OEB STAFF INTERROGATORY 13

5.0 Commitments from Previous OEB Decisions

5.4 What is the status of the IESO's transmission losses study?

Staff IR #13

INTERROGATORY

Reference: Exhibit C, Tab 1, Schedule 1, Pg. 3

Preamble:

The Application states: "The IESO has been working jointly with Hydro One to explore cost effective opportunities for line loss reduction. The IESO will report to the OEB on these efforts in its first revenue requirement submission following the completion of this joint work."

Questions:

a) Please fully describe the work the IESO has undertaken to-date with Hydro One to explore line loss mitigation opportunities.

   i. Please summarize findings identified by the IESO and Hydro One to-date.

   ii. Please provide a timeline for when the IESO anticipates completing the study.

RESPONSE

a) i. and ii. Please see the response to ED Interrogatory 9 at Exhibit I, Tab 5.4, Schedule 5.09.

DRAFT / CONFIDENTIAL

Page Intentionally Blank

ED INTERROGATORY 8

Issue 5.4: What is the status of the IESO's transmission losses study?

Interrogatory No. 5.4-ED-8

INTERROGATORY

Reference: Exhibit B-1-1, p. 3

Preamble: The IESO forecasts 2.9 TWh in transmission losses in 2018.

Interrogatory:

a) Please explain the methodology for calculating the IESO's forecast of 2.9 TWh in transmission losses for 2018; and

b) Please provide the calculations underlying the IESO's forecast of 2.9 TWh in transmission losses for 2018.

RESPONSE

a) and b) Transmission losses are estimated to be 2.2% of electricity demand. This estimate is based on historical experience and validated by market data.

DRAFT / CONFIDENTIAL

Page Intentionally Blank

DRAFT / CONFIDENTIAL

ED INTERROGATORY 9

Issue 5.4: What is the status of the IESO's transmission losses study?

Interrogatory No. 5.4-ED-9

INTERROGATORY

Reference: Exhibit C-1-1, p. 3

Preamble: In the 2017/2018 Hydro One transmission rates case reads, the Board made the following order:

> *"The OEB finds that, given the magnitude of line losses, Hydro One should work jointly with the IESO to explore cost effective opportunities for line loss reduction. Hydro One should also explore, as part of its investment decision process, opportunities for economically reducing line losses. The OEB requires Hydro One to report on these initiatives as part of its next rate application."*

In its decision on the issues list in this proceeding, the Board stated as follows:

> *"The OEB has added a new issue, issue 5.4, on the status of the transmission losses study. This issue will allow ED and others to appropriately examine the IESO's response to the OEB's direction in its 2017 fee application with respect to transmission losses."*

Interrogatory:

Please provide a copy of any draft reports, presentations, or memos prepared by or for the IESO and/or Hydro One pursuant to the OEB's direction in its 2017 fee application with respect to transmission losses.

RESPONSE

In the Board's Decision and Procedural Order No. 5 for the IESO's 2017 Revenue Requirement application, it determined that:

> *…it is premature to consider the IESO's 2017 revenue requirement submission whether transmission losses should be included in the IESO's Regulatory Scorecard given the recent OEB decision in Hydro One's Transmission rates.[1] The decision requires Hydro One to work jointly with the IESO to "explore cost effective opportunities for line loss reduction". The OEB expect the IESO to work with Hydro One and to report on initiatives for economically reducing transmission line losses in the first revenue requirement submission following the completion of the joint work with Hydro One. It would be more appropriate to*

determine whether transmission losses should be included in the IESO's Regulatory Scorecard once this report has been reviewed.

In response to this direction, the IESO has been working with Hydro One to look at cost effective opportunities for line loss reduction in Ontario. These efforts are being informed by a study, led by the consulting firm EPRI, commissioned by Hydro One and supported by the IESO, to investigate and assess current best practices relative to how transmitters, independent system operators, and regulatory bodies are addressing line losses mitigation. The study explores how transmission losses occur, the chief sources of losses and the methods employed by utilities to mitigate losses. This study, *Hydro One Transmission Losses,* is included as Attachment 1 to this exhibit.

The IESO understands that Hydro One will be reporting on its work to address the line loss initiatives, directed by the OEB in its 2017/2018 Transmission Rate Application (EB-2016-0160), in a future transmission rates application. The IESO does not believe that it is appropriate to examine the EPRI report until it has formally been brought forward in Hydro One's transmission rates application. Further, pending the outcome of the proceeding in which Hydro One brings forward the EPRI report, the IESO does not believe that addressing specific questions about transmission losses in this proceeding will be productive or helpful to the Board in its consideration of the IESO's fees and revenue requirement submission. As such and in accordance with the OEB's direction in its decision, the IESO will report back on the completed work in its own subsequent application.

ELECTRIC POWER RESEARCH INSTITUTE

Hydro One Transmission Losses

3002012721

Hydro One Transmission Losses

3002012721

Technical Report, March 2018

EPRI Project Manager

J. Chan

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

REFERENCE HEREIN TO ANY SPECIFIC COMMERCIAL PRODUCT, PROCESS, OR SERVICE BY ITS TRADE NAME, TRADEMARK, MANUFACTURER, OR OTHERWISE, DOES NOT NECESSARILY CONSTITUTE OR IMPLY ITS ENDORSEMENT, RECOMMENDATION, OR FAVORING BY EPRI.

THE ELECTRIC POWER RESEARCH INSTITUTE (EPRI) PREPARED THIS REPORT.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

Electric Power Research Institute, EPRI, and TOGETHER...SHAPING THE FUTURE OF ELECTRICITY are registered service marks of the Electric Power Research Institute, Inc.

Copyright © 2018 Electric Power Research Institute, Inc. All rights reserved.

ACKNOWLEDGMENTS

The Electric Power Research Institute (EPRI) prepared this report:

Principal Investigators
J. Chan

T. Goodwin
Tip Goodwin Consulting, LLC
Southlake, TX

This report describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

Hydro One Transmission Losses. EPRI, Palo Alto, CA: 2018. 3002012721.

ABSTRACT

Hydro One requested EPRI's assistance in preparing a best-practices review of the electric transmission industry concerning how transmission line and transformer losses are being addressed across the industry, and also a review of Hydro One's own efforts at mitigation of transmission losses.

To meet the request, this report presents an overview of what causes losses within the transmission grid, how different mitigation techniques are applied to reduce losses, how the industry is addressing loss mitigation in its planning and capital improvement programs, and obstacles preventing direct loss mitigation efforts. The report also describes Hydro One's accomplishments in mitigation losses on its system and discusses the results of a sensitivity study of 11 Hydro One transmission assets, addressing the magnitude of losses incurred over a year and the impact potential mitigation efforts would have on the level of losses.

The investigation of industry best practices and Hydro One's efforts at mitigating transmission losses showed these key points:

1. Transmission losses and their mitigation are not a focal point of transmission service providers, their independent system operators, or their regulatory bodies. At best, a few entities include the impact on losses that various design options may have in the selection of their project solutions.
2. Transmission Projects are initiated based on system need to ensure adequacy and reliability of supply. No utility is pursuing loss mitigation projects solely based on the potential mitigated loss savings over the life cycle of the asset.
3. The industry's best practices address transmission losses during the design and purchase of assets, such as: reducing losses with proper conductor selection and transformer design.
4. Hydro One design practices are materially consistent with industry best practices for loss mitigation.

Keywords
Energy Efficiency
Losses
Transmission Line

EXECUTIVE SUMMARY

Electric utilities are facing continuing growth in demand for reliable, high-quality, low-cost electricity to meet everyday demands and expanding applications of electricity. To meet these demands, utilities are employing a mixture of increased system efficiencies, conservation efforts, controlled capital expenditure, and a diverse injection of distributed generation, mostly renewable.

Following the Ontario Energy Board's decision in Hydro One transmission rate application, Hydro One (with support from the IESO) requested EPRI to carry out a comprehensive assessment of current best practices in the industry relative to the mitigation of losses in transmission line and station equipment.

The study investigated the current best practices relative to how transmitters, independent system operators, and regulatory bodies are addressing the loss mitigation concern. The research explored how transmission losses occur, the chief sources of losses, the methods employed by utilities to mitigate losses through reducing equipment resistance and upgrading voltage levels, and the incorporation of loss mitigation from a system planning perspective. While driving for a goal of more efficient delivery of electricity, the electric utility industry does not pursue rebuilding and upgrading existing facilities solely for loss mitigation. The lifetime benefits of the mitigated losses do not offset the financial cost of performing the necessary transmission line modifications. In addition, the majority of transmission assets operate at levels 30-40% of their capacity, only operating near capacity a few hours a year if at all. The low load factor means transmission lines generally do not create significant losses and loss mitigation has an even smaller impact.

The study was also intended to better understand Hydro One's own transmission loss mitigation efforts in the context of these industry best practices. The project reviewed Hydro One's accomplishments in loss mitigation to date. A sensitivity analyses was also performed using characteristic data from nine transmission lines and two transformers in the Hydro One system. To assess the potential loss mitigation levels, an assessment was conducted on the level of losses that occurred in 2016 based on available element loading patterns and equipment characteristics for the subject transmission assets and a set of more efficient transmission conductors and transformers that are available.

The investigation in best practices and review of Hydro One's current practices showed these key points:

- Transmission losses and their mitigation are not a focal point of transmitters, independent system operators, or their regulatory bodies. At best, a few entities include the impact on losses that various design options may have in the selection of their project solutions.
- Transmission Projects are initiated based on system need to ensure adequacy and reliability of supply or provide supply to customers. No utility is pursuing loss mitigation projects solely based on the potential mitigated loss savings over the life cycle of the asset.
- The industry's best practices address transmission losses during the design and purchase of assets, such as: reducing losses with proper conductor selection and transformer design.
- Hydro One design practices are materially consistent with industry best practices for loss mitigation.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
INTRODUCTION

Objective

Electric utilities are facing continuing growth in demand for reliable, high-quality, low-cost electricity to meet everyday demands and expanding applications of electricity. To meet these demands, utilities are employing a mixture of increased system efficiencies, conservation efforts, controlled capital expenditure, and a diverse injection of distributed generation, mostly renewable.

Following the Ontario Energy Board's decision in the Hydro One transmission rate application, Hydro One (with support from the IESO) requested EPRI to carry out a comprehensive assessment of current best practices in the industry relative to the mitigation of losses in transmission line and station equipment. The study investigated the current best practices relative to how transmitters, independent system operators, and regulatory bodies are addressing the loss mitigation concern.

The study also assessed how Hydro One is applying the identified best practices in loss management and provided examples of loss mitigation efforts.

