IESO_REP_0272

REPORT

Power to Ontario.
On Demand.

May 27 Milton SS

3 Phase Fault Incident Report

Report to NPCC

Public

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1. Synopsis

- **Extreme Event :** NPCC extreme category contingency, NERC Category D contingency[1]: 3 phase to ground fault with delayed[2] clearing. This is considered a rare event.
- **Duration:** 156 milli-seconds (ms)
- **Root Cause:** switching error
- **Consequential events:** protection further tripped two 500 kV lines
- **Generation loss in Ontario:** An initial 50 MW with a consequential loss of an additional 750 MW 4 minutes after the initial event due to rapid unloading and reloading of two thermal units.
- **Load loss in Ontario:** Approximately 2300 MW (about 12.6% of the load at the time of the event) due to customer equipment protection operation, not due to loss of bulk system elements
- **Impact on Tie lines:** Peak increase of approximately 1000 MW & 980 MW on the Michigan & New York interfaces respectively to levels well within the interface capabilities.
- **Impact on other Control Areas:** The impact on the interconnected system was minimal. Voltage fluctuations and frequency oscillations were damped out within approximately 15 seconds. ITC (Michigan), NYISO, ISO-NE and NBSO reported no adverse impact. There were no other reported impacts.
- **Impact on BES Security:** System response was stable and very well damped. Oscillations subsided within approximately 15 seconds. There was no indication of poorly damped oscillations or of extended "ringing". Load loss was significant and unexpected. This is currently attributed to the length of time (breaker-fail time) to clear the fault, but has not been confirmed.

  Following fault clearing, voltage performance was acceptable and returned to pre-fault levels or above. IESO analysis shows that, with the exception of the significant load interruption, post-contingency voltage performance for this fault and the associated over-tripping would be better than that expected for the most severe fault the system was being operated to withstand.

  All equipment remained well within thermal ratings. Analysis showed that for the configuration on 27th of May, the circuit over tripping resulted in equipment loading

[1] As defined by NPCC Document A2 criterion and NERC Reliability Standard TPL-003-0
[2] The IESO operates to limits for 3 phase faults with normal clearing rather than delayed clearing.

that was not materially different from the thermal loading that is expected from the normal criteria contingencies that the grid was being operated to withstand.

Angle stability performance was assessed. Simulations confirmed that a 3-phase fault cleared in breaker-fail time will cause larger first swing oscillations than a normally cleared fault, but the response was stable, well damped, and well within existing stability criteria.

– End of Section –

2. Summary of the Event

On May 27, 2005, at 15:15 EST a rare 3 phase to ground fault occurred at the Milton transformer station, located 30 km west of Toronto. The fault subsequently led to the loss of approximately 2300MW of load in Ontario and voltage oscillations that were observed by neighbouring interconnected utilities.

The voltage excursions caused numerous individual loads (industrial, commercial and residential) to automatically trip throughout Ontario. Although the majority of load was disconnected in the Toronto area, load losses also occurred to a lesser extent to the far east and west of the province with minor amounts in the north. Intertie flows increased by about 980 MW on the New York interface and by some 1000 MW on the Michigan lines as a consequence of the load loss. Additionally, a small co-generator (50MW) tripped off almost immediately, followed by runback of two thermal units four (4) minutes later for an additional loss of about 750 MW.

The fault occurred during routine switching when operator error caused equipment to be energized, that was inadvertently connected to a grounded device. This resulted in a permanent, three-phase to ground fault. The fault was ultimately interrupted by the Milton KL572 breaker failure protection tripping the Milton KL561 breaker interrupting the fault in 156 ms. In addition, two 500 kV lines terminating at the Milton station were tripped unexpectedly by instantaneous protection originating from their remote terminals.

Frequency fluctuated during the event throughout the interconnected system and oscillations were damped after about 15 seconds. No adverse impacts were reported in neighbouring Control Areas.

Although the three phase fault caused short-lived oscillations on the power system, Ontario's BES is planned and operated to withstand faults that would have greater impacts, albeit shorter lived with less load loss, than the May 27th fault. Subsequent studies by the IESO show that the fault did not exceed the most severe contingency employed by the IESO to establish security limits that were in effect on the 27th of May,2005.

The transmitter and the IESO are currently conducting investigations including a review of the factors contributing to the switching error, including an independent review of the protection operations, and a sensitivity analysis of loads to voltage excursions. A full report will be issued once all the findings are available.

– End of Section –

3. Description of the Event

On May 27, 2005, a three phase ground fault occurred at the Milton transformer station. This subsequently led to the loss of approximately 2300MW of Ontario load. Ontario demand just prior to the fault was 18250 MW. Frequency was normal and all operating security limits were being respected. The IESO net scheduled interchange on the synchronous tie lines was close to zero megawatts (0 MW).

An overview of the Milton Station is illustrated in Figure 1. Prior to the event, the Milton K bus was out of service to provide safety clearances for crews working in the station. Crews were performing tests on the KL572 breaker which was undergoing a major planned overhaul. Upon completion of the test, the K bus was to return to service while KL572 breaker was to remain out of service for further planned work.

At 15:15 EST, without confirming the position of the KL572 breaker and its disconnect KL572-K, the transmitters' operator proceeded to close the KL561 breaker energizing the K bus and the KL572 breaker up to the KL572-L disconnect. A three phase to ground fault was produced through the KL572-G1 ground switch that is located between the KL572 breaker and the KL572-L disconnect. The Milton M572T terminal correctly tripped from its own line protection in 55 ms. However, the fault was still being fed through the KL561 breaker[3]. The KL572 breaker failure protection ultimately tripped the KL561 and interrupted the fault in 156 ms. Protection operations led to the tripping of circuits M572T, M573T and M570V. As well at 15:15:30 EST there was an emergency shutdown of a small 50 MW co-generator.

[3] The KL572 breaker was left in the test position and the 62a timer path disabled due to the pallet switch assembly being removed for breaker maintenance with the advanced breaker position auxiliary contact (aa) in the open position.

