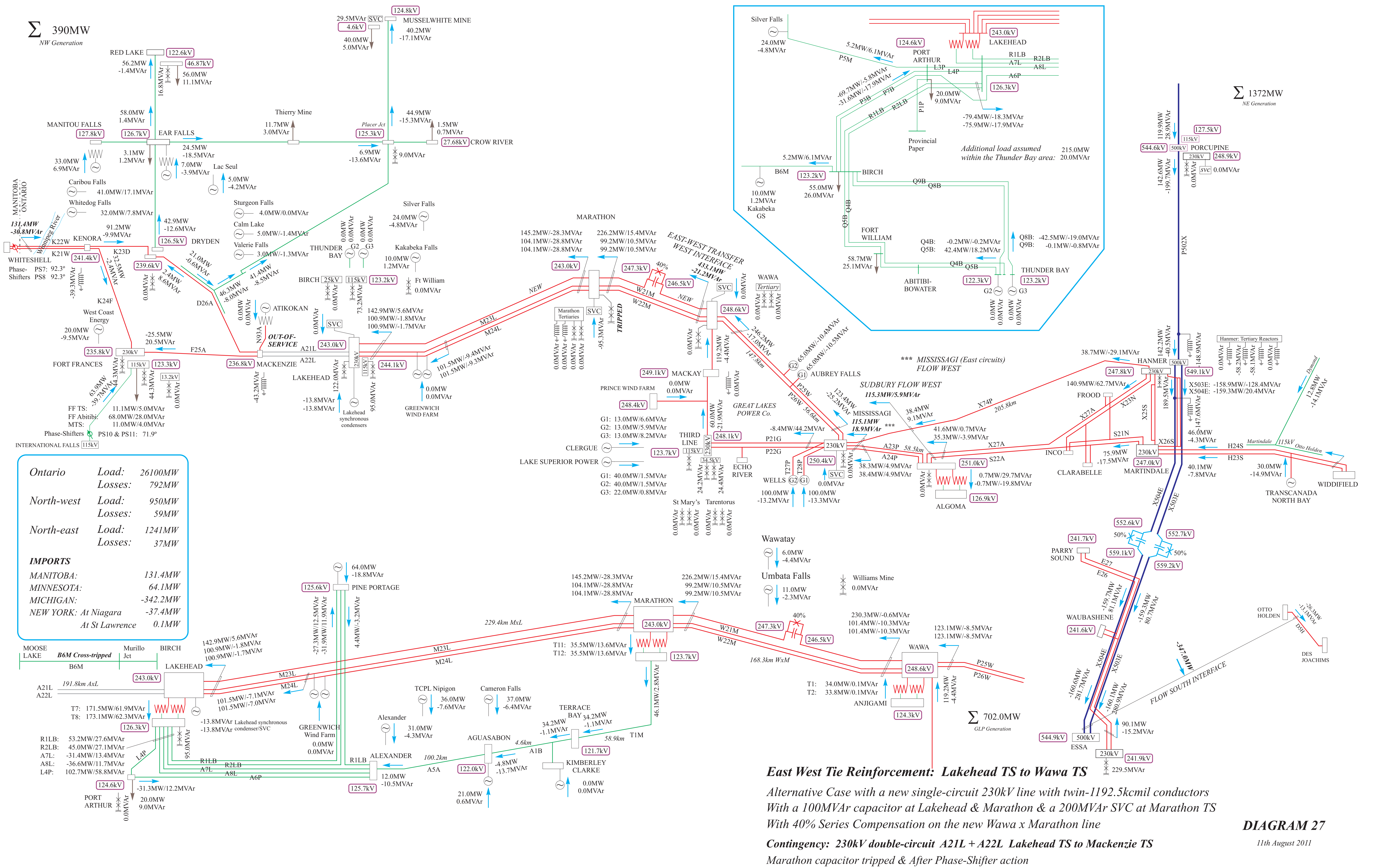
Alternative Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors
With a 100MVAr capacitor at Lakehead & Marathon & a 200MVAr SVC at Marathon TS
With 40% Series Compensation on the new Wawa x Marathon line

DIAGRAM 26

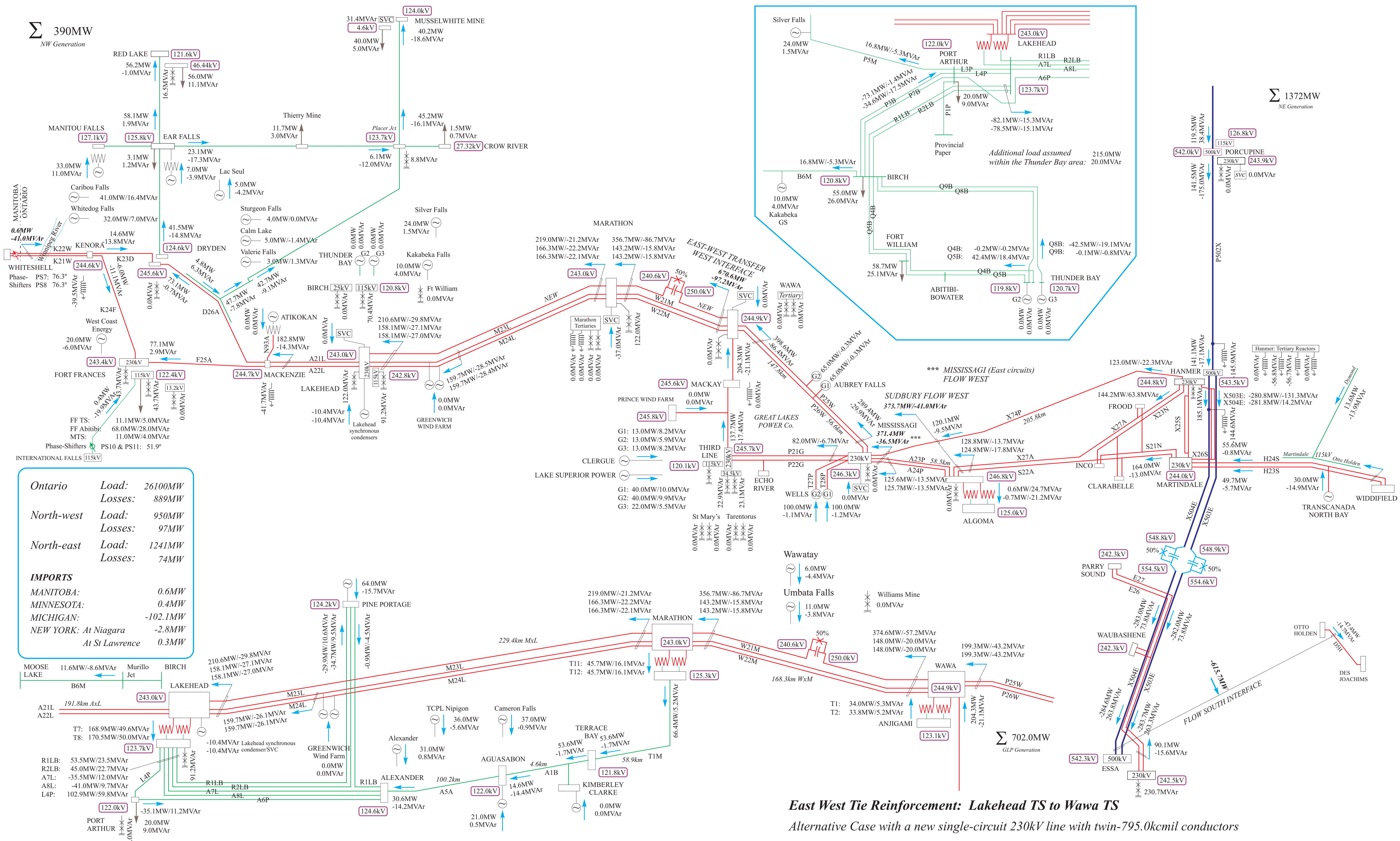
11th August 2011

Contingency: 230kV double-circuit A21L + A22L Lakehead TS to Mackenzie TS

Marathon capacitor tripped & Prior to Phase-Shifter action



Σ 390MW
NW Generation
Σ 1372MW
NE Generation
Σ 702.0MW
GLP Generation
Ontario Load: 26100MW
Losses: 792MW
North-west Load: 950MW
Losses: 59MW
North-east Load: 1241MW
Losses: 37MW
IMPORTS
MANITOBA: 131.4MW
MINNESOTA: 64.1MW
MICHIGAN: -342.2MW
NEW YORK: At Niagara -37.4MW
At St Lawrence 0.1MW
EAST-WEST TRANSFER
WEST INTERFACE
433.1MW
-21.2MVAr
SUDBURY FLOW WEST
115.3MW/5.9MVAr
*** MISSISSAGI (East circuits) FLOW WEST
FLOW SOUTH INTERFACE
-347.0MW
Additional load assumed within the Thunder Bay area: 215.0MW 20.0MVAr
B6M Cross-tripped
OUT-OF-SERVICE
TRIPPED
East West Tie Reinforcement: Lakehead TS to Wawa TS
Alternative Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors
With a 100MVAr capacitor at Lakehead & Marathon & a 200MVAr SVC at Marathon TS
With 40% Series Compensation on the new Wawa x Marathon line
Contingency: 230kV double-circuit A21L + A22L Lakehead TS to Mackenzie TS
Marathon capacitor tripped & After Phase-Shifter action
DIAGRAM 27
11th August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

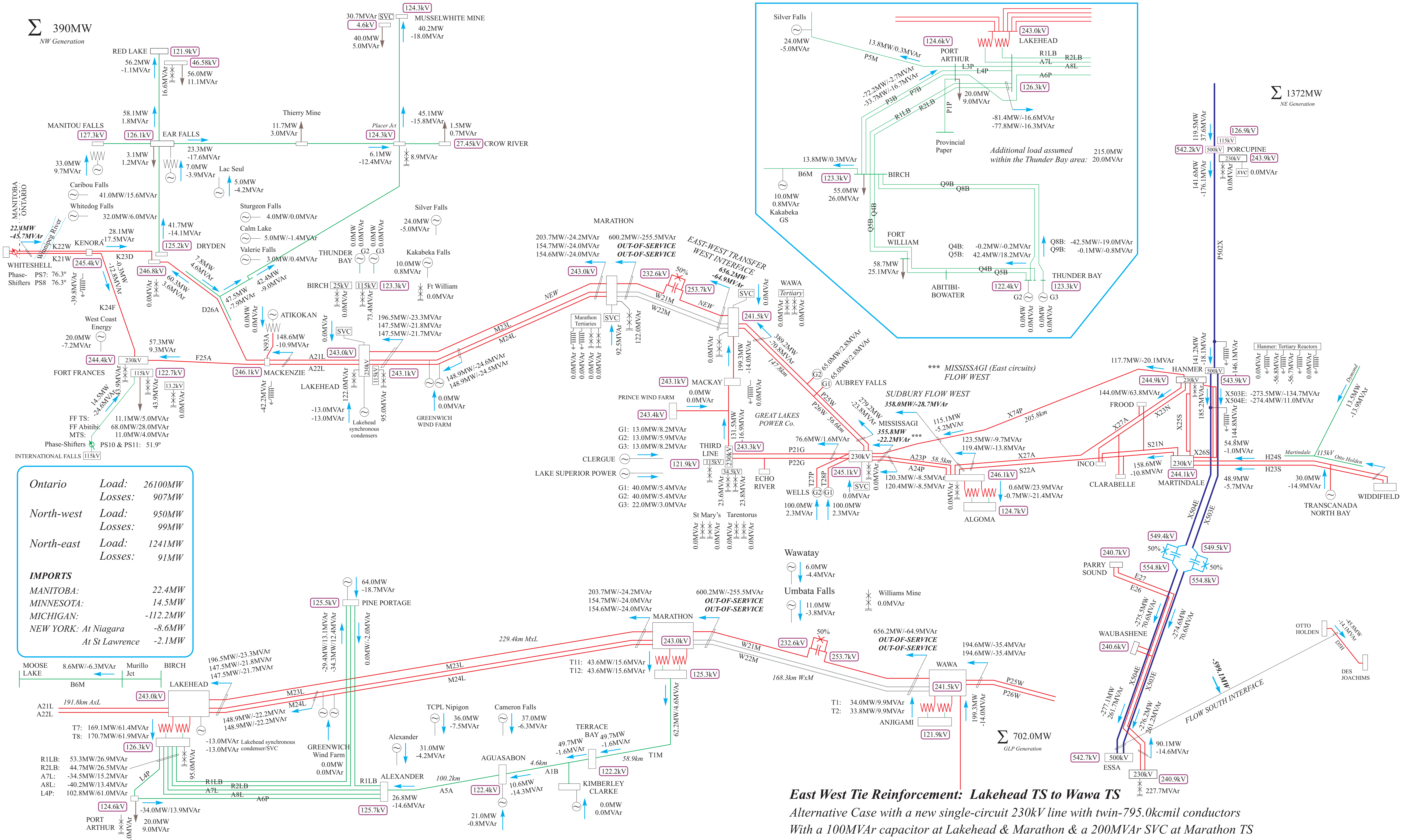
Alternative Case with a new single-circuit 230kV line with twin-795.0kcmil conductors

