IESO_REP_0670

REPORT

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# Manby H1L15 Breaker Incident - July 5, 2010

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## Related Documents

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# 1. Synopsis

- **Extreme Event** (Category D)[1]: a phase-to-ground fault causing a 230 kV breaker to fail explosively, triggering five subsequent faults and removing an entire 230 to 115 kV transformer station from service.

- **Duration:** 3.6 seconds from the beginning of the first fault to the end of the last. Clearance times ranged from 64 to 89 milliseconds while fault magnitudes ranged from 22 to 42 kilo-amps (kA).

- **Root Cause:** internal failure of the breaker

- **Impact on Generation:** no generation loss was linked to the event, however several generating stations reported noticeable swings to their terminal voltages in response to the faults.

- **Impact on Load:** approximately 1550 MW of load was interrupted, 902 MW of which was removed from service by configuration. The remaining 648 MW was triggered by the operation of customer-owned under-voltage protection within surrounding local distribution centres.

- **Impact on Tie lines:** Michigan and New York experienced flow increases of 725 MW and 690 MW from Ontario respectively. Flows were well within interface capabilities and were restored to pre-contingency levels within 12 minutes.

- **Impact on other Reliability Coordinator Areas:** MISO and NYISO reported no adverse impact to their systems.

**- End of Section -**

[1] As defined by NERC Standard TPL-004-0: an extreme event resulting in two or more (multiple) elements removed or cascading out of service.

# 2. Background

The Manby 230 kV to 115 kV Transformer Station (TS) is a Hydro One owned facility responsible for serving load customers in the cities of Oakville, Mississauga, and downtown Toronto. The station is comprised of a west and east yard located within the same station footprint, but electrically separated from one another. Each yard is equipped with 3 – 230 to 115 kV autotransformers, multiple 115 kV and 230 kV breakers, the majority of which are oil-filled, several customer load transformers, and a 336 MVAR rated 230 kV capacitor.

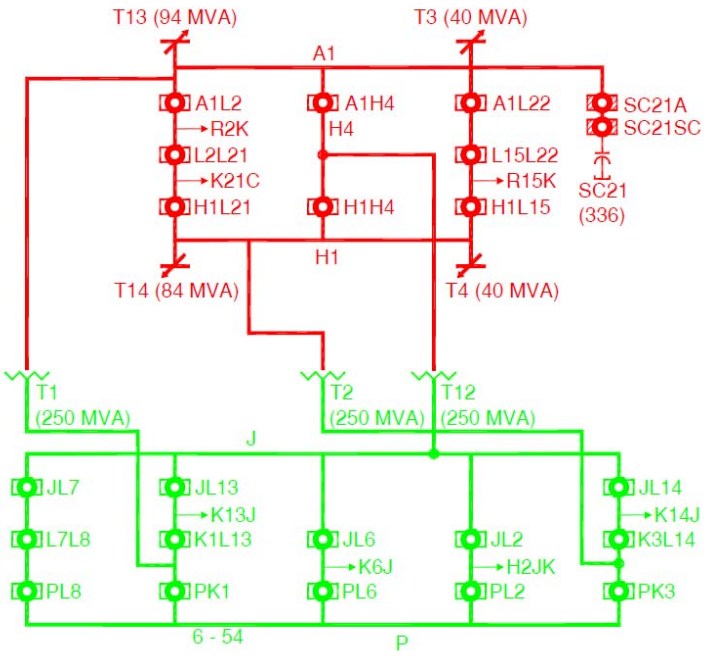


**Figure 1** Manby West Station

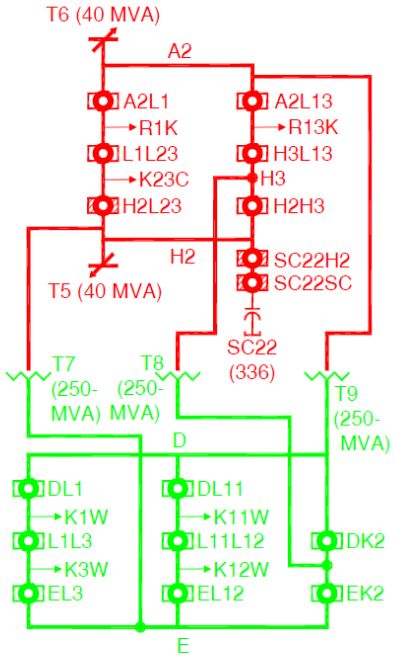


**Figure 2** Manby East Station

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# 3. Description of the Event