Background

Efficiencies are required to address the differences between demand-driven project requirements and the available capital investment in infrastructure that utilities can commit. Efficiency is also critical due to changes in load and the unpredictability of the availability of renewable generation. To address these challenges, utilities are pushing their aging infrastructure to provide a longer service life, and to carry increased loading to meet the demand.

An important aspect of this interaction is the fact that the electric utility infrastructure is aging. Although the book life from an economic standpoint of a utility asset is typically 40 years, its service life in most cases can be exceeded with appropriate maintenance. Utility assets typically are removed or replaced only for failure, end of life, or inadequate capacity. For example, a conductor may be in-service for many decades; and is removed only when increased capacity requirements lead to a reconductoring of the line, or as a result of weathering, the conductor deteriorates and needs to be replaced. Hydro One has been proactive in asset management of existing facilities, identifying infrastructure and equipment that has reached or is reaching its end of life, and is taking steps to repair, or maintain as appropriate, equipment to extend its life.

With time, system topology grows and changes with various load, transmission capacity and generation injection changes. Existing facilities are very seldom removed completely. Rather, the assets are modified or upgraded as needed. One aspect that remains constant with each specific asset is its characteristics relative to current-carrying capability and its associated resistance. Transmission losses are intrinsically related to the resistive properties of the equipment, which cannot be altered. Therefore these parameters may mean the equipment or asset is not as efficient as newer designs and applications of technologies that have been applied in newer-technology equipment.

This report will address the characteristics of losses in current technology applied on transmission systems and what newer-technology has to offer in loss mitigation. The report also addresses what the best practices are being applied across the electric utility industry related to loss mitigation and how Hydro One is applying loss mitigation efforts in managing their transmission system.

2
LOSSES WITHIN THE TRANSMISSION SYSTEM

The section provides a brief overview of how transmission losses occur in an electric utility system and the impact of these losses on electricity delivery.

Sources of Losses

Losses on the transmission system can be attributed to the system configuration/topology as well as the equipment characteristics.

System Configuration/Topology

The size, configuration and topology of the transmission system have a large impact on the amount of losses that can be incurred. As the following section on Equipment Characteristics will disclose, each type of equipment has loss characteristics. Some are fixed per piece of equipment, e.g., the losses associated with a transformer; while other characteristics are attributed to size, e.g., length of a transmission line and kilometers of conductor in operation or voltage class of equipment which influences losses.

Hydro One's transmission system is very large, with substantial distances between generation sources and load demand centers. The transmission system is also an aging asset with lines and equipment that are older technologies that are less efficient than newer technology equipment. Older transmission lines that traverse many kilometers typically used smaller conductors which were adequate based on loading at that time. These lines contribute a large portion of the losses incurred as loading levels have increased. As the transmission system changes to meet reliability and load demand, the topology changes with newer assets added as greenfield installations or as upgrades and replacements of existing assets to meet capacity requirements.

Evolving Industry

The electricity industry is experiencing a new paradigm relative to providing a network to provide cost-efficient and reliable energy to its consumers. At one time, utilities operated in a monopolistic environment and did their planning and design, construction, and operation to meet their specific customer needs. With deregulation, open access allows any company with the wherewithal to build generation. Initially, these new generation forays were by utility or ex-utility interests using typically identifiable sites at the juncture of fuel and water sources and high-voltage transmission lines. That was the first wave, and the transmission grid had to expand to provide adequate transmission capacity to move power from these new nodes to an unconfined array of load nodes.

The next wave of generation encompassed larger-scale renewables. Initially, these facilities, too, were at logical large-scale sites, often remote due to size, which required transmission expansion. Now the size and site-ability of renewable generation mean that it can be placed anywhere. This flexibility creates new constraints and contingency scenarios on both the distribution and transmission grids in their areas.

Transmitters have been required to maintain open access to any requester, and to expand, upgrade, or rebuild many of its assets to meet the new and/or modified load and generation. The most difficult aspect of this expanding market is that it is less than predictable when it comes to reliability. Renewable generators are predominantly fueled by wind and solar and therefore depend on favorable environmental conditions to generate power. However, the transmission system is required to provide capacity whether these renewables are on line or not on line. Thus the transmission system must be designed for both of these two operating scenarios which often require a diametrically different transmission system. Power will flow in one pattern with congestion constraints when renewables are on and a different pattern when they are not.

Daily market drivers (load demand, generation bid pricing, equipment outages, system congestion) make the electric industry a dynamic environment where assets from generation through transmission, and substation are required to perform differently on an hourly basis. For example, the load, which may have been supported by a few large scale generation sources in the past, may now be supported by multiple small scale generation sources throughout the network or a combination of both the large and small-scale generation. The transmission system will need to support each of these delivery path scenarios reliably. The transmission system has become a dynamic topology, physically and operationally.

Equipment Characteristics

Transmission equipment experiences losses while transmitting power. This is a normal and accepted phenomenon in the electrical industry. The amount of losses is governed predominantly by two parameters, which have passive and dynamic aspects.

Passively, the losses are determined, first, by the resistance of the current-carrying component—e.g. the higher the resistance of a conductor, and the longer the length of the conductor, the greater the thermal losses, and, second, by the associated equipment construction—e.g., the core construction of a transformer. These parameters are fixed once the asset is manufactured and installed.

Dynamically, the losses are proportional to the amount of power flowing through the asset, squared. With an ever-expanding demand for capacity, the current level generally increases and the losses increase.

Transmission Lines

Conductors, whether elevated in open air or buried in underground facilities, have a known resistance, which creates heat when the current flows through them. The only alternatives to reduce losses are to use a different conductor with lower resistance or to reduce the current flowing through the equipment.

Any elements within the transmission path that carry current are sources of losses due to joule heating.

Joule heating losses are proportional to the square of the current load. The joule heating causes two operating issues—namely, conductor elongation and increased resistance. The conductor elongation is a driving influence on transmission line design dictating span lengths and structure heights. The elevated resistance accentuates the joule heating with power flow, increasing losses.

On a much smaller scale, losses are attributed to corona discharge around hardware and to conductor and field effects induced on parallel metallic objects, such as pipelines, other electric circuits, railroads, etc. Fortunately, current design practices have reduced these contributions to minimal levels.

Corona consumes energy, creating a line loss, as it ionizes air around energized parts of insulator assemblies and along the conductor. Corona only occurs at high voltage levels, increasing in severity as voltage rises above 230 kV. The voltage causes a gradient around all energized parts. Generally, the shape of the components is smooth enough that the voltage gradient is fairly smooth and low. However, if the surface is rough and has some protuberances, the voltage gradient is distorted, causing high gradient transitions. If the gradients are large enough, the energy causes ionization of the air and corona. The phenomenon requires a high base voltage (i.e., EHV level) and a protuberance (e.g., water droplet ready to drop from the surface, a metal nick sticking out, or bird droppings).

Station Equipment

Equipment, such as transformers, breakers, and switches, have internal current carrying components that are like conductors fixed in their resistive characteristics. Transformers have an additional component of losses associated with the core construction of the transformer and induced currents through them. Newer designs and core materials have provided increased efficiencies that reduce the transformer losses, but their application requires replacement of the existing assets.

Station equipment, breakers, switches, bus conductors and metering equipment all create a small contribution to system losses. Mitigation of losses in stations is limited since the majority of the equipment is sized for withstanding fault levels of current which dictate the design and sizing of components.

Overall, transformers drive station losses and are the focal area for loss mitigation.

Transformer losses have both voltage-related and power-flow-related losses. Voltage-related losses are associated with transformer construction and core materials. Eddy currents develop within the core that contributes to the losses. They are induced by the voltage level and occur anytime the transformer is energized.

Power flowing through the transformer coils experiences losses from the joule heating due to conductor resistance. The level of these losses is proportional to the square of the current flowing through the transformer.

Losses are also incurred from the auxiliary devices on transformers that assist in cooling the unit. Pumps for passing the mineral oil through radiators and fans blowing air across the radiators are used on some units to cool the units. These losses become proportional to the transformer load; the more load transferred through the transformer, the hotter the unit becomes.

Impact of Losses

Losses represent energy, or units of electricity that must be created in the process of generating electricity to replace energy lost. Replacing lost energy has several impacts on the electric system.

Each unit of energy lost must be generated, requiring additional fuel sources. Additional generation capacity may be needed if the cumulative losses cause demand greater than the installed capacity. Additional generation may also cause additional pollutants and environmental impacts depending on type of generation source.

Similarly for transmission lines, additional capacity may be required on certain lines to meet demand at load points. Meeting this demand may require new lines, upgrades, or some other measures to ensure a reliable transmission system.

EPRI performed a study for the New York State Energy Research and Development Authority to assess the level of electric losses across the electric production, delivery and use spectrum. Cumulatively, transmission losses average 1.5 to 5.8%.[1]

An important factor in reviewing the impact of losses on transmission lines is the actual loading that most lines experience under normal operation compared to the actual load-carrying capability of the line. If losses are estimated on capacity, they give a false representation of the actual system losses. This point will be expanded upon in the discussion in the Sensitivity Study in Section 5.

---

[1] *Assessment of Transmission and Distribution Losses in New York*, EPRI, Palo Alto, CA: 2012. PID071178 (NYSERDA 15464).

3
LOSS MITIGATION METHODS

This section reviews constraints to loss mitigation, several general principles related to loss mitigation, the results of utility surveys on loss mitigation efforts, and methods of mitigating losses through reducing equipment resistance, upgrading of voltage level, and power flow control.

Loss Mitigation

Loss mitigation reduces overall demand on the transmission system by requiring less power from generation. However, due to the geographic nature of the power system, a reduction in losses doesn't necessarily lead to fewer transmission and/or distribution facilities. These facilities are still required to serve customers across the utility's service territory.

One of the major constraints to pursuing loss mitigation is the need to justify the benefits of the loss reduction versus the capital expenditure to execute the mitigation. Unfortunately, in most cases, the benefits do not offset the cost of mitigating losses, even when considering the life cycle economics. Initiating and funding projects for the sole purpose of mitigating transmission losses are not typical throughout the industry. Rather the economic benefits realized from different aspects of a project that mitigate losses are part of the life cycle cost analysis of a project that may sway approval of a project or make one project a better choice over another solution. In reality, today loss reduction is driven by available opportunities, not direct need.