With a 100MVAr capacitor at Lakehead & Marathon & a 200MVAr SVC at Marathon TS

With 50% Series Compensation on the new Wawa x Marathon line

DIAGRAM 28

11th August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

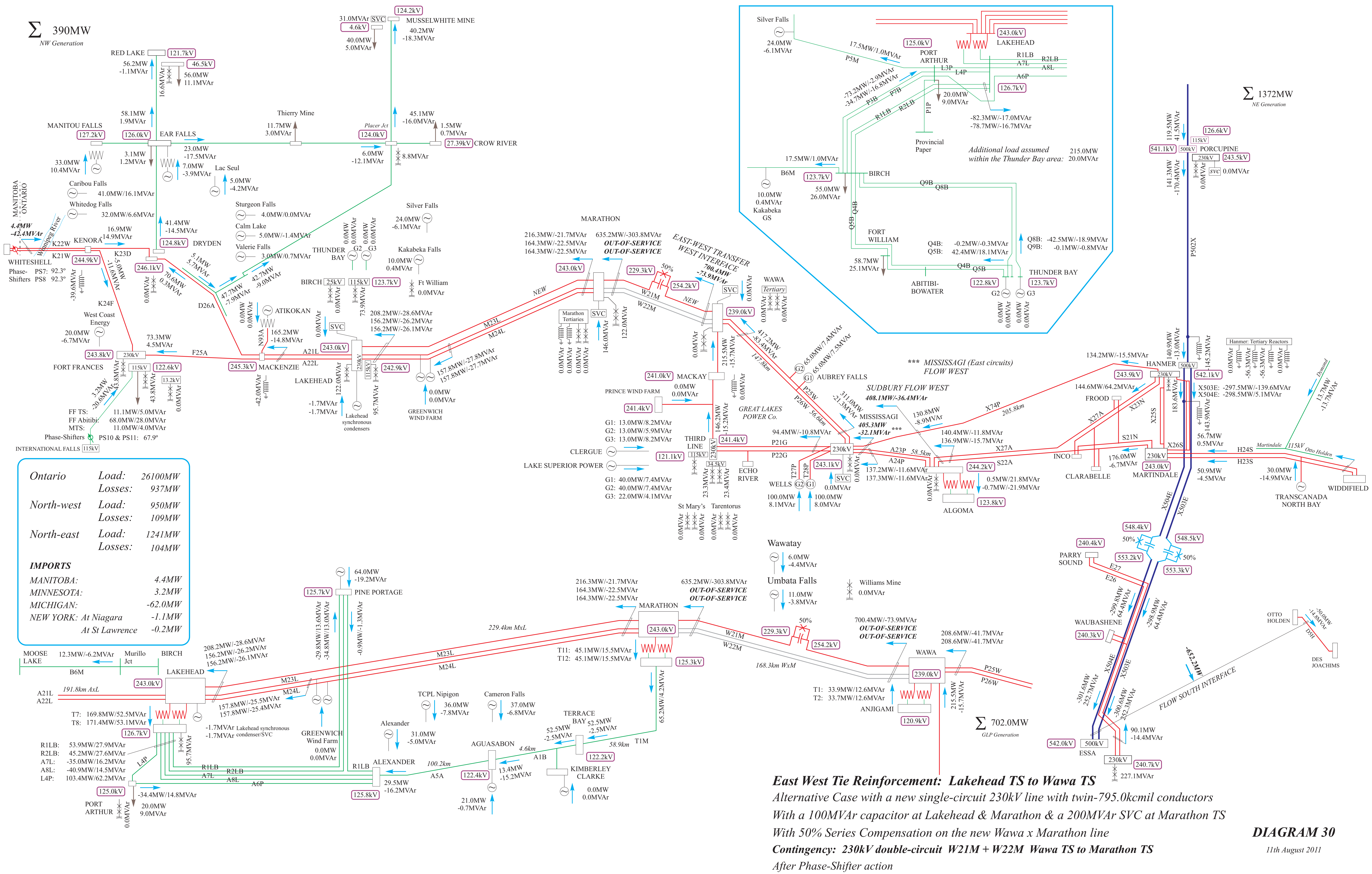
Alternative Case with a new single-circuit 230kV line with twin-795.0kcmil conductors
With a 100MVAr capacitor at Lakehead & Marathon & a 200MVAr SVC at Marathon TS
With 50% Series Compensation on the new Wawa x Marathon line

Contingency: 230kV double-circuit W21M + W22M Wawa TS to Marathon TS

Prior to Phase-Shifter action

DIAGRAM 29

11th August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

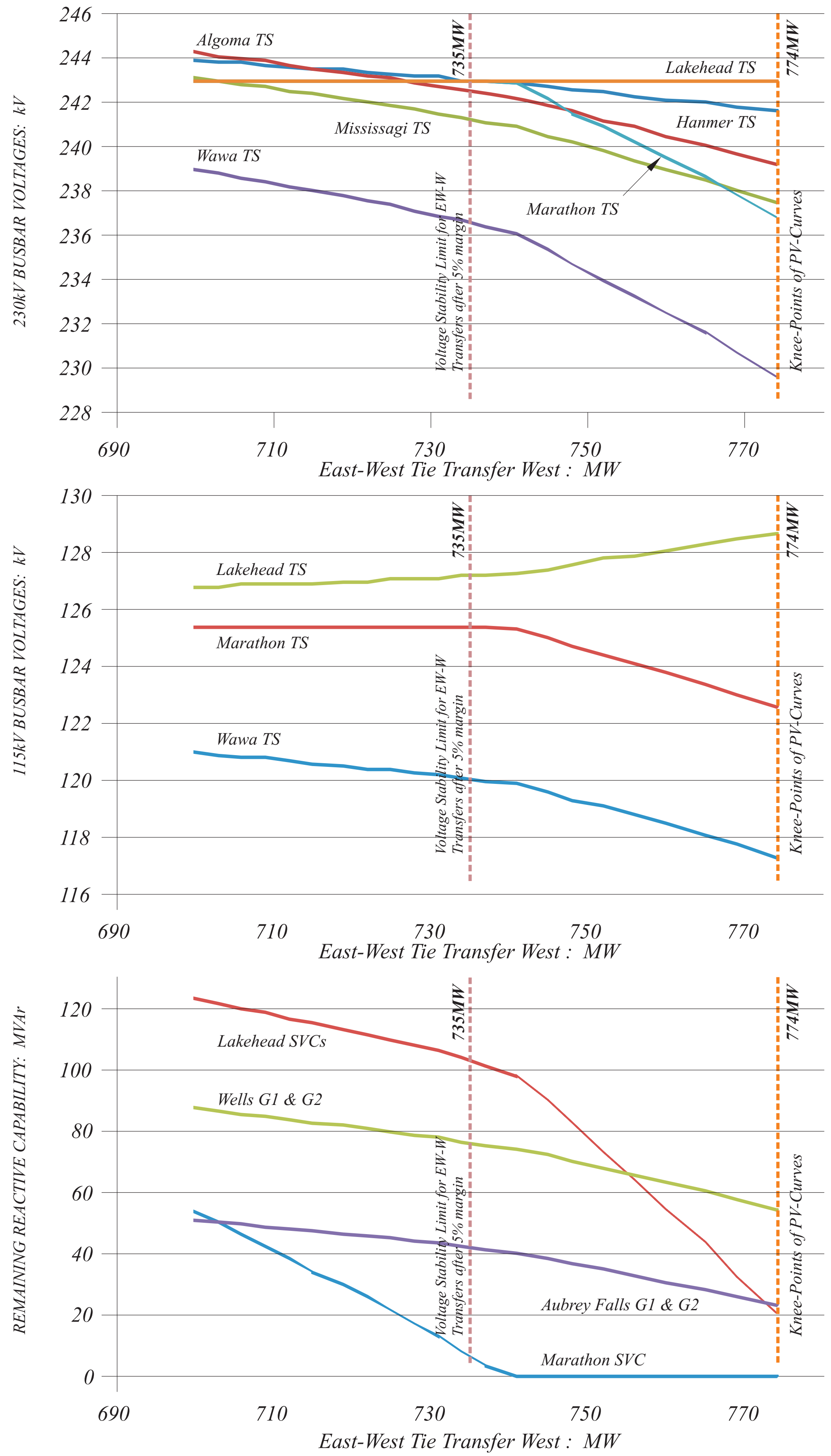
Alternative Case with a new single-circuit 230kV line with twin-795.0kcmil conductors

With a 100MVAr capacitor at Lakehead & Marathon & a 200MVAr SVC at Marathon TS

With 50% Series Compensation on the new Wawa x Marathon line

Contingency: 230kV double-circuit W21M + W22M Wawa TS to Marathon TS

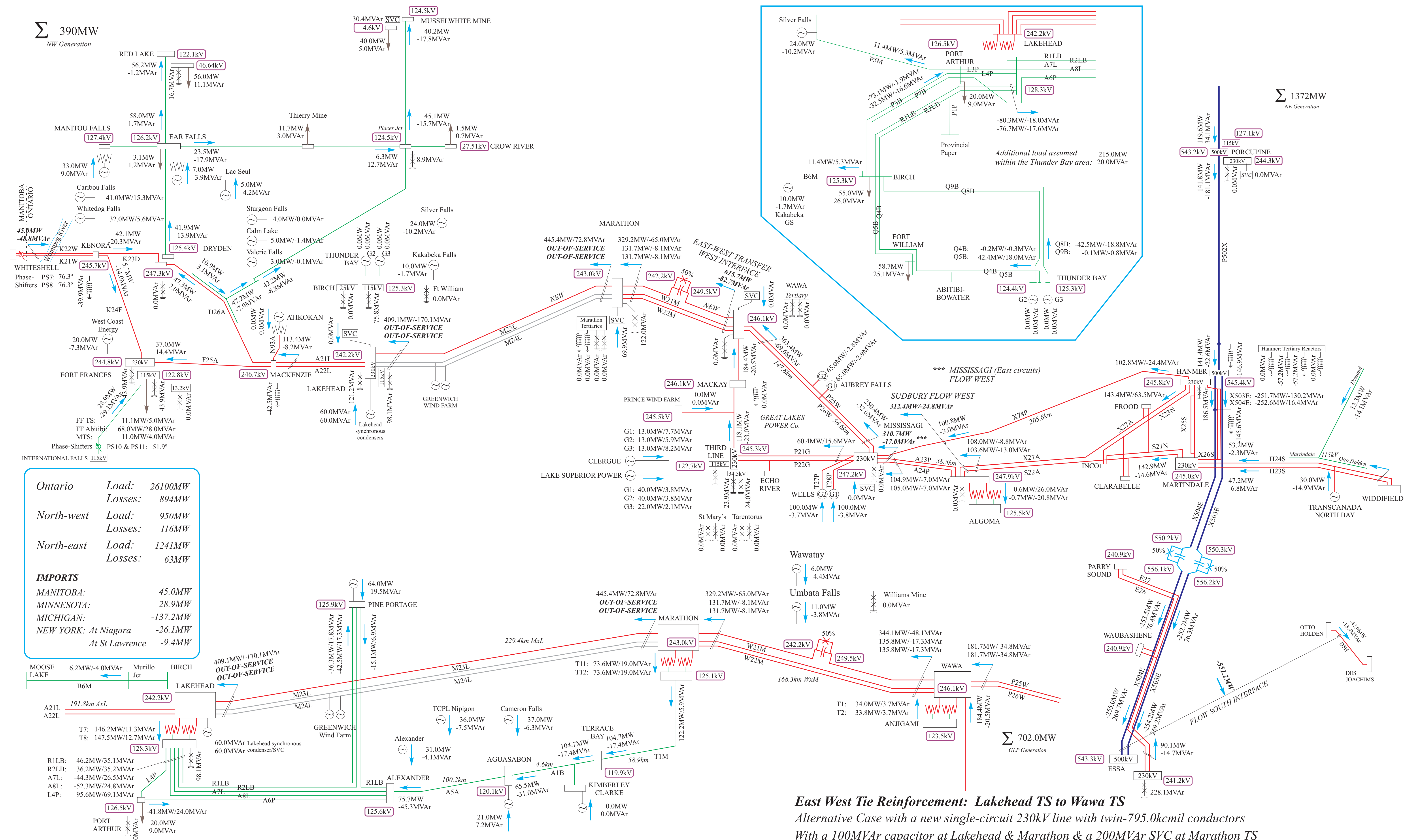
After Phase-Shifter action



PV-analysis
Marathon 200MVAr SVC + series caps on new WxM line

East West Tie Reinforcement: Lakehead TS to Wawa TS
Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors
Contingency: existing 230kV double-circuit Wawa TS to Marathon TS
After Phase-Shifter action