At approximately 15:40 Eastern Standard Time (EST) on July 5, 2010 the Manby West H1L15 oil-filled breaker suffered an explosive internal failure, spreading debris and oil over 150 feet in diameter and causing the breaker to catch fire. Oil spray and debris from the breaker was attributed to subsequent faults on several connected transmission lines and bus-bar sections in the Manby East and West yards, resulting in a total load interruption of over 1550 MW and affecting over 240,000 people in the Greater Toronto Area (GTA). Of the 1550 MW that was automatically removed from service (ARFS), 902 MW were removed by configuration while the remaining 648 MW were in response to the fault surge as a result of customer-owned, low-voltage protection operation within surrounding local distribution centres.

There was no adverse weather occurring in the GTA at the time of the incident. All area voltages and thermal ratings were being respected under normal operating conditions. With the exception of a forced outage to a Manby East 230 kV capacitor, there were no other ongoing outages in either of the Manby yards.

At 15:40:35 EST 230 kV circuit R15K (Richview – Manby West) and the Manby H1 bus were ARFS following normal line and bus protections as a result of the phase-to-ground fault on the Manby West H1L15 breaker. Over the course of approximately 3.6 seconds, five additional faults removed the Manby West A1 bus, K23C, Manby East H2 Bus, R1K, and the Manby East A2 bus from service upon receipt of normal bus and line protections.

The resulting load loss caused the IESO Area Control Error (ACE) to increase to a positive 1580 MW. In addition, multiple 230 and 500 kV stations in Southern Ontario saw bus voltages rise as the need for reactive support was diminished by the loss of load. IESO operators took immediate action in manually dispatching generation and reactive resources to reduce ACE and system voltages back to pre-contingency levels. MISO and NYISO saw increases of 725 MW and 690 MW into their systems on the Michigan and New York interfaces respectively. System voltages were restored to normal within ten minutes. Within twelve minutes, intertie flows were back on schedule as ACE was reduced to 0 MW.

Load restoration efforts began immediately after system conditions were deemed acceptable. As Hydro One required visual inspection of the faulted equipment prior to making it available for use, load transfers were conducted in order to re-supply the GTA load from alternate sources that were unaffected by the incident. This transfer capability can be seen in Figure 3 on the following page. With the exception of one load distribution station and several feeders at another, all load removed by the contingency was restored through load transfers in under two hours from the time the incident occurred.

Load transfers were expedited by utilizing spare capacity from generating units at the Portlands Energy Centre. At the time of the fault, Portlands was in-service generating approximately 75% of its rated capacity. Once load transfers commenced, IESO manually

dispatched the facility to increase output as required. In the absence of Portlands generation, load restoration would have been limited by post-thermal restrictions on the Leaside 230 to 115 kV autotransformers.

