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December 5, 2016

VIA RESS AND COURIER

Kirsten Walli
Board Secretary
Ontario Energy Board
P.O. Box 2319
2300 Yonge Street, 27th Floor
Toronto, Ontario M4P 1E4

Dear Ms. Walli:

RE: EB-2016-0160 Hydro One Networks Inc. ("Hydro One") Transmission Rates Application – Responses to Undertakings J3.3, J5.3, J6.1, J6.4, and J6.5

Hydro One's responses to Undertakings J3.3, J5.3, J6.1, J6.4, and J6.5 are enclosed.

Yours truly,

McCarthy Tétrault LLP
Per:

For: Gordon M. Nettleton

GMN

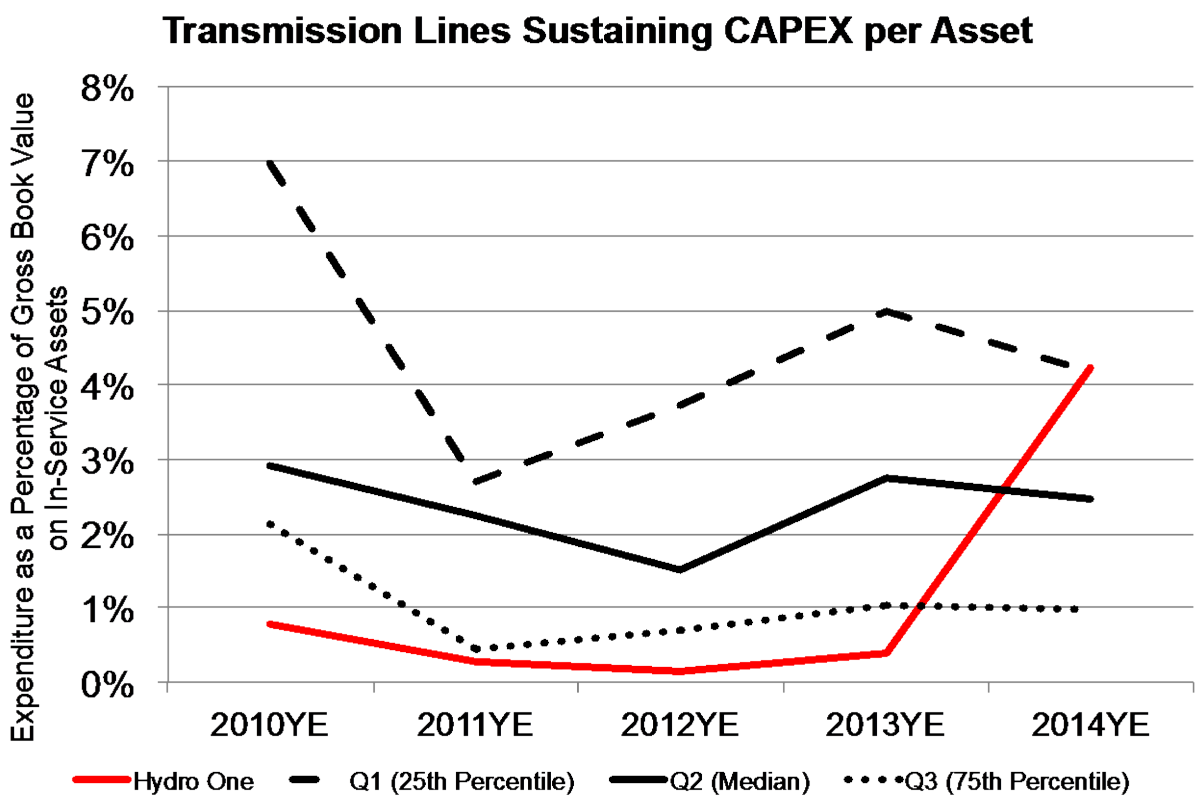
UNDERTAKING – J3.3

Undertaking

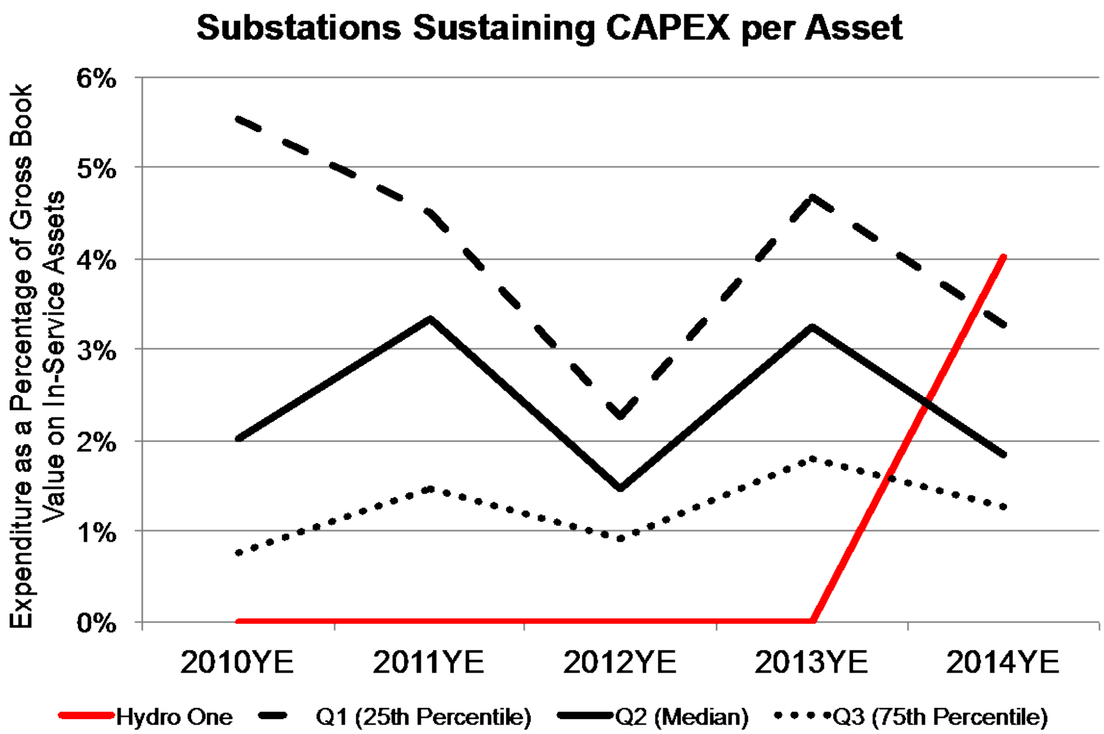
TO PROVIDE FIGURE 10 OF THE NAVIGANT REPORT SHOWING JUST SUSTAINMENT CAPITAL

Response

The figure below provides the results from Figure 10 of the Navigant report, but shows only the Sustaining CAPEX, rather than Total CAPEX.



The figure below provides the results from Figure 15 of the Navigant report, but showing only the Sustaining CAPEX, rather than Total CAPEX.



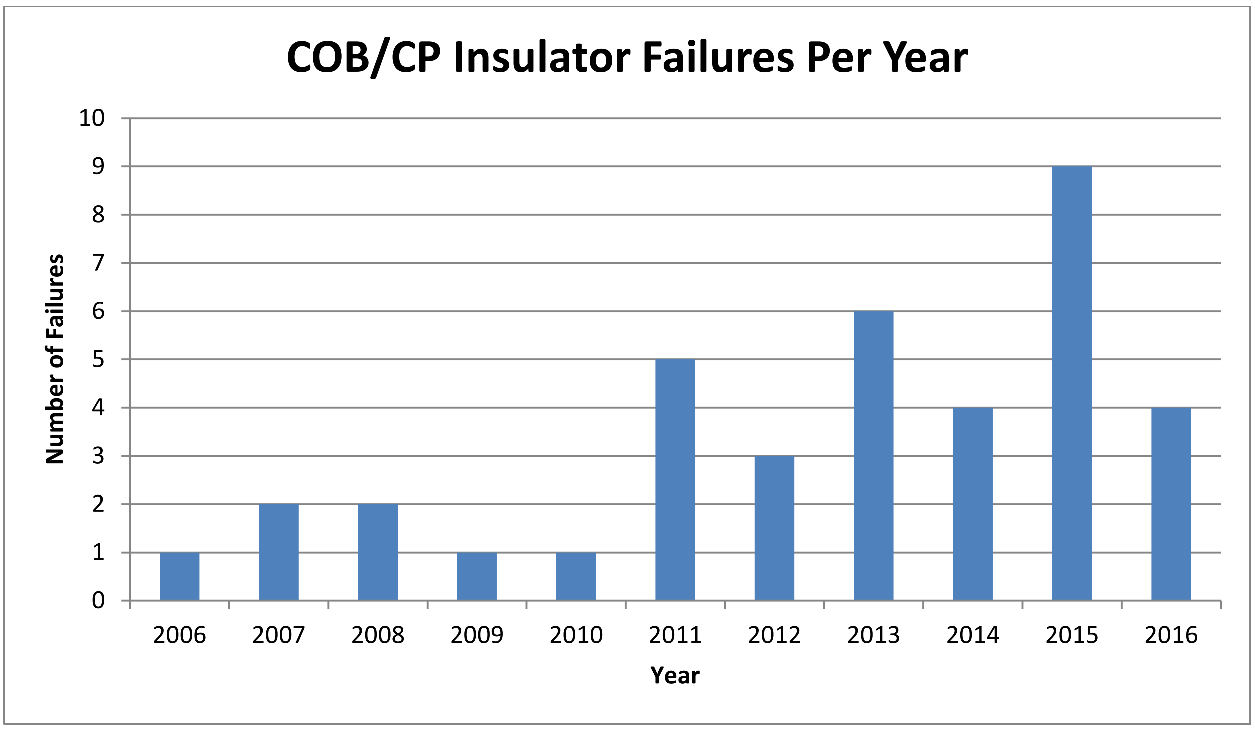
UNDERTAKING – J5.3

Undertaking

TO PROVIDE A LIST OF FAILURES THAT INCLUDES DRIVERS FOR THE MAGNITUDE OF THE SPEND

Response

Hydro One tracks historical insulator failures by insulator type including porcelain, glass and polymeric. Insulator failure by manufacturer is not typically available. The exceptional circumstance with respect to Canadian Porcelain (CP) and Canadian Ohio Brass (COB) related failures has prompted Hydro One to manually review the past ten years' of trouble call reports to derive the graph below.



Witness: Chong Kiat Ng

UNDERTAKING – J6.1

Undertaking

TO PROVIDE A BREAKDOWN OF AGGREGATE CONTRIBUTION OF LINES

Response

Reference is made to Table 1 of Exhibit B1, Tab 2, Schedule 4. Listed below are the lines sub-categories and their respective contributions to the lines equipment total of 69% in that Table 1.

LINES SUB-EQUIPMENT CATEGORIES	Contribution to LINES CATEGORY
INSULATOR FAILURE	26%
STEEL CROSS ARM FAILURE	19%
CONDUCTOR FAILURE	15%
WOOD CROSS ARM FAILURE	13%
SKYWIRE FAILURE	12%
WOOD STRUCTURE FAILURE	7%
HARDWARE FAILURE	3%
OTHER	3%
STEEL STRUCTURE FAILURE	1%

Witness: Scott McLachlan

UNDERTAKING – J6.4

Undertaking

TO FILE ONE OF THE ASSET STRATEGY DOCUMENTS.

Response

To satisfy the request by Schools Energy Coalition that the strategy document pertain to a major asset class, please refer to the attached near-final, draft asset management strategy document for transmission line insulators and surge arresters.

Witness: Chong Kiat Ng

Asset Management Strategy Document

Transmission Line Insulators and Surge Arresters

(DRAFT)

Revision History

Date	Revision	Revision Comments
Dec-2015	R0	New Document

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

Table 1-1 provides a high level overview of the Transmission Line Insulator and Surge Arrester Management Strategy. Only primary risk factors, failure modes and strategies are outlined in Table 1-1.

Asset	Estimated Population (strings)	Life Expectancy (years)	Risk Factors	Failure Modes	Condition Assessment Strategy	Planned Replacement Strategy	Planned Replacement Criteria	Targeted Replacement Programs
Porcelain Insulators	252,000	80	Condition Safety	Cement expansion Damaged shell	Visual inspection	Replaced in conjunction with other work programs	Remaining good shells: 115 kV – 4 230 kV – 10 500 kV – 17	COB & CP SGB
Glass Insulators	126,000	80	Condition	Shattered shell	Visual inspection	Replaced in conjunction with other work programs	Remaining good shells: 115 kV – 5 230 kV – 11 500 kV – 15	None
Polymer Insulators	42,000	30	Demographics Condition Safety	Damaged shed or sheath Elevated temperature	Visual inspection Thermovision	Replace near end-of-life based on condition and demographics	To be determined	230 kV Dead-ends Reliable insulators
Surge Arresters	1,800	30	Condition	Disconnected or broken bond wire Elevated temperature	Visual inspection Thermovision	Replace at end-of-life based on condition Operated to failure	Disconnected or broken bond wire Elevated temperature (+10^{o}C)	None

Table 1-1 – Strategy Summary

2.0 INTRODUCTION

Line insulators are an integral component of the transmission system. They mechanically support and electrically insulate the conductor from the structure and must provide sufficient dielectric strength to prevent short circuits to ground. Insulators are classified into the following material classes, each having their own strategy:

- Porcelain
- Glass
- Polymer

There are approximately 437,000 insulator strings in Hydro One Networks Inc. (HONI) overhead transmission network. They are assessed through visual inspection (all types), infrared thermography (porcelain and polymer) and in-situ live-line electrical testing (polymer only, on a trial basis). Planned porcelain and glass replacement is typically driven by condition and are replaced as part of other work programs, since they have an 80 year life expectancy. A targeted replacement program, driven by safety, is currently underway to address defective porcelain insulators, suffering from cement expansion, manufactured by Canadian Ohio Brass (COB) and Canadian Porcelain. Planned polymer replacement is evaluated on a case-by-case basis and is driven by demographics (30 year life expectancy) and condition. Targeted replacement is being done for 230 kV dead-ends and insulator manufactured by Reliable Insulators Inc.