DIAGRAM 31
1st August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

Alternative Case with a new single-circuit 230kV line with twin-795.0kcmil conductors

With a 100MVAr capacitor at Lakehead & Marathon & a 200MVAr SVC at Marathon TS

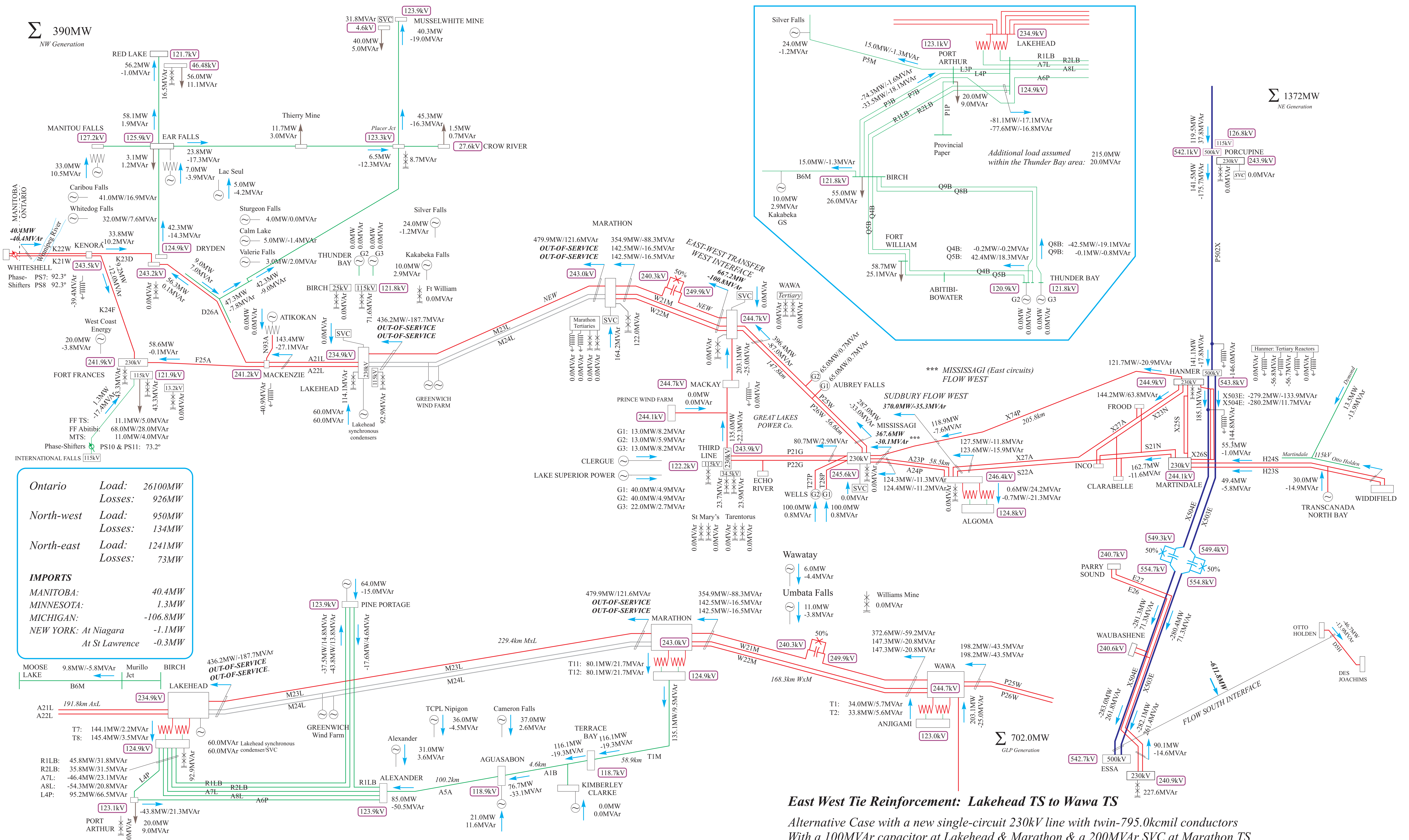
With 50% Series Compensation on the new Wawa x Marathon line

Contingency: 230kV double-circuit M23L + M24L Marathon TS to Lakehead TS

Prior to Phase-Shifter action

DIAGRAM 32

11th August 2011

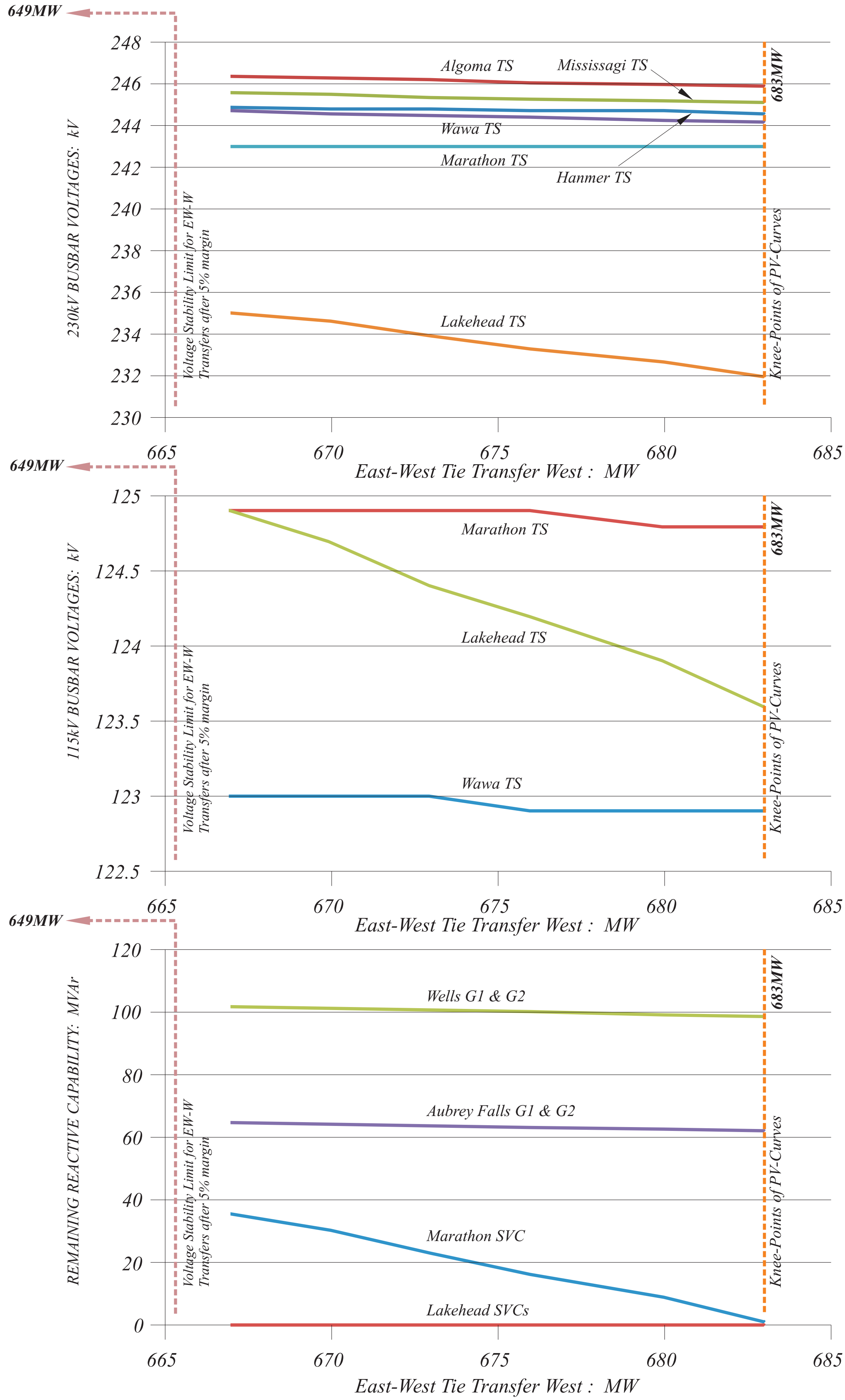


East West Tie Reinforcement: Lakehead TS to Wawa TS

Alternative Case with a new single-circuit 230kV line with twin-795.0kcmil conductors
With a 100MVAr capacitor at Lakehead & Marathon & a 200MVAr SVC at Marathon TS
With 50% Series Compensation on the new Wawa x Marathon line
Contingency: 230kV double-circuit M23L + M24L Marathon TS to Lakehead TS
After Phase-Shifter action

DIAGRAM 33

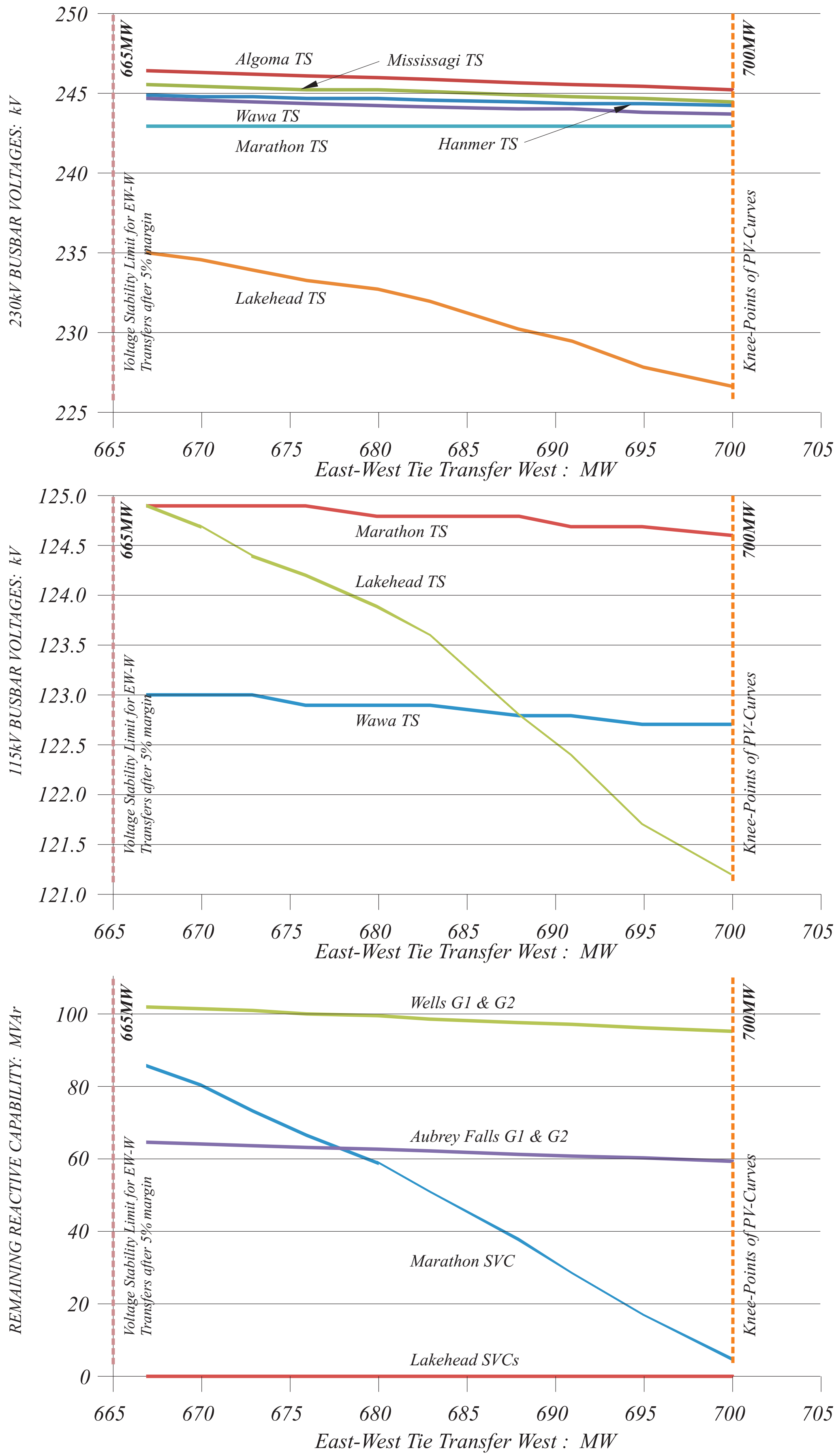
11th August 2011



PV-analysis
Marathon 200MVAr SVC + 50% series caps on new WxM line

East West Tie Reinforcement: Lakehead TS to Wawa TS
Case with a new single-circuit 230kV line with twin-795.0kcmil conductors
Contingency: existing 230kV double-circuit Marathon TS to Lakehead TS
After Phase-Shifter action