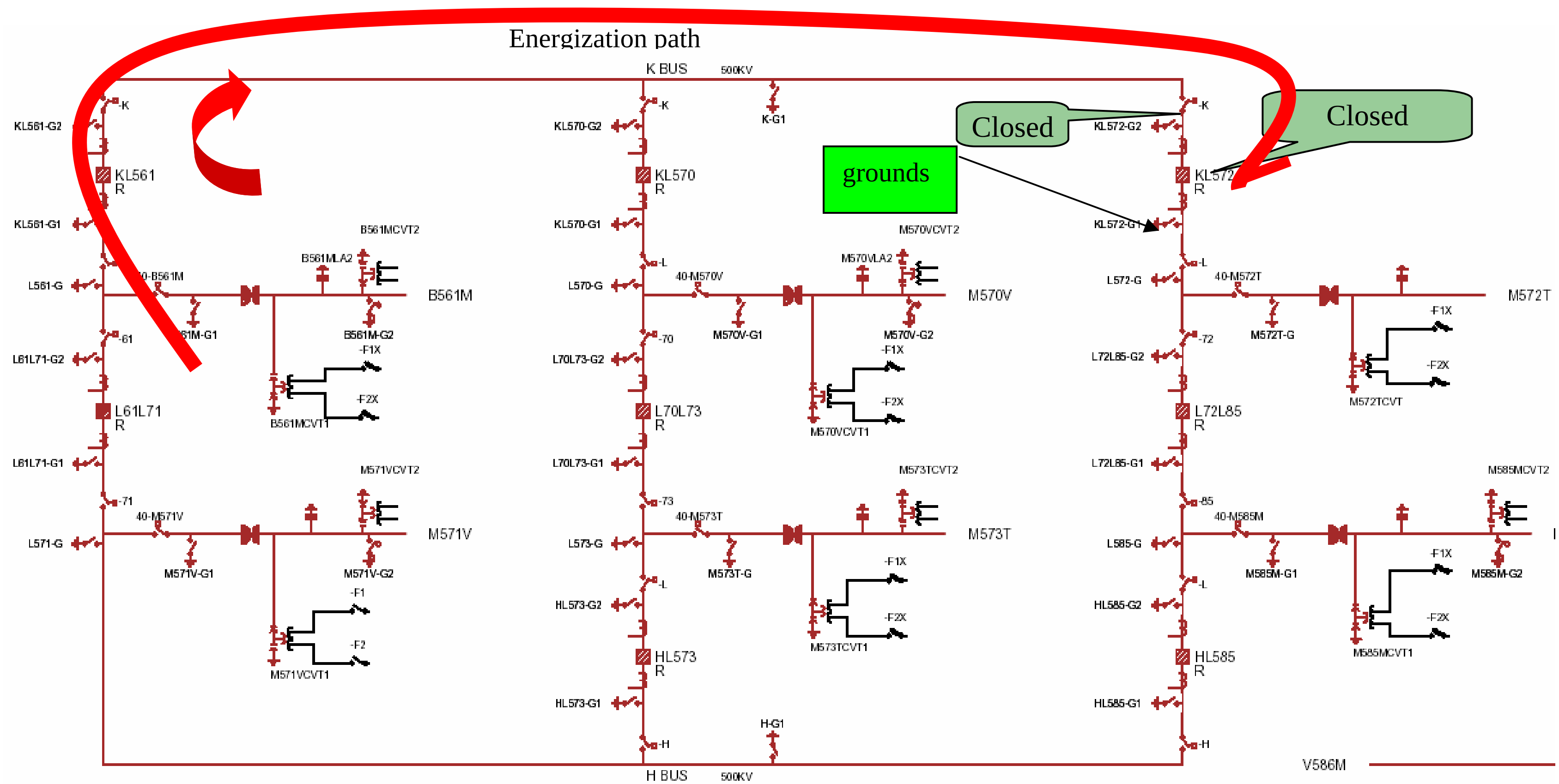


Figure 1: Bus Configuration at Milton SS

The tripping of circuit M572T was expected as the fault was within range of the zone 1 relays at Milton. The M570V and M573T trips were unexpected and conflicted with the fault's location. Initial investigations by an independent consultant have recommended that the "apparent" impedances, observed by remote terminal protections during the fault conditions, be assessed further to help rationalize the protection operations observed and to enable Hydro One to determine the mitigating actions required to prevent the over tripping of these circuits. Investigations are continuing.

Approximately 2300MW of load isolated itself from the Ontario grid partially offset by the loss of a 50 MW generator, causing the Ontario control area to be over generated and it's ACE to exceed 2300MW In order to ease the situation, manual generation reductions were requested. ACE returned to zero within six minutes at 15:21 EST but continued to decrease negative values. This was due to the runback of 2 Nanticoke units four (4) minutes after the initial incident.

As a result of the load loss, voltages on the 230 kV and 500 kV lines in the Greater Toronto Area (GTA) and west increased to approximately 255kV and 555kV, respectively. Detweiler SC12 230kV capacitor tripped on over-voltage and the Lennox R51 and Longwood R3 reactors were automatically switched to help alleviate the 500kV over-voltages. To further aid in the voltage control effort, manual control actions were taken to remove capacitors at Richview, Burlington, Buchanan and Detweiler.

– End of Section –

4. Sequence of Events

4.1 Prior to the Event

Work related to this incident started on May 24/05 when the Milton KL572 breaker was taken out of service for a major overhaul. The breaker was isolated for a work permit on the 24th and work continued each day on the breaker until May 26th. On May 27th, the work on KL572 required the Milton K bus out of service to provide safety clearances to enable testing of KL572. The KL572-K disconnect was requested guaranteed closed to provide grounding continuity and the K bus was isolated with KL572-K closed and the grounding switch, KL572-G2, verified closed. Breaker testing was completed in the early afternoon of the 27th.

At this time, the Hydro One operator communicated with maintenance personnel to confirm that the K bus was to return to service without confirming the position of the KL572 breaker and its disconnect KL572-K. Prior to energizing the K bus, the Hydro One operator believed that the KL572 breaker was open and followed a prepared and checked control room switching plan to restore the K-bus.

4.2 During the Event

15:15:20 – KL561 breaker was closed by Hydro One resulting in a 3 phase to ground fault.

M572T “A” and “B” protection at Milton correctly tripped breaker L72L85 as well as the Trafalgar terminal breakers. (Note that the KL572 breaker was in “test” mode and therefore unable to trip.) M572T cleared instantaneously from Milton SS A & B 21Z1 ground protections sending transfer trip to Trafalgar (50 ms), The Milton K bus cleared after the KL572 breaker fail protection tripped KL561 (156 ms.).

Note: the KL572 breaker fail protection tripped via the 62b timer (105ms). The 62a path had been disabled due to the pallet switch assembly being removed for breaker maintenance and the “a” pallet (advanced breaker position auxiliary contact) was in the open position.

M572T A & B 21Z1 protections also operated at Trafalgar TS. They appeared to have reacted to an unexpected "apparent" impedance but did not interfere with the correct operation of the circuit. No re-closing occurred.

M573T “B” protection at Trafalgar appeared to have reacted to an unexpected "apparent" impedance and detected the fault, tripping the Milton L70L73 and HL573 breakers as well as the Trafalgar terminal breakers. No re-closing occurred.

M570V “A” protection at Claireville also appeared to have reacted to an unexpected "apparent" impedance and detected the fault, tripping L70L73, as well as the Claireville terminal breakers. (Note: the Milton KL570 breaker was out of service prior to the event as part of the K bus outage.) Automatic re-closing occurred at Claireville the terminal only.

15:15:30 – A small co-generator tripped due to “ESD” Emergency Shutdown annunciation.

15:16 – IESO contacted a generation dispatch centre to request manual generation reductions.

15:16 – Lennox R51 and Longwood R3 reactors switched in automatically for voltage control.

15:17:36 – Detweiler SC12 capacitor tripped on over-voltage.

15:18 – Contacted another generator’s control centre to request manual generation reductions.

15:18:19 – Richview capacitors switched out of service for voltage control.