Key Principles Related to Loss Mitigation

Through EPRI's research, a framework around improving transmission efficiencies (including transmission losses) and a methodology for measuring the potential benefits has been developed. The key principles related to transmission efficiency that have been identified are:

- **Efficiency is more than simply reducing losses**: A more economically efficient transmission system that fully utilizes existing assets and incorporates renewable energy sources and storage technologies may actually have higher losses.
- **Efficiency initiatives should not reduce reliability**: Transmitters (e.g., Hydro One) and system operators (e.g., IESO) must focus their efforts first on reliability to meet customer and regulatory expectations. In a simple example, removing a transformer that is not carrying much load may reduce some of the core losses but introduce risks to reliability if another transformer is lost.
- **Efficient transmission will require new and upgraded systems:** The expansion of the grid to meet the challenge of adding renewables and storage capabilities to meet load growth and to replace retiring infrastructure will offer significant opportunities to improve the efficiency of the transmission system. However, the application of better equipment and new technologies and the replacement of less efficient retiring equipment are part of a long-term process that will take many years.
- **Efficiency must be considered in business cases**: Transmission system expansion and refurbishment must incorporate efficiency considerations in the development of projects.

- **A regulatory framework with incentives is needed to encourage transmission loss reduction**: For loss reduction to be a prioritized criterion requires regulatory change to incentivize it. Currently the life cycle benefits of loss mitigation are not large enough to make direct loss mitigation projects justifiable.

These findings have been documented in several reports including:

> *Transmission Efficiency Technology Assessment: Phase 1.* EPRI, Palo Alto, CA: 2008 1010692.
>
> *Transmission Efficiency Initiative: Key Findings, Plan for Demonstration Projects, and Next Steps to Increase Transmission Efficiency.* EPRI, Palo Alto, CA: 2009. 1017894.
>
> *Transmission System Efficiency Technology and Methodology Assessment,* EPRI, Palo Alto, CA: 2010. 1020143.
>
> *Transmission System Efficiency and Utilization Improvement: Summary of R&D Activity and Demonstration Projects.* EPRI, Palo Alto, CA: 2012. 1024345.

Utility Practices on Loss Mitigation

This section lists some of the results of the studies and important factors that other utilities are considering to reduce transmission losses.

New York State Study

Losses can be mitigated in several ways. EPRI performed a study with the New York State Energy Research Development Authority[2] reviewing the issue of line losses in support of NYSERDA's larger investigation into Electricity Efficiency improvements across the state. The New York investigation is much broader than transmission line losses and focused on other efficiency initiatives; but EPRI was asked to participate to provide visibility to the transmission loss impact.

Each utility provided some insight into their current loss calculation methodology and mitigation actions. In general, losses were not tracked or directly measured throughout the industry. Transmission losses were obtained based on a high-level view—measured sales versus generation input.

The utilities also noted the ways they are looking at mitigating losses. Of the eight utilities participating in the project, the following methods were being applied:

- Reconductoring projects (seven utilities)

---

[2] *Assessment of Transmission and Distribution Losses in New York.* EPRI, Palo Alto, CA: 2012. PID071178 (NYSERDA 15464).

- Application of capacitors and shunt devices for reactive power control (five utilities)
- System operating methods for voltage control (two utilities)
- Replacing substation transformers (two utilities)
- Voltage upgrade of circuits (two utilities)

EPRI Utility Survey

Through a utility survey, EPRI researched energy efficiency activities with utilities related to transmission line losses.[3] Table 3-1 provides a summary of the loss mitigation efforts being considered and applied by the 25 EPRI survey respondents, including investor owned, public power, cooperatives, transmission providers, and federal utilities. The respondents covered voltages from 115 to 765 kV. Note that, while many options are being considered, few methods are being actively applied, and few utilities are actively pursuing the efficiency efforts.

Table 3-1
Transmission Loss Mitigation Areas of Interest

Methods Under Consideration	Under Consideration (%)	Actively Applying (%)
Raising Nominal Voltage	33	4
Optimization of Voltage Profile	22	0
Use Lower Loss Conductors	56	0
Re-direct Power Flows	44	8
Bundle Conductor Optimization	11	0
Improve Corona Losses	11	0
Shieldwire Segmentation	22	0
Improve Insulation Losses	11	0
Installation of Low-Loss Transformers	56	8
Convert to DC, Bipole or Tripole	0	0
Switch off Equipment Not in Use	0	0

The survey asked whether the utilities were conducting loss studies. Of the 25 participants, 29% responded that they had done loss studies on lines and some transformers. However, only 14% reported that they had used measured data for their investigation.

When asked by EPRI why the loss studies were performed, 36% reported they needed the data for a rate or regulatory filing. Billing of transmission services accounted for 36% of the reasons. Again the application of actual data in loss quantification was only in 28% of the cases.

---

[3] *Transmission Efficiency Technology Assessment: Phase 1*, EPRI, Palo Alto, CA: 2008. 1010692.

The survey further asked whether the loss considerations were at peak loading. Of the 56% percent that responded, 70% said they made their analysis at peak loss levels using computer simulations, SCADA data was used 25% and 5% were based on transmission studies.

The EPRI study summarized that loss mitigation within the transmission system can be addressed in three general concepts: equipment characteristics, voltage level, and power flow control. In many cases, aspects of these three concerns interplay and contribute collectively to losses and their mitigation. For example, the resistance of the conductors and the amount of current flowing through the conductor define the losses. The greater the current flow, the higher the losses. Coincidentally, the losses are the result of resistance heating; the heat rise causes the conductor resistance to increase, coupling to further cause losses. Voltage and current levels can mitigate congestion—increased power can be accomplished with higher voltage and less current or by maintaining voltage and increasing current. Since losses increase by the square of current flow, I^2R, voltage increases and lower currents improve losses

Equipment Resistance

Joule resistance heating is the greatest contributor to transmission equipment losses. The majority of transmission lines are constructed using electrical grade EC 1350 aluminum strands for current-carrying capacity. Various constructions are available using aluminum alloys, steel, or composite materials for providing additional mechanical strength to the conductor. Figure 3-1 shows cross sections of a traditional steel core ACSR conductor and an ACCC composite core conductor. Typically, a core stranding provides the mechanical strength and supports the aluminum strands. The number of strands and their diameters build up a cross-sectional area that is sized to provide the desired current-carrying capacity. The strand resistance causes joule heating when electrons flow through the conductor, creating a temperature rise. The temperature rise has two effects on the conductor: first, it causes thermal elongation in the strands, which cause the line conductor to expand and sag more. Second, the increased heat causes the resistance to slightly increase, causing additional thermal losses.

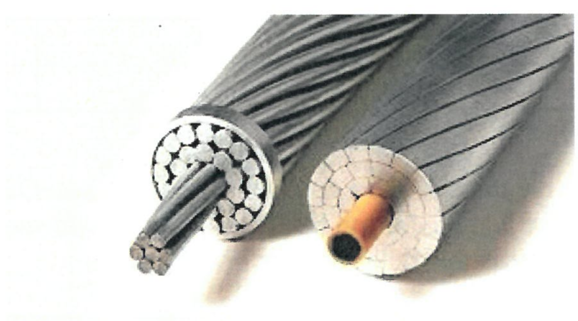


Figure 3-1
Comparison ACSR and ACCC

On any given operating day, the ambient conditions of temperature, wind, and solar radiation affect the thermal stability of the conductor catenary system. As current flows, heat is created from the resistance heating. In addition, under daylight conditions, solar heating can occur. The ambient temperature serves as the base thermal setting. The hotter the ambient, the higher the conductor temperature; conversely, cool days and night reduce the thermal content. Wind blowing across the conductor also cools the conductor. Under power flow, a quasi-steady-state condition develops, where the heat being introduced by resistance and solar heating is balanced by the ambient temperature and wind effects. The transmission line is designed such that the conductor temperature remains below a certain operating temperature with the design power flow. Structure type, heights, and strengths are determined by the conductor selected and the terrain and environmental loadings that will govern design for safety and reliability concerns. Larger conductors provide lower resistance and losses but require taller and stronger structures to perform as required. Thus, a life cycle cost evaluation must be performed of the initial capital expenditures, maintenance costs, cost to deliver power (including losses), and service life.

Figure 3-2 illustrates the cost development of a transmission project, including capital costs and the cost of electrical losses on the transmission line. The Present Worth of Future Requirements for Revenue (PWRR) is the present worth sum of the cost to build a line (increasing cost with increase in diameter) plus the present worth of the future savings attributed to line losses (lower cost of losses with increase in conductor diameter). A range of conductors provide an optimum life cycle cost.

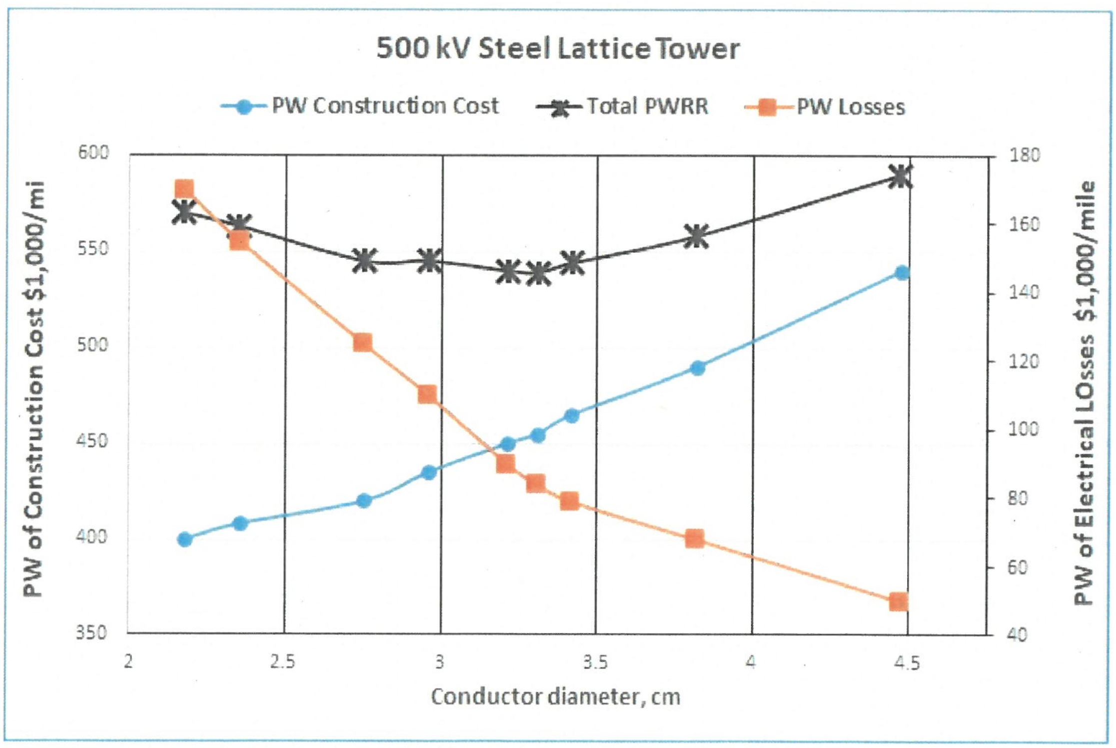


Figure 3-2
Lifetime Cost as a function of conductor diameter

With the different types of conductors available, and various sizes and strandings, an optimization study can be performed to select a conductor that will provide the capacity desired, while maintaining code clearances, optimizing life cycle costs, and mitigating line losses. One of the caveats of conductor selection is that a different conductor could be the best fit for each project. This is not a practical solution, however, for transmission providers to design a transmission line for each unique situation. The costs of maintaining and building unique designs are too high. Rather, utilities typically develop classes of capacity designs that optimize the design and life cycle costs for a manageable number of designs to meet transmission needs. This is particularly true for new construction.

