DISTRIBUTION SYSTEM – SYSTEM CHALLENGES

INTRODUCTION

The electrical distribution system owned and operated by Toronto Hydro-Electric System Limited (“THESL”) is comprised of several components, including an overhead distribution system, underground distribution system, secondary network system and stations. Each of these system components has different characteristics that impact system performance and reliability in different ways. At the same time, there are a number of common critical issues that impact system-wide supply system reliability and asset performance.

THESL’s Asset Management (“AM”) team is investigating cost effective means of mitigating various risks to improve system reliability and safety. This schedule is intended to document and describe various deficiencies and risks (issues) that impact reliability and potential resolutions of the issues to mitigate the risks. These include:

a) Grid System Issues
b) Critical Issues
c) System Wide Issues
d) Other Challenges

These issues relate to key problems that are degrading system performance and integrity: some impact overall system performance, while others are unique to the specific type of distribution system (underground, overhead, secondary network and stations respectively). Some issues have become extremely critical and present high risks to THESL.
OVERVIEW

THESL’s distribution system supplies electricity to approximately 700,000 customers through a network comprised of approximately 15,000 kilometres of overhead circuits, 10,400 kilometres of underground circuit, 139,900 poles, 60,500 distribution transformers and approximately 170 municipal substations (“MS”). Electric power is received from Hydro One Networks Inc. (“HONI”) via 35 transformer substations (“TS”).

The suburban area within the City of Toronto located to the east, west and north of the downtown region is collectively referred to as the “horseshoe” region. Customers within this region are served from the electrical distribution system operating at 27.6kV and 4.16kV, while customers within the downtown region are supplied from the electrical distribution system operating at 13.8kV and 4.16kV. The 4.16kV infrastructure is gradually being phased out of the electrical distribution system, due to its limited capacity, inability to serve load growth, and the high system losses associated with it. A majority of the assets employed on 4.16kV system are old and approaching the end of their useful service lives. In addition, manufacturers of 4.16kV stations and distribution equipment are gradually phasing out products, which will make it difficult to economically operate these systems over the next 15 to 20 year period.

A majority of the distribution system plant within the downtown region is connected in form of radial design configurations, meaning that there are no inter-feeder distribution tie-points. Therefore, should a failure event occur anywhere along a feeder, the entire feeder and the customers connected to it experience a prolonged outage. The commercial/industrial customers served from the radial feeders may have dual supply connections, meaning that they can be manually switched over to a backup feeder, or they may be connected to the secondary network system, meaning that they will see no interruption under a “normal” failure scenario. Should a catastrophic failure occur at a
downtown MS or TS however, the resulting outage would impact all customers served from that station bus and the outage would continue until the impacted station asset(s) has been repaired or replaced.

A majority of distribution system in the horseshoe region employs a looped design configuration, meaning that there are inter-feeder distribution tie-points available. Should an asset failure occur at either the distribution or station levels, power system controllers can restore the system by either remotely controlling Supervisory Controlled & Data Acquisition ("SCADA") enabled switches strategically positioned along the feeder trunk circuits, or by directing the field crew workers to perform manual switching and sectionalizing of the system to isolate the faulted section and restore power to the remaining unaffected sections of the system.

There are system reliability and performance issues related to each of the following sub-systems:

- Underground Distribution System
- Overhead Distribution System
- Secondary Network System
- Stations

THESL’s underground distribution system consists of approximately 16,180 underground switches, 29,780 underground transformers, 10,900 cable chambers, 5,700 circuit kilometres of underground primary and 4,700 circuit kilometres of underground secondary cables respectively. Overall, this underground plant covers approximately 48 percent of the total distribution system within the City of Toronto. For the underground assets evaluated within the Asset Condition Assessment ("ACA") program, 28 percent of these assets fall within the Fair, Poor and Very Poor categories. It is expected that assets which fall into these categories will require replacement over the next ten-year period.
Some of the underground infrastructure in the downtown region is part of the Underground Residential Distribution ("URD") system. This is a system that was constructed approximately 15 years ago as a potential design alternative to replace the existing 4.16 kV infrastructure. In this system, primary cables, switches and distribution transformers are placed underground while secondary voltage connections remain overhead. The primary feeders consist of a main-loop, sub-loop and branch circuits. Customers are supplied directly from either the sub-loops or branch circuits. Each main-loop connects to the sub-loop via a 600A switching vault. Each sub-loop similarly links to the branch circuit via a 200A switching vault. Both sets of these switching vaults contain assets that have heavily deteriorated over time.

The horseshoe region contains direct-buried cross-linked polyethylene (XLPE) cables, which are of older vintage and are deteriorating rapidly. Due to the fact that these cables are direct-buried, service restoration following a cable fault is time consuming, complicated to perform, and disruptive to customers. Air-insulated pad-mounted switches are utilized within the underground distribution system to perform key switching activities. These switches are highly susceptible to tracking and electrical flashovers, resulting in high impact outages to customers.

There are many other assets within the underground distribution system that are approaching, or are past, end-of-life criteria. These include cable chambers within the downtown region which present potential safety hazards to THESL field crew workers, and underground distribution transformers which are subject to contamination, flooding and tank corrosion, which contribute to asset degradation and eventual failure.

THESL’s overhead distribution system consists of approximately 140,000 poles, 8,220 overhead switches, 30,720 overhead transformers, 4,100 circuit kilometres of overhead primary and 10,900 circuit kilometres of overhead secondary conductor respectively.
Overall, this overhead plant covers approximately 53 percent of the total distribution system within the City of Toronto. For the overhead assets evaluated within the ACA program, 50 percent of these assets fall within the Fair, Poor and Very Poor categories. It is expected that assets which fall into these categories will require replacement over the next ten-year period.

The overhead system contains a number of legacy components and construction types. Legacy components include porcelain insulators and arrestors and non-standard animal guards, which have contributed to a worsening reliability trend over the past five-year period. There are many legacy assets and accessories that are installed near sources of salt contamination, including major highways. Legacy construction types include rear lot and box construction, which contain older vintage assets that present safety concerns and operational constraints to crew workers, and have deteriorated past their end-of-life criteria.

The overhead system also contains ageing and deteriorating overhead switches and poles, and overloaded pole-top distribution transformers. There are design-related issues concerning fuse coordination and undersized overhead conductor. There are also potential safety-related issues associated with those overhead assets installed across highways.

THESL’s secondary network system consists of approximately 1,900 network units, 80 automatic transfer switches (“ATS”), 130 reverse power breakers (“RPB”) and 1,070 network vaults. There are 45 secondary networks in all – the majority of which are confined to the downtown region and the Yonge Street and Bloor Street corridors. Of these grids, 22 contain dedicated secondary network system feeders, while 23 contain hybrid feeders, as they also supply overhead and dual radial customers. For the secondary network system assets evaluated within the ACA program, seven percent of
these assets fall within the Fair, Poor and Very Poor categories. It is expected that assets which fall into these categories will require replacement over the next ten-year period.

The secondary network system consists of interconnected low-voltage secondary cables, installed in grid or mesh configurations. The secondary network system offers additional redundancies that the typical Overhead and Underground Distribution Systems do not, as the secondary grid or mesh is energized from multiple primary feeders. Should a single primary feeder encounter an outage, the connected customers will continue to be supplied from the alternate primary circuits, which continue to feed into the secondary grid or mesh. However, should a failure occur directly on a Network Unit, the impacts can be severe including an outage to the entire secondary grid.

Network Units consist of a Network Transformer and Network Protector, which is designed to prevent reverse current flow during an outage scenario on the primary side of the connection. Legacy Fibertop Network Protectors are prone to catastrophic failures, due to the nature of their design. This type of failure could result in a vault fire, which can only be contained by de-energizing the entire secondary grid.

Dual radial customers connected to the hybrid feeders within one of the 23 network grids will be supplied via an ATS or an RPB. These legacy assets are now obsolete, with no support from the original manufacturers. These assets are of older vintage, and their condition continues to deteriorate.

A majority of primary underground cables within the secondary network system are of Paper-Insulated Lead-Covered ("PILC") design, which is gradually being phased out of the system due to the potential health hazards associated with lead material, as well as the ongoing reduction of supply and support for this cable type. Secondary cables within this system are Asbestos-Insulated Lead-Covered ("AILC"), which also introduce a number
of health hazards due to the lead and asbestos material.

THESL’s stations consist of approximately 170 municipal and 35 transformer stations respectively. THESL owns and operates approximately 280 power transformers, 2,100 circuit breakers, 260 switchgear enclosures and 220 direct-current (“DC”) battery systems within these stations. For the stations assets evaluated within the ACA program, 53 percent of these assets fall within the Fair, Poor and Very Poor categories. It is expected that assets which fall into these categories will require replacement over the next ten-year period.