15:18:50 – Burlington capacitors switched out of service for voltage control.

15:19 – Nanticoke G4 and G7 ranback due to low drum boiler trips.

15:19:17 – Detweiler capacitors switched out of service for voltage control.

15:20:41 – Buchanan capacitors switched out of service for voltage control.

15:21 – ACE returned to near zero value.

15:26 – M573T returned to service.

15:30 – M572T returned to service.

16:18 – Milton KL572 breaker isolated and K bus declared available for service.

16:20 – Milton K bus returned to service.

– End of Section –

5. Observations

5.1 System Reliability

While this was a NPCC extreme category and NERC "category D" contingency event, the interconnected system remained stable, exhibiting voltage fluctuations and frequency oscillations that were well damped and subsided within approximately 15 seconds.

5.2 Tie Lines

Immediately following the incident and as direct consequence of the load loss in Ontario, flows on the Michigan & New York interfaces increased by 1000 MW and 980 MW respectively and stabilized at approximately 820 MW and 1180 MW respectively, well within the interties' continuous rating.

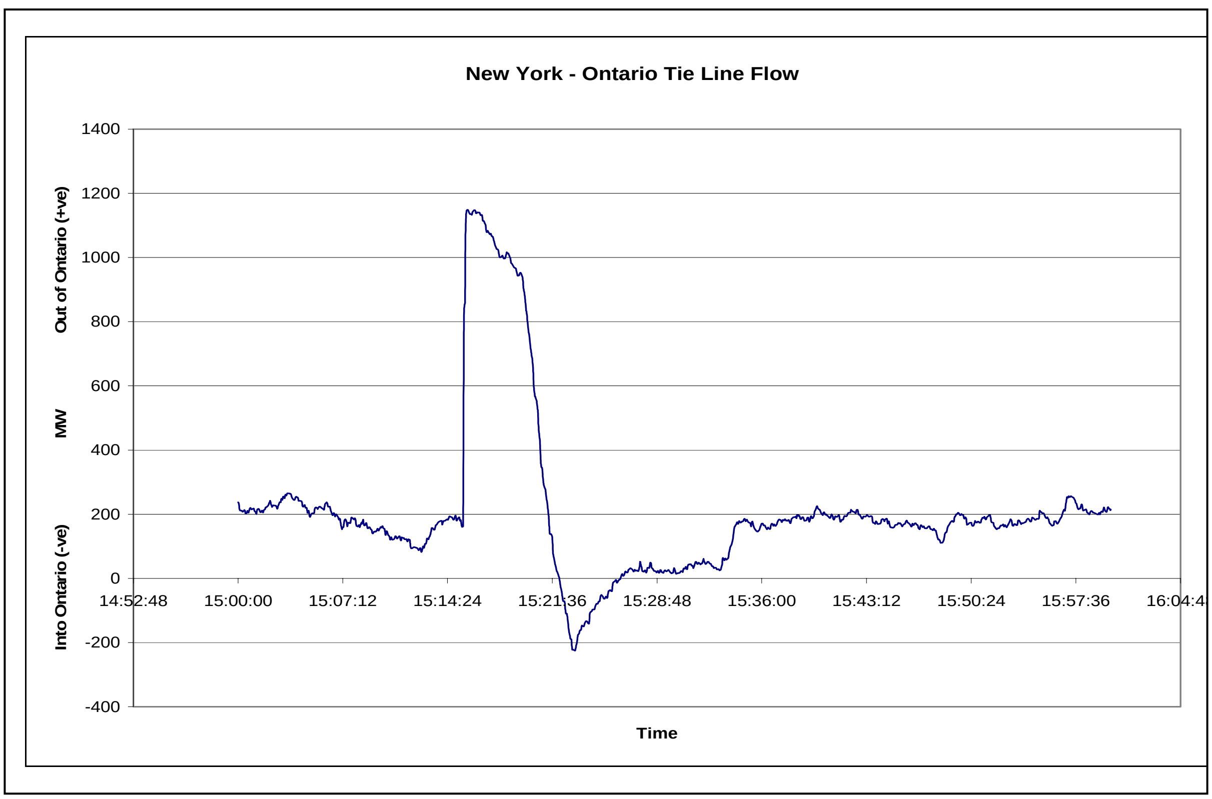


Figure 2: New York-Ontario Tie Line Flow

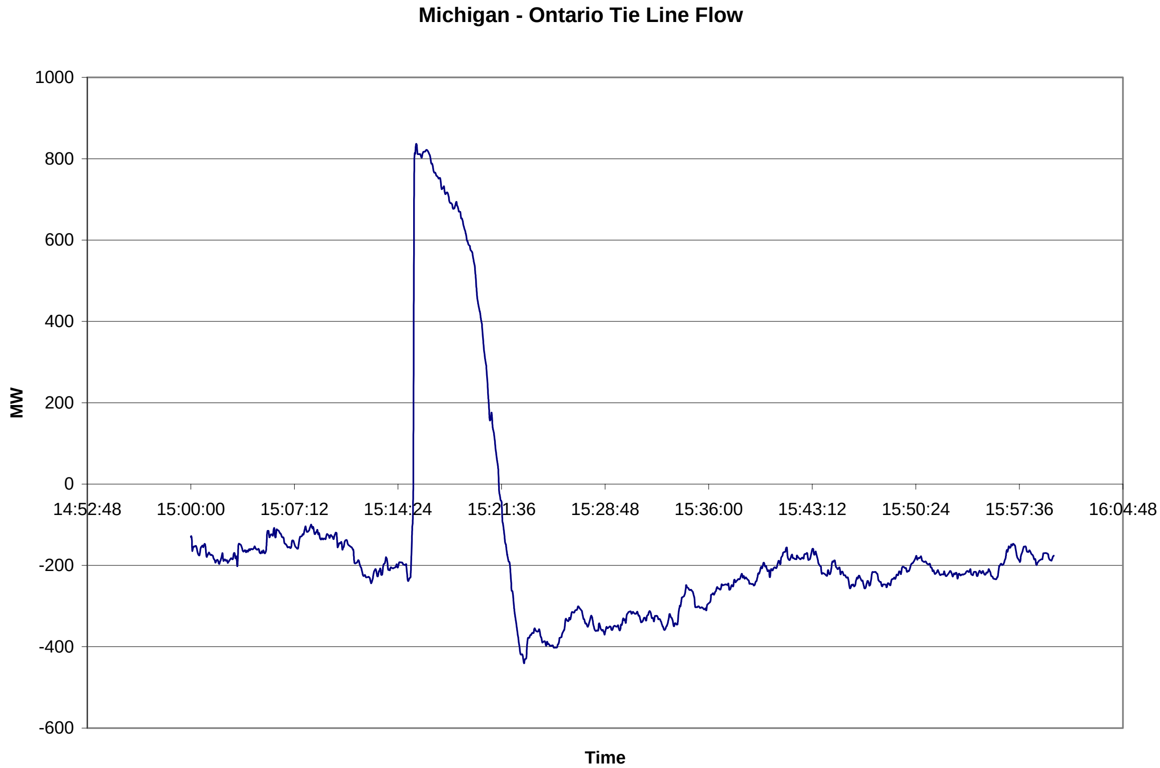


Figure 3: Michigan-Ontario Tie Line Flow

A survey of neighbouring Control Areas indicated that no adverse impact was experienced.