When looking at increasing capacity on existing lines, an economic study is required to select a solution that has supportable life cycle costs. Some projects can be solved with re-conductoring the line on existing structures, with or without modest modifications. Advancements in conductor designs using composite materials for the mechanical support have made this solution viable in many cases. However, some upgrades require significant additional capacity that requires line reconstruction. These solutions revert back to the optimized solutions based on new construction design packages. Note: one of the issues with many of the composite core conductors is their inability to provide conductor sag within acceptable clearance limits.

Voltage Level

Power is equivalent to the Voltage times the Current (VI). So, for an equivalent level of power transmission, the lower the voltage, the higher the current level must be. Increased current means increased line losses. Operating lines at higher voltages reduces losses.

In day-to-day operations, voltage levels fluctuate on lines by a manageable few percent. These changes are not sufficient or intended to mitigate losses. Slightly larger voltage changes are accomplished with Load Tap Change (LTC) transformers, intended for voltage control and reliability concerns. Again, LTCs are not loss mitigation measures, but are a technology to maintain voltage levels at the ends of long transmission lines and power quality.

Transmission grids are developed around specific voltage classes of construction to appropriate bulk power levels. For example, common transmission voltages at a utility may include 69, 138, 230, and 500 kV. Other combinations could be 138, 230 and 345 kV or various combinations of 69, 115, 138, 230, 345, 500, and 765 kV. Changing a voltage class typically calls for a change to a higher level that requires significant system changes. For example, insulator assemblies need to change out to higher class voltages requiring more space, new structure geometry, and probably a complete rebuild. The voltage upgrade becomes a complete rebuild. Voltage upgrades also affect customer equipment and facilities, requiring added expense at their stations, which must be borne by the customer.

EPRI has performed studies and developed a guideline for voltage upgrades that require minimal structure modifications, *Feasibility of Increasing Transmission Line Capacity by Voltage Upgrade.* EPRI, Palo Alto, CA: 2007, 1013984.

EPRI and AEP performed a study investigating the benefits of an overlay EHV system. This example is greater in scale than evaluating the benefit of upgrading the voltage class of a single line, but it exemplifies that grid efficiency can be significantly enhanced when a "large" EHV overlay is used to improve the overall performance of a grid's region. *Evaluation of Efficiency and Utilization Benefits from Extra High Voltage Transmission Overlay.* EPRI, Palo Alto, CA: 2011, 1024617.

Power Flow Control

Since current-driven losses are the most significant driver for line losses, controlling the amount of current that flows through a given line section could reduce losses. Power sources provide electricity which follows the path of least resistance to the points of load.

Another important factor in power flow control and grid operations is that the grid topology changes constantly. It changes from continuous completion of transmission, load, and generation projects. As load changes by the connection of new load points and demand at existing points, the grid itself is inherently dynamic in responding to that load, changing the power flow levels and paths constantly. Interconnection of generation changes due to traditional generation connections, distributed generation, and the burgeoning smart grid impacts constantly changes the flow patterns across the grid. Topology changes daily due to the outages taken to complete emergency as well as planned maintenance on equipment throughout the grid.

Methods used by utilities to "direct" flow include:

- Phase shifters can be used to direct flow over a transmission path.
- Direct Current technology is another way to gain some control over the flow of current. The cost of DC station equipment makes this option viable only for long distance, bulk power transfer over 450 km without intermediate stations.
- Another option is using Flexible Alternating Current Transmission Systems, FACTS. FACTS equipment allows control of the impedance of a line and can direct power down some paths rather than others. FACTS is also typically applied to bulk power transfer lines over longer distance to control reliability characteristics and enhance efficiency.

The power flow control systems require installation of sophisticated equipment at key locations. The solutions noted are not applicable to local issues, but are typically applied for issues that arise for long-haul bulk power transfer cases.

Summary on Loss Mitigation Methods

Loss mitigation can be achieved through application of a variety of technologies including application of equipment that create fewer losses at the same power flow, controlling power flow through lines to prevent high losses attributed to less efficient assets, and upgrading assets to a higher voltage class. Unfortunately, these changes cannot easily be applied to existing assets; they require upgrading, reconductoring or construction of new transmission assets.

Surveys of have shown that the preferred options under consideration are:

- Use of Lower Loss Conductors
- Installation of Low-Loss Transformers
- Raising Nominal Voltage
- Optimizing Voltage Level
- Re-direct Power Flow

One other key aspect is that Reliability is the driving force in transmission system development, maintenance and operations. Efficiency is an aspect of consideration but does not drive or initiate projects.

4
SYSTEM PLANNING PERSPECTIVE

This section summarizes the best industry practices for incorporating loss mitigation in system planning efforts. It reviews different kinds of system planning efforts, including customer connection projects, reliability projects, and economic relief projects. The section also looks at the process of project selection and development, the findings of a CIGRE survey on drivers for transmission investment, how refurbishment and end-of-life drives transmission projects, and a US Department of Energy analysis of opportunities for energy efficiency.

Transmission lines are justified and planned based on capacity requirements. Capacity requirements are attributable to a snapshot in time with a certain transmission grid topology, generation mix, and forecast load built in a nodal model of the grid. Numerous scenarios are configured and run against the transmission grid to test the reliability level of operation and to identify cost constraints due to congestion patterns. The results of those runs identify deficiencies in the grid—i.e., elements in the grid that are inadequate in capacity and become reliability or congestion constraints during scenario solutions. When a threshold of concern established by the responsible operating manager is reached, added transmission assets may be required. Many of the transmission elements are only governed by a few or a singular contingency scenario. Under those conditions, that transmission asset's full capacity may be required. Under all other conditions, that element may be loaded at a significantly lower level. One of the critical aspects of transmission operations, planning, and design is that capacity is required for reliability first, and for congestion cost possibly second. Lightly-loaded lines are the grid's insurance against the contingency.

Responsibility Roles

The responsibility for managing the transmission facilities, and the losses that are realized, is a split responsibility. Mitigation of losses, or the process that leads to mitigation, occurs in all aspects of the utility industry, from the selection of the equipment to the day-to-day decisions on operations. The transmitter such as Hydro One, is responsible for managing transmission assets (e.g., lines, transformers, etc.); and bulk system planning as well as generation dispatch and flow control are the responsibility of the grid system operator, such as the Independent Electricity System Operator (IESO) in the case of Ontario.

Planning for grid enhancements is a shared responsibility between the System Operator (the IESO in Ontario) and the associated Transmitters (such as Hydro One in Ontario).

In Ontario, the provincial Minister of Energy has the authority to set policy objectives for transmission and distribution planning. The Ontario Energy Board established the province's regional planning process framework, which it advances through codes and license conditions.

In Ontario, bulk system planning is carried out by the IESO to ensure sufficient resources are available to meet Ontario's electricity needs, and that the transmission system is capable of delivering electricity to consumers in a reliable and cost effective manner. When designing solutions to address transmission needs, the IESO works collaboratively with stakeholders, including Hydro One, Distributors, and Direct Customers.

At a regional level, planning in Ontario is coordinated between the IESO, Transmitters and Distributers, following the Process for Regional Infrastructure Planning formalized by the OEB in 2013[4]. The process identifies regional transmission and distribution needs and develops plans which recommend solutions for addressing those needs.

Types of Projects

Transmission projects typically fall in the following main categories. These projects, however, have decision points where the outcome will impact transmission losses. The influence that these decisions play in transmission projects will be reviewed as we progress through the following sections.

Customer Connection Projects

Transmitters are required to provide service to load points and access to the grid for generation interconnections. These projects establish the need. Like all projects, they are planned and assessed to provide the best connection at an optimal cost. All of these projects have direct connection components (e.g., the transmission connection from the grid to the point of interconnection [POI]). Other aspects of the project may be associated with reinforcing the grid in the area of the interconnection point (e.g., upgrading existing lines or adding lines to ensure the system meets all reliability criteria once the load or generation is connected).

Reliability Projects

Reliability needs are recognized through planning assessments or through the normal system operations performance of the grid. The IESO and most utility systems are operated on an N-1 or N-2 contingency basis. This means that the grid will remain within all reliability constraints when either one or two elements are lost, no assets are overloaded, and voltages are within acceptable limits.

Planning assessments will indicate if the grid will develop unacceptable voltages or thermal overloads with forecasted load growth. This behavior is recognized, and planning starts to evaluate different options to resolve the issue.

Economic Relief Projects

Economic relief projects are largely associated with congestion relief. Congestion constraints that cause less economical dispatch of generation can have significant financial impacts on customers and market participants.

Project Development and Selection

As the projects are identified to meet one of these three areas, different solution scenarios are proposed and evaluated. Since transmission grids are interactive dynamic systems, the issues and solutions are typically broader in impact than a direct one-on-one solution to issue. Rather issues affect regions, and solutions affect the characteristics of the grid over a broad region. Therefore many solutions have interrelated impacts on other grid operation characteristics. These impacts can be beyond the borders of a single transmission owner or even more owners.

---

[4] https://www.oeb.ca/oeb/_Documents/EB-2011-0043/PPWG_Regional_Planning_Report_to_the_Board_App.pdf

CIGRÉ Findings

CIGRÉ conducted several surveys of its members to assess various drivers for transmission investment. While not a direct survey for loss mitigation efforts, the results of the reports address the prioritization accorded by utilities to address various demands for capital investment for new construction and refurbishing existing assets; energy efficiency and mitigation of losses were among the drivers. The surveys included the following:

Life Cycle Assessment (LCA) of Overhead Lines TB265. CIGRÉ WG B2.15. 2004.

Refurbishment Strategies Based on Life Cycle Cost and Technical Constraints TB448. CIGRÉ WG B5.08. 2011.

Market Price Signals and Regulatory Frameworks for Coordination of Transmission Investments TB692. CIGRÉ WG C5.18. 2017.

Review of Drivers for Transmission Investment Decisions TB701. CIGRÉ WG C1.15. 2017.

The survey participants represented a broad range of committees and study groups constitutes within the utility industry, covering planning, design, operations, and regulatory and financial concerns.