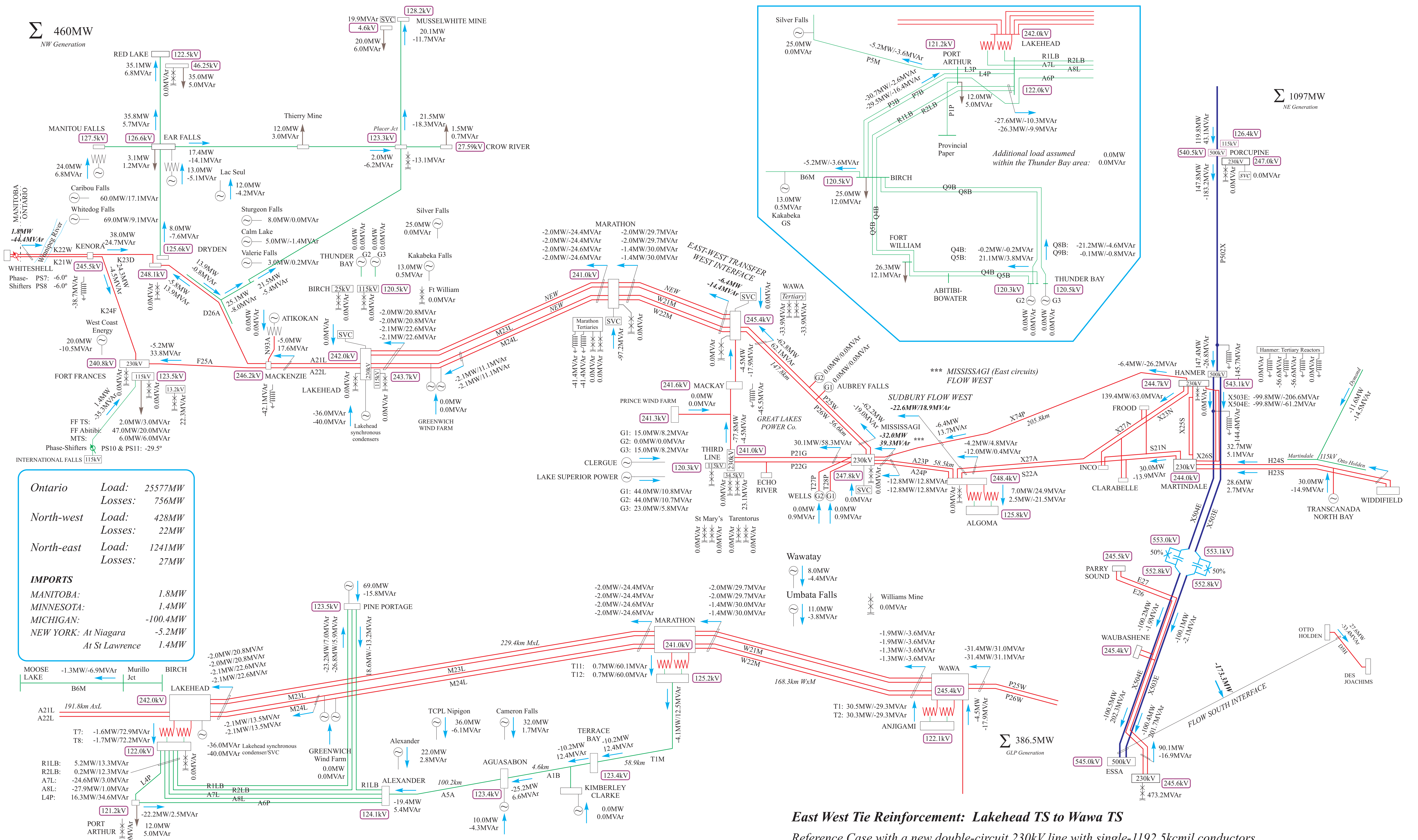
DIAGRAM 34
1st August 2011



PV-analysis
*Marathon **250MVAr***
SVC + 50% series
caps on new WxM line

East West Tie Reinforcement: Lakehead TS to Wawa TS
Case with a new single-circuit 230kV line with twin-795.0kcmil conductors
Contingency: existing 230kV double-circuit Marathon TS to Lakehead TS
After Phase-Shifter action

DIAGRAM 35
1st August 2011

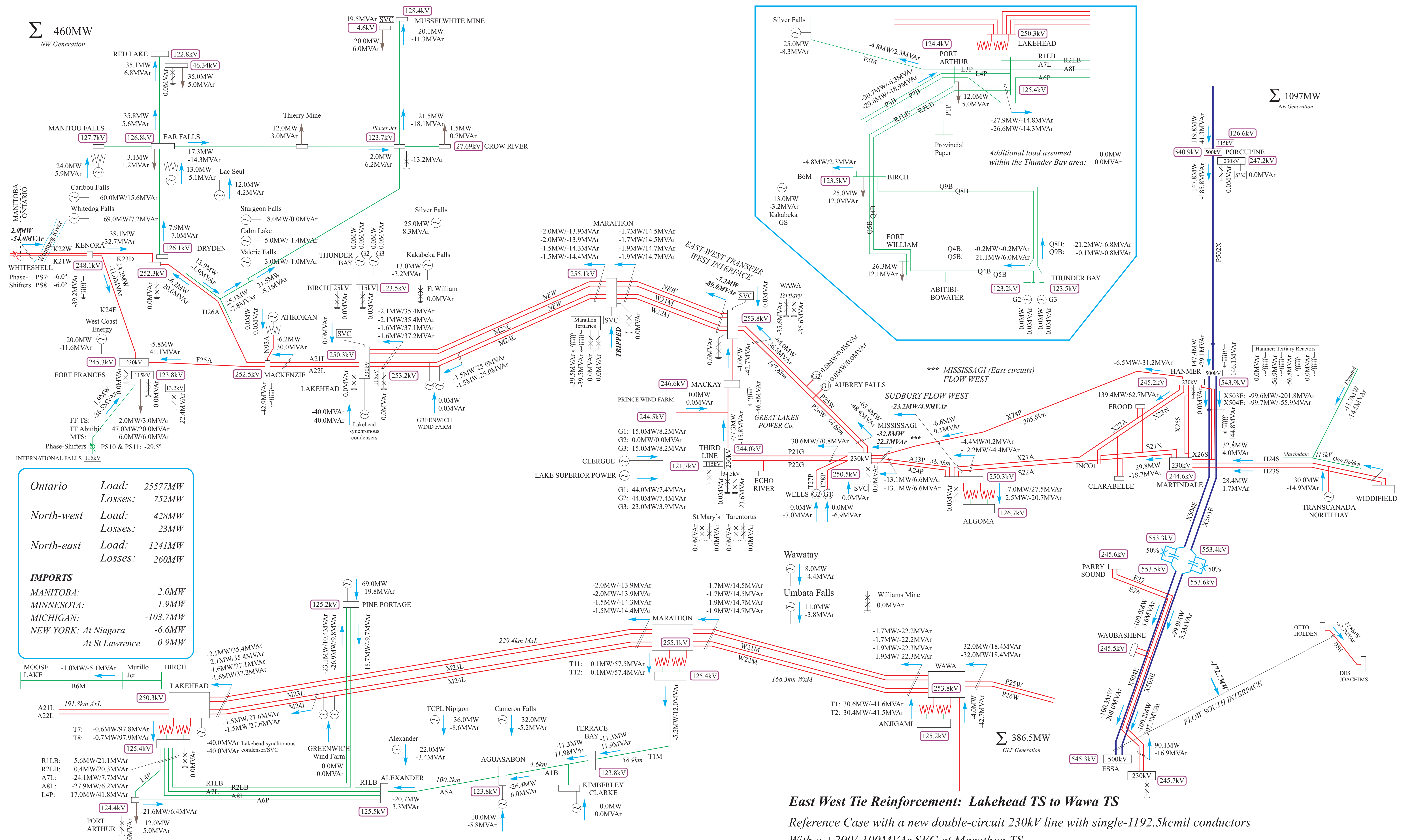


East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
With a +200/-100MVAr SVC at Marathon TS
Condition with reduced loads & transfers of approximately 0MW on the East-West Tie

DIAGRAM 36

11th August 2011



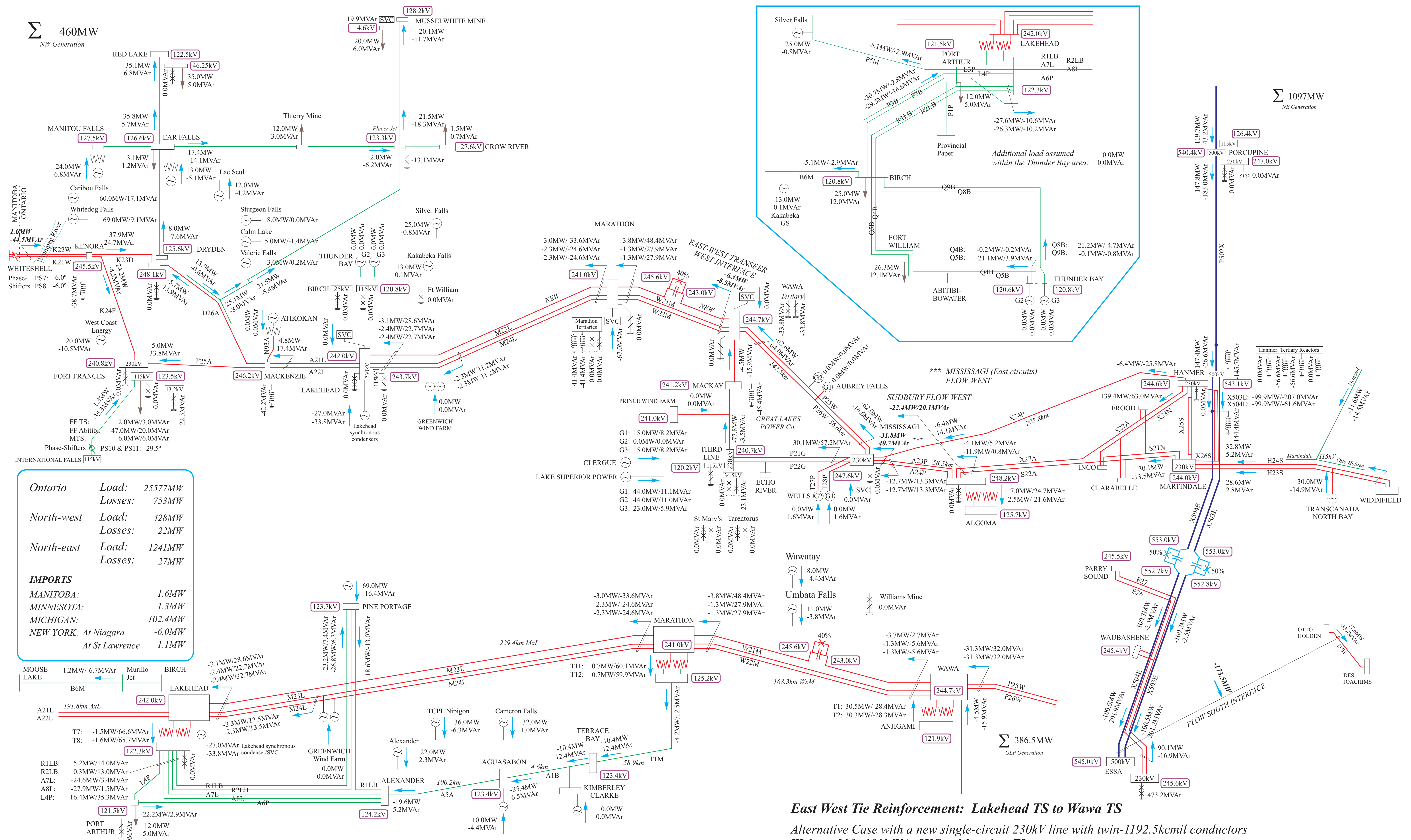
East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
With a +200/-100MVAr SVC at Marathon TS
Condition with reduced loads & transfers of approximately 0MW on the East-West Tie