Transmission line surge arresters (TLSA) are installed between the phase conductor and structure as a remedial option to improve the lightning performance of poorly performing lines. There are approximately 1,800 arresters and to date, they have only been used in 115 kV applications. There is no pre-emptive replacement program; they are operated to failure, failed arresters pose minimal risk.

3.0 SCOPE OF THE STRATEGY DOCUMENT

This Asset Strategy document defines HONI lifecycle management methodology for overhead transmission line insulators and surge arresters. It includes broad information and direction on:

- Asset history
- Failure and degradation mechanisms
- Condition assessment and maintenance
- End-of-life criteria
- Replacement
- New construction
- Practices of other utilities
- Technological innovations

The overall intent of this strategy is to apply a systematic and coordinated approach to optimally and sustainably manage insulator and arrester assets. In addition, associated performance, risk and expenditures are controlled over their life in accordance with corporate strategic objectives.

This document is applicable companywide, for the sustainment and new installation all overhead transmission line insulators and surge arresters. While post and phase-to-phase insulators are used, only suspension type is discussed, they are the most common.

All information in this document is current as of December 2015 unless noted.

4.0 ABBREVIATIONS

CEATI	Centre for Energy Advancement through Technological Innovation
COB (OB)	Canadian Ohio Brass
CP	Canadian Porcelain
DHI	Detailed Helicopter Inspection
DR	Deficiency Report
EPRI	Electric Power Research Institute
HONI	Hydro One Networks Inc.
IEEE	Institute of Electrical and Electronics Engineers
IR	Infrared
LW NCI	Live-Working Non-Ceramic Insulator
MOV	Metal Oxide Varistor
NCI	Non-Ceramic Insulator
RTV	Room Temperature Vulcanization
SGB	Semi-conductive-Glaze Bell
TLSA	Transmission Line Surge Arrester
TODS	Transmission Outage Data System
UAV	Unmanned Area Vehicle

5.0 CORPORATE STRATEGIC OBJECTIVES

This strategy was developed in accordance with HONI's strategic objectives. Table 5-1 outlines the goal of each strategic objective and how this strategy contributes to achieving that goal.

Strategic Objective	Goal	Action
Health & Safety	Ensuring the health and safety of employees, service providers and the public.	Removal and replacement of defective insulators in high risk locations.
Customers	Improve customer satisfaction.	Removal and replacement of defective insulators in poor condition before they affect reliability or public safety. Bundling assessment and replacement with other work programs to minimize customer impact.

Continuous Innovation	Use innovation and technology to improve effectiveness and productivity.	Evaluating new insulator materials and assessment technologies.
Reliability	Provide a robust and reliable electrical system to meet the needs of our customers.	Removal and replacement of defective insulators in poor condition before they affect reliability. Bundling assessment and replacement with other work programs to minimize customer impact.
Environment	Minimize carbon footprint and environmental impact of work programs. Facilitate the delivery of clean and renewable energy. Allow customer to manage and reduce their energy use.	Not applicable.
Employees	Maintain a skilled, competent and engaged workforce.	Not applicable.
Shareholder Value	Ensure increased shareholder value by pursuing growth opportunities and leveraging existing assets, technologies, capabilities and experience.	Not applicable.
Productivity and Cost Effectiveness	Constantly strive for productivity through efficiency and effective management of costs.	Bundling assessment and replacement with other work programs to minimize customer impact.

Table 5-1 – Corporate Strategic Objectives

6.0 STRATEGY DEVELOPMENT PROCESS

6.1 Practices of Other Leading Electricity Companies

Condition Assessment

A number of techniques may be used to evaluate insulator condition, these include:

- Visual inspection
- Hi-tester
- Buzz test
- Infrared (IR) thermography
- Corona camera
- Voltage measurement
- Electric-field measurement
- Acoustic emission
- High-frequency emission

A survey conducted by CEATI polled 22 utilities and found that [1]:

- Visual inspection is the most common and often primary assessment technique used. Most utilities believe that visual inspection is a reliable assessment technique. It is also the most cost effective. Insulators with extensive damage, such as damaged shells, can be visually observed and assumed to have compromised strength. However, it is not possible to identify insulators compromised through internal electrical defects.
- IR thermography and corona cameras are the second and third most popular techniques, respectively. However, of the 80% of utilities that use IR or corona imaging only 15% use both.
- Electrical tests such as the hi-tester and buzz test are used less often since they require live-line work procedures (with moderate safety concerns) and are labour intensive (costly).

Similar to insulators, visual inspection and IR thermography are the most common surge arrester assessment methods. These techniques are considered to be reliable and cost-effective.

End-of-Life and Replacement

For utilities similar to HONI, condition is the driving replacement factor. Quality porcelain and glass insulators will generally last until wood-pole replacement or line refurbishment. For some utilities environmental risk is the primary replacement factor. This is especially true for coastal (salt water) utilities where hardware (pin and cap) corrosion drives replacement; severely corroded hardware may result in mechanical failure. Insulators installed near the coastlines typically have a life span of 30 years. Due to the relative newness of polymer insulators end-of-life criteria is not well understood and many utilities have not developed replacement methodologies.

6.2 Comparison of Networks' Practices with Other Electricity Companies

HONI's strategy is in-line with other leading utilities. Common, cost-effective, in-situ, live-line, non-destructive assessment techniques are used and replacement is driven by condition. We also follow best practices outlined by reputable research groups such as CEATI, EPRI and IEEE [1]-[5].

A notable exception in HONI's strategy is the multi-year replacement program for defective porcelain insulators affected by cement expansion. These defective insulators were predominantly used by Ontario Hydro and not commonly used by other utilities, especially outside of Canada. Details can be found in Sections 8.1.1 and 12.1.2.

7.0 TRANSMISSION ASSET DESCRIPTION DETAILS

7.1 Insulators

Line insulators are an integral component of the transmission system. They mechanically support and electrically insulate the conductor from the structure and must provide sufficient dielectric strength to prevent short circuits to ground. Insulators are classified into the following material classes:

- Porcelain
- Glass
- Polymer

Polymer insulators may also be referred to as polymeric, composite or non-ceramic insulators (NCI). Porcelain and glass are often ubiquitously referred to as ceramic. This document will use the terms porcelain, glass and polymer. Insulators are also categorized into the following three types:

- Suspension — Any insulator intended to primarily carry tension loads such as tangent, dead-end and V-strings. This is the most common type.
- Post — Post insulators may be loaded in tension, bending and compression. For transmission lines, the most common application are horizontal line posts, where the post projects nearly horizontally from the pole and is loaded in flexure by the conductor. At HONI, they are used in special circumstances such as reduced clearance (to minimize right-of-way and structure footprints) and improved appearance applications.
- Phase-to-Phase — Interphase spacers, also called phase-spacers or phase-to-phase insulators, are used to couple two phases together as a means of controlling conductor spacing. They are used in special circumstances where clearances cannot be maintained (reduced structure clearances, long spans, etc.) or where galloping is a concern. Interphase spacers are constructed similarly to polymer, are rated for phase-to-phase voltages (not phase-to-ground) and must be capable of withstanding mechanical forces experienced during galloping and faults.

Furthermore, insulators are used in various configurations such as:

- I-suspension
- V-suspension
- Dead-end
- Strain or semi-strain
- Idler

These materials, types and configurations are illustrated in Figures 7-1through 7-6. A detailed asset description and history can be found in [6] and [7].

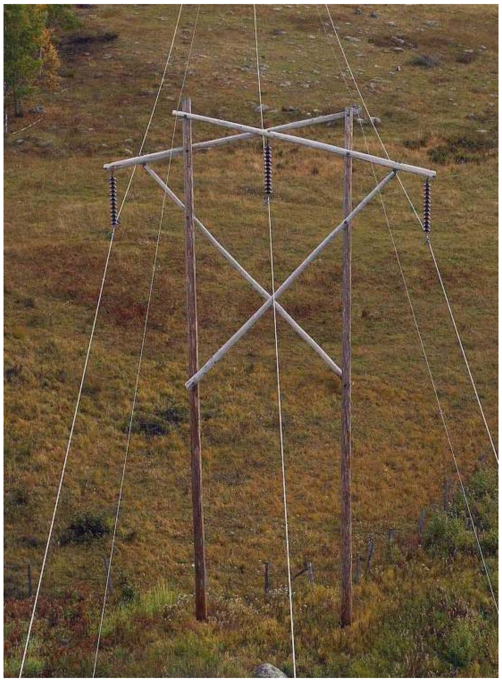


Figure 7-1 – I-Suspension
(K23D, structure 4, 230 kV, porcelain)

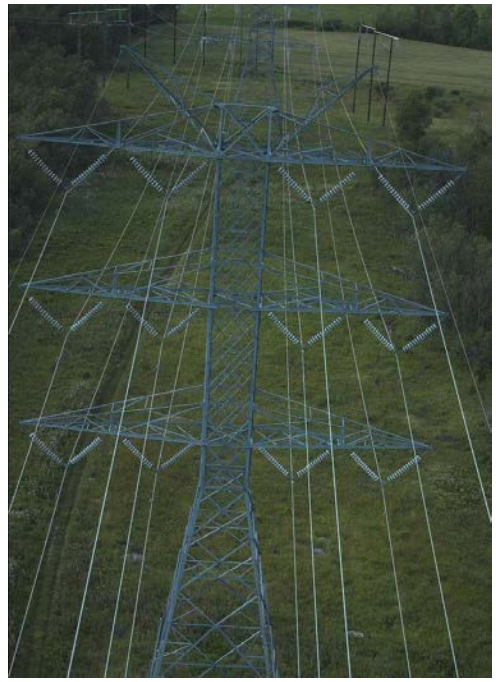


Figure 7-2 – V-Suspension
(K23D, structure B, 230 kV, porcelain)

Figure 7-3 – Dead-end with Idler
(C1P, structure 34, 115 kV, glass)

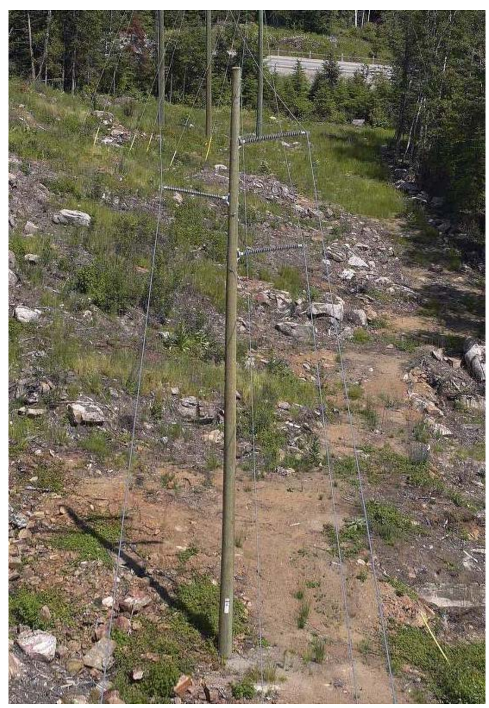


Figure 7-4 – Post
(L5H, structure 444A, 115 kV, polymer)

Figure 7-5 – Semi-Strain (L21S, structure 4, 230 kV, polymer)

Figure 7-6 – Inter-Phase Spacer

HONI does not have a comprehensive database of insulator or arrester information. Generally, insulator material and in-service data is not populated in SAP. Additionally, replacement and assessment accomplishments have not been accurately recorded. Assumptions were made to estimate insulator population, age and diversity. These statistics are not accurate and should be considered a best estimate.

The proportions of insulators by voltage level and material type are shown in Figures 7-7 and 7-8. There are approximately 437,000 insulators strings in HONI's overhead transmission line network. Population was estimated based on structure type (dead-end, semi-strain, suspension, etc.) and average number of insulators per structure. GIS was used to gather this data. Material type proportions were estimated based on experience and best judgment.

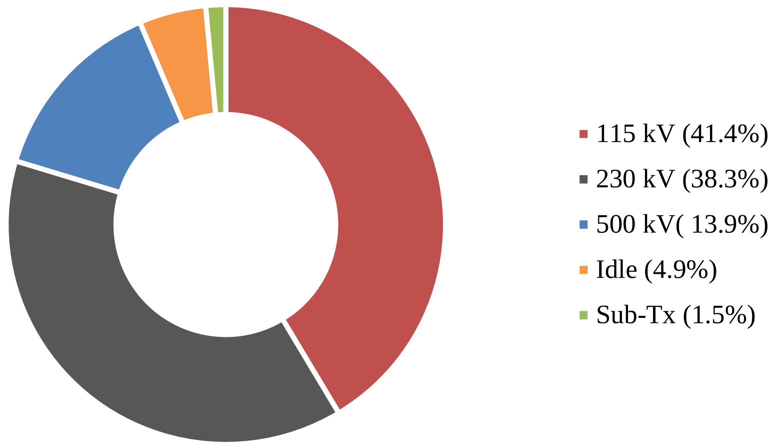


Figure 7-7 – Insulator Voltage

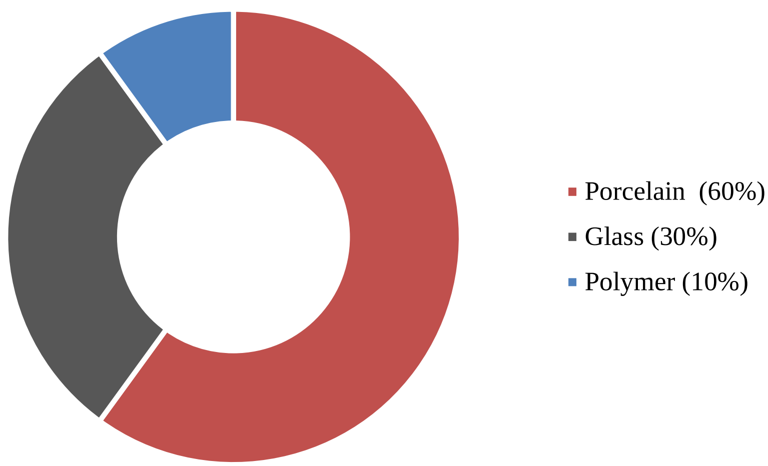


Figure 7-8 - Insulator Material

7.1.1 Porcelain Insulators

In North America, porcelain insulators were first used on telegraph lines as early as 1835. By 1905, insulator designs for power transmission applications, typically scaled up versions of telegraph designs, were developed. The first practical suspension porcelain insulators was used in 1910 by the Hydro-Electric Power Commission of Ontario (former Ontario Hydro and Hydro One) on a 110 kV transmission line from Niagara Falls to Dundas Ontario [6]. A typical cap and pin suspension porcelain insulator unit is shown in Figures 7-9 and 7-10; individual insulating units are referred to as a skirts, discs or shells. Fundamental components include:

- Shell The electrical insulating component. A single fired porcelain member.