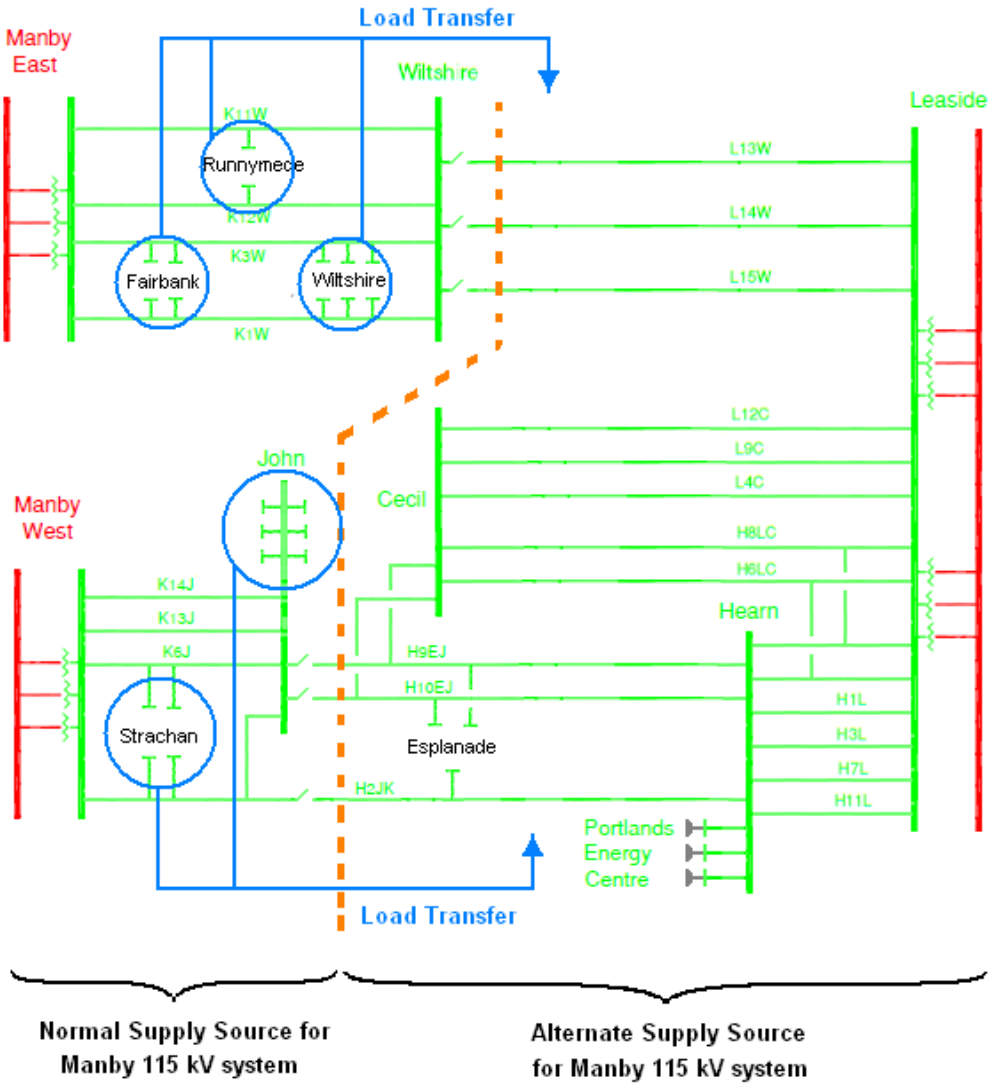


**Figure 3** GTA 115 kV System

By 19:15 EST all the load that was removed by the contingency was restored. All load transfers were reversed by 21:23 EST, returning the Manby East and West systems to normal configuration. All Manby equipment was returned to service with the exception of the Manby H1L15, L15L22, and A1L22 – 230 kV breakers. Two of the three breakers were left damaged while the A1L22 was declared unavailable as it shares the same DC supply as the other two damaged breakers.

**- End of Section –**

# 4. Sequence of Events

| Time | Summary |
|---|---|
| 15:40<br>(t = 0s) | 230 kV circuit R15K (Richview – Manby West) and the Manby West H1 bus were ARFS by A & B normal line and bus differential protections following a phase-to-ground fault on the Manby West H1L15 breaker.<br><br>At t+1.37s, a phase-to-ground fault removed the Manby West A1 bus from service following A & B bus differential protection. With both Manby West busses out-of-service, a load interruption of 523 MW was observed by configuration at the Manby West, Strachan, and John stations.<br><br>At t+1.48s, a 3-phase-to-ground fault occurred on 230 kV circuit K23C (Manby East – Cooksville) followed by a phase-to-ground fault on the Manby East H2 bus at t+1.92s. The faults were cleared by K23C A & B line protections and the Manby East H2 bus differential protection. These two events did not trigger any load loss by configuration.<br><br>At t+2.83s and 3.56s, 230 kV circuit R1K (Richview – Manby East) and the Manby East A2 bus both suffered phase-to-ground faults and were ARFS by A & B line and bus differential protections, respectively. Consequently 369 MW of load that was connected the Manby East, Wiltshire, Runnymede, and Fairbank stations were also removed from service by configuration.<br><br>A total 902 MW of load was lost by configuration. Another 648 MW of load was removed from service by voltage sensitive customer-owned protection operations responding to the faults. |
| 15:41 | The Ontario Area Control Error (ACE) reached +1580 MW as a result of the load loss caused by the contingency. The IESO responded to the ACE deviation by manually dispatching hydro-electric and coal-fired generation to reduce 592 MW and 690 MW respectively, for a total reduction of 1282 MW. The remaining 307 MW of over-generation was automatically reduced by IESO dispatch software once the reduced Ontario demand was accounted for. ACE recovered to 0 MW within 12 minutes. |
| 15:42 | The reduction in Ontario demand caused several bus voltages to increase across Southern Ontario. IESO operators took immediate action to reduce these voltages to acceptable levels by re-dispatching both static and dynamic reactive resources as required. Voltages were restored to pre-contingency levels by 15:48 EST. |