The first survey concerning drivers for transmission investment, *TB701*, 24 respondents were received. 75% were TSOs from state ownership companies; however, of the six non-state respondents, four were TSO respondents from North America, Italy, Spain, and Great Britain.

Three significant drivers were stated for investment: security of supply, connections for demand and generation, and economically driven projects, in that order. Two main drivers were identified for refurbishments: end of useful life (50%) and upgrade of assets (35%).

Table 4-1 provides a summary of how the respondents attributed the various driving factors impacting their project identification and development. It is evident the development of projects and their selection for funding are driven by Long Term Integrated Strategic Basis. Reducing transmission losses is not a singular driving factor, but is embedded as part of the solutions' process for all categories.

Table 4-1
Summary of Percentage of Projects Impacted by External Factors[5]

	Environmental & Societal			Technical			Strategic / General Approach		
Project Category	**Site or Route Access / Space**	**Local opposition / Concerns**	**Statutory / Planning Processes**	**Novel / Unconventional Transmission Tech.**	**Equipment / Tech. Obsolescence**	**Financial**	**Minimum Incremental Approach**	**Long Term Integrated Strategic Basis**	**Renewable Energy Related – State Policy**
Security of Supply	46%	59%	56%	15%	8%	12%	7%	76%	20%
New Connection	50%	68%	58%	18%	5%	14%	7%	65%	40%
Generation Integration	35%	72%	62%	21%	4%	10%	7%	58%	55%
Economic	31%	47%	63%	22%	8%	15%	8%	80%	19%
Market Access	37%	37%	59%	41%	4%	15%	7%	81%	41%
Loop Flows	44%	50%	72%	8%	8%	0%	3%	81%	28%
Refurbishment	36%	57%	64%	21%	50%	7%	14%	36%	14%

Similarly CIGRÉ document, *TB692*[6], focuses on the changing environment that transmission systems must respond to today's unregulated industry. The diversity and granularity of generation sources entering the industry put a different light on the traditional electric delivery system. A new paradigm has arisen where the wires industry will serve as insurance to those depending on distributed generation as their primary source of energy, yet insist that the traditional wires business is ready and willing to provide the energy when the customer needs it with total transparency of the shift. The demand capacity required to support nominal load and the "insured load" must be provided by the wires delivery system. Continuing to support this demand on the transmission system is critical for the future and requires greater coordination during operations and efficiency from planning through operations. Conversely, systems will become less efficient as segments only serve as insurance for contingency loads or customer-choice load (fallback load). Caution must be exercised to avoid creating stranded investments that operate with minimal loading if any.

Furthermore, CIGRE's document, TB448[7], undertaken by CIGRE's Protection and Automation Study Committee addressed the refurbishment and end of life drivers. While the work was largely focused on station equipment used for protection systems, their strategies and application

---

[5] *Review of Drivers for Transmission Investment Decisions TB701. CIGRÉ WG C1.15. 2017.*

[6] *Market Price Signals and Regulatory Frameworks for Coordination of Transmission Investments – TB692, CIGRÉ WG C5.18. 2017.*

[7] *Refurbishing Strategies Based on Life Cycle Cost and Technical Constraints – TB448*, CIGRÉ WG B5.08, 2011.

of life-cost analysis are fully applicable to the development of projects to address concerns with aging or degraded assets and when best to replace them.

Many utilities are facing end-of-life issues with many of their transmission assets. Infrastructure assets reach end-of-life levels due to age, environmental degradation, or obsolescence (e.g., parts are no longer available to repair and maintain older vintage equipment). The question of when to refurbish or replace equipment is a major consideration in planning budgets. The risk of failure or misoperation presents substantial liabilities to the utility and the public. Several sub-drivers in this arena affect the need and justification to replace an existing asset, including:

- Upgrades and expansions of facilities to accommodate load growth
- Obsolescence of equipment, including lack of spare parts, non-maintainable equipment, and inefficiency of operations
- Reliability and availability
- Excessive maintenance costs

The life-cost analysis is especially important in this evaluation because direct justification in a cost-benefit analysis seldom supports a decision to proceed. Rather incorporating all factors of risk, liability, maintenance, and efficiencies to be gained is required to fully justify proceeding to action. Loss mitigation costs and projected benefits are other facets that should be incorporated into these life-cycle studies.

US Department of Energy Policy and Systems Analysis

The U.S. Department of Energy (DOE) in the United States conducted a study into the opportunities for energy efficiencies in transmission and distribution systems[8]. The study's summary identified the advantages, drawbacks, key uncertainties, road blocks to application, and range of loss reduction for the same initiatives that we have identified throughout this report. The key drawbacks identified support the position that major policy changes and investment to the grid are required to reduce losses (e.g., reconductoring lines, replacing transformers, adding reactive power compensation, and FACTS equipment).

The constraint to accomplishing improvements is realizing a positive benefit-to-cost ratio for initiating the project on its incremental benefit. Once again, the long-term strategies incorporating loss mitigation strategies in the expansion, maintenance and refurbishment of the transmission grid are the best means to realize additional energy efficiencies.

Best Practices Summary

As part of this study, contact was made with several Independent System Operators (ISOs), including PJM, CAISO, SPP, ERCOT, MISO, NYISO, and ISO-New England. In addition, the project team also reviewed the ISOs' Planning Criteria and Guidelines, which are available on their websites. Transmission line losses, including station equipment, are not a substantive part

---

[8] *Opportunities for Energy Efficiency Improvements in the U.S. Electricity Transmission and Distribution System*. Oak Ridge National Laboratory, Oak Ridge, TN: 2015.

of any documents. The same is applicable to the Planning Guides and Criteria used by the transmitters within these areas of grid operations.

A few guidelines indicate that loss mitigation benefits attributed to different project solutions may be included in the assessment of the best solution to propose for approval by the ISO and subsequently funded by the transmitter.

Loss mitigation is not used as justification for any project development or required for project evaluations.

Planning Summary on Loss Mitigation

The review of best practices applied across the industry, including international concerns, supports several clear points about the issues associated with incorporating loss mitigation efforts on transmission grids:

- Transmission grids seldom operate at near-capacity levels. The generation – transmission grid – load nodal system is designed for reliability and economic electric delivery with contingencies for the loss of one or many elements.
- The advent and expansion of distributed generation of many forms and sizes affect the transmission grid in ways that we are just beginning to experience and respond to.
- Loss mitigation projects are not self-supporting in that the projected loss savings do not exceed the cost of performing a mitigation project. As such projects with their primary objective being mitigation of transmission losses can seldom be justified based on lifetime savings alone.
- Loss mitigation costs and benefits should be considered in all project development and solution total cost analyses, such that the most cost-efficient solution is pursued that meets all reliability and safety criteria.

5
HYDRO ONE'S LOSS MITIGATION EFFORTS

This section discusses Hydro One's accomplishment in loss mitigation and the potential for additional future loss mitigation. It identifies accomplishments in line losses and station losses; reviews the utility's efforts at operating voltage adjustment; provides a listing of opportunities for Hydro One to mitigate losses; and presents the results of a sensitivity study of Hydro One data, which revealed the potential for future loss mitigation.

Hydro One Accomplishments

Network Characteristics/System Configuration/Network reinforcement

The IESO market rules define the voltage range for each voltage class. The Hydro One transmission network is operated at the upper end of the voltage range; the 230-kV system operates between 240 kV and 250 kV, and the 115-kV system between 121 kV and 127 kV. This helps to reduce losses.

For new projects, consideration is given to converting 115-kV areas to 230-kV supply. Two area supply projects in the Hydro One five year plan to meet capacity needs in the Barrie and Ottawa West areas involve conversion to 230kV supply. While the main reason for the both conversions is the inadequacy and cost of maintaining the existing 115kV supply, both projects also help reduce system losses. The Barrie area project converts an end-of-life 115-kV line and station to 230-kV facilities. The Ottawa West area project converts an existing 115-kV line to a 230-kV line to supply new load.

System reinforcement by building a new line or reconfiguring the system also helps reduce losses. The Southwest GTA Reinforcement project, provides for reinforcement of the existing supply by building a new double circuit 230kV line as the existing lines would be overloaded. The Aylmer-Tillsonburg Project provides for system reinforcement by reconfiguring the network and building a short section of line to provide dual supply to Tillsonburg TS. Capacitor banks will also be installed at Tillsonburg TS. Both projects reduce flows on the existing lines and help reduce losses.

Table 5-1 shows the loss mitigation projected through these three projects.

Table 5-1
Impact of Network Upgrades

Project	Reduction in Peak Losses (MW)	Estimated Annual Energy Savings (MWh)
Barrie Area Transmission Upgrade	0.6	2,238
South Nepean Transmission Reinforcement (Ottawa West)	0.7	1,202
Aylmer Tillsonburg Transmission Reinforcement	1.5	3,778
Southwest GTA Transmission Reinforcement	0.8	2,942

Lines and Station Equipment

Corona Losses

Hydro One has addressed the corona issue throughout its transmission design standards. Conductor diameter selection for high-voltage lines is made with corona mitigation as a parameter. In addition, all hardware assemblies are designed to mitigate corona by providing smooth edges and surfaces of hardware and incorporating appropriate corona and gradient rings to manage the electric field strength around the hardware assemblies.

Conductor Losses

Hydro One implicitly considers the impact of losses in all of its conductor selection for new projects and upgrades of existing lines.

For new projects, conductors are usually selected to satisfy the capacity requirements in the planning criteria based on forecast demand growth. Normally this approach results in the selection of a large conductor that has low losses. For line reconductoring projects, the conductor selection is limited by the existing tower structures. Hydro One has used ACSR TW (Aluminum Conductor Steel Reinforced Trapezoidal Wire) conductor on many projects. This conductor has lower resistance for the same diameter as the ACSR conductor and has lower losses.

Table 5-2 shows the loss mitigation projected through two of the upcoming projects involving line reconductoring.

Table 5-2 Impact of Reconductoring Adjustments

Project	Reduction in Peak Losses (MW)	Estimated Annual Energy Savings (MWh)
Manby TS to Wiltshire TS Conductor Upgrade	0.9	3,615
M30A/M31A Conductor Upgrade	1.4	3,167

Transformer Losses

Hydro One addresses transformer losses in several ways. First, during procurement, each transformer's design and performance are evaluated per requirements and criteria in the purchase specification. HO requires the transformers to be designed to minimize losses at load and while unloaded. Second, overall transformer losses are reduced as transformers of older and less efficient designs at existing stations are replaced with newer more efficient designs due to end-of-life or load growth considerations. This is a gradual and long-term strategy given the economic impact and timing of the replacements.

Samples of the loss mitigation estimates for two transformers that were replaced on the Hydro One system are shown later in the Sensitivity Study and Appendix A.