•	Glaze	Glass-like layer covering the porcelain. It provides a smooth surface and to adds strength to the porcelain shell.
•	Cement	Grout used to attach the hardware (pin and cap) to the shell.
•	Bituminous / Varnish Coating	Protective coating between the pin/cap and cement.
•	Pin	Bottom metallic part of the insulator. Used to connect units (ball/socket connection) or conductor attachment hardware.
•	Ball	Term describing the shape of the lower part of the pin.
•	Cap	The top metallic part of the insulator. Used to connect units (ball/socket connection) or conductor attachment hardware.
•	Socket	Term describing the cavity in the cap.
•	Sand Band	Region where sand has been applied between the porcelain shell and cement.

Figure 7-9 - Porcelain Suspension Insulator Unit

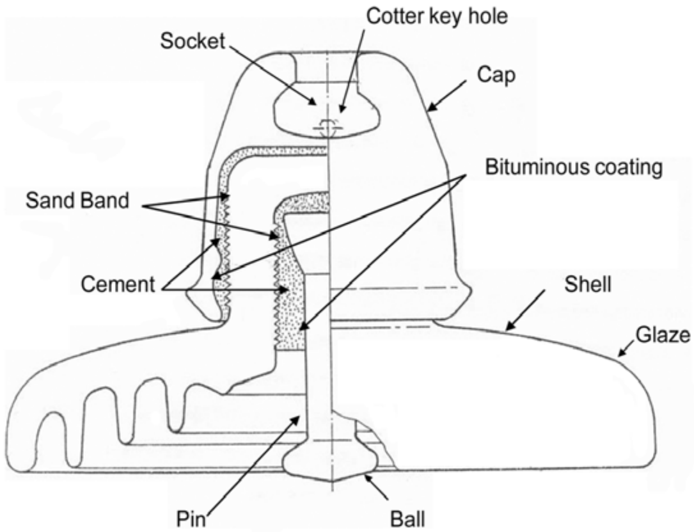


Figure 7-10 - Porcelain/Glass Suspension Insulator Components

While we are unsure of exactly what insulator manufacturers were historically used, it is assumed that most insulators installed between the early 1960s and mid-1980s were either Canadian Ohio Brass (COB) or Canadian Porcelain (CP). This is supported by the general policy to purchase insulators from within Ontario. NGK ceramic insulators were introduced in the early 1980s as a replacement for COB and CP insulators affected by cement expansion (refer to Section 8.1.1). NGK supplied a large number of insulators and is the current porcelain insulator supplier. Small numbers of Lapp, Cegelec and Locke insulators were also used.

7.1.2 Glass Insulators

Glass insulators were developed in parallel with porcelain but initial designs using annealed glass were unsuccessful due to their lower mechanical shell strength. The first successful practical design was not implemented until 1930 when toughened glass was used to overcome the strength issue. Glass insulators were commonly installed from 1947 onward and have been applied to voltages up to 1,000 kV [6]. With the exception of the insulating material (glass), glaze (porcelain specific) and sand band (porcelain specific); glass insulators are identical to porcelain in structure and design. A typical glass insulator is shown in Figures 7-10 and 7-11.

Figure 7-11 - Glass Suspension Insulator Unit

Toughened glass insulators are manufactured by forming molten glass in a mould, after removing the shell from the mould, the surface is rapidly cooled. This process creates permanent compressive forces in the outer and high tensile stresses in the inner layer. The force differential between the outer and inner layers causes the entire shell to shatter in the event of a defect, puncture or crack. This self-shattering (auto-rejection) capability is considered a significant advantage of glass insulators. Intact shells are known to be electrically sound, damaged shells can be easily identified and they still retain their mechanical strength. This self-shattering capability is also a disadvantage. Shattered shells have no insulating properties, whereas a punctured or cracked porcelain shell retains a portion of its insulating capability.

HONI began evaluating the use of glass in the mid-1970s as an alternative to COB and CP porcelain. The first technical specification was developed in 1979, with the first installations taking place in the early to mid-1980s. Sediver is HONI's current supplier; they have supplied the majority of glass insulators used.

7.1.3 Polymer Insulators

Polymer insulators were developed as an alternative to porcelain and glass, with the following benefits:

- Light weight: lower construction and transportation costs
- Vandalism resistance: less susceptible to mechanical damage
- High strength-to-weight ratio: longer spans/new tower designs
- Better contamination performance
- Improved transmission line aesthetics

The first polymer insulator designs were established in the 1960s and installed during the 1970s. Initial designs were plagued with problems and especially suffered from material-aging effects. By the 1980s designs were improved and polymer became generally accepted and used in large numbers on transmission lines. They have been used worldwide on voltages up to 765 kV [6]. HONI began installing polymer at 115 and 230 kV in the mid-1980s. Polymer line insulators are not installed at 500 kV. A picture and schematic drawing is shown in Figures 7-12 and 7-13. Fundamental components include:

- Core — The internal insulating component. It is designed to provide mechanical strength and rigidity. The core material consists of a resin-bonded fiberglass reinforced plastic rod.
- Shed/Sheath — The external insulating housing. It is molded into sheds and sheaths to provide the necessary creepage distance and hermetically seals the core from the environment. The shed and sheaths are manufactured from a polymer compound (ethylene propylene rubber or a silicone rubber). This compound is proprietary and varies between manufacturers.
- End Fittings — Metal end fittings are the mechanical attachment points between the conductor, insulator and structure. These must be mechanically rated and are normally made of galvanized steel.
- Grading Ring — Grading or corona rings reduce electric-field magnitude minimizing corona discharges and associated polymer degradation.

The majority of polymer insulation used are manufactured by K-Line.

Figure 7-12 – Polymer Suspension Insulator

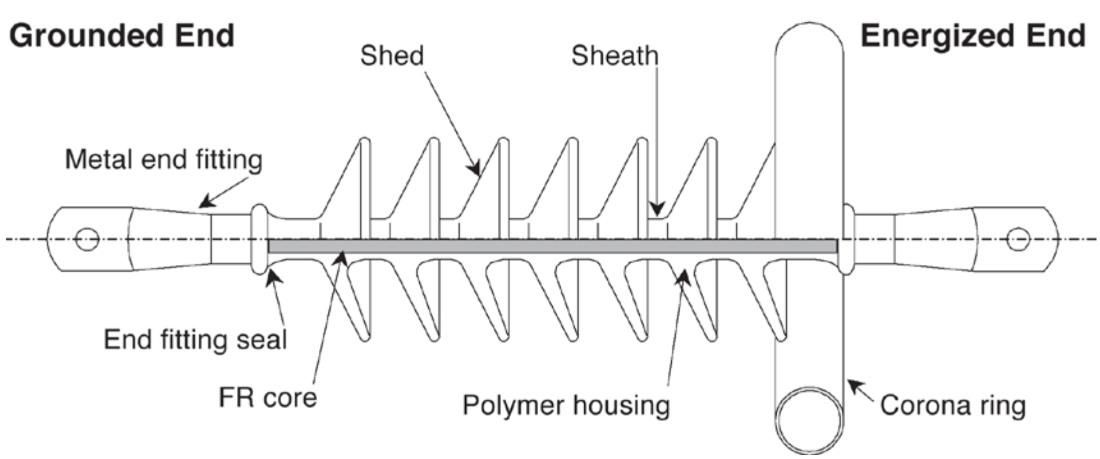


Figure 7-13 – Polymer Suspension Insulator Components

7.1.4 Insulator Condition Assessment

Table 7-1 outlines the various condition assessment techniques. Detailed descriptions can be found in [1]. HONI has experience with the following methods:

- Visual inspection
- Buzz test
- Hi-tester
- Corona camera
- Infrared (IR) thermography

Technique	Detection Parameter	Porcelain & Glass	Polymer	Pros	Cons	Weather Sensitivity Level
Visual Inspection	Visual	Yes	Yes	Simple Safety	Accuracy	Low
Buzz Test	Potential difference	Yes	No	Simple	Operator safety Accuracy Labour intensive	Low
Hi-Tester	DC leakage current / resistance	Yes	No	Simple	Operator safety Accuracy Labour intensive Humidity and contamination may cause false negative	Medium
Voltage Measurement	Voltage across shell	Yes	No	Simple	Operator safety Accuracy Labour intensive	Medium
Electric-field Measurement	Electric-field	Yes	Yes	Simple More sensitive compared to buzz, hi-test and voltage	Operator safety (safer than buzz test) Labour intensive	High
Corona Camera	Partial discharge	Yes	Yes	Safety Cost and time savings Clearly identifies corona under right conditions	Accuracy Expensive equipment Not well proven Requires expertise	Medium
High-Frequency Emission	Electromagnetic noise	Yes	Yes	Fast Potentially can determine defect type	Not well proven (under research) Requires expertise	High
Acoustic Emission	Sound	Yes	No	Safety Fast	Reliability and sensitivity Reflection and misleading Not well proven	Medium

Infrared (IR) Thermography	Temperature	Yes	Yes	Safety Fast	Accuracy Expensive equipment Requires humidity to detect defects	High
Non-Ceramic Insulator Tester	Voltage	No	Yes	Simple	Operator safety Labour intensive Only detects internal carbonization (flash-under or internal tracking) Not well proven	Medium

Table 7-1 - Condition Assessment Techniques

7.2 Transmission Line Surge Arresters

In most cases, transmission line surge arresters (TLSA) are installed as a remedial option to improve the lightning performance of poor preforming lines. They are normally used in areas where suitable footing resistance cannot be easily or cost effectively obtained (in the case of shielded lines) and function by limiting insulator overvoltages, preventing flashover and therefore momentary interruptions. Arresters may also be used to control switching overvoltages and improve power quality to sensitive customers.

The application of line arresters began in the 1980s; they have successfully been applied to voltages up to 800 kV, though their use above 230 kV is less common.

There are two types TLSA:

- Non-gapped line arresters (gapless)
- Externally gapped line arresters (gapped)

Non-gapped arresters contain metal oxide varistors (MOV) within a polymer housing and are installed between the phase conductor and structure with connection leads. One of the leads is fitted with a disconnect device that will sever the arrester in case of electrical failure preventing a permanent line fault. The metal-oxide varistor, doped zinc-oxide, provides a non-linear voltage-current relationship with a high impedance (no current flow) under normal voltage and low impedance during overvoltage conditions (allowing fault current to flow through the arrester). A non-gapped 115 kV arrester is shown in Figure 7-14.

An externally gapped arrester is a metal oxide arrester installed in series with an external spark gap (that will flashover during overvoltage conditions). These arresters are not commonly used (never been used by HONI) and will not be discussed in this document.

TLSA are either:

- Suspended from the structure
- Suspended from the line

These configurations are shown in Figures 7-15 and7-16. Installation configuration is dependent on clearances and work-methods used. Figure 7-17 illustrates fundamental arrester components.

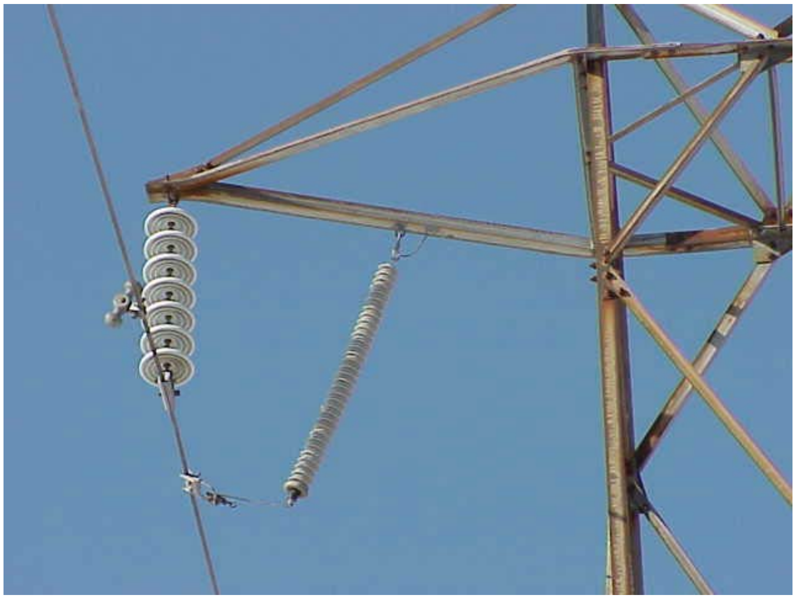


Figure 7-14 - Transmission Line Surge Arrester
(Q6S, structure 142, 115 kV)

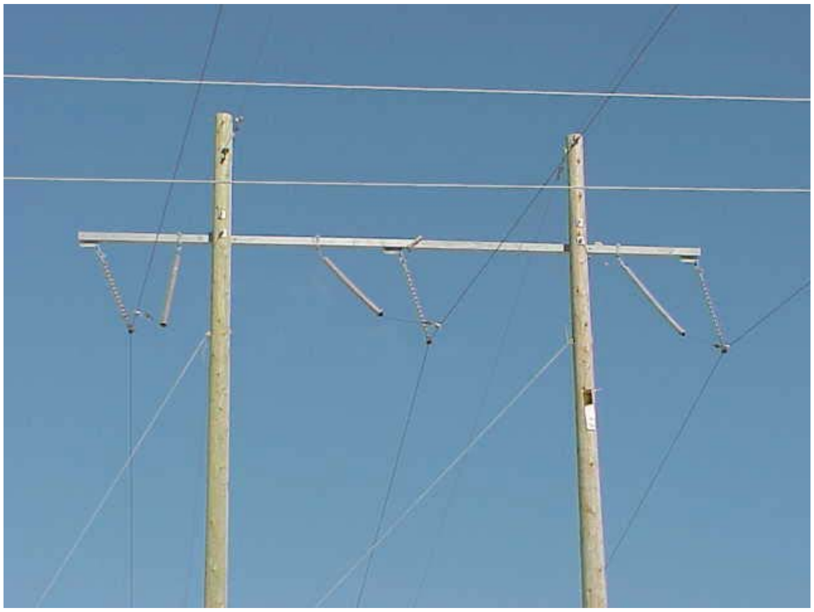


Figure 7-15 - Arrester Configuration – Suspended from Structure
(Q6S, structure 142, 115 kV)