Ontario generation was immediately dispatched down by the IESO to reduce the tie line flows. The Area Control Error (ACE) returned to pre-incident levels in 6.10 minutes and to zero in 6.20 minutes, well within the Disturbance Control Standard of 15 minutes.

5.3 Load

Approximately 2300MW of load was isolated from the Ontario grid due to the fault at Milton. A sharp drop was observed in Ontario Demand, which was approximately 18,250 MW pre-fault and fell to approximately 15,950 MW post contingency.

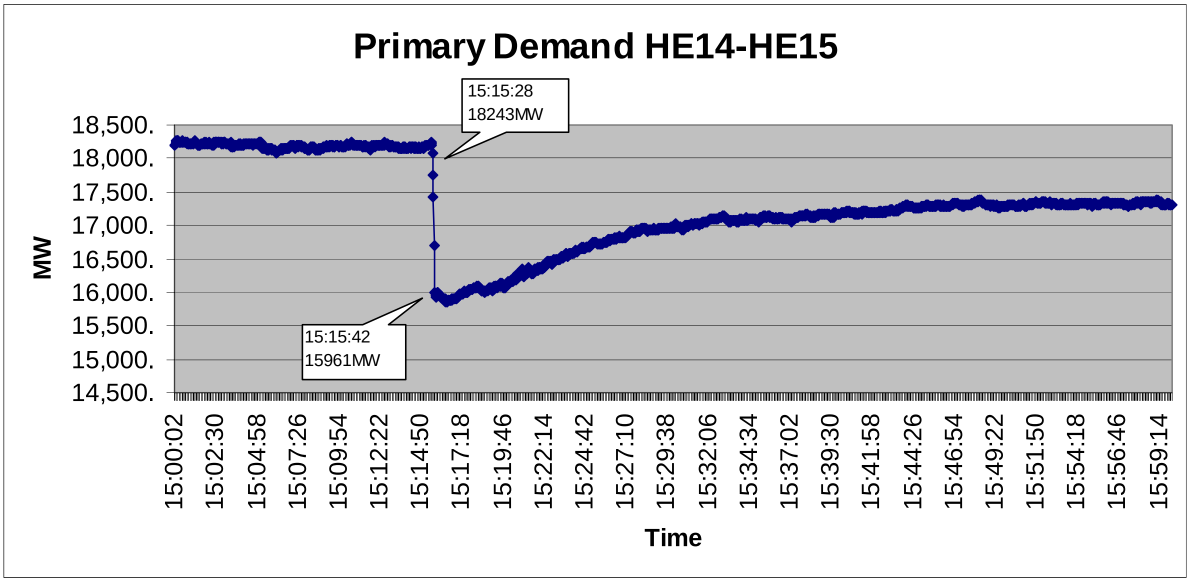


Figure 4: Ontario Primary Demand

Metering data for declining loads at the time of the fault showed the physical scope of the load loss to be fairly widespread. However, a larger concentration of affected loads was centered in the Greater Toronto Area, specifically in the Milton, Claireville and Richview regions.

The IESO conducted a survey with potentially affected customers regarding the reasons for customer equipment tripping. The preliminary responses to-date indicates load interruptions were mainly due to under-voltage trips that affected sensitive electronic control equipment. The responses also showed that the load loss mostly affected industrial customers. There is also indication, yet to be confirmed, that numerous computer systems and servers were also impacted by the incident. The diagram below shows a general picture of the extent of the load loss experienced during the event. It should be noted that the minor load losses in the far extremes of the province may have been due to normal process reductions on a Friday afternoon and not attributed to the fault at Milton.

Within an hour of the initial event, all but 800MW of the load loss had recovered. The latter did not appear to return, but this can again be attributed to it being late on Friday afternoon and the fact that some processes took longer to restore.

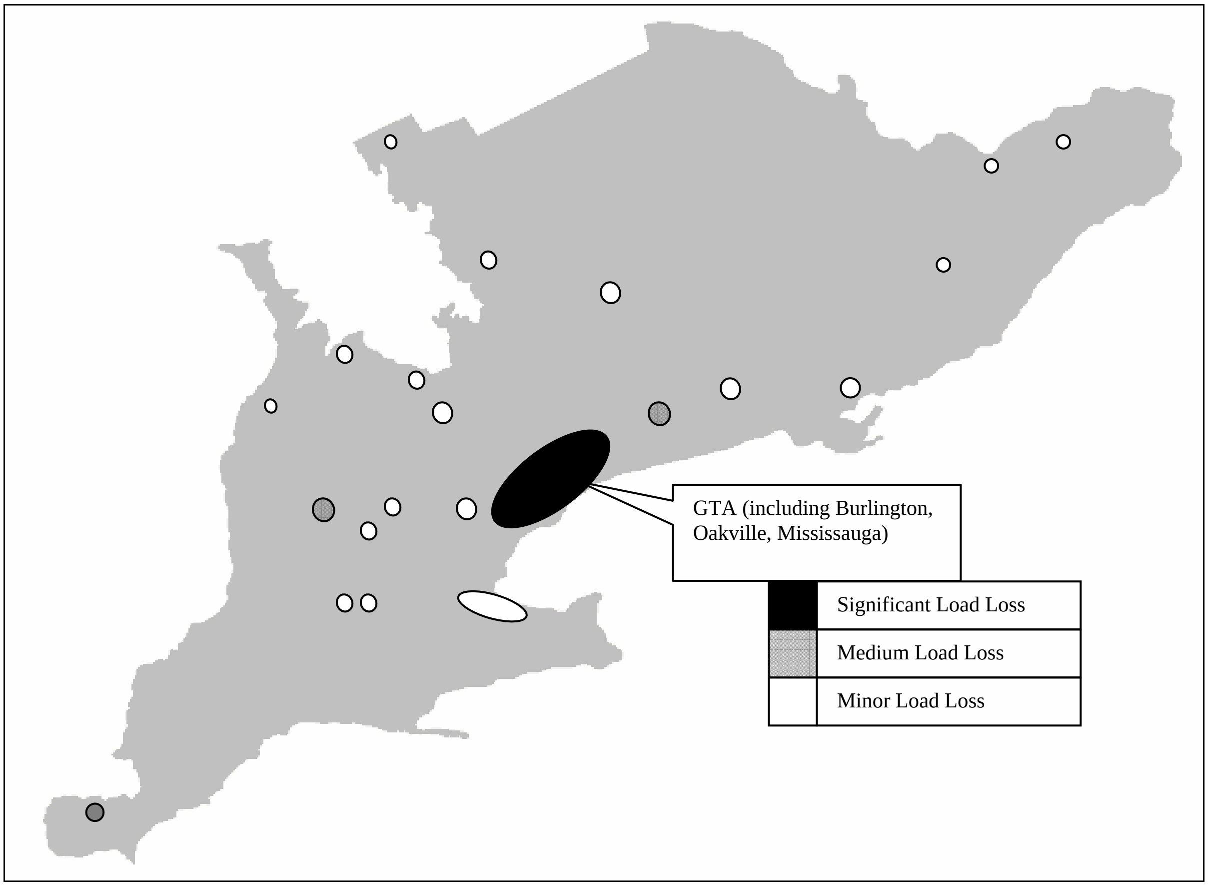


Figure 5: Approximate Extent of Load Loss During Milton Event

5.4 Generation

Coincident to the fault at Milton, a small co-generator tripped on Emergency Shutdown annunciations. Shortly after, at 15:19 EST, Nanticoke G4 and G7 ran back due to boiler trips for a total generation loss of 750MW.