Contingency: Marathon SVC tripped

DIAGRAM 37

11th August 2011

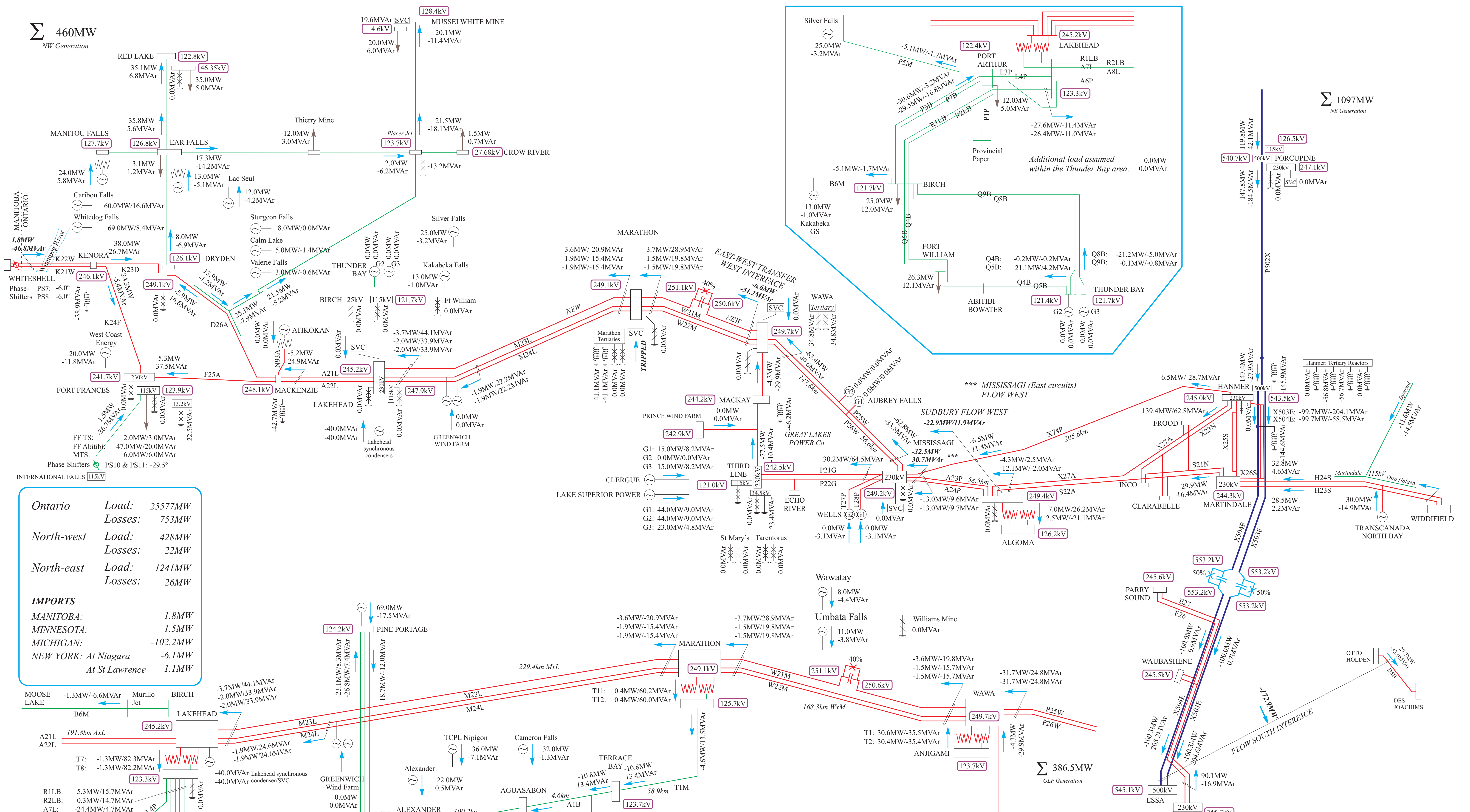


East West Tie Reinforcement: Lakehead TS to Wawa TS

Alternative Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors
With a +200/-100MVAr SVC at Marathon TS
With 40% series compensation at the mid-point of the new Wawa TS to Marathon TS line
Condition with reduced loads & transfers of approximately 0MW on the East-West Tie

DIAGRAM 38

11th August 2011



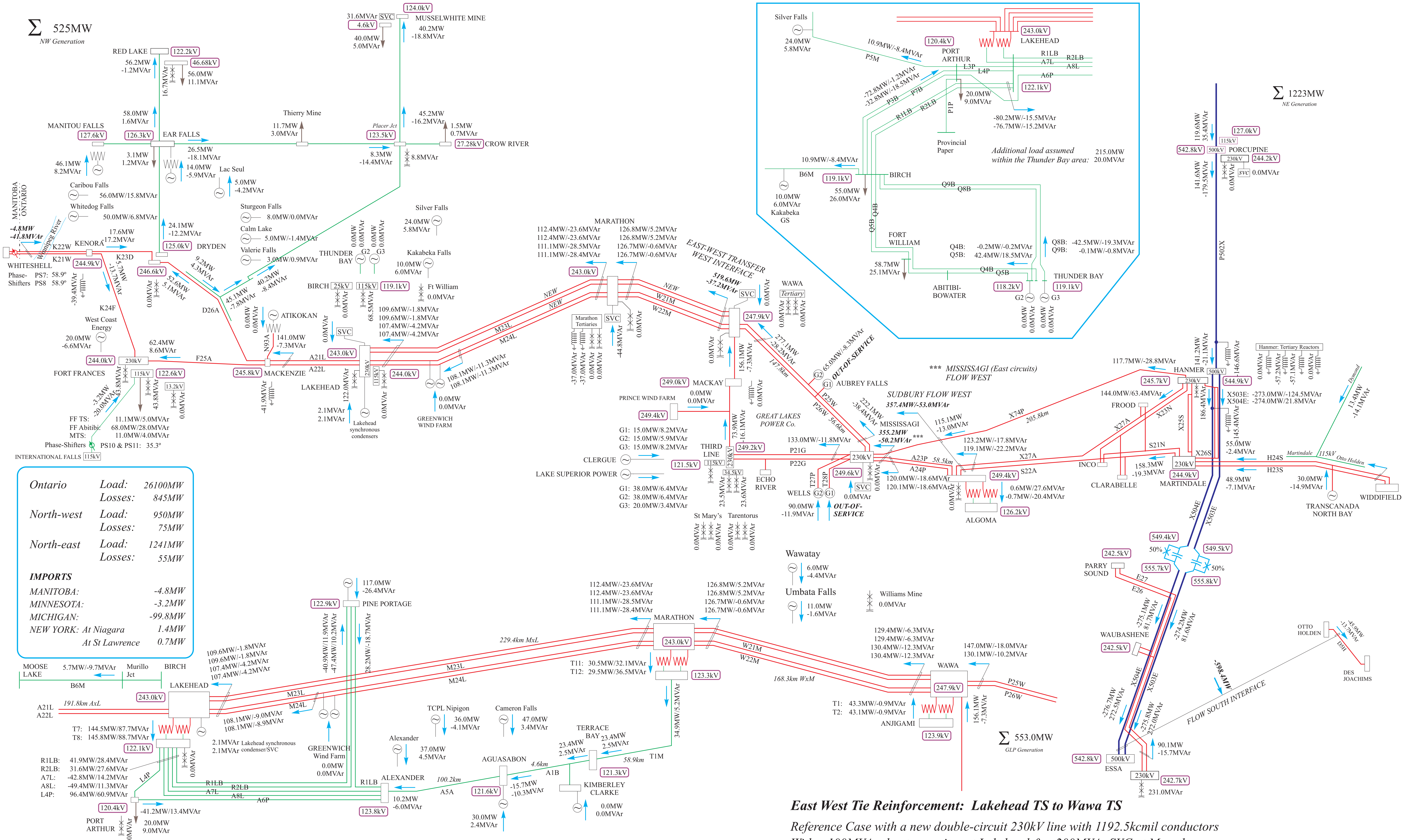
East West Tie Reinforcement: Lakehead TS to Wawa TS

Alternative Case with a new single-circuit 230kV line with twin-1192.5kcmil conductors
With a +200/-100MVAr SVC at Marathon TS
With 40% series compensation at the mid-point of the new Wawa TS to Marathon TS line
Condition with reduced loads & transfers of approximately 0MW on the East-West Tie

Contingency: Marathon SVC tripped

DIAGRAM 39

11th August 2011

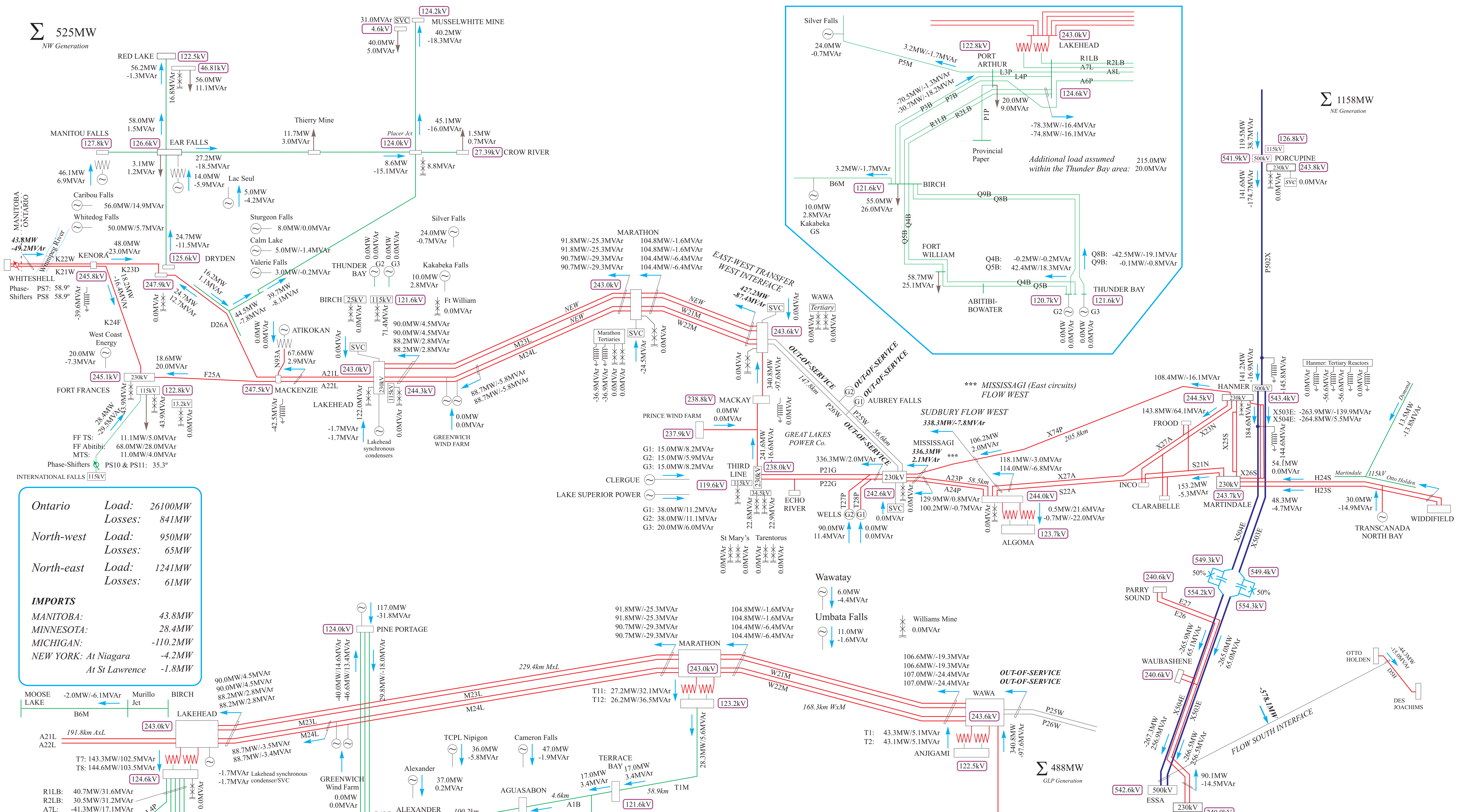


East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with 1192.5kcmil conductors
With a 100MVAr shunt capacitor at Lakehead & a 200MVAr SVC at Marathon
With one unit at Aubrey Falls GS & at Wells GS out-of-service
With an EW Tie transfer of 500MW westwards & a Sudbury Flow West transfer of 350MW