Figure 7-16 - Arrester Configuration – Suspended from Conductor (A1B, structure 2, 115 kV)

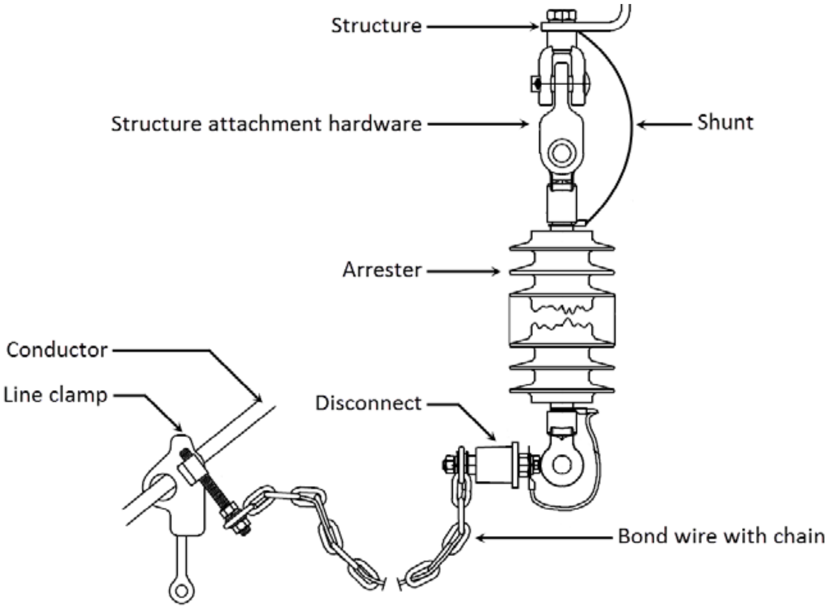


Figure 7-17 - Transmission Line Surge Arrester Components (Structure Suspended)

HONI began installing arresters in the mid-1990s on select line sections suffering from poor lightning performance. Arresters are not included in new line designs but installed after the fact, if lightning performance is an issue. To date, only non-gapped arresters at 115 kV have been used.

8.0 OPERATIONAL ASSET MODEL FOR TRANSMISSION ASSET

8.1 Porcelain Insulators

8.1.1 Degradation, End-of-Life and Failure Mechanisms

Porcelain insulator technology is well proven and has been used for over 100 years. Degradation and failure of quality porcelain is atypical and is normally not a concern, however, one-off failures do occur and there are known issues affecting specific vintages.

Porcelain units are defective and have reached end-of-life if any of the following conditions are met:

Cracked Shell

Observation	Cracked shell
Cause	Cement expansion, thermal expansion or poor quality

Damaged Shell

Observation	More than one-quarter (1/4) of the shell is chipped or broken
Cause	Vandalism, handling or cement expansion

Glaze Damage

Observation	Damage or removal of glazing
Cause	High/sustained power arcs, punctures or continuous discharge activity

Electrical Test

Observation	Failed test when using approved test device
Cause	Cracked/damaged shell, puncture, glaze damage or internal defects

These are the most common failure modes seen at HONI. They may lead to reduced electrical and mechanical strength increasing reliability and safety risks in the form of higher interruption frequency/duration and potential conductor drops respectively. Defects may not warrant replacement, refer to Section 12.1.2 for replacement criteria.

Cement Expansion

It is well know that insulators manufactured by Canadian Ohio Brass (COB) and Canadian Porcelain (CP) between 1965 and 1982 suffer from a phenomena known as cement expansion or cement growth. The purpose of the cement is to bond the pin to the porcelain, refer to Figure 7-10. Cement expansion creates radial cracks in the cement and porcelain shell resulting in two possible failure modes:

1. Mechanical Failure — where the pin separates from the porcelain causing a conductor drop
2. Electrical Failure — where the cracked porcelain reduces insulating properties

This phenomenon is illustrated in Figures 8-1 and 8-2.

Extensive research done by Ontario Hydro Research [8] has determined that the primary cause of cement expansion is the hydration of magnesium oxide, MgO or periclase, to magnesium hydroxide, $Mg(OH)_2$ or brucite ($MgO + H_2O \rightarrow Mg(OH)_2$). A secondary factor is excess sulphate reacting to form expansive calcium sulpho-aluminate phases.

It is generally agreed that COB and CP insulators manufactured between 1965 and 1982 will fail. Laboratory testing conducted by Ontario Hydro Research and field observations has shown that expansion is related to wetting (from rain or humidity) and tensile stress. Therefore, insulators in dead-end configurations are more susceptible to failure. Time to failure is unknown and is dependent on mechanical load and environmental conditions. For perspective, the first recorded failures were reported by the Nova Scotia Power Corporation in 1979 [9] and one of the most recent notable failures occurred in March 2015 on V76R [10]. On March 16, 2015, the centre phase insulator on structure 84 of V76R failed causing the conductor fall to the ground in the International Plaza Hotel parking lot in Etobicoke. The resulting failure investigation was the basis of COB and CP replacement strategy.

An effort was made to remove COB and CP insulators in dead-end configurations. Removal began in the 1980s and continued into the 2000s but due to the lack of insulator data and poor record keeping it is difficult to know if all dead-end COB and CP insulators were removed.

Figure 8-1 - Porcelain Insulator Unit Affected by Cement Expansion (V79R, Structure 50E, April-2015)

Figure 8-2 - Porcelain Insulator Unit Affected by Cement Expansion (V79R, Structure 50E, April-2015)

8.1.2 Life Expectancy

Quality porcelain insulators have a life expectancy of 80 years and are assumed to last for the life of the line.

8.2 Glass Insulators

8.2.1 Degradation, End-of-Life and Failure Mechanisms

While not as well proven as porcelain, glass insulators are an established, mature and reliable technology used by many utilities worldwide. To date, HONI has not experienced any major issues with glass. The degradation and failure of quality glass insulators is atypical and should not be a concern, however, one-off failures do occur.

Glass units are defective and have reached end-of-life if:

Shattered Shell

Observation	Shattered shell
Cause	Vandalism, lightning, power arcs or spontaneous shattering

As discussed, cracks and punctures result in shattering of the shell. Shattered shells reduce the insulating properties (creepage distance) increasing the likelihood of flashovers (momentary interruptions) but are still mechanically sound.

Defects may not warrant replacement, refer to Section 12.2.2 for replacement criteria.

Pyrex Insulators

Glass insulators manufactured by the Pyrex Corporation do not use toughened glass. Therefore, these insulators must be evaluated using the same methodology as porcelain, since punctures may not cause shattering. Pyrex insulators can be identified by their translucent, brownish colour, compared to the clear or greenish tint normally found in glass insulators. A Pyrex glass insulator is shown in Figure 8-3.

Figure 8-3 - Pyrex Glass Insulator

8.2.2 Life Expectancy

Quality glass insulators have a life expectancy of 80 years and are projected to last for the life of the line.

8.3 Polymer Insulators

8.3.1 Degradation, End-of-Life and Failure Mechanisms

Utilities, including HONI, have experienced numerous issues with polymer insulators including:

- Tracking and erosion of the sheath and shed material, leading to flashover
- Chalking[1] and crazing[2] of the insulator surface, resulting in increased contamination collection, arcing and flashover
- Reduction of contamination flashover strength and increase in contamination-induced flashovers

[1] Chalking is a surface condition wherein some particles of the filler become apparent when exposed to the weather, forming a powdery surface.
[2] Crazing is a surface micro fracture of a depth less than or equal to 0.1 mm.

- Deterioration of mechanical strength
- Loosening of end fittings
- Bonding failures and breakdowns along the rods sheath interface
- Water penetration followed by electrical and mechanical failure (due to brittle fracture)

These issues are discussed in detail in [6], [11] and [12]. A large number of these issues affected the first and second generation of polymer designs. Currently, the most common failure mechanism is moisture ingress. Moisture ingress is often caused by improper end-fitting seals or polymer degradation caused by excessive electric fields due to the lack of or undersized corona rings. This failure mode can lead to electric and mechanical failure.

Polymer insulators are defective and have reached end-of-life if:

Cracks, Splits and Punctures

Observation	Surface cracks on rubber shed or sheath
Cause	Continual dry discharge activity, strong wetting discharge activity, harsh environment, aging or poor design/manufacturing

Torn or Damaged

Observation	Torn or damaged shed or sheath
Cause	Mishandling during shipping/storage/installation, animal/bird or gunshot damage

Exposed Rod

Observation	Exposed rod and damage or severe degradation of rubber sheath
Cause	Excessive electrical activity, harsh environment, poor design/manufacturing or mishandling during shipping/storage/installation.

Tracking

Observation	Significant flash marks (electrically conductive paths along the surface of shed or sheath)
Cause	Leakage currents on highly contaminated polymer insulator surface

End Fitting Damage and Slippage

Observation	End fitting not fully seated, degraded sealant or rust surrounding end fitting seal
Cause	Continual dry discharge activity, strong wetting discharge activity, harsh environment or poor design/manufacturing

Electrical Test

Observation	Failed test when using approved insulator test device
Cause	Flash-under or internal tracking

These defects may lead to reduced electrical and mechanical strength increasing reliability and safety risks in the form of higher interruption frequency/duration and potential conductor drops respectively.

8.3.2 Life Expectancy

Considerable research is being done to determine the life expectancy of polymer insulators. Based on available data, it is significantly less than quality glass and porcelain. Experts from Kinectrics and EPRI indicate that 30 years is a reasonable expectation. For design, planning, assessment, maintenance and replacement purposes; HONI uses a 30 year life expectancy. This life expectancy assumes quality insulators from reputable manufacturers that were handled and installed properly (appropriate corona rings).

8.4 Transmission Line Surge Arresters

8.4.1 Degradation, End-of-Life and Failure Mechanisms

Modern metal oxide arresters have a well-proven track record and are considered reliable devices. The most common failure modes experienced by HONI are disconnected (operation of the disconnection device) or failed bond wires. Surge arresters are defective and have reached end-of-life if:

Disconnected or Failed Bond Wire

Observation	Disconnected or broken bond wire
Cause	Large impulse, thermal runaway, aging or mechanical failure

Elevated Temperature

Observation	Elevated temperature (compared to adjacent arresters) or hotspot of 10 degrees Celsius or more
Cause	Internal defect, thermal runaway or aging (permanent change of the non-linear characteristic of the MOV blocks)

Similar to polymer insulators, the housing can degrade or be damaged allowing moisture ingress leading to internal faults, refer to Section 8.3.1. For arresters, moisture ingress will raise the internal temperature or force the disconnect to operate (easily visually identified). Therefore, it is not worth the time, effort or cost to examine the housing condition in detail.

Disconnected or failed bond wires render the arrester inoperable and therefore unable to provide any reliability improvement. Disconnected arresters pose minimal system risk.

Bond Wire Failure

Arrester bond wires, typically stranded tinned copper conductor, fatigue over time, especially if under tension, resulting in failure. This failure mechanism is exacerbated by wind-induced motion. Examples of failed and frayed bond wires are shown in Figures 8-4 and 8-5. New arresters address this issue by weaving the bond wire through a chain, alleviating bond wire stress.

Figure 8-4 - Failed Arrester Bond Wire

Figure 8-5 - Frayed Arrester Bond Wire

8.4.2 Life Expectancy

Since arresters are a relatively new technology, their life expectancy is unknown. Life expectancy is assumed similar to polymer insulators, 30 years.

9.0 FUNCTIONAL STANDARDS

This strategy is to be applied in conjunction with applicable HONI standards, procedures and policies. These documents, industry best practices and research papers influenced strategy development and are referenced throughout this document. Refer to Section 16.0.

10.0 MANAGING RISKS

10.1 Demographics

Insulators

There are approximately 415,000 in-service transmission line insulator strings in the system, 437,000 if idle lines are included. Insulator age profile is shown in Figure 10-1 and is based on structure in-service date. This data was extracted from GIS. Due to the lack of data, demographics cannot be categorized by insulator type.