Summary of Current Practice and Opportunities

As the study has shown, the majority of loss mitigation tasks must be resolved during the development of different project solutions to the mandated generation and load interconnections, regulatory, and reliability projects. Reduction in transmission losses is considered at the planning level as one of many priorities that the IESO and Hydro One must balance. Economic impact assessments of losses are conducted when such losses could reasonably be consequential to the selection of a least cost plan.

Energy efficiency projects do not justify their funding solely based on improving the socio-economic-environmental issues that efficiency can derive. However, Hydro One already addresses many of the identified means to mitigate losses in their current practices listed in Table 5-3. Hydro One practice is summarized in Table 5-3below.

Table 5-3 Summary of Hydro One Practices

Methods Under Consideration	HO Current Practice
Raising Nominal Voltage	Due to expense, voltage upgrades are driven more by reliability and adequacy concerns. Will continue to evaluate conversion of 115kV systems to 230kV operation for cost effectiveness and reduction of losses.
Optimization of Voltage Profile	System is already operating close to equipment limits.
Use Lower Loss Conductors	Currently use ACSR or compact ACSR TW conductors for capacity needs. Consider use of larger size conductors which have lower resistance, where cost effective, in the future. Hydro One does not use ACCC conductors because of poor performance under ice loading conditions.
Re-direct Power Flows	Power flow at any given time is dependent on the connected load and generation. Losses are a factor considered in the overall optimization of the generation dispatch by the IESO.
Bundle Conductor Optimization	Use bundled conductors for 500 kV
Improve Corona Losses	Insulator Hardware systems have been designed to eliminate corona. Conductor sizes also selected to avoid corona.

Shieldwire Segmentation	Not used due to high tower ground potential rise.
Improve Insulation Losses	Considered during insulation coordination design of insulator assemblies and structure configurations.
Installation of Low Loss Transformers	Purchase specifications include cost of losses and vendor transformer designs and quotations are assessed based on lowest lifetime costs including the cost of losses.
Convert to DC, Bipole or Tripole	Currently there are no HVDC systems in the province.
Switch off Equipment Not in Use	Not used due to safety and reliability concerns. Uncertainty as to the availability of equipment when it is required to be back in-service.

Sensitivity Study

Hydro One provided loading information and conductor and transformer characteristics for nine transmission lines and two load transformers to allow the performance of a sensitivity analysis to see how much loss mitigation could potentially be achieved on a sample of Hydro One assets. The sensitivity study is further described in Appendix A.

The power flow data was provided in the format of the hourly average line flow or transformer loading for the assets for every hour in 2016. One of the significant aspects of the loading data is the fact that the assets were loaded much less than their full thermal capacity. Table 5-4 shows that only three of the lines are loaded over 30% above average. .

Table 5-4 Sample Line Descriptions and Annual Load Factor

Line #	Voltage (kV)	Section Length (km)	Conductor Size	Conductor Material	Conductor Stranding	Conductors Per Bundle	Average Loadflow
1	230	7.3	1780.0 (kcmil)	ACSR	59/19	1	38%
2	500	208.7	585.0 (kcmil)	ACSR	26/7	4	19%
3	115	6.9	605.0 (kcmil)	ACSR	54/7	1	39%
4	115	40.0	336.4 (kcmil)	ACSR	26/7	1	23%
5	230	12.1	1192.5 (kcmil)	ACSR	54/19	1	13%
6	230	12.0	1192.5 (kcmil)	ACSR	54/19	1	31%
7	230	168.3	795.0 (kcmil)	ACSR	26/7	1	11%
8	230	116.8	795.0 (kcmil)	ACSR	26/7	1	24%
9	230	30.4	795.0 (kcmil)	ACSR	26/7	1	14%

This is not an indication that Hydro One is underutilizing its assets. Rather it is proof that the way transmission grids are operated per NERC requirements of meeting N-1 contingency criteria means many assets are lightly loaded, supporting the heavier loaded assets for occasions when they fail or are take on outage for maintenance. In addition, economic dispatch of generation to meet loads on the system governs line loading.

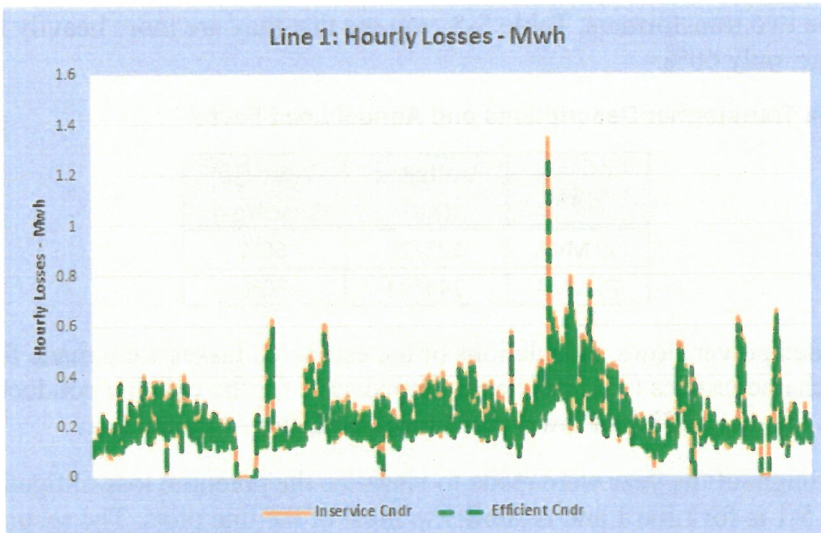
In the case of the two transformers, Table 5-5, you see that they are more heavily loaded, but again, on average, only 60%.

Table 5-5 Sample Transformer Descriptions and Annual Load Factor

Asset	Voltages (kV)	Average Loadflow
50 MVA	121/28	60%
75 MVA	244/44	60%

Using the provided power flows, calculations of the estimated losses were made for every hour using the asset characteristics (e.g., resistance-impedance) for the existing conductor or transformer and the more efficient lower resistance conductor or transformer.

Hourly plots throughout the year were made to visualize the potential loss mitigation. The first frame in Figure 5-1 is for Line 1 and is similar to most of the line plots. The second frame in Figure 5-1 is for the 500 kV line, where loading levels averaged just under 20% for 2016. In both cases there is a marginal difference between the losses calculated for the in-service conductor versus the more efficient conductor for the loading profiles of Hydro One.



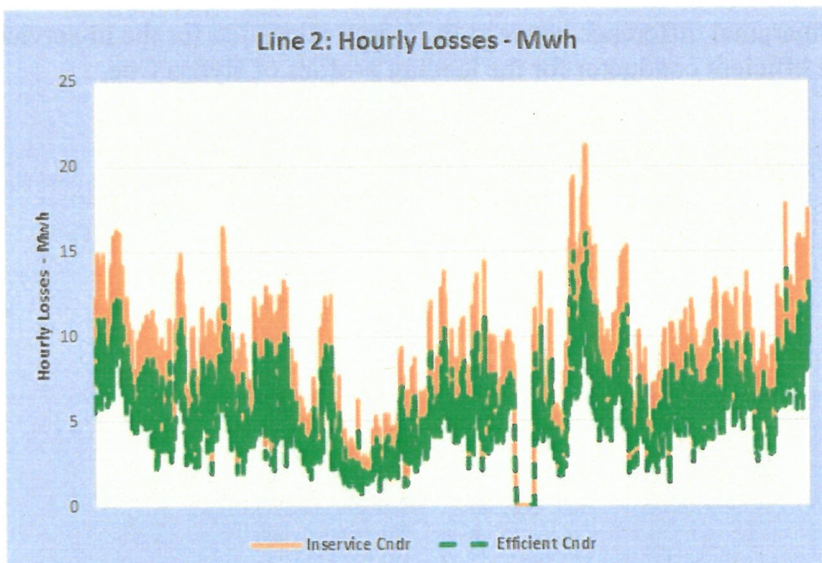


Figure 5-1
Sample Plots for Transmission Lines

Hourly plots throughout the year were also made to visualize the potential loss mitigation for the two transformers. The results are shown in Figure 5-2. The constant No-load losses are shown in each frame for the in-service unit and a potentially more efficient design transformer of the same size. The hourly tracking data represents total losses (i.e., No-load plus the losses from power flow).

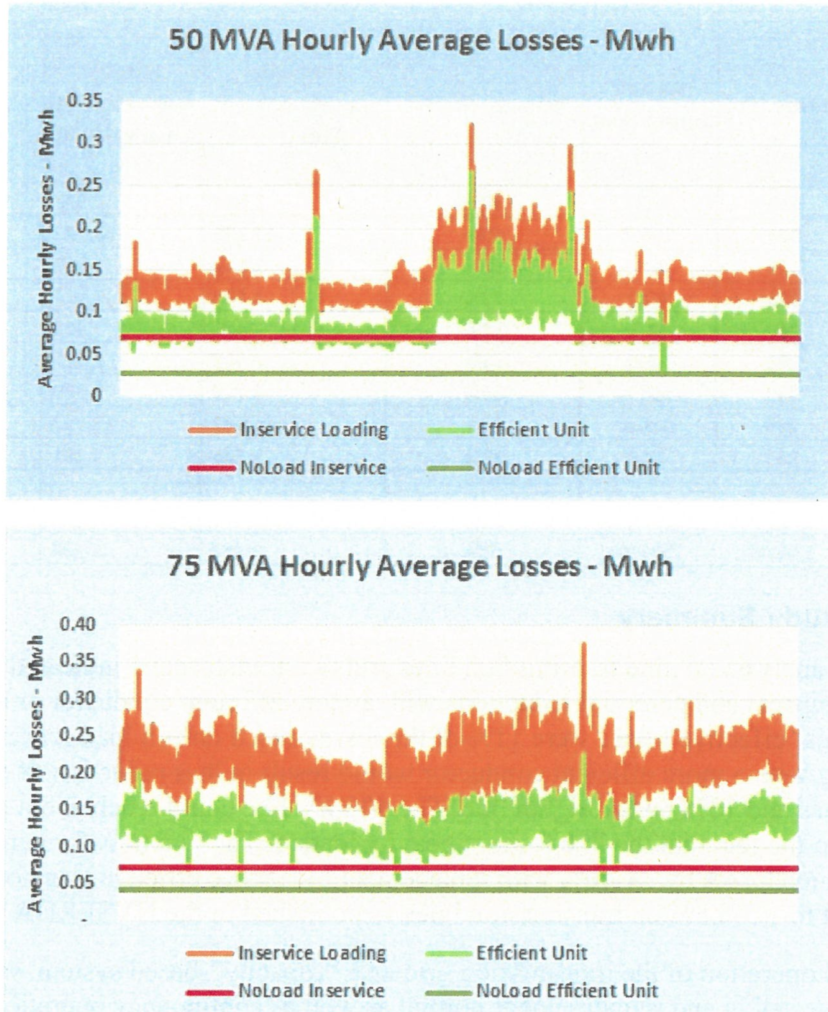


Figure 5-2
Sample Loss Plots for Transformers

Newer transformers offer more benefits as they are more efficient with lower losses than older units. However, replacement costs are high and transformer replacement is not undertaken for loss mitigation alone.