Major station assets requiring replacement over the next ten years include older obsolete switchgear, legacy air blast and 27.6kV oil circuit breakers, older vintage batteries and power transformers. Improvements must also be made to the control and communications systems used to control SCADA-enabled devices and return corresponding telemetry.

At the system level, THESL is facing a number of challenges that impact overall system performance. Over the past ten years, overall system reliability has been getting worse, due to worsening asset condition, ageing infrastructure, legacy designs and components as well as additional risks associated with the overhead, underground and secondary network and stations systems, in addition to risks on the system as a whole. This is further illustrated in Figure 1, which provides a breakdown of customer interruptions (“CI”) and customer hours interrupted (“CHI”) at the system level and defective equipment levels, respectively.

System CI (Total) and CHI (Total) respectively include all outage events due to asset and non-asset-related (weather, animal or externally-related) incidents. Results show, that although CHI has been declining, the number of customers experiencing interruptions has
increased over the last two years. As further described below, increasing customer interruptions will result in higher economic costs to customers, because it is the initial outage event, which interrupts customers’ on-going operations that produces the greatest economic impact on the customer.

System Defective Equipment CI and CHI respectively include only those outage events pertaining to defective equipment, and do not include non-asset-related events. While the Defective Equipment CHI results are similar to the System results as a whole, the Defective Equipment CI results appear to be improving in contrast to the system as a whole. This suggests that some success has been achieved in the last three years with respect to asset-level reliability. Continued capital investments in system assets will be required in order to maintain this improvement trend.

The risks associated with system outages can be quantified into a cost, where various direct and indirect cost attributes associated with in-service asset failures are taken into account, including the costs of customer interruptions; the costs of emergency repairs and replacement; and the indirect costs associated with potential catastrophic failures of assets. Because the event portion of the outage results in the largest economic impact on the customer, this portion of the outage also contributes the most to the quantified risk cost.

When accounting for overhead and underground distribution transformers and switches, poles, underground cables and network unit assets installed within the overhead, underground and secondary network systems respectively, the total quantified risk across a ten-year period is approximately $7 billion. This quantification contains the costs associated with replacement of the assets as well as the reliability-based impacts to customers. This illustrates that THESL’s distribution system is exposed to a tremendous amount of asset-related risks. This is further explained as part of the risk quantification
approach applied within the Feeder Investment Model (“FIM”) described in Exhibit D1, Tab 7, Schedule 1.

Figure 1: System Level CI and CHI

The short-term improvements with respect to the System Defective Equipment CI curve illustrated in Figure 1 can be attributed to the underground distribution system, as a result of the ongoing efforts to replace poorly performing underground equipment such as direct-buried XLPE. Challenges still remain however, with respect to the remaining population of this cable type, along with URD switching vaults, air-insulated pad-mounted switches and deteriorating cable chambers. Resolving these issues will allow for continued improvement of the underground system over the next three years. From a
reliability perspective, other parts of the system – in particular the overhead distribution
system – have been getting steadily worse over the past ten-year period, mostly related to
asset conditions.

Apart from the specific focus on asset replacement for system reliability and performance
improvement, there are other issues and challenges that must also be taken into
consideration. These include issues of a more critical nature creating health and safety
risks, loss of supply risks, capacity risks, and system-wide issues related to operational
risks.

Critical issues include:

• Safety-related issues pertaining to legacy construction (Standardization)
• Inadequate contingency and operational constraints in the downtown region
  (Downtown Contingency)
• Potential for public exposure to live electrical connections (Secondary
  Upgrades)
• Feeders continuously experiencing high volume of interruptions (Worst
  Performing Feeder)
• Insufficient capacity in some areas to account for new customers or perform
  long-term load transfers (Load Growth)
• Lack of control over critical transmission assets and supply sources (Security of
  Supply)
• Erosion and degradation of Station building properties (Stations Infrastructure)
• Replacement and/or installation of new distribution plant resulting from third-
  party construction activities (Externally-Initiated Plant Expansion)

System-wide issues include:

• Feeder utilization, operating flexibility and restoration
Finally, there are other challenges that THESL will continue to face over the long-term. These include:

- Relocation of existing distribution plant due to third-party construction activities (Externally-Initiated Plant Relocations)
- Replacement of failed distribution assets and service restoration (Reactive Capital)
- Connection of new customers and electric-vehicle infrastructure to the distribution system (Customer Connections)
- Hiring of new staff to ensure the transfer of critical technical knowledge from those staff on the verge of retirement (Engineering Capital)

**GRID SYSTEM ISSUES**

**Underground Distribution System**

The underground distribution system contains many ageing assets which are approaching their end-of-life criteria. Figure 2 illustrates historical reliability for the entire underground distribution system and for underground defective equipment, respectively.

Underground CI (Total) and CHI (Total) for the underground distribution system includes both asset-related and non-asset-related failure events, such as dig-ins and adverse environment. Results show, that while CHI has been declining, the number of customers experiencing interruptions has increased over the last two years, which is consistent with the System Level CI and CHI, respectively.

There has been some success achieved with respect to underground distribution system
reliability over the past three-year period, and this is illustrated in Figure 2, with respect
to the underground defective equipment CI and CHI values, respectively. These
reliability metrics only account for asset-related outage events. In particular, the
underground defective equipment CI has improved in the last three-year period, which is
in contrast to the total CI for the underground distribution system. This suggests that
while improvements are being made to mitigate outages produced by underground
defective equipment, non-asset-related failures due to dig-ins and adverse environment
are still resulting in an overall decline in total underground system reliability.

The improvements made to the underground defective equipment CI are largely due to
the recent and ongoing efforts to replace direct-buried XLPE cable. Capital investment
programs like these will need to continue over the next ten-year period such that further
improvements to defective equipment reliability can be realized. CHI has also been
improving over the last three years for the entire underground system, and also for
defective equipment as a sub-category. When considering both asset-related and non-
asset-related failures collectively, reliability has declined compared to 2001.

The underground distribution system suffers from a high risk of in-service asset failures.
These assets are costlier to replace, and typically carry a greater probability of failure
compared to their overhead counterparts. Underground cables, transformers and switches
installed within the underground distribution system carry a quantified risk of
approximately $5 billion across a ten-year period, when various direct and indirect cost
attributes associated with in-service asset failures are taken into account, including (a) the
costs of customer interruptions, (b) the costs of emergency repairs and replacement, and
(c) the indirect costs associated with potential catastrophic failures of assets.

Underground cables are the largest contributors towards this total quantified risk.
Specifically, underground direct-buried XLPE cables account for 62 percent of the total
risk within the underground distribution system. It should be noted this quantified risk value does not take into account non-asset-related risks, which would also contribute to the underground system total risk value. Further breakdowns of these quantified risks are provided for specific underground system asset classes.

Figure 2: Underground Distribution System CI and CHI

Key assets that contribute to the majority of underground distribution system issues have been identified as follows:

- Underground Direct-Buried XLPE Cables
- PILC Cables
- Air-Insulated Pad-Mounted Switches
- URD System
- Cable Chambers
Underground Distribution Transformers

The issues associated with these assets are further described in the remainder of this schedule. In order to allow for continued improvements to the underground distribution system, these issues must be targeted and addressed.

Underground Direct-Buried XLPE Cables

Over the past three years, there have been improvements to underground system reliability, mostly attributed to a very extensive series of replacement programs for underground direct-buried XLPE cable. These cables, many of which are unjacketed, were directly installed into the earth between the 1970s and 80s. Due to the nature of their installation, these cables have been constantly exposed to neutral and sheath corrosion from the surrounding soil, resulting in corrosion and damage to the outer neutral conductors as well as contributing to the degradation of insulation strength.

The manufacturing processes employed in these early vintage XLPE cables did not have sufficiently strict quality controls to (a) keep out the impurities from the insulation system or (b) provide reliable sealing of the insulation system to prevent moisture ingress. The steam curing process employed in the manufacture of early vintage XLPE cables also resulted in moisture being trapped in the insulation system. Due to these manufacturing defects, these cables have suffered from high rates of premature insulation failure.

When an insulation failure occurs with this particular cable type, the only intervention that will provide quick service restoration is to repair the cable using a splice. This splicing procedure repairs the cable at the splice location only; the remainder of the cable continues to deteriorate and failure probability continues to increase over time. The outage, and other subsequent outages on the cable, will be prolonged due to the additional
time required to perform switching to isolate the faulted cable, to locate the fault, to
evacuate at the faulted cable location to expose the faulted cable, to splice repair, and to
complete switching and restore service. Excavation activities typically result in the
breakup of roadways and sidewalks, which result in disruptions to the neighborhoods.
Approximately 877 kilometres of direct-buried XLPE cables remains in-service within
the system with approximately 677 kilometres of this cable believed to be unjacketed.

Unjacketed direct-buried cables have a useful life of 22.5 years, while jacketed direct-
buried cables have a useful life of 40 years. Approximately 60 percent of direct-buried
XLPE cables are beyond their respective useful lives. Out of approximately $5 billion in
quantified risk within the underground distribution system across a ten-year period,
underground cables account for approximately $2.6 billion and direct-buried XLPE
cables account for approximately $1.6 billion.