DIAGRAM 40

11th August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with 1192.5kcmil conductors

With a 100MVAr shunt capacitor at Lakehead & a 200MVAr SVC at Marathon. With one Aubrey + one Wells unit

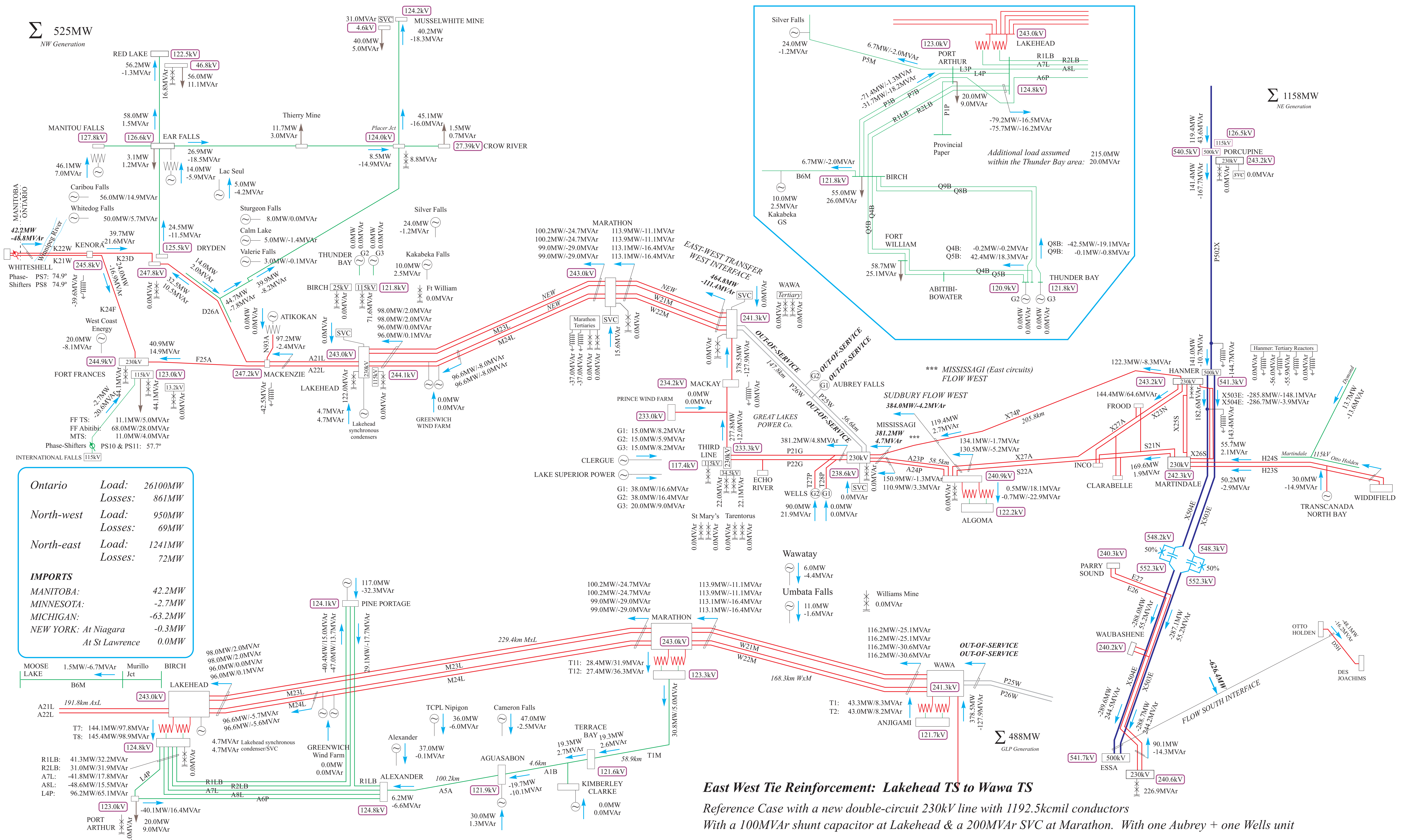
With an EW Tie transfer of 500MW westwards & a Sudbury Flow West transfer of 350MW

Contingency: 230kV double-circuit involving circuits P25W & P26W - Mississagi to Wawa

Prior to Phase Shifter action

DIAGRAM 41

11th August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with 1192.5kcmil conductors

With a 100MVAr shunt capacitor at Lakehead & a 200MVAr SVC at Marathon. With one Aubrey + one Wells unit

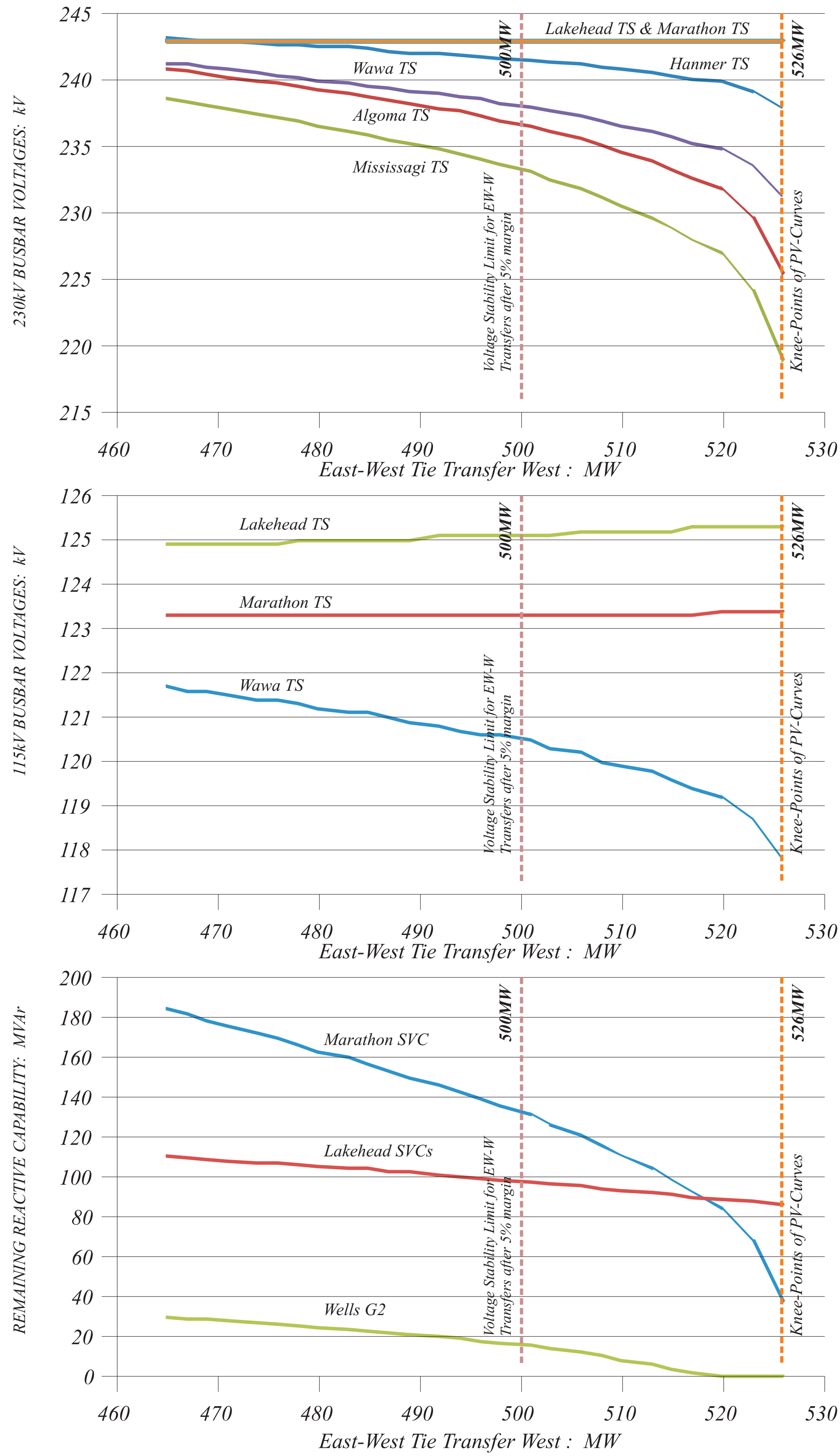
With an EW Tie transfer of 500MW westwards & a Sudbury Flow West transfer of 350MW

Contingency: 230kV double-circuit involving circuits P25W & P26W - Mississagi to Wawa