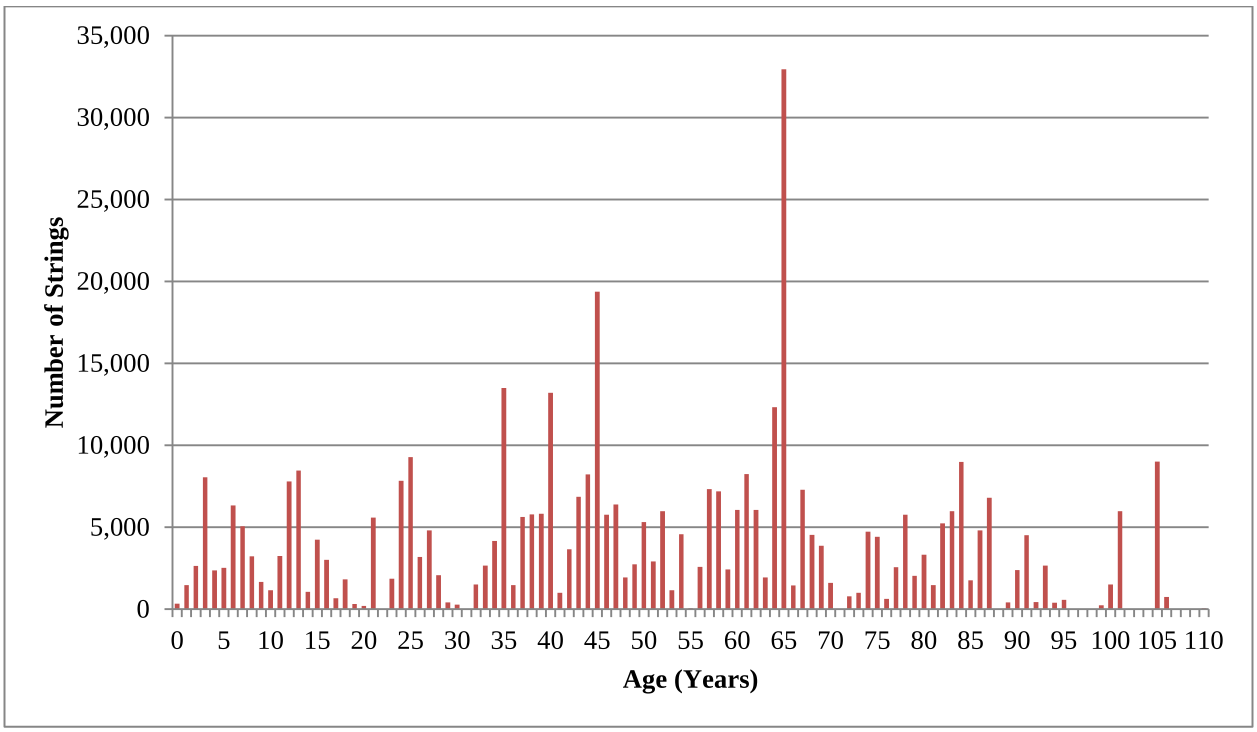


Figure 10-1 – Insulator Demographics

Demographics (age) is not a driving risk factor for the replacement of porcelain or glass insulators since their life expectancy is 80 years or more and significant condition degradation is not expected to occur over time. Quality porcelain and glass insulators are not the limiting factor in a transmission lines life-span, therefore demographic risk is low. Replacement is done as part of other work programs such as wood-pole replacement (~50 years) and line refurbishment (~80 years, driven by conductor condition).

Polymer insulators have a life expectancy of 30 years and their condition degrades with age. First-generation polymers (more problematic compared to recent generations), installed in the mid-1980s, are approaching end-of-life and will soon need to be evaluated for replacement. Unfortunately, due to lack of records, their installation dates and locations are unknown; therefore replacement will be evaluated on a case-by-case basis as they are discovered. It is anticipated that a replacement program will have to developed in the near future. The risk of aged polymer is considered to be medium to high.

Surge Arresters

There is no data on surge arrester demographics, other than that installation began in the mid-1990s and life expectancy is 30 years.

While the non-linear characteristics of the MOV may change and degradation of the polymer housing occurs over time. Arresters are considered functional until their disconnect device has operated, regardless of age. The demographic risk to the system is low.

10.2 Condition

Insulators

There is insufficient quantifiable data to make any meaningful conclusion of insulator condition risk based on historical trends. Only a small portion of insulators have been electrically tested and assessed insulators in good condition were not recorded (corrected in late 2015).

Based on experience, quality porcelain and glass insulators have an extremely low failure rate and are not expected to degrade over time, therefore condition risk is minimal. However, a vintage of defective porcelain insulators (cement expansion) poses substantial risk and have been targeted for replacement. These insulators account for roughly 25% of the insulator population.

Due to their material properties, polymer insulators degraded over time, especially in the presence of high electrical fields [6] [11] [12]. Aged polymer insulators are considered to be in poorer condition and are targeted for replacement. Polymer risk condition is medium to high.

Surge Arresters

Similar to polymer insulators, arresters degrade over time and aged arresters are generally in poorer condition. Condition is the driving replacement factor and is determined by visual inspection. Since failed arresters pose minimal system risk, condition risk is low and they are operated to failure.

10.3 Performance

Insulators

Figures 10-2 and 10-3 illustrate the frequency and duration insulator caused forced interruptions between 2005 and 2014 and is summarized in Table 10-1. Outage data does not identify insulator type (ie. porcelain, glass or polymer) or root cause. Detailed data is not available through the Transmission Outage Data System (TODS). The accuracy of these charts is only as precise as the data in TODS; misclassified interruptions may or may not be reflected. It is anticipated that this strategy will improve performance by removing defective insulators before they cause an interruption. System performance if not a driving factor for insulator sustainment and the risk is low.

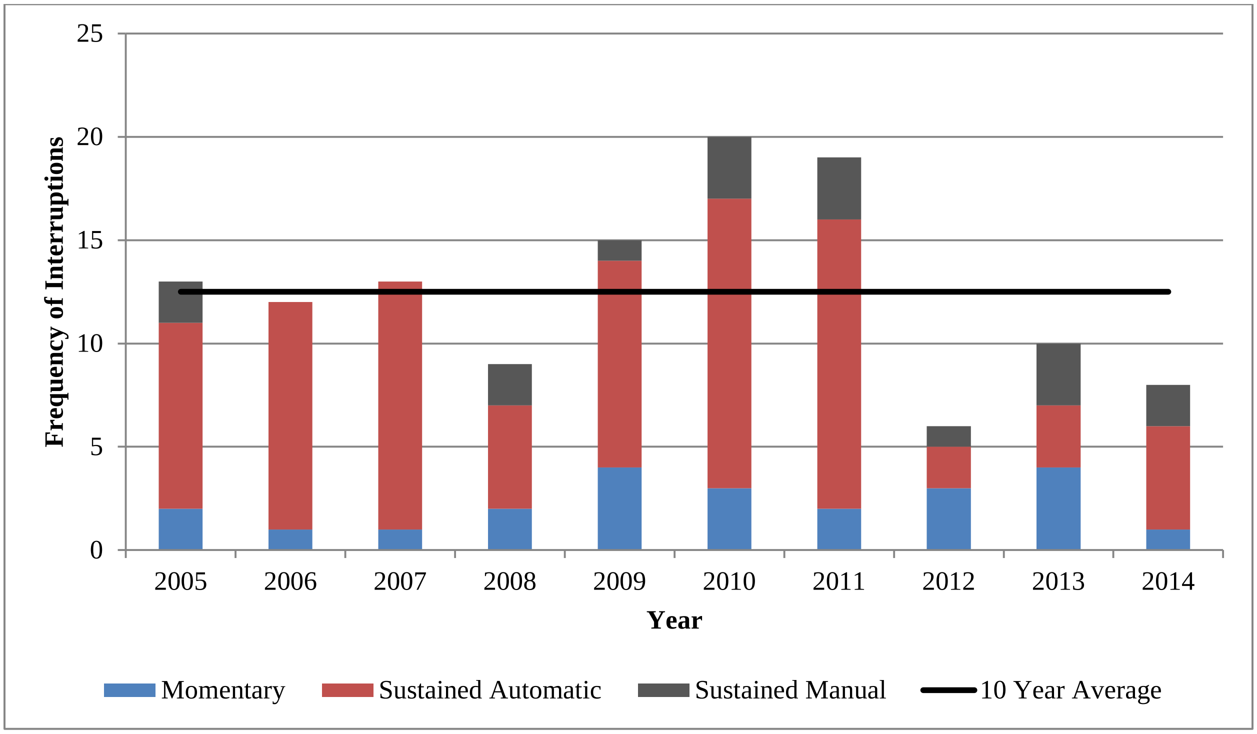


Figure 10-2 – Insulator Frequency of Interruption

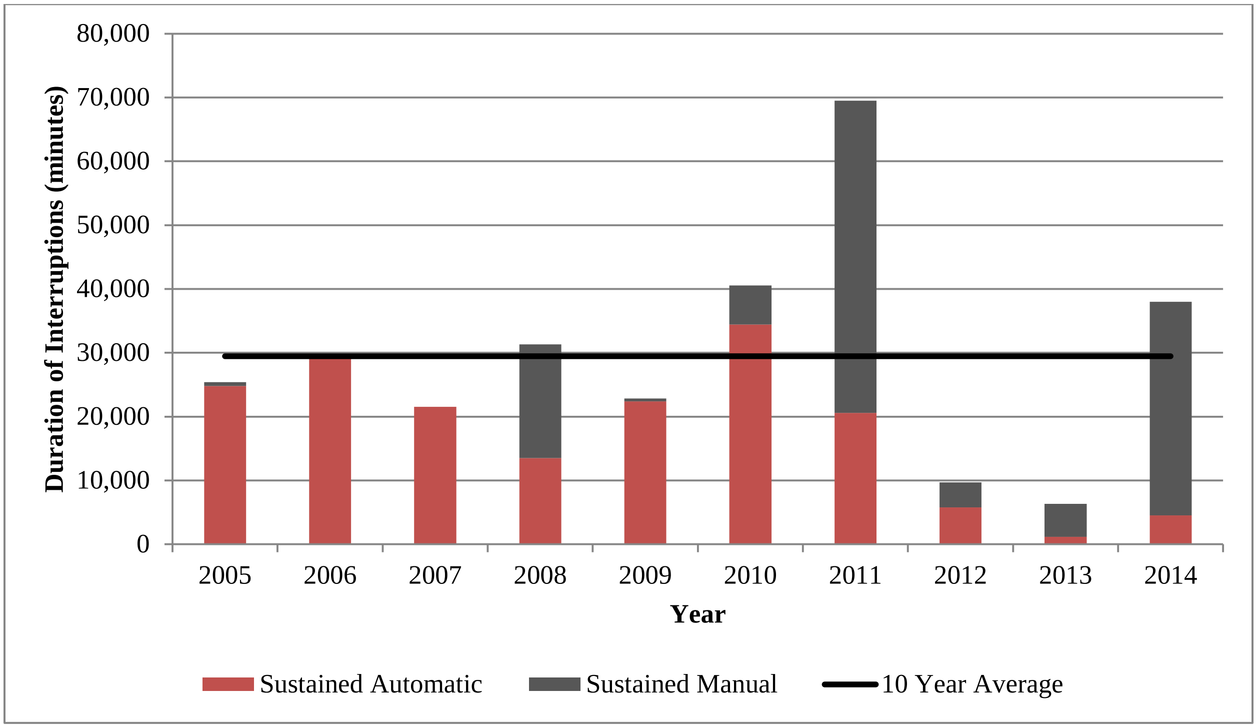


Figure 10-3 – Insulator Duration of Interruptions

	10-Year Average	10-Year Average per 100 circuit km
Frequency	12.5 interruptions per year	0.04 interruptions
Duration	29,489 min per year	98.3 min

Table 10-1 – Insulator Performance Summary

Surge Arresters

Transmission line surge arrester outage data is not tracked in TODS. In the event of an electrical arrester failure the disconnect device will server it from the system, therefore, it is suspected that the number of arrester related interruptions is extremely low. The arrester strategy will have little to no effect on performance risk, which is low.

10.4 Utilization & Criticality

Insulators

Insulators are used on all lines (some of which are critical) at all voltages and must be appropriately rated to withstand everyday operational and overvoltage (switching surges and faults) conditions. Due to their ubiquitous use and well understood rating selection, risks associated with utilization and criticality are not driving sustainment factors.

Surge Arresters

Arresters are used to improve lighting performance. This performance improvement is more noticeable on radial feeds and customers fed from a single supply. Therefore, arresters are more likely to be applied to radial single supply or critical lines where improved performance is desired. Similar to insulators, arresters must be rated for their application and is evaluated on a case-by-case basis. Since arresters are considered operational until condition dictates (severed bond wire) the utilization and criticality risk is minimal and does influence sustainment.

10.5 Obsolescence

Presently there are no obsolescence risks impacting the sustainment of insulators or arresters. There are a variety of suitable suppliers.

10.6 Economics

Work in progress.

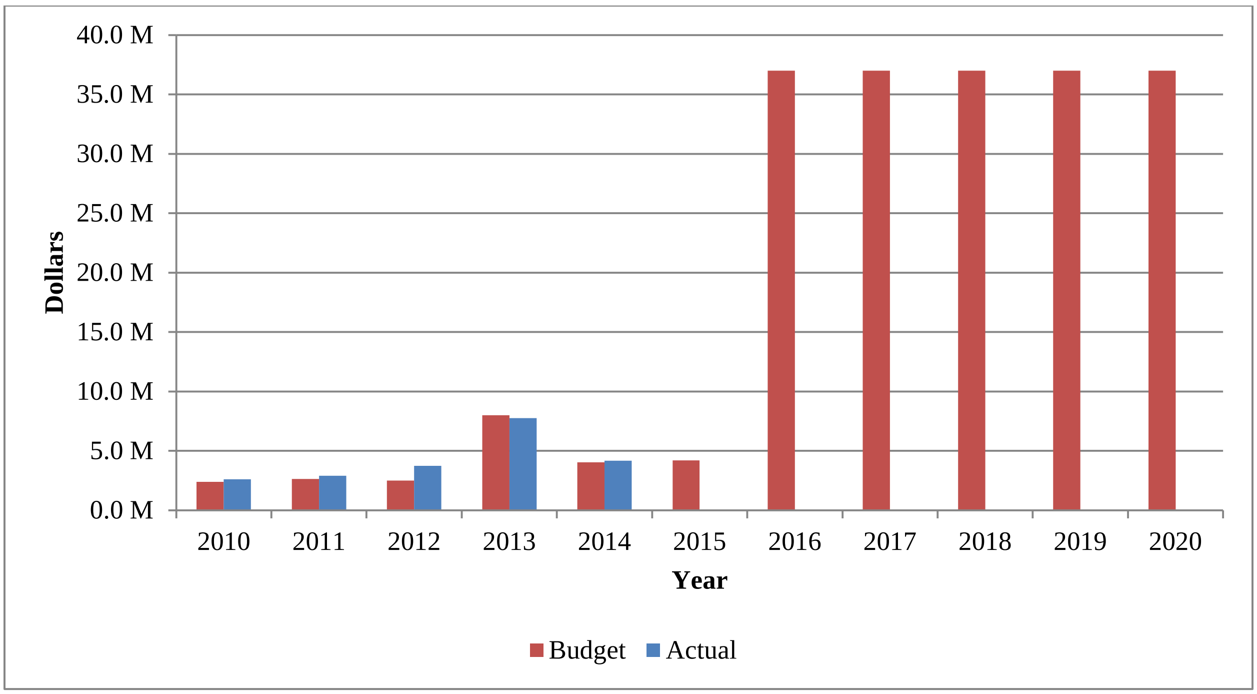


Figure 10-3 -

10.7 Safety

Insulators

Many insulators are used on structures near roads, water, urban areas, golf courses, educational facilities, health care facilities and railways. In the event of a mechanical failure (conductor drop) these locations pose the highest risk to the public. For planned replacement programs, insulators having a higher public safety risk are prioritized for replacement. The replacement of insulators affected by cement expansion is being driven by safety and the risk is considered high.