The tripping of the co-generator, according to the unit owner, was attributed to a protection relating to the gas turbine. Due to the sudden sharp increase in the RPM of the low speed shaft brought on by the frequency deviation on the grid, the “shaft shear” protection operated and tripped the generation unit. The co-generator has asked the manufacturer to investigate possible methods to de-sensitize the protection logic.

At 15:16 EST, an Ontario generator was contacted by the IESO to implement manual generation reductions of 2000 MW in response to the large positive ACE. Initially, a number of hydroelectric generators (Beck II, Beck E bus, Canyon, Otter, Holden and Des Joachims) were reduced. At 15:21 EST, the generator dispatch centre further updated the IESO and it was decided to reduce all Nanticoke units as well as Lennox to minimum. Nanticoke G4 and G7 were unloaded quickly at a higher than normal rate and tripped as a consequence. Due to these unusually high rates, G4 experienced a low drum level boiler trip and ran back, it was subsequently taken off line. G7 suffered a similar runback to station service load but was kept online. Shortly after the unload request, a reload request was issued by the IESO due to the rapid recovery of a majority of the load lost. However, with respect to Nanticoke G4 and G7, the units were unable to affect the turnaround.

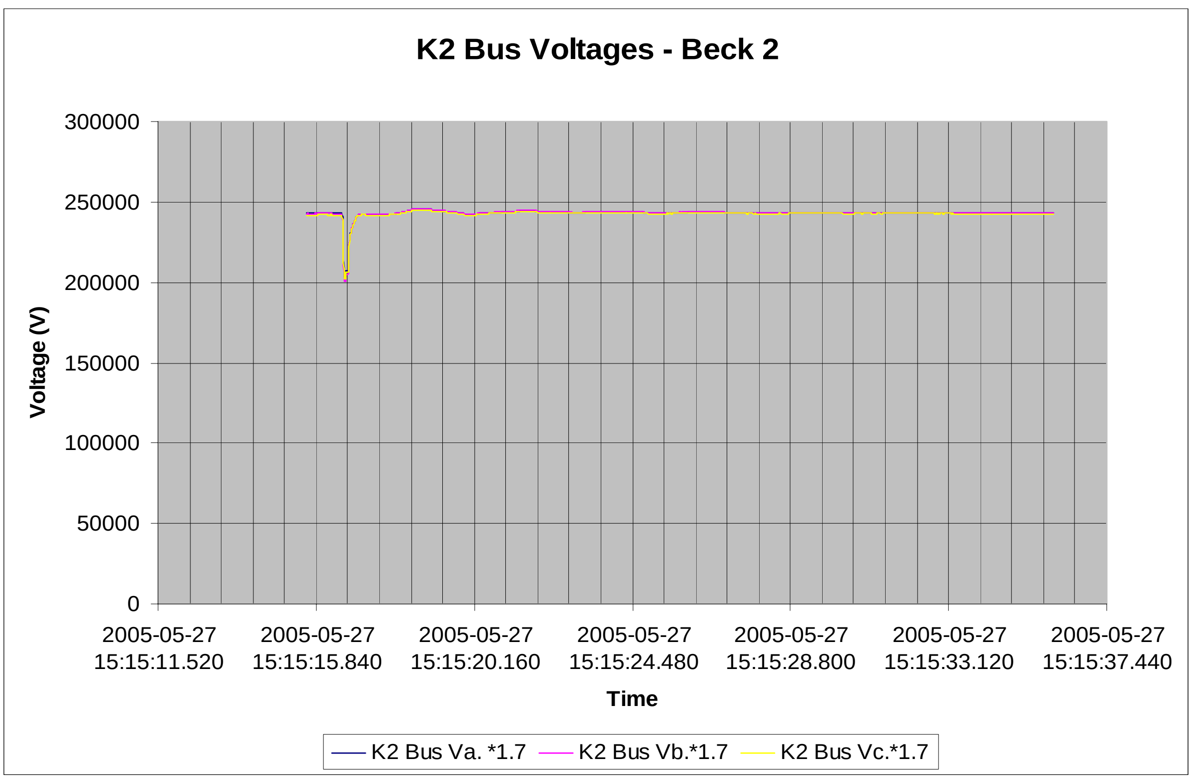
5.5 Voltages

As a result of the significant load loss in the Greater Toronto Area (GTA), 230kV voltages in the GTA and west increased to approximately 255kV and 500KV voltages increased to approximately 555kV.

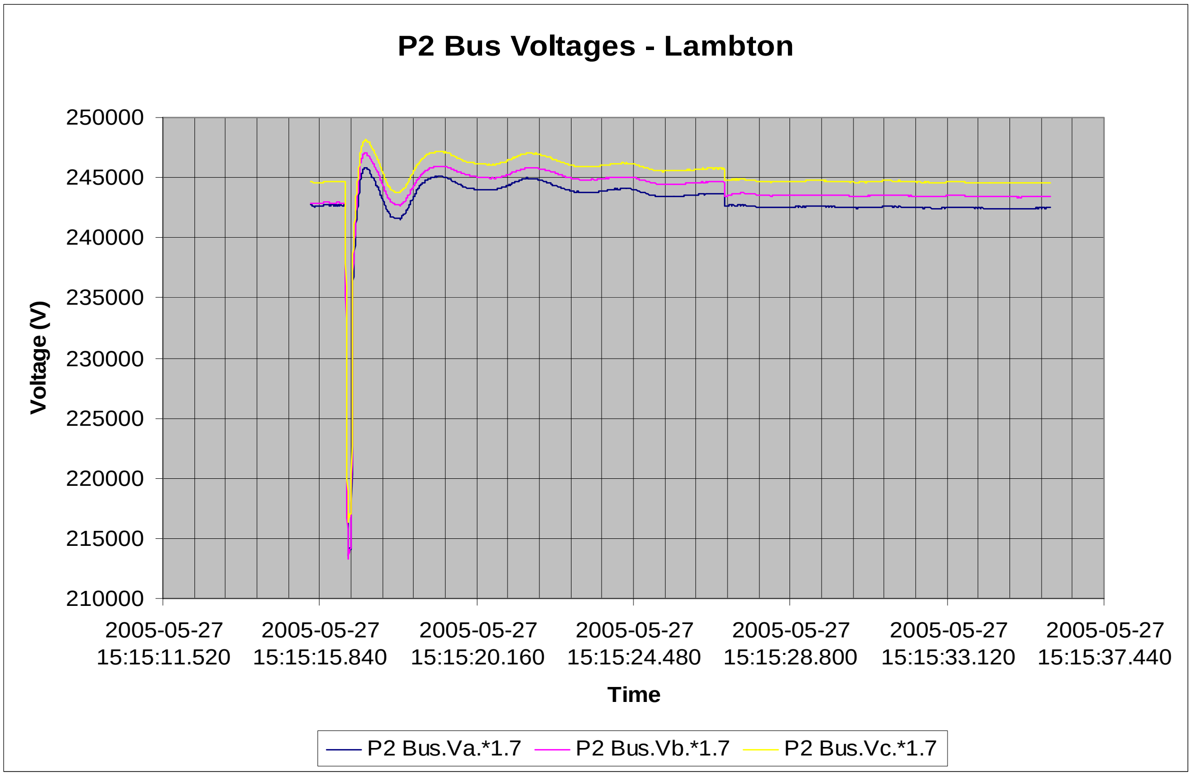
Graph #1 illustrates the voltage profile at the Sir Adam Beck Complex on the Ontario – New York interface at Niagara. Graph #2 and 3 illustrate the voltage profiles on the Ontario – Michigan interface at the Lambton generating station in the Sarnia area and at Keith transformer station in the Windsor area respectively.