| Time | Summary |
|---|---|
| 15:46 | Load restoration efforts began by opening all off-potential breakers in the Manby East and West yards, disconnecting both from the rest of the system. With Hydro One declaring all out-of-service equipment unavailable at Manby until an inspection could be made, load restoration commenced from Leaside TS via the Leaside – Wiltshire corridor, an alternate supply point for loads normally supplied from Manby. |
| 15:57 | The following Reliability Coordinator Information System (RCIS) message was issued by the IESO: "A major system contingency has occurred resulting in approx 1500 MW of load loss in the GTA. IESO is working on restoration of this event." |
| 16:12 | With a return-to-service time for the Manby West yard unavailable, switching arrangements began to allow for the John and Strachan loads to be alternatively supplied from the Hearn switching station (SS) via 115 kV circuit H2JK (Hearn – John – Manby). |
| 16:19 | 60 MW of load was restored at Runnymede |
| 16:23 | 40 MW of load was restored at Fairbank. As a result of the load restoration, the Leaside – Wiltshire corridor was becoming thermally restricted. Load restoration was ceased at the stations until thermal conditions improved. |
| 16:28 | Hydro One declared the Manby East H2 bus available for service. While directing switching to place the bus on potential from the R1K circuit, the Manby East L1L23 230 kV breaker received a low air alarm, making it unavailable. The H2 bus restoration would be delayed until an alternate path could be determined. |
| 16:30 | With the expectation of re-supplying the interrupted load from the Leaside end of the GTA, Portlands generating station (GS) was directed to increase output in order to alleviate post-contingency thermal limits on the 230-to-115 kV Leaside autotransformers. |
| 16:46 | 39 MW of load restored at Strachan from Hearn SS via H2JK. Due to H2JK thermal restrictions, Esplanade T11 was disconnected from the circuit to allow for more load to be restored at Strachan. Another 37 MW of load was restored at Strachan by 17:14. |
| 17:22 | Manby East H2 bus and T8 on potential restoring station service. This switching also allowed the Manby East station service and T5 distribution transformer to be placed back in-service, restoring 65 MW of load. |
| 17:24 | Remaining load at Runnymede restored. |
| 17:37 | Hydro One declared all equipment in the Manby East 115 kV yard available for service with the exception of the T9 230-to-115 kV auto-transformer and 115 kV D bus. As a result, the Fairbank, Wiltshire, and Runnymede distribution stations could be transferred back from Leaside to Manby East supply. |
| 17:45 | 150 MW of load restored at John after switching was completed to allow the station to be supplied from Leaside TS and Hearn SS. With the increase in load, Portlands GS was directed to provide additional reactive support to improve area voltages. |

| Time | Summary |
|---|---|
| 17:48 | Fairbank, Wiltshire, and Runnymede switched back from Leaside to Manby East supply. Hydro One and Toronto Hydro were given permission to restore the remaining load at Wiltshire and Fairbank. |
| 18:04 | The Manby East T9 230-to-115 kV transformer and 115 kV D bus were place in-service after being declared available. As a result, all Manby East 115 kV equipment has been restored to service. |
| 18:11 | R13K (Richview – Manby East) 230 kV circuit placed back in-service |
| 18:24 | All Manby West 230 and 115 kV equipment declared available for service with the exception of the R15K 230 kV circuit terminal breakers, one of which being the H1L15 breaker that failed explosively. |
| 18:45 | All load supplied from the Manby East yard has been restored. |
| 18:52 | All load supplied from the Manby West yard has been restored with the exception of a low-tension Toronto Hydro feeder due to an equipment issue. This load was restored at 19:15 after repairs were made. |
| 21:23 | Strachan and John stations transferred back from Leaside and Hearn to Manby West supply. |