Surge Arresters

There are normally no safety issues associated with arresters.

10.8 Environment

There are generally no environmental risks associated with insulator or arrester failure and sustainment.

10.9 Prioritization of Asset Investments

Insulators

Once insulator condition warrants replacement, they are primarily prioritized by condition (likelihood of failure) and safety (consequence of failure). Criticality and performance risks are considered to a lesser extent. Implementation of this prioritization is discussed in Section 12.0.

Surge Arresters

Due to the small arrester population prioritization is not necessary; they are replaced based on condition on an as discovered basis.

11.0 TECHNOLOGY INNOVATION OPPORTUNITIES

11.1 Corona Camera

Daytime corona cameras are a relatively new technology that has been developed over the past ten years and is being applied by a limited number of utilities; it has yet to become a common assessment method. The most value is gained by combining IR and corona detection.

Corona is a phenomenon of high voltage applications. It is created under conditions where localized electric fields exceed a critical value (corona inception voltage) causing air to ionize, leading to partial discharge activity. Utilities attempt to limit corona because in addition to audio noise, radio/TV interference and power loss, corona damages system components (especially polymer insulators). Corona at the energized end fitting of a polymer insulator is shown in Figure 11-1.

In late 2014, in conjunction with EPRI, the Ofil DayCor corona camera was trialed. The trial concluded that:

- Corona cameras are an easy-to-use device and works as intended.
- Interpreting the discharge activity requires considerable experience.
- Corona cameras have a very limited application at HONI, particularly for detecting defective insulators.

Ultimately, full-scale program implementation of a as an assessment tool was not recommended. However, for small-scale initiatives such as analyzing circuits with poor reliability, there may be value in hiring a contractor (ie. Kinectrics) to evaluate and interpret the results.

Details can be found in [1] and [13]

Figure 11-1 – Corona Activity

11.2 Unmanned Area Vehicles

Unmanned aerial vehicles (UAV), commonly known as drones, are remotely piloted aircrafts. They are equipped with gyro-stabilized cameras and can be used for detailed visual assessment of overhead lines. UAVs are an emerging technology for utility applications. Since they may be able to replace climbing inspections there is significant value from a safety and cost point of view. HONI, EPRI, CEATI and many other utility are currently evaluating their use. Effectiveness, battery limitations and potential regulatory obstacles need to be overcome/evaluated before full scale implementation.

11.3 Super-Hydrophobic Coatings

Academic research is being done on the use of super-hydrophobic coatings. These coatings can be applied to any insulator type or incorporated into polymer materials. Hydrophobic insulators inhibit the formation of conductive water tracks that increase the likelihood of leakage currents, icing, contamination and deterioration (all leading to flashover). By controlling the surface structure at the nano-level, super hydrophobic properties can be realized. The degree of hydrophobicity, or wettability, is gauged my measuring the water droplet contact angle. The larger the contact angle, the more hydrophobic. See Table 11-1 for a comparison of different materials. While this technology is still in the academic research stage, there may be application potential in regions with heavy contamination or where icing is a concern.

Material	Water Droplet Contact Angle (degrees)
Steel	70 - 75
Human Skin	75 - 90
Hydrophobic	> 90
Teflon	108 - 112
RTV Coating	110
Super-Hydrophobic Coating	>160

Table 11-1 – Water Droplet Contact Angles of Various Materials [14]

11.4 Polymer Coated Glass Insulators

Polymer coated or silicone on glass insulators are conventional glass insulators coated in a silicone layer. See Figure 11-2. The silicon adds hydrophobic properties improving its ability to withstand contamination. For evaluation purposes, Sediver's silicone on glass insulators were trialed on M570V structure 109B and M571B structure 109 in 2012. This area is subject to significant contamination (near Highway 407) and requires frequent insulator washing. Trial insulators were not washed. In 2015 they were visually inspected. The polymer coatings appeared to be in good condition, no significant aging or deterioration was observed. The colour of the polymer had changed from the original light gray to dark gray but this may be due to contamination build up. It was noted that the coating is extremely delicate and it is almost impossible for it not to damage during transportation, handling and installation. This technology is still under evaluation. Refer to Figure 11-2

Figure 11-2 - Silicone on Glass Insulator

12.0 ASSET STRATEGY

12.1 Porcelain Insulators

12.1.1 Condition Assessment

Visual Inspection

Insulators are visually inspected from the air or ground, this is the most common and cost effective assessment method used by utilities. There are no dedicated assessment programs; assessments take place as part of climbing inspections, DHI, helicopter and foot patrols. Defective shells are noted in SAP as a Deficiency Report (DR).

Thermovision

Defective insulators sometimes exhibit temperature abnormalities. Thermovision can detect partially punctured shells that generate heat due to arcing between the cap and pin. In wet conditions, punctures create a cold spot since the shell cannot support a voltage and leakage currents on healthy shells generate heat.

Insulators are assessed as part of the thermovision program. Practice is to compare the temperature of adjacent insulators (same type and vintage); any anomalies are flagged for follow up review.

Electrical Testing

As of 2015 there is no formal porcelain insulator testing program. Past practice was to electrically test porcelain using a hi-tester or buzz fork. The hi-tester is the preferred method, since it provides more accurate results but it is highly dependent on humidity. Relative humidly above 50% increases the likelihood of false negatives.

Testing is done live-line and requires structures to be climbed or the use of a lifting device, this poses moderate safety risks. It is also labour intensive and time consuming, therefore costly. It costs $924 and $1,383 (2015 dollars) to test a single and multi-circuit structure respectively. The testing budget is approximately $1M per year and practice was to test all dead-ends and 25% of suspensions on a given line-section.

The testing program was driven by the COB and CP cement expansion issues. Since it is not known when cement expansion will occur, insulators must be tested repeatedly. Testing focused on steel structures with in-service dates between 1965 and 1982. Wood pole structures were excluded since their life expectancy is 50 years (insulators are replaced as part pole replacement). A formal insulator electrical testing program is no longer needed since COB and CP insulators on high risk structures will be removed and the failure rate of quality porcelain insulators is low. Testing may be done on a case-by-case basis and is driven by reliability.

Post 1985, NGK was the primary porcelain supplier and is currently the only approved supplier. NGK porcelain has a failure rate of 1/100,000 pieces per year [15], therefore, elimination of the testing program does not pose significant risks to reliability, customers or safety. Due to the high cost, moderate safety concern, low failure rate and minimal risk there is no value in routine electrical testing.

12.1.2 Replacement

If insulators require replacement, practice is to replace insulators and associated hardware on all phases. For multi-circuit structures, all insulators are replaced, if feasible (based on outage availability, safety, etc.). Insulators in close proximity to each other are likely to be of similar vintage and condition, therefore, it is economically beneficial to replace them all. If insulators on adjacent circuits (same structure) cannot be replaced, for any reason, and they do not meet replacement criteria, they should not be rescheduled for replacement, since an economic benefit cannot be realized. This is applicable to porcelain, glass and polymer.

Planned Replacement

There is no on-going planned porcelain replacement program. Porcelain insulators are replaced as part of line refurbishment and wood pole replacement. However, individual insulators may be replaced for the reasons noted in Section 8.1.1, this is done on an as-needed basis. Planned replacement is reserved for insulators that have prematurely reached end-of-life due to manufacturing defects, improper functionality or poor design. Replacement programs are in place for COB, CP and semi-conductive glazed bells.

Insulators are not planned for replacement unless the number of remaining good units reaches:

Voltage (kV)	Number of Remaining Good Units	Typical Number of Units
115	4	7

230	10	14
500	17	24-26

Table 12-1 - Porcelain Insulator Number of Remaining Good Units [16]

Table 12-1 outlines the minimum number of insulator units required to perform live-line work and are based on surge studies conducted by Ontario Hydro Research. Intent is to keep the system in a condition where live-line work can be performed minimizing customer and system impact.

Emergency (Demand) Replacement

Emergency replacement is done at the discretion of field personnel to ensure safety and system operation.

Targeted Replacement – Canadian Ohio Brass and Canadian Porcelain

In 2016, a province wide replacement program will begin. Due to the high safety risk, COB and CP insulators on high risk structures will be replaced. There are approximately 34,000 circuit structures with defective COB or CP insulators, roughly 15,000 have been identified as high risk. High risk structures include structures at road, water and rail crossings and structures near urban areas, golf courses, educational and health care facilities.

In parallel, EPRI will be testing COB and CP insulators to determine remaining strength and life expectancy. Testing will include resistance measurements (Megger), AC withstand, mechanical and electrical (M&E) tests and thermo-mechanical cycling. Based on these results the risk of failure will be evaluated to determine replacement timeline. Lower risk insulators are in areas where the consequence of failure is less. However, cracked or chipped COB or CP low risk insulators should be targeted for planned replacement regardless of the number of remaining good shells.

Details of the test plan and risk assessment methodology can be found in [17].

Semi-conductive Glazed Bell (SGB) Insulators

In the early 1970s, Ontario Hydro Research developed a novel insulator design, semi-conductive-glaze bell-shape (SGB), as part of their compact line R&D program [18] [19]. These insulators can be seen in Figure 12-1. A semi-conductive glaze in combination with a redesigned insulator shape reduced string lengths by 50% and allowed 230 kV lines to be constructed to 115 kV clearances. While SGBs proved successful for Ontario Hydro, they have not been used for some time and it is not known whether other utilities adopted the design.

It is not possible to obtain new SGBs therefore a replacement initiative has been undertaken. Due to their unique design, structure modification will likely be required to accommodate conventional insulators. Kinectrics used to refurbish damaged/degraded SGBs but no longer offer this service. While there is a small quantity of spares, they have been earmarked for emergency replacement. Due to safety concerns SGBs replacement can only be done with the circuit out-of-service.

SGBs are suspected to be installed on E26, E27, M6E, M7E, C14L and C17L.

Figure 12-1 - Semi-conductive-Glaze Bell-Shaped Insulators
(C14L/C17L, str 7, 230 kV, porcelain)

12.2 Glass Insulators

12.2.1 Condition Assessment

Visual Inspection

Glass insulators are visually inspected for shattered shells using the same methodology as porcelain, see Section 12.1.1.

Electrical Testing

The technology used to assess porcelain insulation (hi-tester and buzz fork) can be applied to glass but does not provide additional value beyond visual inspection. Glass insulators with intact shells have no internal cracks or electrical punctures. Any defects or stress (internal or external) in the glass shell will lead to shattering, leaving the cap and pin mechanically connected and clearly visible. Because of this behaviour, inspection is simply done visually.

12.2.2 Replacement

There are currently no replacement programs for glass. Planned and emergency replacement strategies are identical to porcelain with the exception of the number of remaining good units, see Table 12-2.

Voltage (kV)	Number of Remaining Good Units	Typical Number of Units
115	5	7
230	11	14
500	15	24-26

Table 12-2 - Glass Insulator Number of Remaining Good Units [16]

12.3 Polymer Insulators

12.3.1 Condition Assessment

Visual Inspection

Polymer insulators are visually inspected using the same methodology as porcelain and glass, see Section 12.1.1.

Thermovision

IR thermography is a common technique used by utilities to assess polymer. It is particularly sensitive to developing defects between the housing and core. Generally, any polymer insulator showing a heat rise on the shaft is tracking internally. Figure 12-2 illustrates a temperature anomaly.

Insulators are assessed as part of the thermovision program. Practice is to compare the temperature of adjacent insulators (same type and vintage); any anomalies are flagged for follow up review.

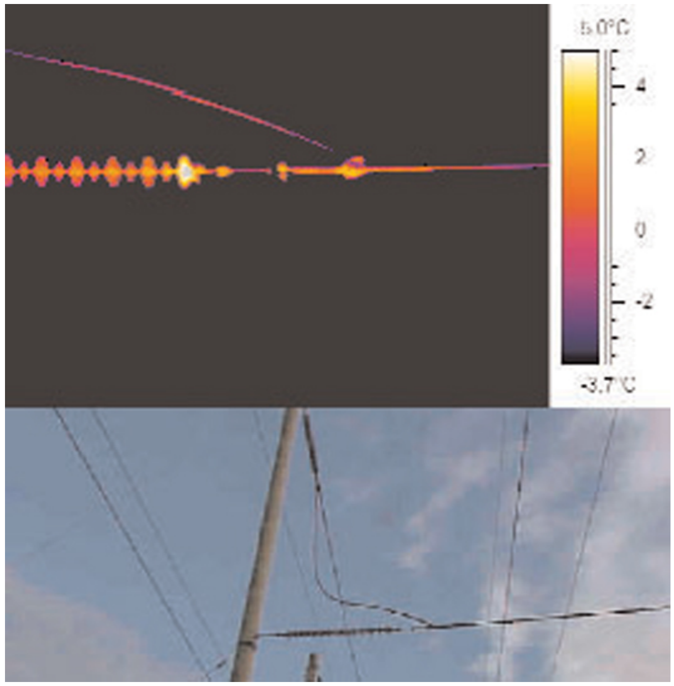


Figure 12-2 - Polymer Insulator Temperature Anomaly

Electrical Testing

EPRI has worked with industry partners to develop a live-working non-ceramic insulator (LW NCI) testing tool to assess the condition of polymer insulators. It is capable of detecting internal conductive defects, where carbonization has occurred. The electrical integrity is evaluated by generating a high-frequency high-voltage signal using a resonant power supply. The resulting voltage signal and resonant frequency between measurement points is compared to a reference signal to determine electrical integrity. Testing is done live-line and requires structures to be climbed or the use of a lifting device, this poses moderate safety risks. It is also labour intensive and time consuming, therefore a costly activity.