Note that non-tree-retardant XLPE cable-in-conduit carries many of the same risks as
direct-buried cables, in terms of the impurities within the cables’ insulation produced
during the manufacturing process. Approximately seven percent of these cables are
beyond their respective useful lives.

**Underground PILC Cable**
PILC cable consists of a conductor (typically copper) surrounded by oil-impregnated
paper insulation, lead sheath, and an optional linear low-density polyethylene jacket.
There are approximately 3,910 conductor kilometres of 13.8kV PILC underground cable
in service within THESL’s distribution system.

The majority of PILC cable is situated in the downtown area, with a very small
percentage in the horseshoe region. Out of the total population of PILC cable in
THESL’s distribution system, approximately 1,260 conductor kilometres, or 32 percent
are found within the secondary network system, with approximately 2,650 conductor
kilometres, or 68 percent associated with the underground distribution system.

There are several types of PILC cables within THESL’s electrical distribution system that
vary in age and/or reliability:

- PILC B – Belted cable that is very old and more prone to failure
- PILC H – Shielded, unjacketed
- PILC HJ – Shielded, jacketed
- PILC J – Unsheilded, jacketed
- PILC MIND – Mass-impregnated non-draining (i.e., the oil is very viscous)
- PILC SL – Single conductor

PILC cables are very robust and have a useful life rating of 75 years. While PILC cables
have proven to be very reliable, there are a number of ongoing issues associated with
these assets. Today, only one North American manufacturer continues to manufacture
and supply PILC cables. Typical maintenance, splicing and termination activities for this
particular cable type are complicated, and require a highly skilled workforce. As the
experienced workforce retires, the knowledge and skills associated with installing and
repairing PILC are declining at a faster rate than they can be transferred to the remaining
workforce despite extensive training.

There are potential environmental issues with respect to the lead sheath as well as
potential polychlorinated biphenyl (“PCB”) contamination within the oil that impregnates
the paper insulation. There also are potential health risks associated with the molten lead
that is used as part of the lead splicing procedure, along with risks when this particular
cable type is exposed to high temperatures.
Despite the reliable performance of these assets, THESL has a growing concern with respect to leaking PILC cables, known as “leakers”, where the oil begins to leak from installed PILC splices, or where the lead jacket splits from repetitive load cycling or movement at duct faces and racks. Leakers are considered by THESL to be defects that may present a hazard to workers.

Finally, there are many instances of PILC installed within clay tile ducts. The majority of these ducts have already exceeded their useful life criteria, and many have already collapsed. Collapsed clay tile ducts can increase the time to remove failed cable from the duct structure, and in some cases make it impossible to remove. This can result in prolonged outages.

**Air-Insulated Pad-Mounted Switches**

Air-insulated pad-mounted switches are used to facilitate circuit branch and main feeder switching, load transfer and isolation, and provide fusing/protection in distribution systems. This equipment is comprised of an above grade medium voltage switch mounted on a hollow, below grade foundation. The switch is installed inside a sheet metal enclosure, which provides a barrier to safeguard public from live parts and protects the equipment from direct exposure to the weather elements. These switches have a useful life of 30 years.

The switchgear insulation and inter-phase barriers are susceptible to contamination from dust particles that breach the enclosure. This contamination along insulated surfaces can build up gradually over time. When this contamination is combined with moisture from condensation, it can result in insulation tracking and phase-to-phase or phase-to-ground flashover. This ultimately results in the destruction of the air-insulated pad-mounted switch, along with an outage to the connected customers. These assets have historically been a significant contributor towards defective equipment reliability. Figure 3 below
however, shows the trend over the past five years for CI and CHI has been gradually improving. This is partially due to the increased maintenance being performed on these assets.

It should be noted that while the reliability of this particular asset has been improving, the resulting outage impacts following an equipment failure continue to be substantial. Typically, these assets are installed on the feeder trunk circuits, meaning that the entire feeder will experience an outage. In many instances, multiple feeders will converge at a single air-insulated pad-mounted switch to produce tie-points, used for load transfers and sectionalizing. However, this also produces a greater impact if the asset fails, as multiple feeders will experience the resulting outage. Out of approximately $5 billion in quantified risk within the underground distribution system across a ten-year period, underground switches account for approximately $2.1 billion and air-insulated pad-mounted account for approximately $90 million, respectively. Figure 4 illustrates an example of a contaminated compartment within an air-insulated pad-mounted switch.

![Figure 3: CI and CHI due to Air-Insulated Pad-Mounted Switch Asset Failures](image-url)
The URD system is a below-grade system that was designed to allow for grade-level operation for the purpose improving crew safety. This design was intended to provide a high level of reliability and fast restoration of power through switching and sectionalizing.

The majority of the switching equipment and accessories within the URD switching vaults have suffered from accelerated degradation, due to their exposure to salt, water and
contamination ingress which have collectively created a highly corrosive environment. The lack of stainless steel material applied to the switching asset enclosures has made these assets particularly vulnerable to degradation. Poor condition of the below-grade URD equipment has resulted in difficulties when performing outage restoration. Fault Circuit Indicators (“FCI”) in the URD system are known to provide erroneous readings, leading to longer restoration times.

Figures 5 and 6 illustrate the condition and degradation of this switching equipment contained within the URD switching vaults. Apart from the condition of this equipment, all URD switching equipment is manually operated, which can result in a longer outage, when compared to SCADA-operated switches.

Figure 5: Switching Equipment within URD Vault
The degradation of cable chambers has become a serious reliability issue in recent years, as many of these chambers have already approached or exceeded their end of life criteria. Cable chamber degradation factors include cracks in the concrete, corrosion of steel beams/exposed rebar, and rusting of covers and frames. Cable chambers that have exceeded their end of life criteria also present potential safety hazards to THESL workers.

The cable chamber roof degrades at a faster rate than the chamber as a whole. The roof has a useful life of 25 years, compared to the entire cable chamber, which has a useful life of 60 years. This means that roofs must be replaced on a separate cycle from the chamber itself. Approximately 43 percent of all cable chamber roofs are past their useful life criteria. Examples of damaged cable chamber roofs are illustrated in Figures 7 and 8, respectively.
1 Figure 7: Damaged Cable Chamber Roof

2 Figure 8: Damaged Cable Chamber Roof
Underground Distribution Transformers

There are three sub-classes of underground distribution transformers that exist within the underground distribution system. These include submersible, pad-mounted and building vault transformers. Collectively, 24 percent of these assets are past their useful life criteria.

Submersible transformers have the greatest chance of failing, due to the nature of their installation. These assets are installed below grade within the street allowance, with passive ventilation which exposes the space to the elements. As a result, these assets are continuously exposed to sources of contamination, including dirt, debris, road salt and water. The accumulation of dirt may result in the clogging of the submersible drainage system, which can ultimately lead to flooding within the vault, and accelerating the corrosion of the transformer enclosure.

Corrosion of the transformer enclosure will ultimately lead to exposure and leakage of the dielectric oil medium, which will eventually result in the failure of the asset. Contamination on the termination components may result in the erosion of the insulation material, ultimately resulting in a flashover. Figure 9 illustrates a typical submersible transformer installation. Out of the total submersible transformer population, 23 percent of these assets are past their useful lives.

Building vault and pad-mounted transformers possess slightly reduced failure probabilities when compared to their submersible equivalents, as these assets are better shielded from the elements. It should be noted however, that a greater percentage of building vault transformers, are past their useful life criteria, at 35 percent. Out of approximately $5 billion in quantified risk within the underground distribution system across a ten-year period, underground transformers account for approximately $400 million.
Overhead Distribution System

The overhead distribution system contains many ageing assets which are approaching their end-of-life criteria. Figure 10 illustrates the historical reliability for the entire overhead distribution system and for overhead defective equipment, specifically.
Figure 10: Overhead Distribution System CI and CHI

Overhead CI (Total) and CHI (Total) for the overhead distribution system includes both asset-related and non-asset-related failure events, such as adverse weather, animal contacts or other foreign interference, lightning, human interference and tree contacts. The Overhead CI (Total) value has been steadily improving over the past three-year period. This is consistent with the recent decline in foreign interference and lightning-related events. The overhead CHI (Total) value has been seeing similar improvements in the past year.

By contrast, there has been an increase in the overhead defective equipment CI over the past three-years. The overhead defective equipment CI and CHI values, respectively
account for asset-related outage events. Therefore, while the overhead distribution system as a whole has seen recent improvements, overhead system assets are continuing to fail with each outage impacting an increasing number of customers. Conversely, improvements to the overhead defective equipment CHI indicate that the typical outage duration for these customers has declined.