Detweiler SC12 was automatically removed from service on over voltage and Lennox R51 and Longwood R3 automatically switched into service to control the 500kV voltages. Control actions were taken to switch out 230kV capacitors at Richview, Burlington, Buchanan and Detweiler.

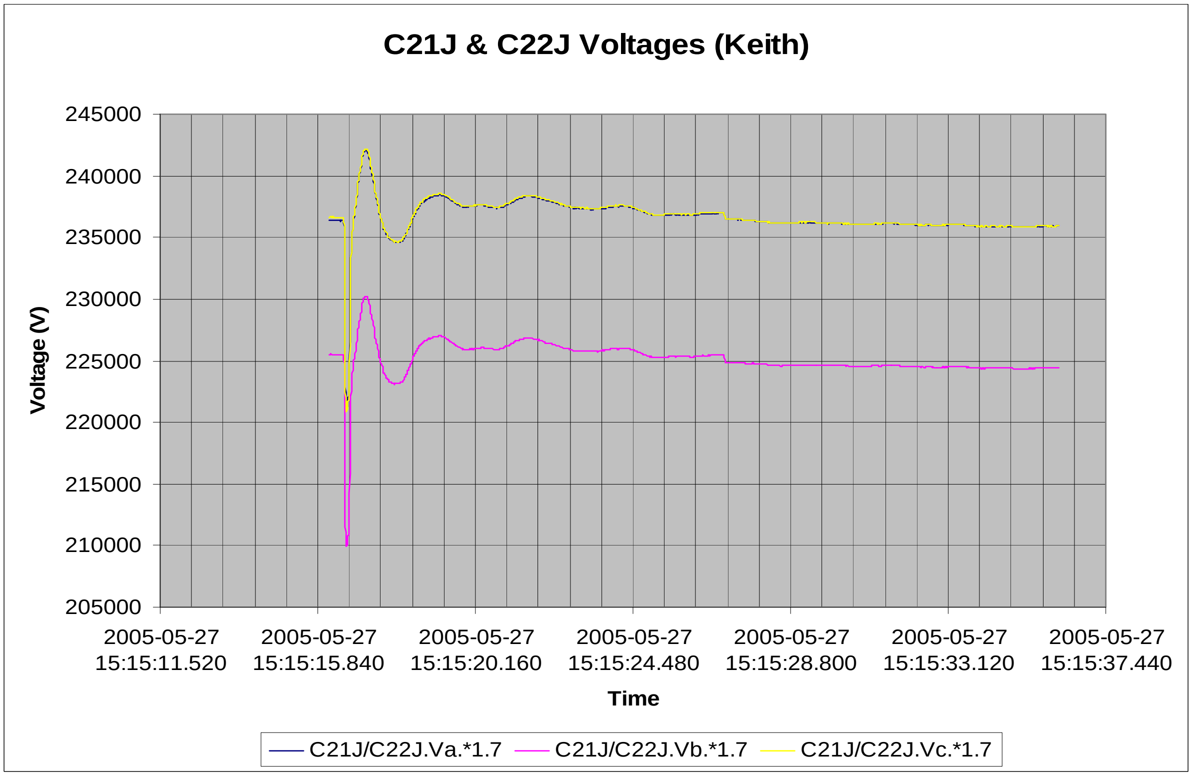
Graph 1



Graph 2



Graph 3



5.6 Frequency

Frequency fluctuations resulting from the fault were experienced throughout the Interconnection. From the graph[4] below, the range of the deviation extended from roughly 59.94 hertz to 60.16 hertz. These swings are well damped as can be seen in the graph and subsided within approximately 15 seconds.