After Phase Shifter action

DIAGRAM 42

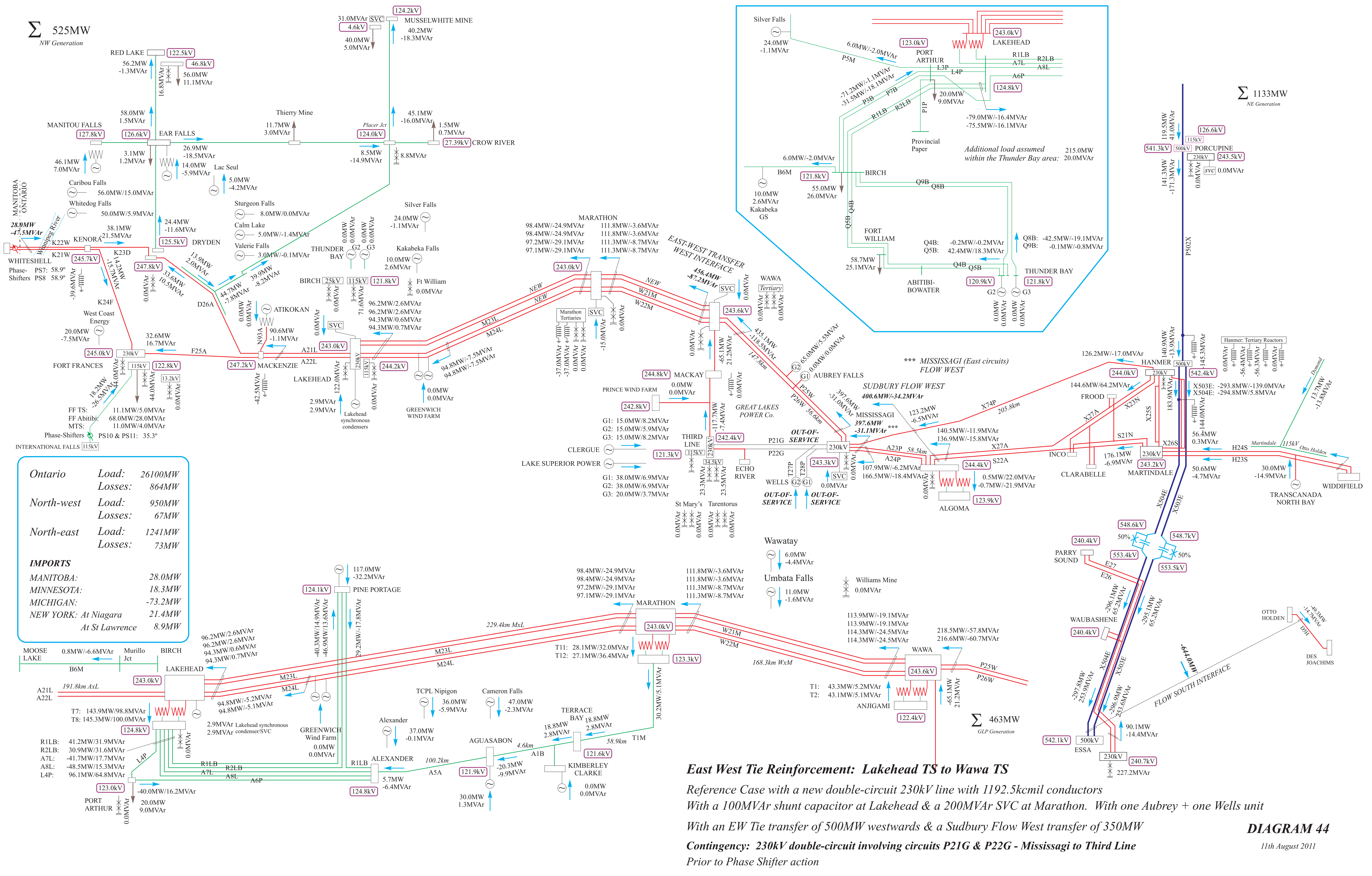
11th August 2011



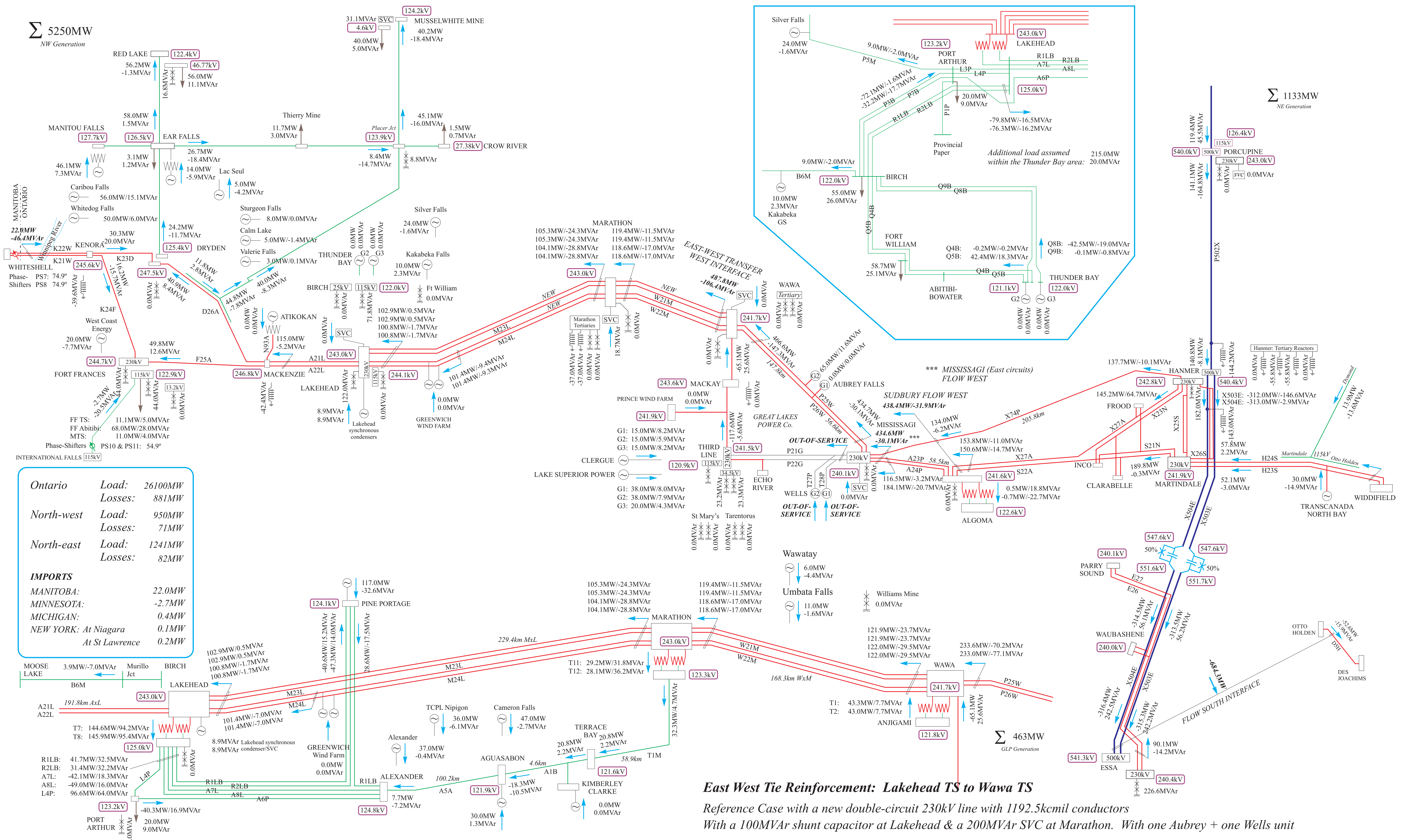
PV-analysis
Marathon
200MVAr SVC

East West Tie Reinforcement: Lakehead TS to Wawa TS
Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
Contingency: 230kV double-circuit P25W + P26W Mississagi TS to Wawa TS
After Phase-Shifter action

DIAGRAM 43
7th August 2011



Σ 525MW
NW Generation
Σ 1133MW
NE Generation
Σ 463MW
GLP Generation
Ontario Load: 26100MW
Losses: 864MW
North-west Load: 950MW
Losses: 67MW
North-east Load: 1241MW
Losses: 73MW
IMPORTS
MANITOBA: 28.0MW
MINNESOTA: 18.3MW
MICHIGAN: -73.2MW
NEW YORK: At Niagara 21.4MW
At St Lawrence 8.9MW
EAST-WEST TRANSFER
WEST INTERFACE
456.4MW
-87.2MVAr
SUDBURY FLOW WEST
400.6MW/-34.2MVAr
*** MISSISSAGI (East circuits) FLOW WEST
FLOW SOUTH INTERFACE
Additional load assumed within the Thunder Bay area: 215.0MW 20.0MVAr
RED LAKE
EAR FALLS
MANITOU FALLS
DRYDEN
KENORA
WHITESHELL
FORT FRANCES
INTERNATIONAL FALLS
MACKENZIE
LAKEHEAD
MARATHON
WAWA
MACKAY
MISSISSAGI
THIRD LINE
ALGOMA
HANMER
PORCUPINE
MARTINDALE
ESSA
PARRY SOUND
WAUBASHENE
OTTO HOLDEN
DES JOACHIMS
TRANSCANADA NORTH BAY
WIDDIFIELD
PINE PORTAGE
ALEXANDER
AGUASABON
TERRACE BAY
KIMBERLEY CLARKE
ANJIGAMI
PORT ARTHUR
BIRCH
THUNDER BAY
FORT WILLIAM
East West Tie Reinforcement: Lakehead TS to Wawa TS
Reference Case with a new double-circuit 230kV line with 1192.5kcmil conductors
With a 100MVAr shunt capacitor at Lakehead & a 200MVAr SVC at Marathon. With one Aubrey + one Wells unit
With an EW Tie transfer of 500MW westwards & a Sudbury Flow West transfer of 350MW
Contingency: 230kV double-circuit involving circuits P21G & P22G - Mississagi to Third Line
Prior to Phase Shifter action
DIAGRAM 44
11th August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with 1192.5kcmil conductors

With a 100MVAr shunt capacitor at Lakehead & a 200MVAr SVC at Marathon. With one Aubrey + one Wells unit

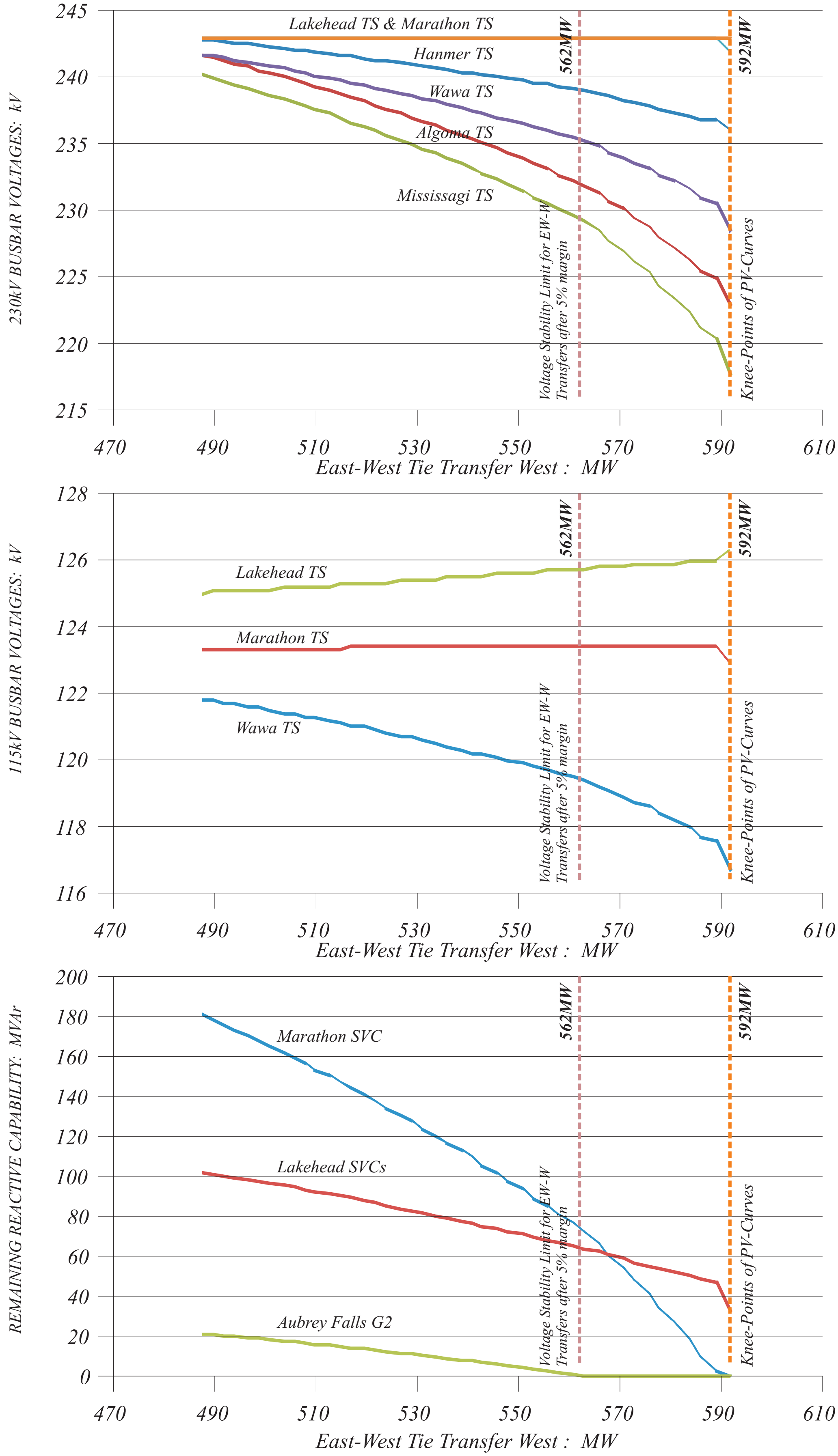
With an EW Tie transfer of 500MW westwards & a Sudbury Flow West transfer of 350MW

Contingency: 230kV double-circuit involving circuits P21G & P22G - Mississagi to Third Line