Overall reliability for the overhead distribution system has not significantly improved from the 2001 reliability levels. From a defective equipment standpoint, reliability has actually declined when compared to 2001.

In contrast to the underground distribution system, the overhead distribution system is constantly exposed to a greater number of non-asset related risks, including weather-related, animal-related and other externally-initiated events that can lead to sustained outages. The overhead distribution system carries significant risks should assets fail. The total asset risks associated with overhead pole-top distribution transformers, switches and poles can be quantified to a total of $1.7 billion over a ten-year period, where various direct and indirect cost associated with in-service asset failures are taken into account including (a) the costs of customer interruptions (b) the costs of emergency repairs and replacement and (c) the indirect costs associated with potential catastrophic failures of assets. It should be noted this quantified risk value does not take into account non-asset-related risks, which would also contribute to the overhead system total risk value. Further breakdowns of these quantified risks are provided for specific overhead system asset classes.

A number of key issues have been identified within the Overhead System, including:

- Ageing poles with reduced strength
- Legacy assets and accessories near sources of contamination
- Bare and undersized overhead conductor
• Legacy rear lot and box construction
• Improper fuse coordination
• Heavily loaded pole-top transformers
• Manual and remote-controlled gang-operated load break switches
• Overhead circuit design
• Overhead line crossings over highways

These issues are further described in the remainder of this schedule. In order to allow for continued improvements to the underground distribution system, these issues must be targeted and addressed.

**Ageing Wood Poles with Reduced Strength**
As part of THESL maintenance activities, each wood pole within the overhead distribution system is inspected and assessed in terms of condition and strength on a ten-year cycle. This inspection data feeds into the ACA program, which assigns condition grades and quantified condition scores to distribution system assets on a scale from 0 (Very Poor) to 100 (Very Good).

From the ACA program, more than 50 percent of the wood poles within the overhead distribution system have been identified as possessing a condition grade of Very Poor, Poor or Fair with most of these poles having a condition score of Fair. It is expected that these poles will require replacement over the next ten-year period. Out of the total $1.7 billion in quantified risk across a ten-year period within the overhead distribution system, poles account for approximately $650 million.

**Legacy Accessory Assets Susceptible to Sources of Contamination**
Legacy accessory assets installed on poles include pole-top transformers, overhead switches, porcelain insulators and arrestors, and non-standard wildlife guards. Over
time, porcelain insulators can develop hairline cracks that will lead to eventual failure. Porcelain insulators and arrestor assets are highly susceptible to contamination, resulting in electrical tracking and flashovers. Salt spray on elevated roadways is one of the more prevalent contaminants that impacts the performance of these particular accessory assets. Assets such as overhead switches can also be directly impacted by these contaminants.

Failure of porcelain insulators or arrestors will result in an outage upstream to a protective device. In the case of the feeder trunk circuit, the resultant outage will impact the entire feeder up to the circuit breaker. When these assets are damaged, they can present a safety risk to workers who are handling or working on this equipment. Porcelain equipment also possesses a higher tendency for leakage current over time, resulting in higher system losses as opposed to the standardized polymeric equivalent accessories. Non-standard “Guthrie” wildlife guards have proven to inadequately shield the electrical connections of pole-top transformers from animals such as birds, squirrels and raccoons.

**Bare and Undersized Overhead Conductor**

While bare conductor has a very long useful life of over 60 years when compared to most other distribution assets, these assets are also the most susceptible to tree contact interruptions, due to the lack of conductor insulation, and their proximity to mature trees.

Tree contact interruptions have fluctuated over the last ten years. These interruptions increased in quantity from 2004 to 2006, and decreased from 2007 to 2009. There has been a 17 percent increase in CI and 49 percent increase in CHI from 2009 to 2010. Overall, tree contacts contribute eight percent to the System Average Interruption Frequency Index (“SAIFI”) and 15 percent to the System Average Interruption Duration Index (“SAIDI”). Brush tree contacts account for 10 percent of the total tree contact outages and although they do not generally result in sustained interruptions, they can be
disruptive to customers using sensitive equipment without surge protection or
uninterruptible power supplies.

There are also specific locations along the feeder trunk portion of overhead distribution
circuits that need to be upgraded to remain properly sized and coordinated with the
remainder of the circuit. The application and effectiveness of feeder tie-points during an
outage event are limited by the carrying capacity of the total circuit path between the tie
feeder circuit breaker, the tie switch and the failed asset location on the impacted feeder.
Any portion of conductor along this path that is undersized will reduce the carrying
capacity and create a weak link in the circuit, thus making the tie-point ineffective and
unusable during an outage event. Under these circumstances, additional switching
operations are required to make use of an alternative tie-point, which can result in a
prolonged outage.

**Legacy Rear Lot and Box Construction**
Legacy construction types contribute to operational constraints for THESL field workers,
resulting in prolonged outages to customers. This includes rear lot overhead plant, much
of which is inaccessible by standard THESL vehicles and machinery. Much of the rear
lot overhead plant was originally installed in the 1940s and 1950s, and these assets
continue to age and deteriorate over time. Due to the placement of these assets between
customers’ backyards, it is extremely difficult to access these assets and perform standard
maintenance and replacement activities. Local trees and plants in the area have also
grown over time and many of these have come into direct contact with the rear lot assets,
as illustrated in Figures 11 and 12, respectively.

All work activities relating to rear lot infrastructure must be performed manually. If a
transformer, switch or other accessory fails within a rear lot area, the crew worker must
climb the pole to disconnect the asset and remove it from the system. This procedure can
also introduce safety hazards if the pole strength has been comprised. Should a pole lose its structural integrity, it is more likely that a failed pole in a rear lot will cause property damage and introduce potential safety hazards to nearby residents.

Figure 11: Rear Lot Overhead Plant
Box construction is another legacy construction type installed predominantly on 4.16kV system feeders. This construction type also poses similar operational constraints, as it is difficult to maintain, and to replace attached assets. Box construction is designed with multiple energized circuits installed and attached to the same pole. As a result, performing any replacement or maintenance work on these assets may introduce potential safety hazards to crew workers. In addition, box construction is no longer a THESL construction standard. Assets associated with both of these construction types are of older vintages and continuing to deteriorate over time. Examples of box construction are illustrated in Figures 13 and 14 respectively.
1 Figure 13: Box Construction Overhead Plant

2 Figure 14: Box Construction Overhead Plant
Improper Fuse Coordination

Proper fuse coordination is essential to ensuring that outages on lateral circuits do not cascade onto the feeder trunk circuits. When an outage occurs on a fused lateral circuit, the resulting fault current that travels to the faulted location will travel through the fuse, thus melting the fuse link and opening/isolating the circuit. Each fuse is rated to a specific current size, meaning that a specific amount of fault current will result in the melting of the fuse link.

There are known locations where these lateral fuses do not properly coordinate with upstream fuses or the circuit breaker. In these instances, the fuse link will not melt as desired, resulting in the fault current cascading to the upstream assets. In cases where a fuse is improperly coordinated with the circuit breaker, the entire feeder will experience an outage.

Pole-Top Transformers

There are many instances of pole-top transformers that were installed more than 20 years ago, where the load has now increased substantially due to new homes and businesses that have developed over time in the areas served by these transformers. As a result, these transformers have now become overloaded.

Normal day-to-day operation of a distribution transformer results in a de-polymerization effect, where the paper insulation gradually degrades over time within the dielectric transformer oil. As this occurs, the transformer oil gradually turns to sludge, and its dielectric properties are reduced. Failure of the paper insulation results in an internal failure of the transformer and outage to the connected customers. When any transformer exceeds its loading capacity, the increased heat travelling through the winding coil will result in an accelerated degradation of both the winding paper insulation as well as the dielectric transformer oil.

In general, many overhead transformers are ageing and nearing their end-of-life criteria.
In fact, 31 percent of all overhead transformers have already surpassed their useful life criteria of 35 years. Overloading transformers accelerates their deterioration. Out of the total $1.7 billion in quantified risk across a ten-year period within the overhead distribution system, pole-top transformers account for approximately $280 million.

There also exists a population of Completely Self-Protected (“CSP”) transformers within the overhead distribution system. These are an outdated transformer type which contains built-in fault current protection in the form of an internal fuse. When these assets fail, the entire asset must be replaced, regardless of whether the transformer failed or the fuse reacted to a downstream secondary fault. Ultimately, this can result in a prolonged outage. In contrast, typical pole-top transformers have external fusing, which allows the fuse to be easily replaced should it react to a downstream fault without replacing the transformer.

**Manual and Remote-Controlled Gang-Operated Load Break Switches**

Along the feeder trunk circuits, overhead gang-operated load break switches are strategically placed to perform load transfer, sectionalization and isolation operations. Many of these switches are remote-controlled by power system controllers via the Supervisory Control and Data Acquisition (“SCADA”) system. Many of these switches are of older vintage, and nearing their end-of-life criteria.