**- End of Section -**

# 5. System Impact

## 5.1 Impact on Bulk Electricity System (BES) Reliability

The interconnected system remained stable following subsequent faults at Manby. As seen in the figure below, each fault was cleared within 90 milliseconds while oscillations were damped within 250 milliseconds. The most severe fault occurred approximately 1.5 seconds after the Manby H1L15 failed explosively. This was the result of a 3-phase fault on 230 kV circuit K23C (Manby East – Cooksville).

The frequency trend illustrated below is measured locally at the Claireville 500 to 230 kV transformer station and is a function of how disturbance recorder equipment calculates frequency. The fault and switching actions distort the local voltage waveform, and will appear as frequency spikes at local recorders. It is displayed below for the purpose of easily indentifying the timing and relative severity of each fault. The actual or global interconnection frequency remained very stable throughout the event, experiencing a deviation of less than 0.04 Hz once the load loss was realized.

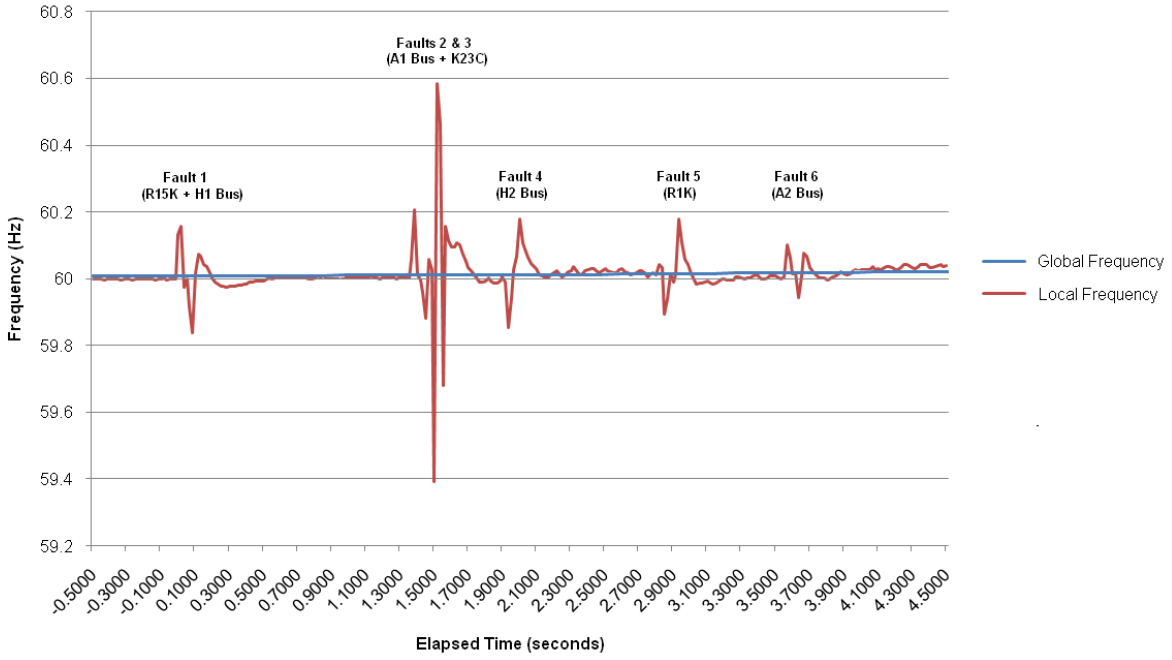


**Figure 4** Frequency Trends – July 5th, 2010

## 5.2 Impact on Tie Lines

The Michigan and New York tie-lines saw an increase of 725 MW and 690 MW out of Ontario respectively. Flows were restored to pre-contingency levels within 12 minutes following IESO operator efforts made to reduce ACE to 0 MW. No adverse impact was reported by the IESO's neighboring reliability coordinators.