After Phase Shifter action

DIAGRAM 45

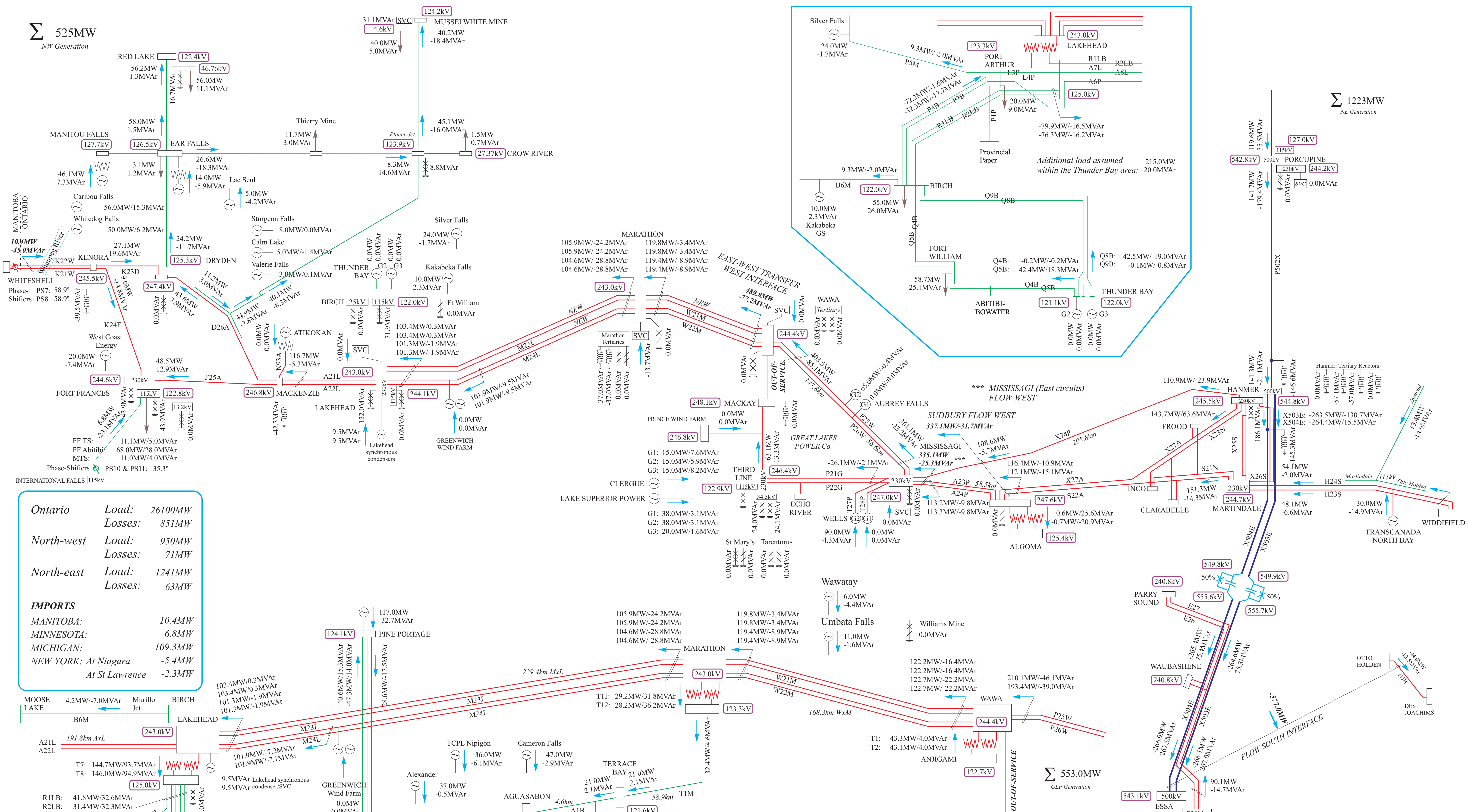
11th August 2011



PV-analysis
Marathon
200MVAr SVC

East West Tie Reinforcement: Lakehead TS to Wawa TS
Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
Contingency: existing 230kV double-circuit P21G + P22G Mississagi to Third Line
After Phase-Shifter action

DIAGRAM 46
7th August 2011



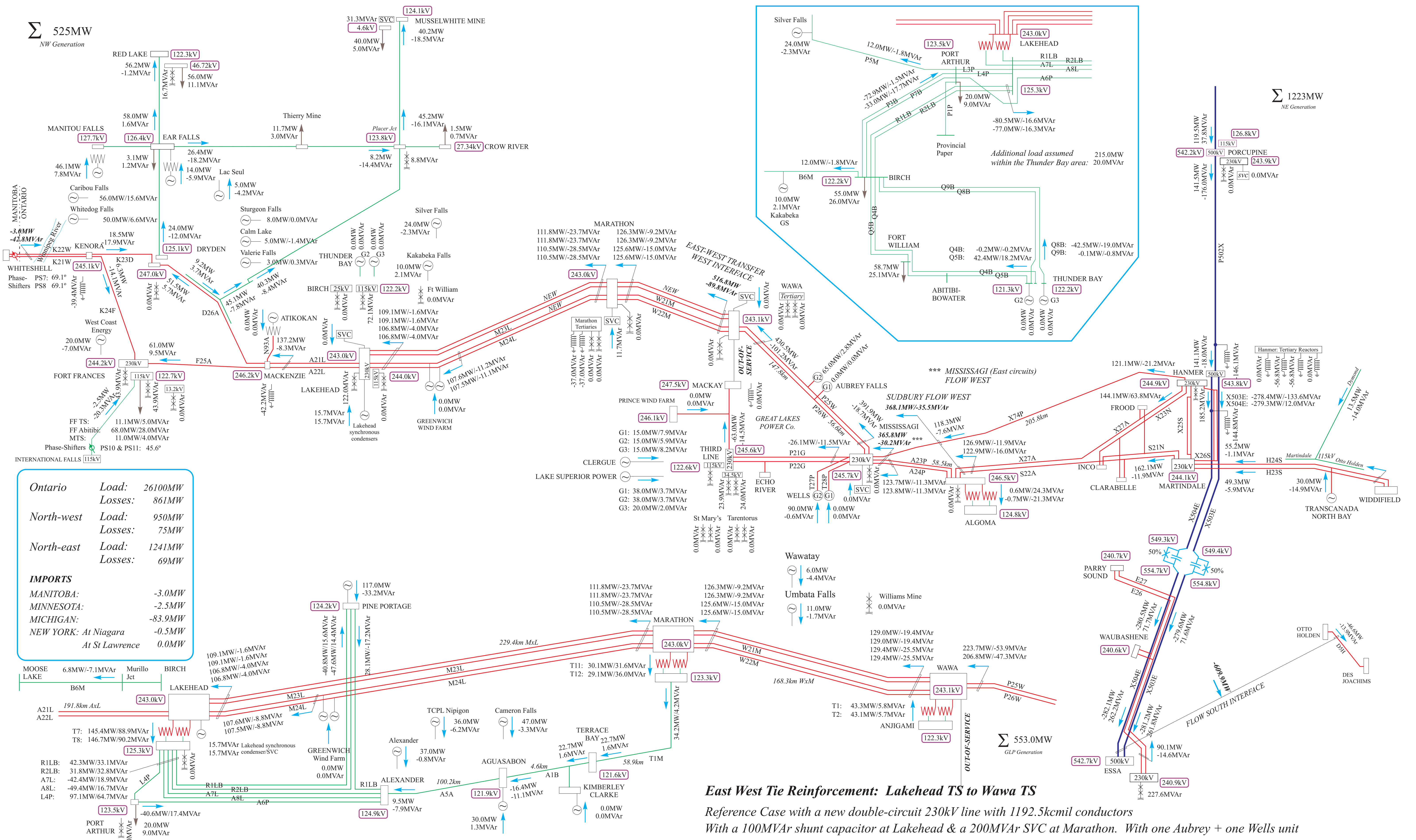
East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with 1192.5kcmil conductors
With a 100MVAr shunt capacitor at Lakehead & a 200MVAr SVC at Marathon. With one Aubrey + one Wells unit
With an EW Tie transfer of 500MW westwards & a Sudbury Flow West transfer of 350MW

Contingency: 230kV single-circuit involving circuit W23K - Wawa to MacKay
Prior to Phase Shifter action

DIAGRAM 47

11th August 2011



East West Tie Reinforcement: Lakehead TS to Wawa TS

Reference Case with a new double-circuit 230kV line with 1192.5kcmil conductors

With a 100MVAr shunt capacitor at Lakehead & a 200MVAr SVC at Marathon. With one Aubrey + one Wells unit

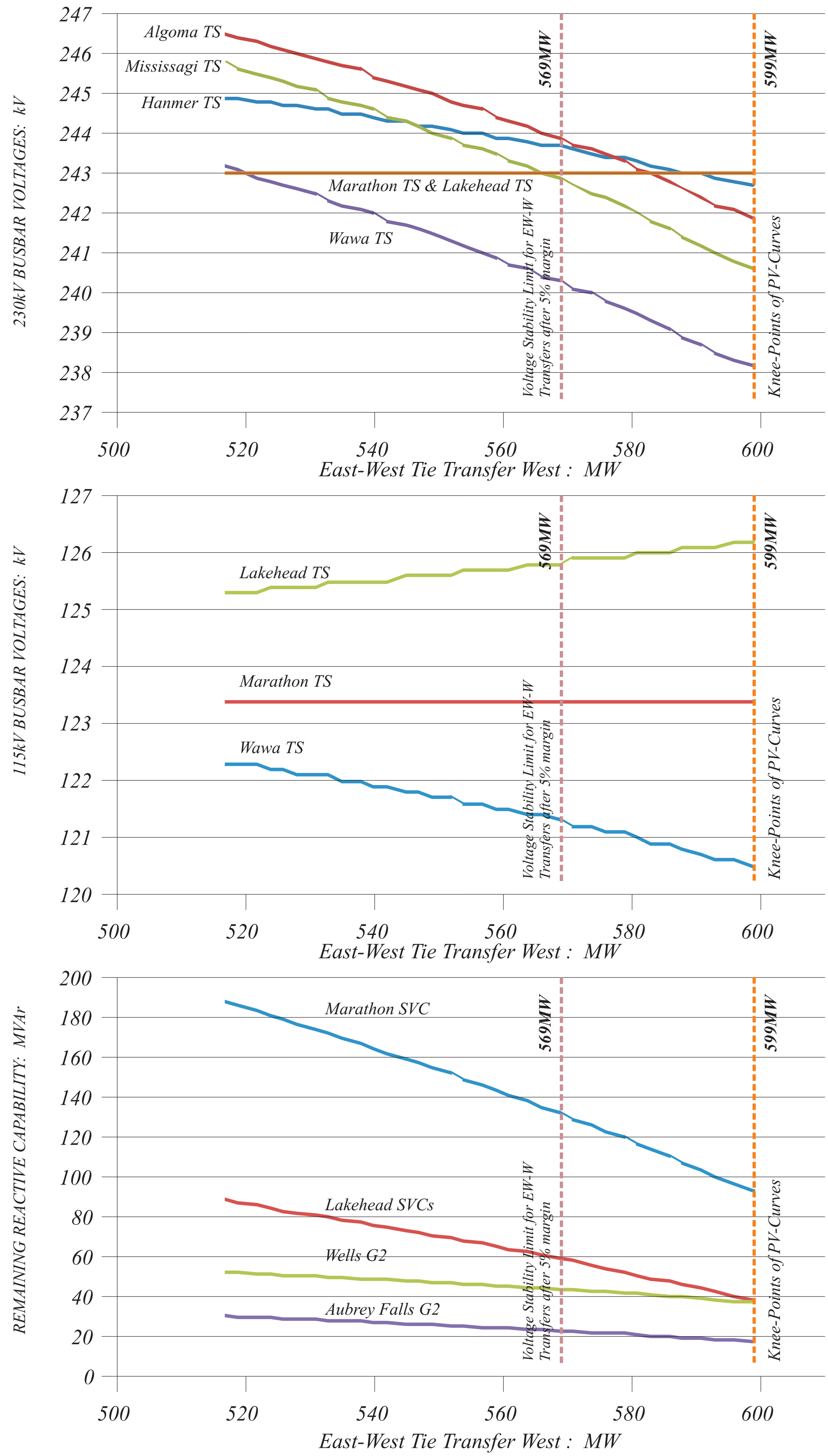
With an EW Tie transfer of 500MW westwards & a Sudbury Flow West transfer of 350MW

Contingency: 230kV single-circuit involving circuit W23K - Wawa to MacKay

After Phase Shifter action

DIAGRAM 48

11th August 2011



PV-analysis
Marathon
200MVAr SVC

East West Tie Reinforcement: Lakehead TS to Wawa TS
Case with a new double-circuit 230kV line with single-1192.5kcmil conductors
Contingency: 230kV single-circuit K23G Wawa TS to MacKay TS
After Phase-Shifter action

DIAGRAM 49
7th August 2011