Approximately 29 percent of manual gang-operated switches are past their useful lives. As these assets continue to age, corrosion develops around the mechanical linkages, which eventually leads to mechanical failure of the switch during operation. Corrosion accelerates within harsh environments such as major industrial or high traffic locations. The total number of load breaking operations will also contribute to overall wear and tear of these assets. Out of the total $1.7 billion in quantified risk across a ten-year period attributed to the Overhead system, overhead switches account for approximately $760
Overhead Circuit Design
The majority of the overhead distribution system contains radial fused lateral connections, which cannot be restored from an alternative source should an upstream outage take place. For example, should a permanent tree contact, insulator, arrestor or pole failure occur anywhere on an overhead circuit, all customers downstream from this location to the radial circuit termination will experience the resulting outage. In addition, there are many portions of single-phase overhead circuit that are connected directly to the feeder trunk circuit. If a failure occurs on any portion of these single-phase circuits, the resulting outage will impact all customers on the feeder.

Overhead Line Crossings over Highways
There are a number of instances where THESL-owned overhead conductors cross major highways. At these crossings, there is a potential public safety risk in the unlikely event that one of these lines was to fail and fall onto oncoming traffic.

Secondary Network System
Within the City of Toronto downtown core, 40 percent, or 600 MVA of the system load is supplied from the secondary network system. The secondary network system is the most reliable system configuration in Toronto, with a SAIFI of 0.08 and a SAIDI of 14.4 over the past five years. Figure 15 illustrates the historical reliability for the entire secondary network system and for secondary network defective equipment, respectively.
Secondary network CI (Total) and CHI (Total) include both asset-related and non-asset-related failure events, such as adverse environment or human interference. The secondary network CI (Total) value has been slowly improving over the past three year period. However, the secondary network CHI (Total) value has been increasing over time, and saw a larger increase in 2010. This means that while the number of customer interruptions is decreasing, the outage duration for these events is increasing. The network defective equipment CI and CHI, which include only the asset-related failure events, follow a similar trend to that shown for overall secondary network system reliability.
In 2006, the reliability data indicates that half as many outages took place, compared to 2005 and 2007. The number of customer interruptions associated with these outages was low, resulting in very low CI and CHI, both at the secondary network system level, and defective equipment levels, respectively. Overall, reliability has improved slowly since 2005, and continued investment is necessary to ensure that this improvement is sustained.

The vast majority of the civil and electrical infrastructure within the secondary network system is between 40 and 70 years old, with many assets nearing their end-of-life criteria. The secondary network system carries significant risks associated with asset failure. The total asset risks associated with network units can be quantified to approximately $230 million across a ten-year period, when various direct and indirect cost attributes associated with in-service asset failures are taken into account, including (a) the costs of customer interruptions, (b) the costs of emergency repairs and replacement and (c) the indirect costs associated with potential catastrophic failures of assets.

This quantified risk does not account for the primary or secondary underground cables, switches or network vaults installed within the secondary network system. This quantified risk value also does not take into account non-asset-related risks, which contribute to the secondary network system total risk value. Further breakdowns of these quantified risks are provided for specific secondary network system asset classes.

A number of key issues have been identified within the Secondary Network System, including:

- Fibertop network units
- Legacy network equipment (ATS and RPB)
- Network vaults
- Overloaded primary cables
- AILC secondary cables
**Fibertop Network Units**

A network unit consists of a network transformer, network protector and primary switch used to isolate the asset from the primary circuit. The purpose of the protector is to open and isolate the secondary side of the circuit from the primary side should a fault current be detected on the primary side of the circuit. This action prevents the possibility of reverse current from flowing from the secondary to the primary side of the circuit.

Normal failure modes for a network unit include a winding fault within the network transformer, transformer oil leaks through the base of the transformer tank and deterioration of the primary switch. A catastrophic failure can occur when a failure occurs directly at the Network Unit, and the protector is unable to perform its desired operation in opening the circuit to prevent reverse power flow. This ultimately results in both the primary and secondary sides of the circuit supplying the fault. A vault fire could potentially be triggered from this event. To extinguish this type of fire, the vault location must be completely de-energized which may require all primary feeders supplying the secondary grid to be dropped. This will lead to a substantial outage to all customers on the secondary grid.

Fibertop network protectors have the greatest probability of catastrophic failure, due to the nature of the connections made from the protector to the secondary grid cables. This is further illustrated in Figure 16. These connections are made extremely close to the surface of the fibertop protector, and they are spaced very closely together. The fibertop surface is extremely permeable to moisture and contamination. This surface permeability, in combination with the minimal spacing of the secondary connections, can result in inter-phase tracking between these connections, which could then trigger a catastrophic failure event.
There are approximately 300 fibertop network in the secondary network system, which accounts for only 15 percent of the total population of network units. Despite the small population, these specific units contribute 88 percent to the total risk costs associated with all network units, with a total of $18.1 million in quantified annual risks. This is further illustrated in Figure 17. Across a ten-year period, these costs total approximately $185 million.

Legacy Network Equipment (ATS and RPB)

There are 23 network grids containing hybrid feeders which supply overhead and dual radial customers, in addition to the standard secondary network customers. Customers with dual radial configurations are connected to the network via an ATS or an RPB.

A typical ATS installation consists of two supplying transformers and the ATS itself. One of the supplying connections will be “Normal,” which is the typical supply point to the customer, while the second connection is the “Standby” or alternate connection.
The ATS is designed to automatically switch over from Normal to Standby connection should an interruption occur on the Normal connection. However, ATS units have proven to be somewhat unreliable in performing this particular automatic switching operation, leaving the connected customer with a sustained outage.

A typical RPB installation is slightly different, as two supplying transformers are connected to two RPBs, with one connection being the Normal, and one being the Standby. Like the ATS, RPBs are also designed to manually close on the interrupted feeder, such that the alternative supply can be deployed to the customer. As is the case with ATS assets, RPBs have also proven to be somewhat unreliable in performing this operation.
The reliability and performance of these two asset types is due to their old age and deteriorating condition, lack of manufacturer support and lack of available parts to perform necessary repairs. As these assets are now obsolete, it is difficult to perform required maintenance activities. There are critical parts for these assets that are no longer available, and as a result alternative parts need to outsourced. The lack of available replacement parts creates a longer-than-usual downtime for these assets while repairs are being performed, along with substantial labour resource requirements. Approximately 29 percent of ATS assets are past their useful life criteria.

**Network Vaults**

Network Vaults represent the underground civil infrastructure which can house two or more network units, RPBs, ATSs, compact radial design (“CRD”) and associated primary and secondary cable connections. Based on recent civil inspections, between 15 and 30 percent of inspected network vaults have been classified as having the worst inspection score of 5 (High Risk). For many existing vaults, the rebar and I-beam in the roofs have become corroded due to salt and water contamination, as well as to old age. These issues are further illustrated in Figure 18. Network vaults that are past their end of life criteria can pose risks to crew safety as well as the reliable operation of the secondary network system.

As is the case with cable chambers, the roof of a network vault will degrade at a faster rate than the vault as a whole. The network vault roof has a useful life of 25 years, compared to the useful life of 60 years for the entire vault. An example of a deteriorated network vault roof is illustrated in Figure 19. Rebuilding or relocating a network vault is difficult because THESL must continue to maintain supply to customers. In tandem with a typical vault rebuild, adjacent cable chambers will usually need to be rebuilt, along with replacement or piecing out of PILC and AILC cables.
Figure 18: Corroded I-Beams within Network Vault

Figure 19: Cracked Network Vault Roof
Overloaded Primary Cables

The secondary network system contains approximately 1,360 kilometres of primary cable, of which approximately 93 percent is PILC cable type. There are many challenges associated with PILC cables, including potential safety risks and obsolescence. These challenges are further outlined within the “Grid Issues – Underground Distribution System” subsection found at Exhibit D1, Tab 9, Schedule 1.

In addition to these issues, certain PILC cables within the secondary network system have been identified as being loaded above 300A under either normal or emergency operating conditions. When this loading benchmark has been surpassed, these primary cables are in danger of approaching their normal and emergency carrying capacity thresholds. The normal loading threshold for PILC cables is 381A, while the emergency threshold is 428A. For TR-XLPE cables, the normal loading threshold is 288A, while the emergency threshold is 328A.

Normal operating conditions are defined as when the secondary network system is operating normally, with all primary feeders in service supplying the grid. Emergency operating conditions are defined as when one primary has failed or has been de-energized for planned work (first contingency), which will force the remaining feeders to pick up the entire network load.