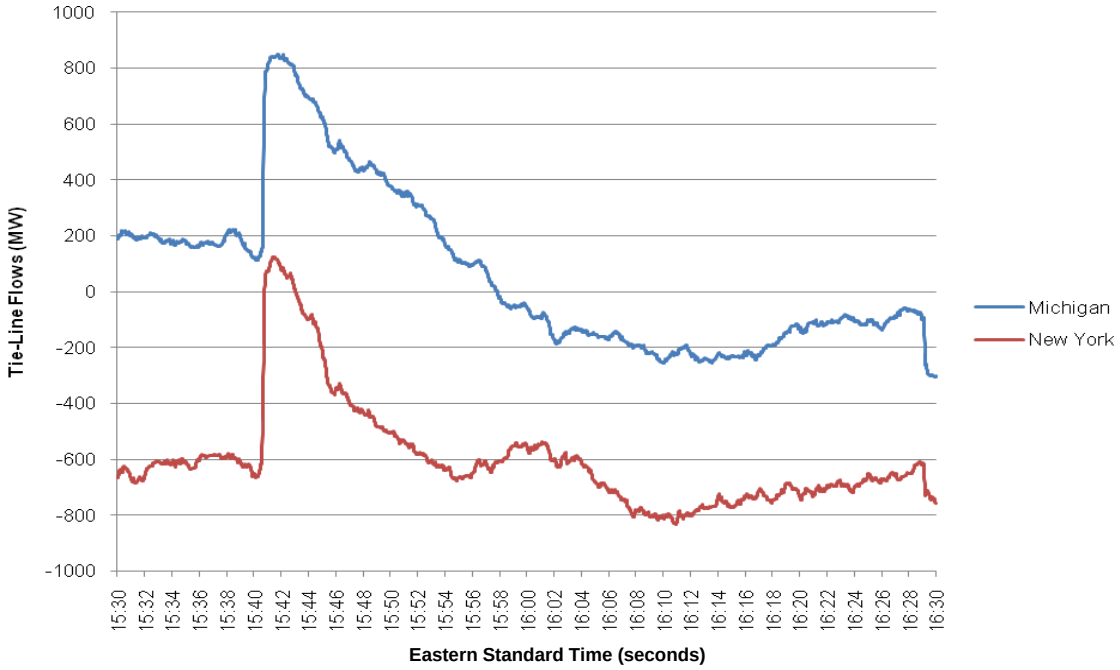


**Figure 5** Ontario to Michigan and New York Tie-Line Flows – July 5th, 2010

## 5.3 Impact on Load & Voltages

Approximately 1550 MW of load was interrupted as a result of the multiple fault occurrences at the Manby West and East yards. Ontario demand dropped from 24,509 MW to 22,915 MW causing voltages to rise at multiple 230 and 500 kV stations in Southern Ontario as the need for reactive support was diminished by the loss of load. Voltages were quickly reduced to pre-contingency levels through the re-dispatch of both static and dynamic reactive resources. The voltage profile at the Richview 230 kV switching station, located approximately seven kilometers from Manby, shows this response in the following figure.