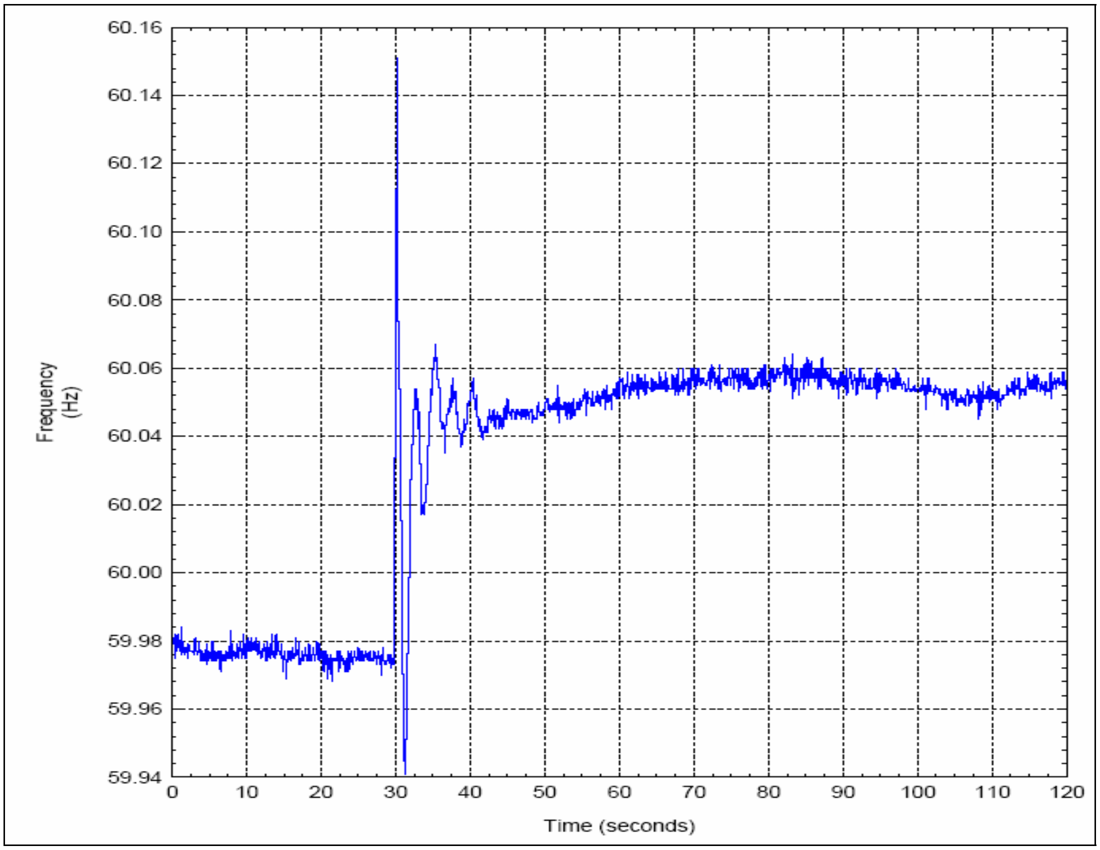


Figure 6: Frequency

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[4] Frequency graph provided with the permission of Kestrel Power Engineering Ltd

6. Reliability Analysis

To assess the risk to the reliability of the IESO-controlled grid several simulations were performed to determine the thermal, voltage and angle stability performance of the potential over-tripping of three 500 kV circuits (Milton to Trafalgar M572T and M573T, and Milton to Claireville M570V). The IESO will be assuming, until the apparent incorrect protection operations are resolved, that any 3-phase fault at Milton may result in over tripping of these three circuits. The station layout is such that under normal conditions, this could lead to the entire loss of the Milton station.

Thermal Loading

Post-contingency thermal loading on the Claireville autotransformers is slightly higher for loss of Milton than for normal contingencies, but is mainly due to loss of M572T + M573T, which is a recognized contingency, and does not appear to be higher than for the loss of a Claireville autotransformer. Therefore respecting additional contingencies is not required for local autotransformer loading.

Loss of Milton will remove two 500 kV circuits between Milton and Claireville, but most of the loading on these circuits will be picked up on the remaining Bruce to Claireville and Middleport to Claireville circuits, so no additional contingencies need to be simulated for thermal loading when all circuits are in service. These contingencies could be added to the real-time security analysis to ensure there are no unexpected thermal restrictions. For planned outage conditions, the potential for local thermal overloads should be assessed on an individual basis.

To recognize the effect of a load loss in Ontario on the Ontario tie lines, distribution factor analysis was performed to determine the expected post-contingency pickup on each tie for a load loss in Ontario.

The total immediate load loss for this incident was about 2300 MW. However, experience and judgement strongly suggest that a significant amount of this load loss is attributable to the fact that this fault was cleared in breaker-fail time (about 156 ms) rather than normal clearing less than 70 ms. This is substantiated by recent other faults in southern Ontario which cleared in normal time exhibiting much less load loss: for example a fault (~ 1996) on Milton Claireville 500 kV circuit resulted in a load loss of about 650 MW, and May 2005 fault at Detweiler 220 kV near a large load centre resulted in a load loss of about 350 MW. The IESO operates to limits for 3 phase faults for normal clearing rather than delayed clearing.

A normally cleared[5] (less than 70 ms rather than delayed clearing of 156 ms) 3 phase 500 kV fault in south central Ontario near the load centre is therefore expected to pose little risk of overloading the ties and hence a reduction in export limits is not required. IESO will initiate an investigation to determine the sensitivity of load in south central Ontario to low voltages during 3-phase faults.

[5] The IESO operates to limits for 3 phase faults for normal clearing rather than delayed clearing.

Post-contingency Voltage Performance

Although the over tripping was significant, and beyond normal criteria, voltage performance was not expected to be worse than would be observed following the simultaneous loss of the two most critical 500kV circuits; which is normally the worst contingency for voltage performance in southern Ontario. Power flow tests were performed to confirm this.

Simulations were performed under summer peak demand conditions, with 6 Bruce, 7 Nanticoke, 4 Pickering, 4 Darlington, 2 Lennox, 4 Lambton, and 3 Brighton Beach units; conditions much more stressed than on 27 May.

Based on these tests the worst voltage performance results from the loss of two 500 kV circuits. Other faults, including the actual fault, and the loss of the entire Milton station, although beyond normal criteria, exhibit a better post-contingency voltage performance than the most severe contingency that the IESO safeguards against. As an example, the post-contingency voltage decline following loss of two 500 kV circuits is about 4% at Claireville, 5% at Middleport, and 10% at Orangeville. For loss of the entire Milton station, the voltage declines are less than 3% at Claireville and Middleport, and about 4% at Orangeville.

Following a contingency, voltage performance will generally improve with coincident load loss, provided the load loss is not excessive to the point of creating overly high voltage that will trip equipment. Therefore, under normal conditions, respecting additional contingencies is not required for voltage performance.

Stability Analysis

IESO analysis was conducted to compare the dynamic performance of i) a normally-cleared 3-phase fault on M570V (a Milton to Claireville 500 kV circuit), ii) the actual fault, iii) a 3-phase fault with delayed clearing followed by the loss of the entire Milton station, and iv) 2-phase to ground fault and loss of two 500 kV circuits). Conditions approximating 27th of May were simulated.

Dynamic simulations confirmed that the faults with delayed clearing exhibited larger first swing oscillations, but were stable, and well damped. All of the 3-phase faults exhibited similar responses and damping. The loss of two 500 kV circuits exhibited smaller oscillations but slightly lower post-contingency voltages. All simulations exhibited very stable responses.

These well matched previous studies that have shown that the worst normal criteria faults are 3-phase normally-cleared faults on the 500 kV system at Milton or Claireville. These faults caused the largest angle and power oscillations of the faults tested. The most important factor was the type of fault; single-phase or two-phase to ground faults exhibited much smaller oscillations. The most critical stability limits in southern Ontario are related to Bruce instability, but the most restrictive faults for Bruce stability involve 2-phase to ground faults on two specific 500 kV circuits. The Bruce stability limits are normally much higher than the voltage limits in southern Ontario, and much higher than the voltage limits that were in effect on 27th of May, 2005.

The recent IESO comprehensive transmission review also simulated 3-phase normally cleared faults on the 500 kV system (M571V), and 2-phase to ground faults on two other 500 kV circuits. These showed acceptable results and performance similar to that described above. The study also simulated loss of the entire Milton station following a 3-phase normally-cleared fault. These tests, performed at about 70% peak load and high transfers, showed a stable and acceptable performance.

Based on the present studies, it can be concluded that the current risk of over tripping for a 3-phase normally cleared fault at Milton will not result in instability. Additional or more restrictive stability limits are not recommended at this time.

– End of Section –

7. Conclusions

The fault was the result of human error in executing established procedures and processes.