Table 5-6 summarizes the results of the loss mitigation comparison. For the transmission lines, the potential benefits of reconductoring existing lines are limited. The loss mitigation percentage is not significant, and it would not offset the costs to install the replacement conductor. This example validates why line loss mitigation projects are not self-justifying themselves.

Newer transformers offer more benefits as they are more efficient with lower losses than older units. However, replacement costs are high and transformer replacement is not undertaken for loss mitigation alone.

Table 5-6
Loss Mitigation Potential

Asset	Voltage (kV)	Section Length (km)	Average Loadflow	In-service Approx Annual Losses (Mwh)	Efficient Approx Annual Losses (Mwh)	% Loss Reduction
1	230	7.3	38%	1,987	1,922	3%
2	500	208.7	19%	63,185	48,772	23%
3	115	6.9	39%	1,567	1,510	4%
4	115	40.0	23%	3,000	2,617	13%
5	230	12.1	13%	451	428	5%
6	230	12.0	31%	2,438	2,311	5%
7	230	168.3	11%	3,785	3,589	5%
8	230	116.8	24%	14,442	13,752	5%
9	230	30.4	14%	1,225	1,161	5%
50 MVA	121/28	50 MVA	60%	1,230	815	34%
75 MVA	244/44	75 MVA	60%	1,887	1,134	40%

Sensitivity Study Summary

The sensitivity analysis on nine transmission lines and two transformers indicated the following potential loss impacts and potential reductions with a more efficient conductor or transformer design. The lines' effective losses were 11% of the losses based on full load power flow. Reconductoring with a more efficient conductor would result in loss reduction of only 3-5% for seven of the lines and 13% on the eighth line. The 500-kV line could reach about a 23% reduction due to the fact that the line is more heavily loaded. The two transformers have the potential to reduce losses by 34-40% with replacement by a more efficient transformer. Losses in general amount to 1.5-5.8% on transmission lines as published in the NYSERDA report[9].

The design and operation of the transmission grid as a "capacity"-based system, with adequate capacity to serve safely and reliably under normal as well as contingency operations due to loss of one or more elements, cause many transmission assets to operate normally in ranges of 30-50% of their full rated capacity. The cushion of capacity is needed to meet reliability criteria when system models indicate the capacity is needed for contingencies. The fact that assets operate at lower load factors also greatly reduces the impact of potential losses due to full capacity levels.

[9] *Assessment of Transmission and Distribution Losses in New York*, EPRI, Palo Alto, CA: 2012. PID071178 (NYSERDA 15464).

6 CONCLUSIONS

Hydro One requested EPRI's support in preparing a comprehensive assessment of current best practices in the industry relative to the mitigation of transmission losses for line and station equipment. This report addresses how losses are realized during the operation of the transmission grid and various mitigation techniques that can be applied to reduce losses. More importantly, the study investigated the current industry best practices relative to how transmission system providers, independent system operators, and regulatory bodies are addressing the loss mitigation concern.

Conclusions

The investigation in best practices showed these key points:

1. Transmission losses are not avoidable.
2. Losses can be mitigated to a limited extent with appropriate application of design.
3. Transmission losses and their mitigation are not a focal point of transmitters, their independent system operators, or their regulatory bodies. At best, a few entities include the impact on losses that various design options may have in the selection of their project solutions.
4. Transmission grids seldom operate at near-capacity levels. The generation – transmission grid – load network system is designed for reliability and economic electric delivery with contingencies for the loss of one or many elements.
5. Transmission Projects are initiated based on system need to ensure adequacy and reliability of supply or provide supply to customers. No utility is pursuing loss mitigation projects solely based on the potential mitigated loss savings over the life cycle of the asset.

Hydro One design practices are materially consistent with industry best practices for loss mitigation.

7
REFERENCES

Argonne National Laboratory. *The Design, Construction, and Operation of Long-Distance High-Voltage Electricity Transmission Technologies*. Argonne National Laboratory, Chicago, IL. 2007.

Benedict, E., T. Collins, D. Gotham, S. Hoffman, and D. Karipidics, D. 1992."Losses in Electric Power Systems". ECEE Technical Reports Paper 266: 1992.

CAISO. *Transmission Economic Assessment Methodology (TEAM)*. California Independent System Operator, CA. 2004.

CIGRE. *Life Cycle Assessment (LCA) For Overhead Lines – TB265*. CIGRÉ WG B2.15. 2004.

CIGRE. *Increasing Capacity of Overhead Transmission Lines – Needs and Solutions – TB425*. CIGRÉ WG B2/C1.19. 2010.

CIGRE. *Refurbishing Strategies Based on Life Cycle Cost and Technical Constraints – TB448*, CIGRÉ WG B5.08. 2011.

CIGRE. *Market Price Signals and Regulatory Frameworks for Coordination of Transmission Investments – TB692*, CIGRÉ WG C5.18. 2017.

CIGRE. *Review of Drivers for Transmission Investment Decisions – TB701*. CIGRÉ WG C1.15. 2017.

Connecticut Siting Council. *Life Cycle 2012 – Connecticut Siting Council Investigation into Life Cycle Costs of Electric Transmission Lines*. New Britain, CT. 2012.

DG Energy – European Commission. *Identifying Energy Efficiency Improvements and Savings Potential in Energy Networks, Including Analysis of the Value of Demand Response*. Belgium. 2015.

EASTERN INTERCONNECTION STATES PLANNING COUNCIL. *Report for 2025 Summer and Winter Roll-up Cases*. Eastern Interconnection Planning Cooperative – Steady-State Modeling and Load-Flow Working Group. 2016.

EASTERN INTERCONNECTION STATES PLANNING COUNCIL. *Market Structures and Transmission Planning Processes in the Eastern Interconnection*. Eastern Interconnection States Planning Council. 2012.

EASTERN INTERCONNECTION STATES PLANNING COUNCIL. *Co-optimization of Transmission and Other Supply Resources*. Eastern Interconnection States Planning Council. 2013.

EASTERN INTERCONNECTION STATES PLANNING COUNCIL. *Transmission Planning White Paper*. Eastern Interconnection States Planning Council. 2014.

EPRI. Feasibility of Increasing Transmission Line Capacity by Voltage Upgrade. EPRI, Palo Alto, CA. 1013984. 2007.

EPRI. *Transmission Efficiency Technology Assessment: Phase 1*. Palo Alto, CA. 1010692. 2008

EPRI. *Transmission Efficiency Initiative: Key Findings, Plan for Demonstration Projects, and Next Steps to Increase Transmission Efficiency*. Palo Alto, CA. 1017894. 2009.

EPRI. *Transmission System Efficiency Technology and Methodology Assessment*. Palo Alto, CA. 1020143. 2010.

EPRI. *Evaluation of Efficiency and Utilization Benefits from Extra High Voltage Transmission Overlay*. Palo Alto, CA. 1024617. 2011.

EPRI. Assessment of Transmission and Distribution Losses in New York. Palo Alto, CA. PID071178 (NYSERDA 15464). 2012.

EPRI. *Tennessee Valley Authority (TVA) Transmission Grid Modernization Roadmap*. Palo Alto, CA. 1026503. 2012

EPRI. *Transmission System Efficiency and Utilization Improvement: Summary of R&D Activity and Demonstration Projects*. Palo Alto, CA. 1024345. 2012.

EPRI. *AC Overhead Line Design Guide: 2016 Edition*. EPRI, Palo Alto, CA. 3002007720. 2016.

EPRI. *EPRI Increased Power Flow Guidebook – 2016: Increasing Power Flow in Lines, Cables, and Substations*. Palo Alto, CA. 3002007734. 2016.

EPRI. *Guide for Operating Overhead Lines at High Temperatures: Utility Shunt Applications and Strand Testing*. Palo Alto, CA. 3002007740. 2016.

EPRI. *Guide for Selection and Application of High-Temperature Conductors: Selection and Specifications*. Palo Alto, CA. 3002007741. *2016.*

EPRI. Wholesale Electricity Market Design Initiatives in the United States: Survey and Research Needs. Palo Alto, CA. 3002009273. 2016.

ERCOT. *ERCOT Nodal Protocols – Section 13: Transmission and Distribution Losses*. ERCOT, Austin, TX. 2017.

ERCOT. *ERCOT Planning Guide Section 13: Regional Planning*. ERCOT, Austin, TX. 2017.

Forsten, K.. "The most economical energy savings might be found in grid efficiency." *Fortnightly*. 2010.

Hogan, W. *"Transmission Benefits and Cost Allocation." Harvard University. 2011*

IESO. *Ontario Planning Outlook – A technical report on the electricity system prepared by the IESO*. Independent Electricity System Operator. 2016.

Jaussaud, J., F. Clerc, and D. Coisnard. "The challenge of reducing energy losses in transmission systems – RTE's approach and objectives". CIGRÉ 2010. C1-306. 2010.

Leman, J. "Electrical Considerations of Large Transmission Lines." Power Engineers, Inc.. 2009.

Litvinov, E. "Local Marginal Pricing – WEM 301." ISO New England, MA. 2011.

Liu, L. and A. Zobian. "The Importance of Marginal Loss Pricing in an RTO Environment". Cambridge Energy Solutions. 2002.

Ministry of Energy. *Achieving Balance – Ontario's Long-Term Energy Plan*. Toronto, ON. 2013.

MOES. *Utility Infrastructure Improvements for Energy Efficiency*. Minnesota Office of Energy Security, Minnesota Department of Commerce. 201.

NYISO. *NYISO Transmission System Losses Exploration Study*. New York Independent System Operator by ABB. 2009.

Oak Ridge National Labs. *Opportunities for Energy Efficiency Improvements in the U.S. Electricity Transmission and Distribution System*. Oak Ridge National Laboratory, Oak Ridge, TN. 2015.

Pfeifenberger, J. and D. Hou. "Seams Cost Allocation: A Flexible Framework to Support Interregional Transmission Planning", Southwest Power Pool. 2012.

PJM. *A Survey of Transmission Cost Allocation Issues, Methods and Practices*. PJM, Audubon, PA. 21721132. 2010.

RUS. *RUS Bulletin 1724E-301 – Guide for the Evaluation of Large Power Transformer Losses*. Rural Utilities Services, Washington, DC. 1997.