Figure 20 shows that at least 29 percent of all network feeders are overloaded under emergency operating conditions, and two percent of all network feeders are overloaded under normal operating conditions. Figure 21 highlights the total quantities respectively of feeders that are overloaded under normal and emergency operating conditions, as well as new or recently upgraded feeders and feeders that must be reviewed for load transfers.
Table 7: Status of Network Cables

<table>
<thead>
<tr>
<th>Status</th>
<th>Quantity</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overloaded under Normal Criteria</td>
<td>3</td>
<td>2%</td>
</tr>
<tr>
<td>Overloaded under Emergency Criteria</td>
<td>41</td>
<td>29%</td>
</tr>
<tr>
<td>New or Upgraded Feeder</td>
<td>29</td>
<td>21%</td>
</tr>
<tr>
<td>Load Transfer</td>
<td>15</td>
<td>11%</td>
</tr>
</tbody>
</table>

Figure 20: Overloaded Network Cables

- Overloaded under Normal Criteria: 3 feeders (2%)
- Overloaded under Emergency Criteria: 41 feeders (29%)
- New or Upgraded Feeder: 29 feeders (21%)
- Load Transfer: 15 feeders (11%)

Underground AILC Cables

AILC cable consists of a conductor (typically copper) surrounded by asbestos-based insulation and covered in a ductile lead sheath. All AILC cables are rated to 600V, and are installed as #4, 2/0, 250 MCM and 500 MCM sizes in the field. These cables account for 68 percent of the secondary voltage (600V) connections within the secondary network system.

These cables present potential health hazards to crew workers due to the asbestos material. In addition, most of this cable is deteriorating and nearing its end-of-life criteria. Replacement of these cables also produces additional challenges in that the...
entire civil plant (network vault) must typically be replaced as well.

Stations

There are a number of stations assets that are either obsolete, pose safety risks to crew workers or have approached or surpassed their useful lives. The average age of Station assets is 33 years.

A number of key issues have been identified with respect to Stations assets, including:

- End-of-Life Obsolete Switchgear Equipment
- End-of-Life Power Transformer Equipment
- End-of-Life Oil Circuit Breakers
- Control and Communications Systems
- End-of-Life Batteries and Chargers

End-of-Life and Obsolete Switchgear Equipment

Switchgear assets are used to subdivide power flow to distribution feeders and provide the ability to switch the connected distribution feeders to open or closed positions. There have been many safety-related and technological advances in switchgear technology which have made the existing population of older vintage switchgear obsolete and thus un-replaceable on a like-for-like basis. As per the ACA program, 61 percent of these assets fall into the Fair, Poor and Very Poor categories, and will require replacement over the next ten years.

Due to the age and obsolete nature of these switchgear assets, it can become extremely complex to perform maintenance and repair tasks. Under a normal switchgear failure scenario, the entire bus, connected feeders and customers will experience an outage. Under a catastrophic failure scenario, a flashover explosion could occur within the switchgear, resulting in a potentially serious safety risk to crew workers, and the
mandatory replacement of the entire switchgear enclosure and the assets contained within it.

End-of-Life Power Transformer Equipment

Many of the power transformers within THESL’s 4.16kV distribution system are approaching end-of-life criteria. In fact, approximately 45 percent of the power transformer population has already surpassed their useful lives. In addition, 58 percent of these assets have received ACA ratings of Fair, Poor or Very Poor and will require replacement over the next ten-years.

A normal failure of a power transformer is defined as an internal winding fault. This typically occurs due to the failure of the winding paper insulation, which will gradually de-polymerize and degrade as the transformer ages over time. The amount of load within the transformer will directly influence the “hot spot” temperature on the winding, which will gradually deteriorate both the paper insulation as well as the dielectric transformer oil. As this occurs, the transformer oil gradually turns to sludge, and its dielectric properties are reduced.

The resulting power transformer failure produces different consequences depending on the location and configuration of the asset and the station itself. The horseshoe region contains inter-feeder ties, which allow power system controllers to perform load transfers in the case of a station outage. Some stations may have multiple transformers, which may be capable of picking up the lost load. In the case of a catastrophic failure, the internal transformer fault is so severe that a serious explosion results and multiple assets at the impacted station are destroyed. In either case and due to the complexities of transporting a new transformer to the site, it can be quite challenging to replace a failed power transformer and to repair associated equipment at the site. It can take anywhere from three to seven days to transport a spare transformer to a given site.
End-of-Life Obsolete Oil Circuit Breakers

Many circuit breakers within THESL’s distribution system are older and approaching their end-of-life criteria. Based on the ACA program, 92 percent of the oil circuit breaker assets have been classified as being in Fair, Poor or Very Poor condition. These assets will require replacement over the next ten-year period. In general, oil circuit breakers installed within the 27.6kV system are now obsolete, and pose reliability and environment risks should they fail.

Depending on the installation and configuration of a particular breaker, an internal failure within a circuit breaker can result in an outage to a feeder, bus or entire station. With respect to oil circuit breakers, potentially serious safety and environmental risks can be introduced from oil leaks and due to the potential for the dielectric oil medium to ignite under the high pressures and temperatures introduced by fault current. These conditions have the potential to result in a more serious explosion.

Control and Communications Systems

The majority of THESL-owned circuit breakers at 13.8kV and 27.6kV stations can be remotely-controlled by the power system controllers via the SCADA system. Through SCADA, the Control Centre and engineers alike can view other statistics, including loading and temperature. These systems allow for an improvement to system security and outage response times.

There are some circuit breakers at select 4.16kV stations that do not possess SCADA capabilities and thus their loading and other statistics cannot be monitored. Manual switching must be performed for these assets whenever the circuit breaker needs to perform an open or close operation.

In addition, certain stations contain obsolete remote terminal units (“RTUs”), which are
no longer supported by their manufacturer. Currently, power system controllers must
dispatch crew workers to these substations to prevent the corresponding circuit breakers
from performing reclosing operations. This situation greatly increases the time required
for crews to complete their work.

Finally, the existing copper communication system which is used to permit
communication between the control centre and the SCADA-enabled devices installed
across the electrical distribution system does not currently offer the larger bandwidth that
will be required by new technologies such as feeder automation.

End-of-Life Batteries and Chargers
DC battery systems power the relays and control sensors, which in turn are used to detect
fault currents such that the circuit breaker will operate in accordance. Many of these
assets are ageing and approaching their end-of-life criteria. Should these battery systems
fail, the circuit breakers will be unable to react to fault current, resulting in their failure to
operate. These assets possess a useful life of 20 years. However, field data suggests that
these assets may fail prematurely between 10 and 15 years of age.

CRITICAL ISSUES

Standardization
THESL plans, designs and constructs distribution system assets in accordance with
approved standards. The standards are developed by THESL to achieve the objectives of
public and employee safety in compliance with the requirements of Ontario Regulation
22/04.
There are some assets in service that were installed prior to the development and adoption of the standards currently in use. These legacy installations are left over from the amalgamation of the former utilities of Toronto Hydro, Etobicoke Hydro, North York Hydro, Scarborough PUC, East York Hydro and York Hydro into the current THESL.

As a result, the continued operation of these legacy installations represents a critical system issue for THESL. Examples of legacy equipment that no longer meets current THESL standards are:

- Porcelain Hardware
- Posi-Tech Switchgear
- SCADAMATE R1 Units
- Grounding

**Porcelain Hardware**

Porcelain or glass hardware represents a growing concern for THESL, as these assets not only contribute to poor system reliability, but also contribute to potential safety hazards to the public and crew workers. When these assets fail catastrophically, there is the potential for serious safety hazards in the form of shattering porcelain material or the entire hardware falling to the ground.

Examples of porcelain hardware which represent critical issues include porcelain pothead terminations and porcelain in-line switches. These terminations are installed on PILC cables on the 4.16kV and 13.8kV system voltages respectively.

Porcelain in-line switches have the potential of falling to the ground, following a major flashover or arching event. Porcelain arrestors and insulators have also contributed negatively to the overhead system reliability, and have been identified as an Overhead Grid System Issue.
Posi-Tech Switchgear

The current method of grounding a 200Amp Posi-Tech switch installed within the 4.16kV system is difficult to perform by crew workers, due to the design of the switch component. In order to facilitate the installation of grounds, the live primary cable must be removed from the switch. This presents a potential safety hazard to THESL crew workers, and there is no alternative method to safely ground these switches.

SCADAMATE R1 Units

SCADAMATEs are gang-operated load break switches that are remotely-controllable by power system controllers via the SCADA system. Older vintage SCADAMATEs, known as R1 units, have created near-miss safety issues with employees due to corrosion within the motor compartment. When this corrosion occurs, these switches will unexpected operate during a routine maintenance procedure. This corrosion is the result of moisture penetration within these motor compartments. Figure 22 illustrates the motor compartment installed on a SCADAMATE R1 switch.
Numerous legacy submersible transformer installations have been identified as lacking an adequate number of ground rods to ensure that the resistance to earth is sufficiently low. This could result in an unacceptably high step or touch potential in the earth surrounding the vault should a fault occur.