A polymer testing program has been developed utilizing the LW NCI tester and will begin in 2016. Intent is to evaluate program effectiveness after one to two years to ensure value. Defective insulators will be removed from service and laboratory tested to verify condition. If only a small percentage of insulators are found to be defective, it may not be worthwhile to continue with the testing program.

As discussed, moisture ingress is a common failure mechanism, causing internal tracking and potentially mechanical failure. On March 26, 2014 a dead-end insulator mechanically failed on K6J (115 kV). Root cause was a manufacturing defect. Sixteen additional dead-end insulators were removed and sent to EPRI for study. The analysis revealed that test dye penetrated to the core on three units and past the outside seal on ten units (no manufacturing defects were found), refer to Figure 12-3 [20]. This indicates a potential for moisture ingress. These insulators were 16 years old. If internal carbonization occurred the LW NCI tester should be able to detect the conductive path.

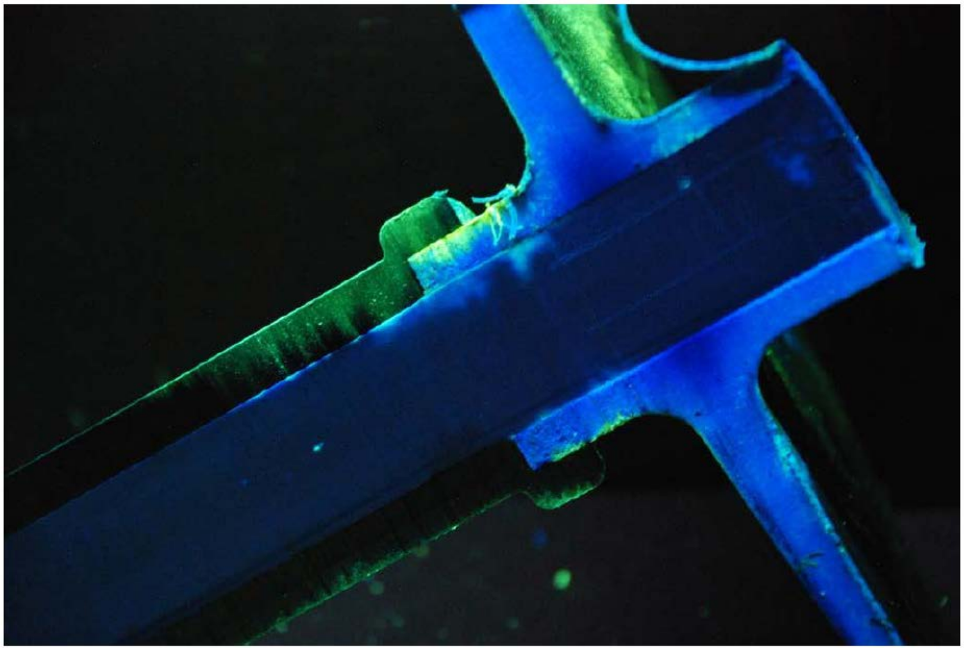


Figure 12-3 - Failed Dye Penetration Test
(K6J, structure 1, center phase, 115 kV, polymer)

12.3.2 Replacement

Planned Replacement

Since the life expectancy of polymer is substantially less than the conductor and structures, proactive replacement is required. Polymer should only be replaced with polymer in special circumstances. Refer to Section 12.5. Preference is to use porcelain or glass whenever practical.

Planned replacement is reserved for insulators that have reached end-of-life (30 years), manufacturing defects, improper functionality, reliability concerns and poor design.

Minor defects do not necessarily warrant replacement, best judgement should be used. Polymer insulators should be replaced if there is any damage to the sheath or shed damage is near (or progressing near) the sheath. Damage sheaths are a significant concern since water ingress can lead to failure. Shed damage does not mechanically compromise the insulator but may cause reduced insulation properties. It is not recommended to replace polymer due to shed damage only.

Emergency Replacement

Emergency replacement is done at the discretion of field personnel to ensure safety and system operation.

Targeted Replacement – 230 kV Dead-ends

On August 24, 2006 and April 22, 2007 on K24F and K23D respectively two 230 kV polymer dead-end insulators failed mechanically resulting in conductor drops. The root cause was determined to be undersized corona rings. High electric-field gradients lead to silicone degradation exposing the fibreglass rod to moisture. Once water penetrates the fiberglass, deterioration is rapid, ultimately leading to brittle failure. The fiberglass rod was exposed in both cases and similar damage was noted on other samples removed from service. The damaged sheath is shown in Figure 12-4.

Following a failure investigation and risk assessment, it was determined that all 230 kV polymer dead-end insulators shall be removed from the system and polymers will not be used in 230 kV dead-end configurations. Removal of 230 kV insulators is thought to be complete but if any were missed, they will be scheduled for replacement.

It should be noted that these were first generation K-Line 230 kV polymer insulators designed in 1989 and manufactured in 1996 and 1997. These insulators included a small four inch corona ring and passed corona testing. K-Line modified their insulator design in 1998 to include larger corona rings (8.25 inches, current design uses a ten inch ring), thicker sheath and more robust weather shed. Current procurement technical specifications [21] have strict electric-field limits.

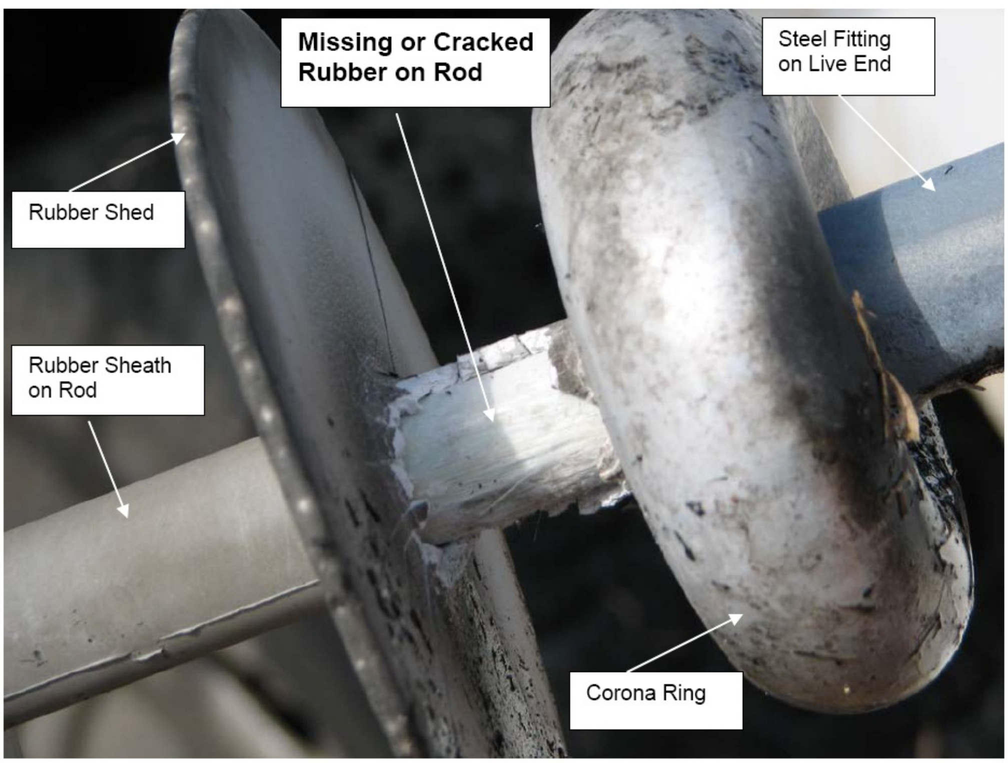


Figure 12-4 - Failed 230 kV Polymer Insulator with Exposed Core

As a point of interest, Kinectics performed corona testing comparing K-Line's 1989 and 1998 designs. Figures 12-5 and 12-6 visually demonstrate corona severity under wet conditions; corona is significantly less under dry conditions. Details can be found in [22].

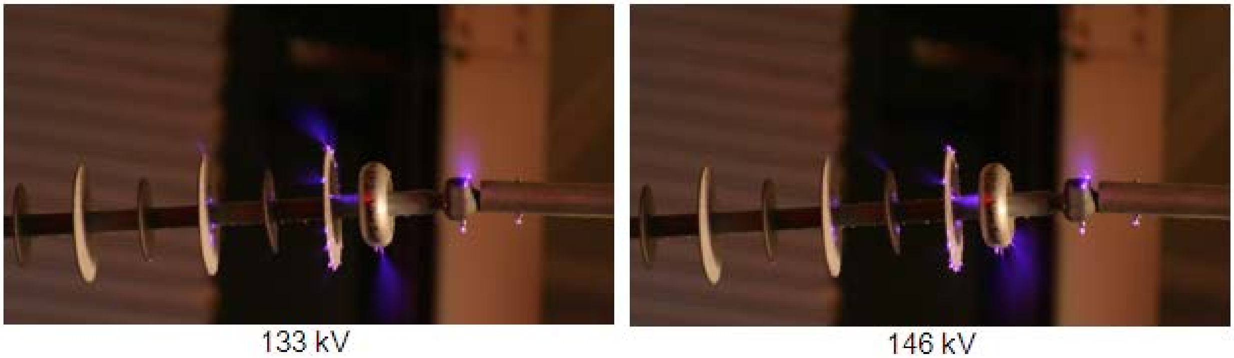


Figure 12-5 - Corona Severity, K-Line Insulators, 1989 Design (4 inch corona ring), Wet Conditions

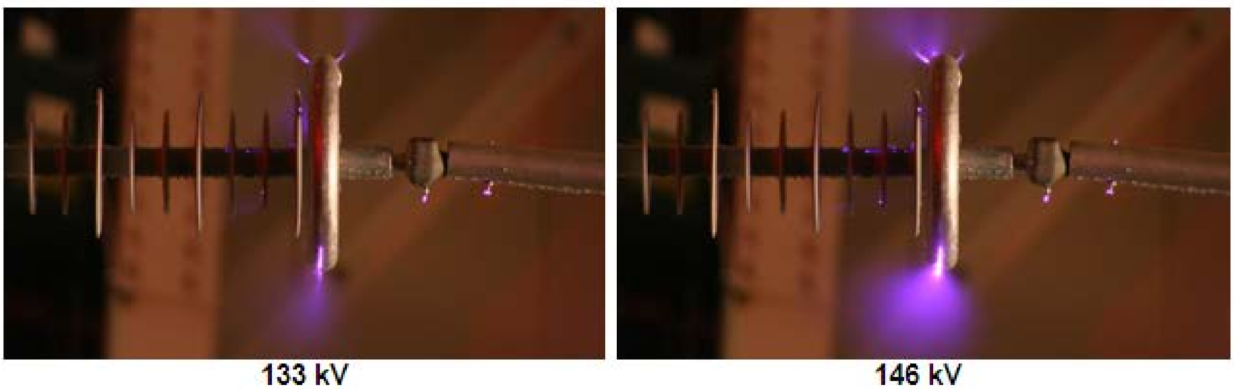


Figure 12-6 - Corona Severity, K-Line Insulators, 1998 Design (9.375 inch corona ring), Wet Conditions

Targeted Replacement – Reliable Insulator Inc.

Insulators manufactured by Reliable Insulator Inc. (Reliable) were installed as part of a pilot program mainly on the Q circuits in the Niagara region during the late 1980s. The exact number of insulators installed is unknown but it is believed that they have been installed on less than 10 structures. Due to an insulator failure on May 18, 2015 on Q24HM (230 kV), structure 139, resulting in a conductor drop, all Reliable insulators shall be replaced (once identified). The failure mechanism was moisture ingress at the end fitting, which eventually compromised the insulator rod. A helicopter patrol of the Q circuits was done in July 2015 to identify any Reliable insulators. Remaining insulators will be removed once located. Reliable insulators used an early polymer design and can be identified by their large shed spacing, see Figure 12-7.

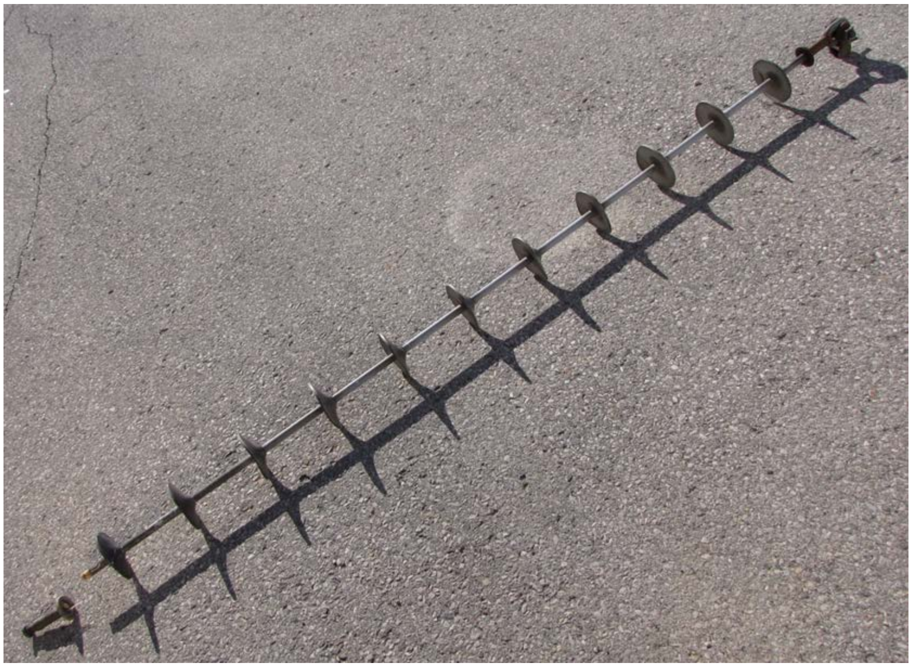


Figure 12-7 - Failed Reliable Insulator
(Q24HM, structure 139, 230 kV, polymer)

12.4 Surge Arresters

12.4.1 Condition Assessment

Visual Inspection

Arrester bond wires are visually inspected from the air or ground, this is the most common and cost effective assessment method used by utilities. Disconnected or failed bond wires can be easily identified, refer to Figures 12-8 and 12-9.