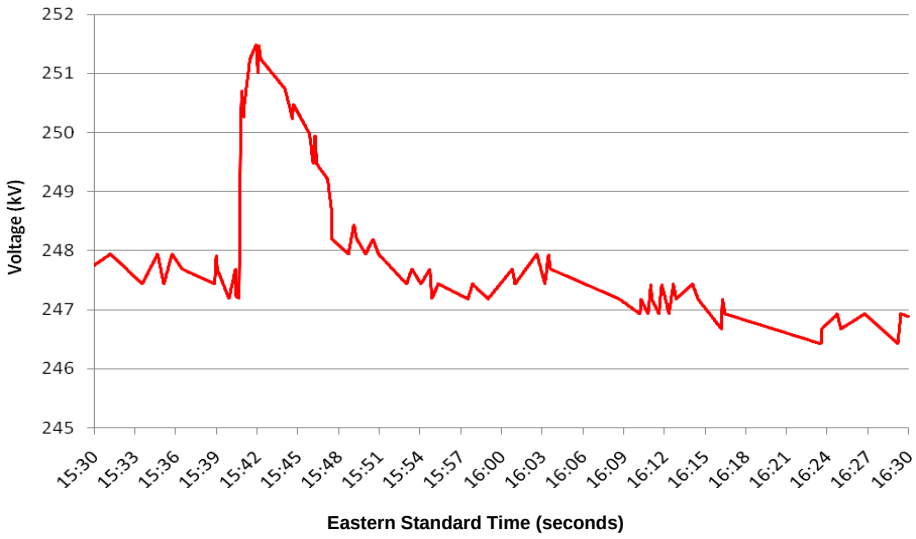


**Figure 6** Richview Switching Station 230 kV Voltage – July 5th, 2010

Of the 1550 MW of load removed from service during the incident, 648 MW were removed by voltage sensitive customer-owned protection operating in response to the faults. This response, which has seen an increase in magnitude year-over-year, is believed to be attributed to the installation and operation of highly sensitive breakers within residential homes. As a result, an increase in sympathetic load loss can be expected to continue with the expansion of new-home construction.

Figure 7 below illustrates how the remaining 902 MW of load removed by configuration was manually restored following the breaker explosion. Total load restoration was completed in just over three and a half hours.

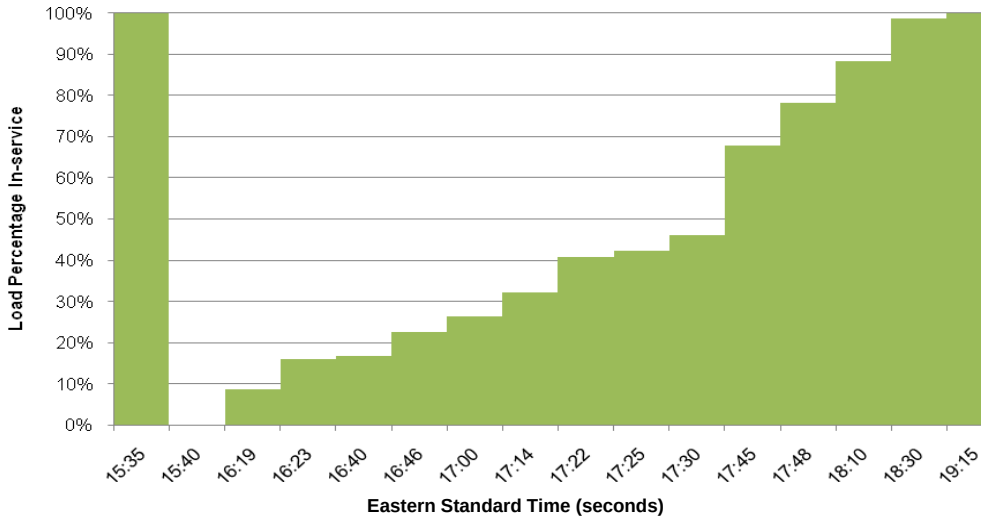


**Figure 7** Percentage of Manual Load Restoration – July 5th, 2010

## 5.4 Impact on Generation

Ontario Power Generation and Bruce Power both reported terminal voltage swings at the Pickering and Bruce nuclear generating stations, respectively. All units remained stable following each fault experienced at Manby.

In order for ACE return to normal, a combination of hydro-electric and coal-fired generators were verbally dispatched down at 15:41 EST to compensate for the temporary load loss. By 16:00 EST, IESO software was re-configured to account for the load profile change and all generators were returned to automated dispatch.

As discussed earlier, the availability of the Portlands Energy Centre allowed for an expedited load restoration once load transfers were initiated from Manby to Leaside supply. More load was available for transfer as the Leaside 230 to 115 kV autotransformers were not as thermally restrictive as they would have been if Portlands was unavailable.

**- End of Section -**

# 6. Conclusions

## 6.1 Preliminary Investigations by Hydro One

The fault originated internally on the Manby West 230 kV H1L15 breaker. Each subsequent fault that occurred on several Manby busses and emanating 230 kV circuits are believed to be the result of the oil and parts that were shot from the breaker once it exploded. It is believed that the oil became contaminated from the debris and smoke that resulted coincident with the explosion. As indicated in the figure below, the timing and location of each subsequent fault was likely based on the proximity of the faulted equipment to the H1L15 breaker.