Integrated power system stability was not jeopardized. There is no evidence that this fault created conditions that could result in a blackout. This is considered a rare event which NPCC classifies as an “extreme” event, and as a "Category D" contingency by NERC. It was no more severe than the most severe normal criteria contingency that the Ontario system was being operated to withstand. Furthermore it was less severe than the most severe contingency, used by the IESO to develop security limits. The longer fault clearing time than the most severe normal criteria contingency, precipitated to the greater load loss.

The impact on the interconnected system was minimal. Voltage fluctuations and frequency oscillations were well damped (damping was better than criteria) and subsided within approximately 15 seconds. ITC (Michigan), NYISO, ISO-NE and NBSO reported no adverse impact.

Some line protections appeared to have reacted to unexpected "apparent" impedance created during the fault.

Initial investigations by an independent consultant have recommended that the "apparent" impedances, observed by remote terminal protections during the fault conditions, be assessed further to determine its source and to enable Hydro One to determine the mitigating actions required to prevent the over tripping.

– End of Section –

8. Actions Taken to date

8.1 Hydro One:

- Implemented a process that requires that all 500KV remote switching operations via SCADA control involve two (2) operators.
- Hired an independent third party to review the protection operations to investigate and determine the cause of the protection overreaching.
- Are assessing the factors that contributed to the switching error and will conduct formal training regarding “lessons learned” with all operating staff.
- Have initiated a review of its switching procedures, including a comparison with other transmitter practices.
- Are considering improvements to the tools that would prevent or reduce the probability, of this type of event recurring in the future.

8.2 IESO:

- Examined the impact of a normally cleared 3 phase fault at Milton together with the tripping of the three circuits that tripped in this event and determined that the impact was less severe than the normal criteria contingencies that the IESO-controlled grid is already operated to withstand.
- Performed a number of power flow tests to confirm that, although the noted over-tripping is significant and **beyond normal criteria**, system voltage performance is not worse than would be expected following the most severe **normal criteria** contingency (simultaneous loss of 500 kV circuits with normal clearing time)[6]. The other faults examined, including the loss of the entire Milton station, although beyond normal criteria, exhibit a better post-contingency voltage performance than the most severe normal criteria faults. It was concluded that respecting additional contingencies is not required for voltage performance. Even with incorrect tripping of circuits at Milton, the Ontario power system and the interconnected system is secure.

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[6] Although, the most severe **normal criteria contingency** that the system is designed to withstand demonstrates a post-contingency voltage performance that is worse than this incident, such a fault in south central Ontario has previously resulted in a load loss of less than 700 MW. The IESO believes a significant amount of this incident's load loss is attributable to the fact that the fault was cleared in breaker-fail time (about 156 ms rather than the normal clearing time of less than 70 ms).

- To recognize the effect of a significant load loss in Ontario on the Ontario tie lines, distribution factor analysis was performed to determine the expected post-contingency pickup on each tie for a load loss in Ontario. The IESO believes a significant amount of this incident's load loss is attributable to the fact that the fault was cleared in breaker-fail time (about 156 ms). A normally cleared[7] (of less than 70 ms rather than delayed clearing of 156 ms) 3 phase 500 kV fault in south central Ontario near the load centre is expected to pose little risk of overloading the ties.

- Performed stability studies to confirm dynamic performance and angle stability studies simulating the specific fault, including the tripping of three circuits which showed a stable and well damped response, and is consistent with previous studies. Normally, and as on May 27th, the system is restricted by thermal and voltage limits that are much lower than the established stability limits.

- Surveyed load customers and nearby Control Areas to assess the impact

- Is continuing to work with Hydro One and the generators to collect more data and to complete the final review.

- Will support NPCC and NERC in any subsequent investigations.

– End of Section –

[7] The IESO operates to limits for 3 phase faults for normal clearing rather than delayed clearing.

9. Outstanding Issues

9.1 Switching procedures

Hydro One will investigate how its present switching procedures should be modified to prevent this type of operator error. Recommended changes will consider practices employed by other transmitters. Training will be provided to all staff involved in the switching process on lessons learned.

9.2 Line Protections

Hydro One's independent consultant's initial investigations revealed that:

- the Milton M572T terminal correctly tripped through zone 1 protection at Milton;
- zone 1 protections at the Trafalgar terminal also detected the fault; and
- unexpected tripping of Milton M570V and M573T lines was initiated from remote terminals

Based on the evidence provided by the independent consultant, it is suspected the line protections responded appropriately to observed apparent impedances.

Investigations are continuing to determine the cause of the unexpected protection operations and to explain the "apparent" impedances seen by the remote terminal protections.

– End of Section –

10. Recommendations

1 Hydro One to continue its investigations into protection operations to determine the cause of the unexpected tripping and rationalize the "apparent" impedances seen by the remote terminal protections.[8]

2 Once Hydro One has completed their full review of the protection operations, necessary remedial actions should be undertaken.

3 Hydro One to continue its review of switching procedures and adjust accordingly.

4 IESO and Hydro One to conduct an investigation of the sensitivity of load in south central Ontario to voltage excursions such as caused by 3-phase to ground faults on the transmission system.

[8] Note: Members from the NPCC's Task Force on System Protection have been requested and have agreed to aid in Hydro One's investigation.

Appendix A: General Summary of HV Line Protections used at Milton SS

A.1 Direct Under-reaching

Direct under-reaching is achieved by setting the zone 1 fault detectors at both ends to reach about 80% of the line section from the terminal. When the zone fault detector picks up, the local breaker is tripped immediately. In the meantime, transfer trip is sent via communication channels to the other end to energize the transfer trip receive relays. The advantage of direct under-reaching is high speed tripping. The fastest tripping happens when the fault occurs within the overlapping area between the zone 1 mho relays, causing instantaneous independent tripping at both ends. Although transfer trips are sent, tripping has already been initiated by the time they arrive. If the fault is located outside of the zone 1 of one terminal, transfer trip will be received from the other terminal and cause tripping.

A.2 Permissive Overreaching

A second type of instantaneous line protection is provided by permissive tripping. This type of protection covers the cases which cannot be covered by zone 1 detectors. Permissive tripping also provides an alternative instantaneous protection to direct under-reaching, with separate fault detectors and a separate communication channel.

Zone 2 phase and ground distance relays are set about 125% of line length or maximum apparent impedance of the line. For a fault on the protected line section, the zone 2 fault detectors at both ends are picked up. They send a permissive signal to each other. Upon receiving the permissive signal from the opposite end, the local trip relays at both terminals will be energized and thus, the fault is cleared. If the fault occurs outside of the line, then it is seen by the zone 2 fault detector at MILTON, for example, and not seen by its counterpart at CLAIREVILLE. MILTON sends a permissive signal to CLAIREVILLE. As the zone 2 relay at CLAIREVILLE is not picked up, no tripping will occur at CLAIREVILLE. Since no permissive signal is sent from CLAIREVILLE to MILTON, no tripping will occur at terminal MILTON either. In summary, for permissive overreach, instantaneous tripping can only occur at a terminal if 1) the zone 2 fault detector of that terminal is picked up, and 2) permissive signal is received from the other terminal.

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