Instances of non-conformance to current standards have also been identified for various pole-top transformer locations, including the lack of a ground rod, incorrect connectors or wire sizes, the transformer case or H2 bushing connection not being properly installed or the transformer not being properly bonded to the system neutral. Each of these critical issues contributes to potential safety hazards for crew workers and the public.
Downtown Contingency

As stated under Grid System Issues, the majority of distribution plant within the
downtown region is connected as part of a radial design configuration, i.e., there are no
inter-feeder distribution tie-points between distribution feeders. Instead, each downtown
region station is configured in a “back-to-back” manner, meaning that there is a normal
and standby bus, with two power transformers supplying both of these buses. Should one
power transformer fail, the second can continue to supply the customers. If a feeder
outage occurs, customers can be switched over to the alternative supply.

However, if a catastrophic failure were to occur to a power transformer resulting in a
station failure, or to a switchgear enclosure or circuit breaker resulting in a bus failure, all
customers would experience a sustained outage until repairs at the station are completed.
This circumstance is due to the lack of distribution tie-points, along with a lack of
connection points directly between stations.

Recent events have resulted in significant prolonged outages as a result of this radial
configuration. In 2009, a malfunction with the fire suppression system associated with
the HONI power transformer equipment at Dufferin TS resulted in water penetration and
eventual flooding to the THESL-owned switchgear installed in the building’s lower level.
As customers could not be transferred to other stations, a total of 34,308 customers were
impacted, with some without electricity for up to 24 hours on the coldest winter day of
the year. A similar flooding incident took place in 2005 at the Terauley station, where
3,556 customers in the downtown core were interrupted for ten hours.

A recent study was performed for Dufferin, Windsor and High Level/Bridgman stations
to quantify the risks associated with the installed assets, including Power Transformers,
Circuit Breakers, Switchgear Enclosures and the DC Battery System. This risk
quantification accounts for various direct and indirect cost attributes associated with in-
service asset failures including: (a) the costs of customer interruptions, (b) the costs of emergency repairs and replacement, and (c) the indirect costs associated with potential catastrophic failures of assets. The quantified annual risk for the three stations total $35.6 million.

Secondary Upgrades

Secondary electrical plant installed in the field is constantly subjected to natural and man-made environmental factors such as water, salt and contamination ingress, and wide variations in temperature. Corrosion and degradation of components occurs and, eventually, the integrity of connections may deteriorate to a point where live electrical wires become exposed. Figure 23 illustrates a typical handwell and internal connections, along with some of the typical degraded elements found within it. Figure 24 illustrates a handwell with heavily contaminated and flooded electrical connections.

Figure 23: Typical Handwell Degradation Factors
Examples of such connections include metallic handwell and pole handhole connections which supply streetlights. A series of safety-related incidents occurred in 2009 resulting in a Level III Emergency, where all handwell and pole connections were secured as part of a short-term response activity. Until these connections are fully repaired and standardized as part of a long-term activity, the risks associated to the system due to these assets will remain.

Worst Performing Feeders

THESL has adopted both CI and CHI statistics in order to assess reliability at the feeder
level as part of the Worst Performing Feeder (“WPF”) program. This program aims to
target feeders which are experiencing sustained interruptions, measured over a rolling 12-
month period. A subset of this program is known as Feeders Experiencing Sustained
Interruptions (“FESI”), which examines those feeders that have surpassed a certain
threshold of sustained interruptions within the 12-month rolling period. Through this
program, a number of deficiencies concerning THESL distribution plant have been
identified, including deteriorated assets that have exceeded their end-of-life criteria, as
well as legacy overhead accessories that continue to contribute to outages.

There are 41 feeders that have experienced seven or more sustained interruptions within
the rolling period from January to December 2010; these feeders are assigned a
classification of “FESI-7”. These 41 feeders have collectively contributed to 37 percent
of System CI and 32.3 percent of System CHI. The FESI program has added an
additional 20 feeders for 2010 that were not part of this classification in 2009. If
improvement work on these feeders is deferred, the number of feeders considered to be
“worst performing” could potentially double by the end of 2013.

Load Growth

Windsor TS was constructed in 1950 and expanded in 1968 to become the largest 13.8kV
substation in Toronto. This station currently supplies approximately 304 MVA of load to
customers within the downtown core. Windsor TS is nearing its available firm capacity,
and it is expected that this station will not be able to support the expected load growth
associated with waterfront redevelopment programs. There is currently insufficient space
available at Windsor TS to expand and construct a new bus to support additional
distribution feeders. In addition, many of the air-blast switchgears installed at this station
have reached or are approaching their end-of-life criteria and must be replaced. Prior to
these asset replacements however, the existing customers must be transferred over to
another substation.
As noted in the Downtown Contingency section under Critical Issues (Exhibit D1, Tab 10, Schedule 2), a risk quantification study was performed for all assets installed at Windsor TS. This risk quantification accounts for various direct and indirect cost attributes associated with in-service asset failures including (a) the costs of customer interruptions, (b) the costs of emergency repairs and replacement and (c) the indirect costs associated with potential catastrophic failures of assets. Annual risks associated with Windsor TS total $16.3 million.

Apart from the load growth issues at Windsor TS, there are also other parts of the electrical distribution system experiencing similar problems. Weak points have been identified within the current set of 115kV transmission lines between Wiltshire TS, and Leaside TS. These transmission lines are nearing their available capacity under normal conditions. Should an emergency occur due to failure of either Manby TS or Leaside TS, these lines would be unable to carry the additional load under first contingency scenarios. Similarly, Manby TS currently operates above its ten-day limited time ratings ("LTR") during peak load periods due to load growth. As a result, these buses require load relief.

**Security of Supply**

The 13.8kV electrical distribution system which supplies the downtown core is currently supplied by two major sources owned by HONI. These include Manby TS, which supplies 30 percent of the total load and Leaside TS which supplies 70 percent of the total load. THESL does not control the maintenance or operational activities at Leaside and Manby TS. This supply arrangement is illustrated in Figure 24.

Portlands Energy Centre ("PEC") could supply 550 MW of load back onto the grid should a failure occur at either Leaside or Manby stations. Should a partial or full outage occur at Manby TS, or should a partial outage occur at Leaside TS, it is estimated that the connected customers will experience up to a four-hour sustained interruption until they
are re-supplied.

Due to the fact that Leaside supplies a significantly larger portion of the downtown load than Manby, the available capacity from Manby and Portlands together is insufficient to re-supply all customers currently supplied by Leaside. Under a worst case scenario, should either a Leaside Full Failure or Loss of Supply (both Manby and Leaside TS fail) event occur, the required repair work could result in an outage lasting up to three-weeks. During this time, rolling outages would need to be implemented in order to address the unsupported load.

Figure 24: Downtown Core Supply Sources

Using this information, along with occurrence rates defined by a recent OPA study
entitled *Qualitative Assessment of Extreme Contingencies at Cherrywood, Leaside, Richview and Manby Transformer Stations*, THESL was able to quantify the total risks associated with all potential catastrophic failure events for Manby and Leaside stations. To define the impact of these asset failures on customers, the total gross domestic product for the City of Toronto downtown region was utilized. Based on these inputs, the total annual risk quantified amounts to $23.5 million under a worst case scenario.

**Stations Infrastructure**

The MS buildings are some of the oldest parts of THESL’s electrical distribution system. These assets require investment and maintenance to maintain their functionality. Under a worst case scenario, poorly maintained station infrastructure can result in serious damage to THESL assets contained within the building.

Sources of infrastructure risk include substructure/foundation degradation involving exterior walls, floor construction, basement walls, roofs and foundations; interior degradation to doors, walls, floors and plumbing fixtures; and exterior degradation to windows, water supply and sewer systems. Figures 25 and 26 illustrate situations where infrastructure flooding and exterior cracks developed due to insufficient infrastructure investments.
Figure 25: Flooding within Stations Infrastructure

Figure 26: Exterior Cracks to Stations Infrastructure
Externally-Initiated Plant Expansion

There are various infrastructure improvements occurring throughout the City of Toronto (“City”), often initiated directly by the City or by third-party agencies such as GO Transit/Metrolinx, Toronto Transit Commission (“TTC”) and Business Improvement Area (“BIA”) groups. THESL will ultimately be required to respond to these improvements in order to accommodate the load growth in new developments and replace ageing infrastructure in redeveloped areas.

Once a development in a given area has been energized, the City institutes a road opening moratorium for up to five years. Should THESL choose not to respond to these development activities, new assets cannot be installed and existing assets cannot be replaced until the moratorium is lifted. Therefore, THESL must remain aware of these ongoing developments, and respond to them.

SYSTEM-WIDE ISSUES

Feeder Utilization, Operating Flexibility and Restoration

Within a looped distribution system, tie-points are utilized as part of the restoration activities, to perform load transfers between tie feeders, sectionalizing and isolating the affected circuit. To perform these functions effectively, there must be an adequate number of tie-points to other unique feeders.