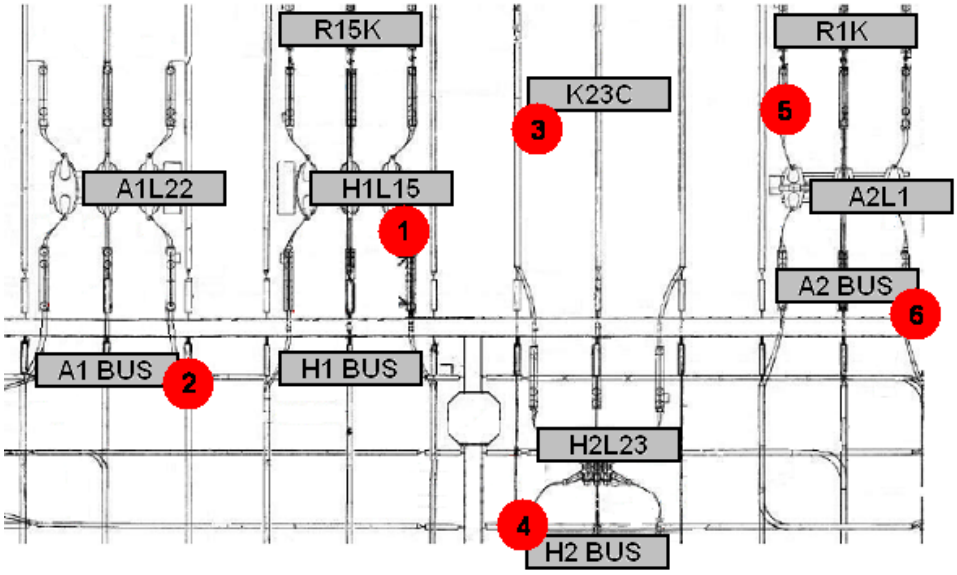


**Figure 8** Manby East and West Station Layout with Fault Order & Location

Power system disturbance recorded data supports the fact that six independent faults occurred in the Manby West and East yards. Hydro One analysis showed primary line and bus-differential protections operated correctly as each fault was cleared by their respective zone within design criteria timelines. Hydro One's review of this data shows no evidence of any relay equipment saturation which could have led to protection misoperation.

Hydro One has deemed the cause of the failure on the H1L15 breaker the result of oil breakdown due to a high particulate count. The breaker has been in-service for the past 32 years and was not a candidate for replacement. It was determined to be in healthy condition based on previous maintenance and sampling schedules.

## 6.2 Actions to Date

By July 9, 2010, all station equipment that was contaminated by soot and smoke from the explosion was cleaned to eliminate the risk of flashover conditions on station equipment.

The Manby West L15L22 breaker, which shares the R15K circuit terminal at Manby with the failed H1L15 breaker, had its above ground cable tray damaged by debris from the explosion. A close inspection of the tray revealed no damage to the cables. The Manby West A1L22 breaker, which sits adjacent to the L15L22 was also declared unavailable as it shares a common DC supply with the other two damaged breakers. Repairs were made to the L15L22 cable tray and the DC supply issue was resolved on the A1L22 breaker within several days. Both of these breakers were made available for service on July 10, 2010. These actions allowed the R15K circuit terminal at Manby to be restored to service with the exception of the failed H1L15 breaker.

The H1L15 breaker was replaced with an SF6-gas breaker on August 20, 2010. This replacement completed the restoration of all equipment at the Manby East and West stations since the incident occurred.

Hydro One identified 39 other breakers across the province that are of the same make and model as the Manby West H1L15. Of the 39 identified, 12 are currently in-service at the Manby station. Since the incident, all of these breakers had two separate oil samples taken and analyzed by two separate labs. This analysis found that no other breakers were at risk such that they would need to be forced out of service for maintenance or replacement.

As part of its ongoing investigation, Hydro One has given consideration to move the normal oil analysis maintenance from a 3 year cycle to an annual cycle.

**- End of Document -**