There are no dedicated assessment programs; assessments take place as part of climbing inspections, DHI, helicopter and foot patrols. Defective arresters are noted in SAP as a DR.

Figure 12-8 - Surge Arrester Connected Bond Wire (A1B, structure 2, 115 kV)

Figure 12-9 - Surge Arrester Disconnected Bond Wire (A1B, structure 1, 115 kV)

Thermovision

Arrester IR thermography follows the same methodology as polymer insulators and is another common assessment technique to detect degradation. Figure 12-10 illustrates a temperature anomaly. Any anomalies are flagged for follow up review.

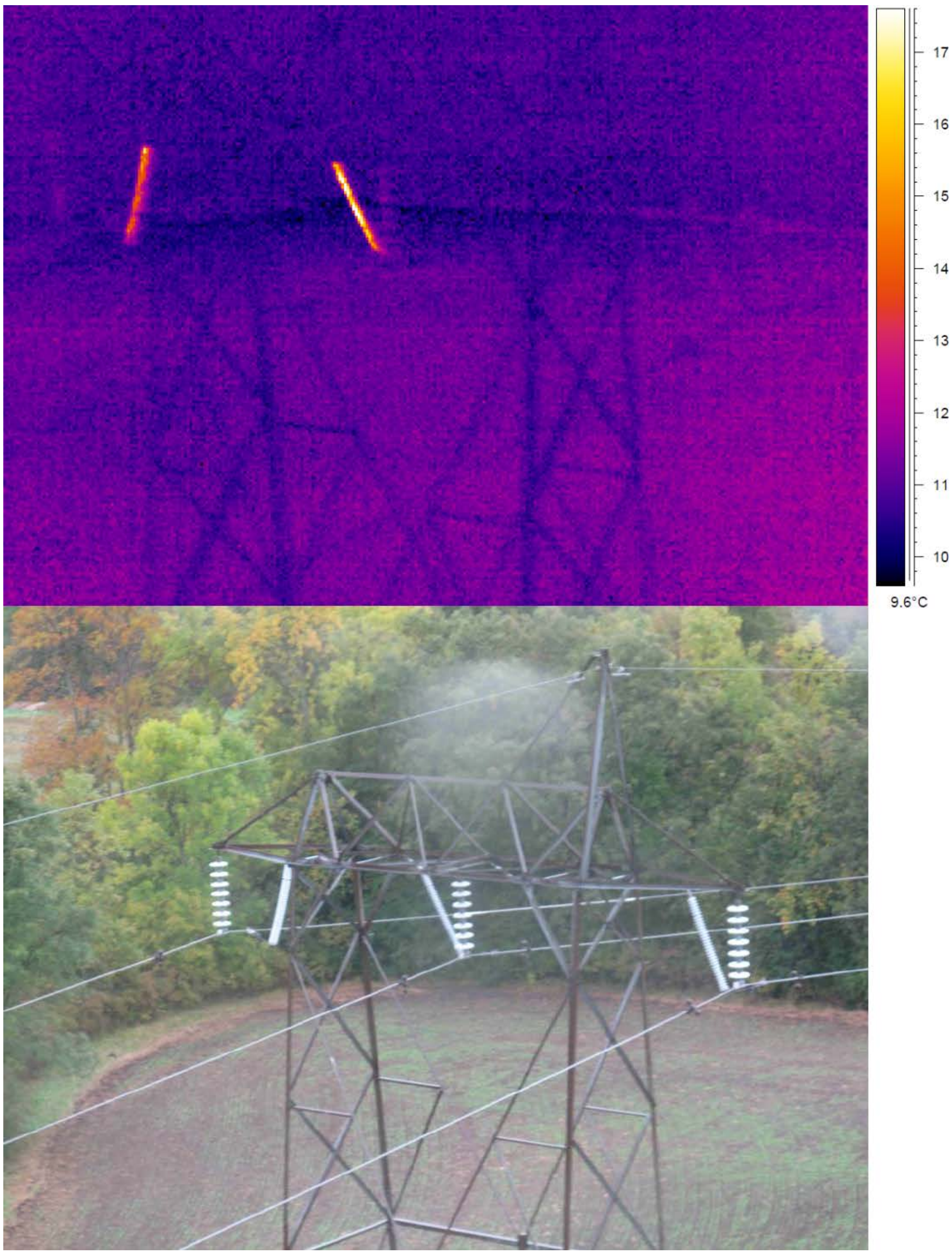


Figure 12-10 - Thermovision Elevated Temperature Reading (Q6S, structure 218, 115 kV)

12.4.2 Replacement

Transmission line surge arresters are not a primary system component; they are added to improve lightning performance. Their failure does do not normally result in outages and does affect the operability of the line, though lighting reliability may be reduced. Therefore, arresters are not proactively replaced and are operated to failure.

Arresters with disconnected or failed bond wires or elevated temperatures (greater than 10 ^{o}C when compared to adjacent arresters) are planned for replacement.

If arresters require replacement, practice is to replace all arresters on the circuit structure. For multi-circuit structures, all arresters are normally replaced, if feasible (based on outage availability, safety, etc.). Arresters in close proximity to each other are likely to be of similar vintage and condition, therefore, it is economically beneficial to replace them all. If arresters on adjacent circuits (same structure) cannot be replaced, for any reason, and they do not meet replacement criteria, they should not be rescheduled for replacement, since an economic benefit cannot be realized.

12.5 New Construction & Replacement

Insulators

For transmission lines, preference is the use of porcelain or glass insulators wherever practical. Polymer insulators are limited to special circumstances such as:

- Regions with heavy contamination
- Temporary and emergency structures
- Where vandalism is likely to occur

Polymer insulators are applied in accordance with [21], [23] and [24]. For permanent installations, their use is limited to 115 and 230 kV suspension, semi-strain and strain structures. They will not be used on dead-ends, over roads, railways and waterways or publicly accessible areas.

Transmission Line Surge Arresters

Due to the common failure mode of broken bond wires, arresters are now installed such that the bond wire is reinforced and not under tension (ie. weaved through a chain, see Figure 7-17).

Since arresters installation is costly they are only installed on a select number of structures as determined by Special Studies.

12.6 Laboratory Testing

It is possible to accurately determine the electrical and mechanical properties of in-service insulators through lab testing. Routine lab testing of in-service insulators is not recommended since it does not provide significant value beyond on-site assessment. Lab testing is reserved for failure investigations and to determine the overall condition of aged insulators suspected to suffer from systemic defects.

12.7 Diversity

Non-systematic risk is minimized by ensuring asset diversity. Multiple types of insulators from various manufacturers are used. A well-proportioned asset mix will reduce the financial, reliability, customer, safety and/or environmental impact in case of manufacturing defects, substandard design, etc.

In June 2015 a directive was issued by the Director of Engineering Services, in agreement with Transmission Asset Management, to maintain an approximate 50/50 mix between porcelain and glass insulators (for upcoming projects).

Porcelain and glass are the preferred insulator types and shall be used wherever practical. Polymer insulators are only used in special circumstances as defined in [23].

For constancy, ease of maintenance and replacement reasonable effort is made to use the same insulator type for entire line-sections. It is understood that this may not be possible in all situations.

12.8 Purchasing

Insulators and surge arresters purchased by HONI are, at minimum, electrically and mechanically compliant with well-recognized industry standards and/or internal HONI standards. Specifying these standards is beyond the scope of this document.

13.0 IMPLEMENTATION PLAN

13.1 Condition Assessment

Continue to use visual inspection through helicopter patrols, DHI and foot patrols as the primary assessment method for insulators and arresters. Funding previously allocated to porcelain testing will be shifted to polymer testing beginning in 2016. There will be no change to OM&A funding.

Specialized laboratory testing to determine condition severity and life expectancy of COB and CP insulators will be done my EPRI and take place in 2016. Results from this program may affect future COB and CP insulator replacement capital expenditure. Testing is being funded through the RD&D EPRI budget.

13.2 Replacement

To replace defective COB and CP insulators in high risk areas the capital budget has been increased from $7M to $37M per year from 2016-2020, this represents a $150M increase (to be approved).

Develop polymer replacement program as need (risk) dictates.

13.3 As Built Data

To enable effective and efficient asset management, Service Providers are required to populate as-built data (to enable asset registry update).

14.0 STRATEGY MAINTENANCE

This Asset Strategy will be maintained by Hydro One's Director, Transmission Asset Management – Planning and Operating and will be reviewed annually. The Strategy Owner will be accountable to confirm that this Strategy is current in all material respects. Suggestions for changes should be forwarded to the Transmission Asset Management Division – Planning and Operating.

15.0 ISSUING AUTHORITY

This Asset Strategy is issued on authority of Director, Transmission Asset Management – Planning and Operating and is effective immediately. Questions about the application of the Strategy should be addressed to the Transmission Asset Management Division – Planning and Operating.

Author	Tyler Wales, P. Eng. Network Management Engineer Transmission Asset Management
Owner	CK Ng, P. Eng. Director, Transmission Asset Management Planning and Operating
Recommendation for Approval	______________________ ___________ Walter Kloostra, P. Eng. Date Manager, Lines Asset Strategies and Maintenance planning programs Transmission Lines Asset Management
Approval	______________________ ___________ CK Ng, P. Eng. Date Director, Transmission Asset Management Planning and Operating
Effective Date	

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UNDERTAKING – J6.5

Undertaking

TO PROVIDE THE MAIFI FOR THE OVERALL HYDRO ONE NETWORK.

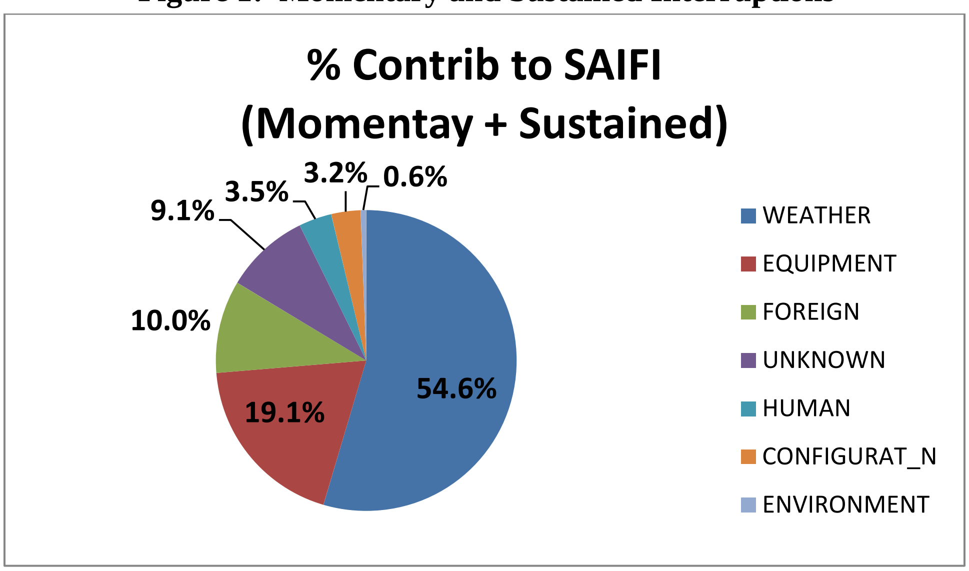
Response

Hydro One's overall transmission system MAIFI is illustrated by the following table and figures.

Table 1: Breakdown of Interruptions

2011-2015 Totals			
Primary CAUSE	**% Contrib to SAIFI (Momentay + Sustained)**	**% Contrib to SAIFI (Momentary)**	**% Contrib to SAIFI (Sustained)**
WEATHER	54.6%	69.5%	38.6%
EQUIPMENT	19.1%	9.6%	29.3%
FOREIGN	10.0%	5.1%	15.2%
UNKNOWN	9.1%	11.1%	6.9%
HUMAN	3.5%	1.8%	5.3%
CONFIGURATION	3.2%	2.4%	3.9%
ENVIRONMENT	0.6%	0.4%	0.8%
Totals	**100%**	**100%**	**100%**

Figure 1: Momentary and Sustained Interruptions



Witness: Scott McLachlan

Figure 2: Sustained Interruption Categories

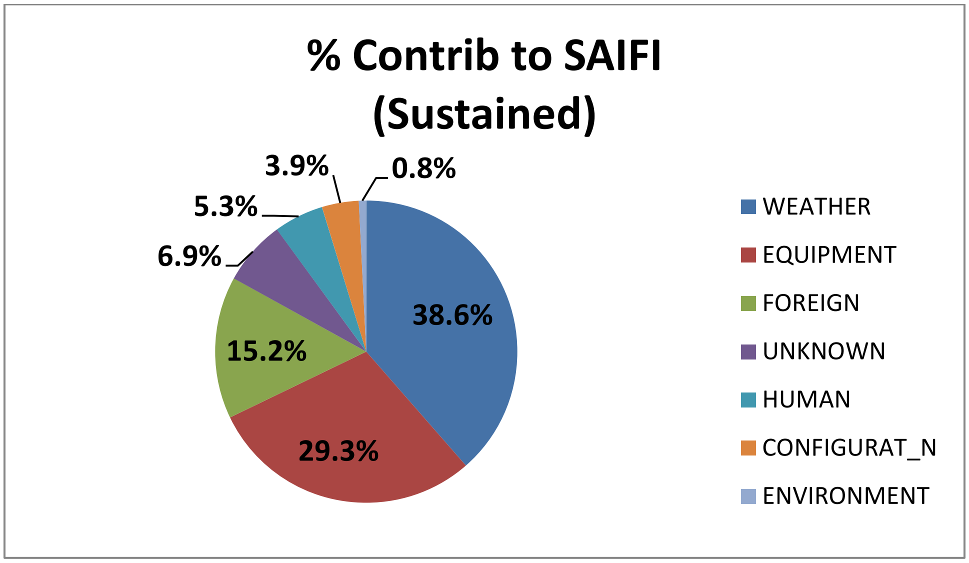


Figure 3: Momentary Interruption Categories