Currently, there are a number of feeders within the “horseshoe” region that possess less than three available tie-points to three unique feeders. Under normal system operation, this type of configuration would meet minimum requirements. However, should these circuits experience an outage, it will take longer for the power system controllers to perform load transfers, sectionalize and isolate the affected circuit. If any of the tie circuits are at or near their carrying capacity, this can result in a prolonged outage.
Figure 27 provides the breakdown of number of feeders for particular utilization levels. The largest number of feeders fall into the 25 to 50 percent utilization, and 50 to 75 percent utilization categories, respectively. The greater the utilization value for a given feeder, the less flexibility there is for power system controllers to shift a desired amount of load to this given feeder. In an instance where a nearby tie feeder does not have the available capacity to accept the load transfer, the outage will be prolonged until the faulted asset has been replaced or until the power system controller has completed a series of complex switching operations to re-route power to the affected circuit.

Figure 28 provides the total number of available unique tie-points for all distribution feeders at the 27.6kV system level. There are a total of 49 feeders that possess two or fewer tie-points, including four feeders which do not possess any tie-points at all. These four feeders are essentially operating under a radial configuration, where any asset failure would result in an outage to all connected customers. A potential resolution to this issue would be to install new unique tie-points for those feeders that currently have two or less unique tie-points.
The majority of the THESL distribution system contains manually-operable or SCADA-controlled feeder tie-points. During an outage, it can take many hours to properly utilize these switches to perform the complex sectionalizing, load transfer and isolation procedures that are required. During this time period, power system controllers must also perform additional activities, such as checking for available feeder capacities and performing fault locating along the circuit.

![Figure 28: Quantity of Unique Feeder Tie-points for 27.6kV THESL Distribution System Feeders](image)

Fault locating activities can be difficult and time consuming to perform, both for the power system controller as well as the field crews. There are many parts of the system that do not have properly functioning fault indicator systems, or have no fault indicator systems at all. This ultimately can result in a prolonged outage, particularly for fused lateral connections. Fault indicators can also be useful in providing data on momentary interruptions, which can disrupt customers with sensitive equipment.

**Power Quality**

As new electronic devices penetrate the consumer market, from entertainment devices for
residential consumers, to energy efficient drive systems for industrial customers, THESL
will be faced with the new challenge of focusing not only on the reliability of supply, but
also the quality of power supplied. Voltage sags are an inevitable side effect of faults in
the system. New electronic drives are sensitive enough that they will “shut down” when
the voltage sags or dips to a level typically seen during system faults. To an industrial
customer, this is judged as a power outage since their process stops. However, in reality
the voltage sag is a power quality issue, resulting from power outages to other customers
in the system. These power outages could take place not only within the THESL
electrical distribution system, but also in HONI’s transmission system.

**THESL System Reliability when compared to World Class Cities**
In 2009, a study was conducted by Capgemini to compare the reliability of THESL to
other world class cities. This comparison was performed based upon the SAIFI and
SAIDI parameters, with the primary comparison index being SAIDI. Cities for
comparison were selected based upon the following criteria:

- **City size:** Population had to be greater than one million people in the core city
  and more than three million in the metropolitan area.

- **City reputation:** City had to have a name that was recognizable to everyone in the
  room and an attractive place to visit or live.

- **Industry reputation:** Selected cities had to have an active electric utility, well
  known to and a member of various technical societies.

- **Transient population:** No large population of transient people living in temporary
  housing within the margins of the city with makeshift (temporary) utilities.

Ultimately, selected cities that fit within the categories described above were Hong Kong,
China; Tokyo, Japan; Paris, France; New York City, New York; Miami, Florida; and
London, England. Reliability and system data was collected and reviewed for each city
and compared to that of THESL’s distribution system. As highlighted in Figure 29,
Toronto’s system SAIDI of 74.5 is three times worse than the international average of 23.9. When compared to each individual system SAIDI, Toronto’s system is up to 40 times worse. Toronto also had the highest system SAIDI of all of the international cities evaluated in this study.

Figure 29: System Reliability when compared to World Class Cities

The electrical systems of these other world class cities were closely examined and studied in order to make appropriate comparisons to THESL’s own system, design and asset configurations. Recommendations from this report focused on modernization improvements at the system design level, as opposed to asset replacements. Examples of these improvements included introducing new system configurations to improve contingencies up to N-2 levels, introducing looped configurations to existing radial designs, introducing distributed generation and energy storage solutions and introducing a third line of supply into the downtown core.

This report concluded that THESL’s current-state reliability levels may have negative impacts on the City’s growth potential as well as overall attractiveness to corporations.
looking to establish a major North American hub. From this study, it is clear that THESL
is far behind other world-class cities in terms of its system design, performance and
reliability. It is clear that THESL will need to go above and beyond traditional asset
replacement techniques, in order to significantly improve reliability, and align itself to
match the reliability and performance levels of utilities of other world class cities.

OTHER CHALLENGES

Externally-Initiated Plant Relocations
THESL has relocations planned based on proposed projects from City Water, City
Transportation, City Bridges, Ministry of Transportation Ontario (“MTO”), TTC and GO
Transit. This includes:
- MTO: 16 bridge rehabilitations
- City: Installation of 450 kilometres of water works, 265 kilometres of road work
  and rehabilitation of 56 bridges.
- GO Transit: Expansion of lines west of Union station, affecting approximately 22
  locations where THESL infrastructure crosses the rail right of way.
- TTC: New Underground Light Rail System along Eglinton and an extension of
  the Sheppard Subway line from Downsview to the Scarborough Town Center.
THESL engineers will need to initiate corresponding projects in parallel to manage any
and all plant relocation efforts.

Reactive Capital
Each year THESL must install capital assets on a reactive basis to replace failed
distribution assets and restore service to customers. The resulting expenditures occur in
all key parts of the electrical distribution system, including the overhead, underground,
secondary network and stations systems.
Spending on reactive activities has been increasing over 2005 to 2011, as illustrated in Figure 30. Based upon this trend, THESL projects that reactive capital work will continue to increase across the system.

For the underground distribution system, reactive spending has increased approximately 25 percent over the past five-year period. This is mostly due to repair of direct buried primary and secondary cable assets. Repair of these assets is particularly costly because additional time must be spent to locate and repair the faulted cable location. Ultimately, underground distribution assets require more investment, due to the greater time and cost to replace or repair these assets on a reactive basis.

Reactive spending for the overhead distribution system has increased at a rate far less than spending on the underground system. Overhead pole assets account for a substantial portion of these reactive activities. There also has been a recent increase in the failure rate for first-generation SCADAMATE switches, which contributes to total overhead.

**Figure 30: Total Annual Corrective Repairs (2005-2011)**

![Graph showing annual corrective repairs from 2005 to 2011](image)
system investments. Stations reactive spending typically targets the replacement of
SCADA control equipment and sensors connected to circuit breaker assets. While
reactive spending for stations infrastructure is far less than for other parts of the
distribution system, spending for these assets is increasing at a far greater rate. Historical
reactive spending trends for the overhead, underground and stations systems respectively
are illustrated in Figure 31.
Figure 31: Total Annual Corrective Repairs per System Type (2005-2011)
**Customer Connections**

THESL is obligated to connect a building or facility on property which is directly adjacent to or abuts the public road allowance where THESL has distribution facilities of the appropriate voltage or potential availability of capacity, as per Section 28 of the *Electricity Act, 1998*.

Subject to all applicable laws, THESL will make all reasonable efforts to connect any customer that applies for connection. Customer connections and upgrades are considered to be demand work as they are driven by individual customer requests. Failure to allocate appropriate funding towards customer connections would impede THESL’s ability to comply with the *Electricity Act, 1998*, and provide excellent customer service. In particular, funding must be allocated for connecting new customers from the West Donlands and Queens Quay redevelopment projects. Downtown region revitalization activities and related supporting developments currently underway or being planned, demand THESL investments.

Apart from connecting new customers, THESL will also need to address the impacts from electric vehicles (“EV”). Infrastructure to support EVs will be required in homes, workplaces, parking lots, shopping malls and other public venues. THESL will need to be prepared for the potential load impacts from a growing EV population, as well as the different charging scenarios that will materialize.

**Engineering Capital**

The design, construction and operation of the THESL electrical distribution system is driven by sound engineering principles and industry experience. THESL employs engineers, technologists, design technicians and power system controllers to ensure that the electrical distribution system is designed and managed such that efficient and reliable service can be maintained.
THESL’s Workforce Staffing Plan shows that about 150 staff are expected to retire over the 2012-2014 period, and that over 50 percent of these retirements will occur within the supervisor, engineering, trades and technical positions. This could result in depletion of these job categories by an estimated 50 percent on average. Staff members on the verge of retirement are also most knowledgeable about the issues associated with THESL’s legacy infrastructure and distribution system. As a result, additional engineers, technicians, technologists and PSCs will need to be hired to ensure that an orderly knowledge transfer of critical system information and functions takes place at a sustainable rate.