Wong, L. *A Review of Transmission Losses in Planning Studies*. California Energy Commission. CEC-200-2011-009. 2011.

A
APPENDIX A

Loss Calculations for Sample Hydro One Data

Hydro One supplied loading data for nine transmission lines and two transformers. With the data provided, the project team could calculate estimates of the losses incurred throughout the year and make a comparison to an alternative conductor or transformer design that is more efficient from a losses perspective. A range of line lengths, voltage classes and conductor sizes was provided as shown in Table A-1. Of particular note is the average power flows for the lines. All lines are loaded at 40% or lower capacity typical of transmission networks.

Table A-1
Sample Transmission Line Descriptions

Line #	Voltage (kV)	Section Length (km)	Conductor Size	Conductor Material	Conductor Stranding	Conductors Per Bundle	Average Loadflow
1	230	7.3	1780.0 (kcmil)	ACSR	59/19	1	38%
2	500	208.7	585.0 (kcmil)	ACSR	26/7	4	19%
3	115	6.9	605.0 (kcmil)	ACSR	54/7	1	39%
4	115	40.0	336.4 (kcmil)	ACSR	26/7	1	23%
5	230	12.1	1192.5 (kcmil)	ACSR	54/19	1	13%
6	230	12.0	1192.5 (kcmil)	ACSR	54/19	1	31%
7	230	168.3	795.0 (kcmil)	ACSR	26/7	1	11%
8	230	116.8	795.0 (kcmil)	ACSR	26/7	1	24%
9	230	30.4	795.0 (kcmil)	ACSR	26/7	1	14%

The in-service conductors are ACSR (Aluminum Conductor Steel Reinforced), which have a steel core strand. The steel stranding increases the conductor's resistance and thus losses. The ACCC (Aluminum Conductor Composite Core) has a composite core rather than a steel core and has trapezoidal-shaped aluminum strands that allow for a greater area of aluminum for the same overall conductor diameter; both characteristics provide lower losses... Figure A-1shows a side-by-side cross-section view of the ACSR (left) and ACCC (right). The aluminum strands are the same electrical grade aluminum. The cores are different: galvanized steel versus a carbon-composite matrix core.

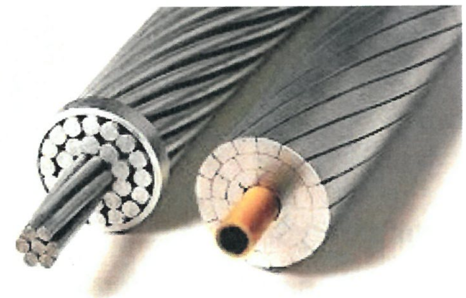


Figure A-1
Cross Sections: ACSR and ACCC

The following sets of charts for each line, Figure A-2 to Figure A-10, identify the power flow in a histogram showing loading level frequency on the vertical axis. Note that, all of the loadings are skewed to lower load factors, in quantity and level.

The second frame shows the hourly loading as a load factor, % of line capacity, during the course of the year. Finally, each line has a plot of the line losses calculated for the in-service conductor and an appropriate more efficient alternative, ACCC conductor. Note how seldom, the load factors peak and how short the peak loadings are throughout the year.

Table A-2 contains a comparison of the line losses for the in-service conductor and a more efficient alternative.

Similar data was provided for two transformers on the Hydro One system for analysis—a 50 MVA and a 75 MVA transformer. Hourly average loading was provided, as well as the No-load and Loaded losses measured at manufacture by the vendor (Figure A-11 and Figure A-12).

The 50-MVA unit shows a slightly skewed lower loading histogram, while the 75-MVA unit shows a near normal distribution. Both units averaged a 60% load factor for the year.

The third plot in the two sets provides a plot of the losses estimated for each unit using the hourly average loading values. For a transformer, there are No-load losses associated with just energizing the unit and the eddy current hysteresis in the coils. That value remains constant while the unit is energized. In this case, the in-service units had 71- and 72-kW losses for the 50- and 75-MVA units, respectively. When the units carry load, they incur additional joule heating losses, and those losses follow the loading pattern. In plot three of the two sets, the loss curves, other than the No-load, contain the sum of the Load-loss and No-load losses.

In comparison, Hydro One supplied transformer characteristics for replacement transformers that would be purchased according to their new specifications that require improved efficiency by the transformer vendors. The No-load loss levels are considerably lower, 27 and 43 kW for the 50- and 75-MVA units, respectively.

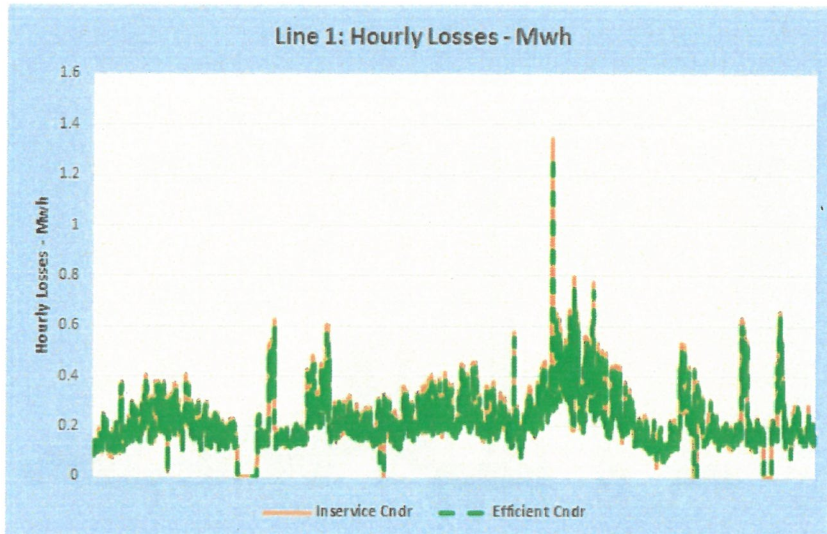


Figure A-2
Line 1 Loading and Loss Comparison

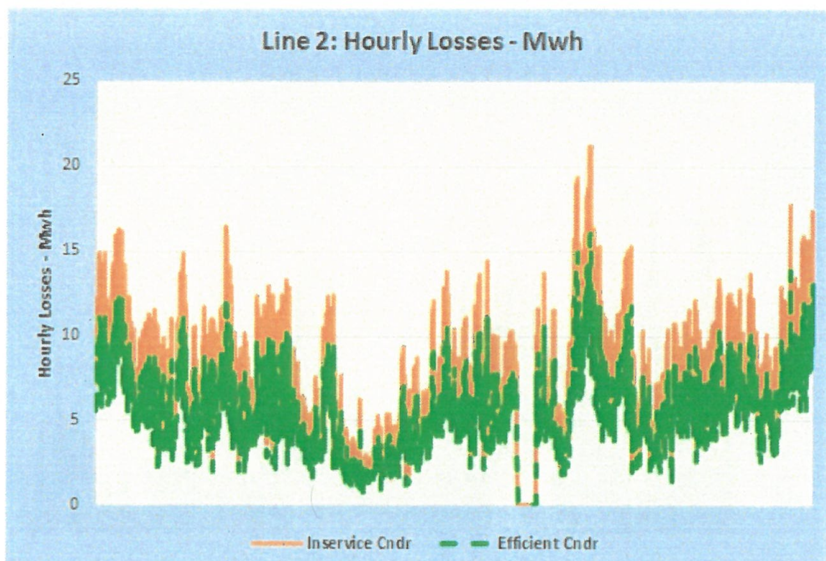


Figure A-3
Line 2 Loading and Loss Comparison

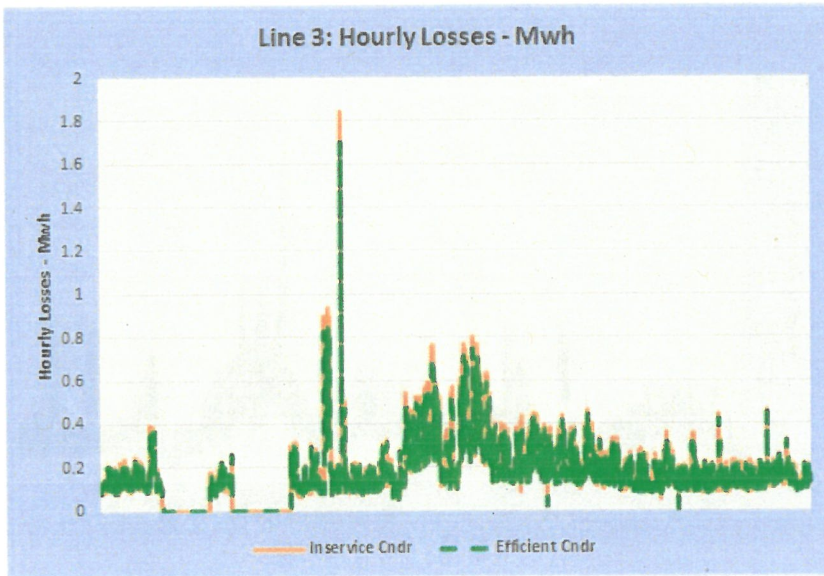


Figure A-4
Line 3 Loading and Loss Comparison

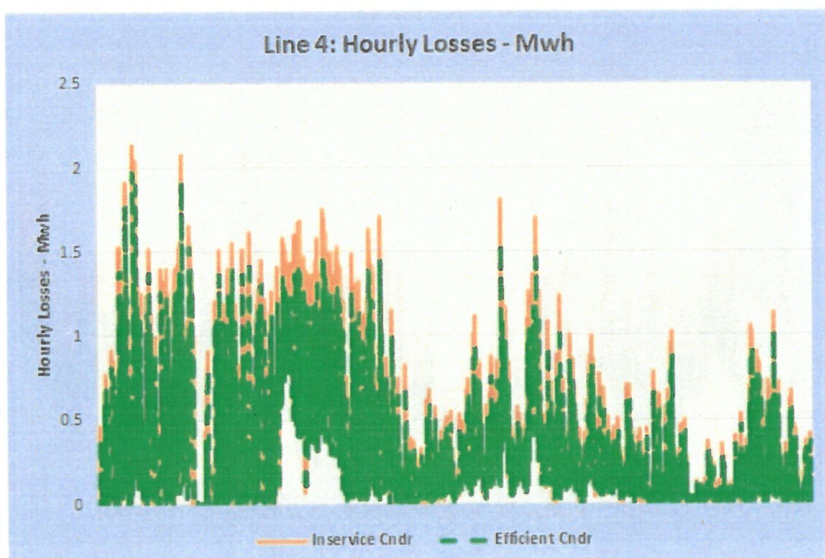


Figure A-5
Line 4 Loading and Loss Comparison

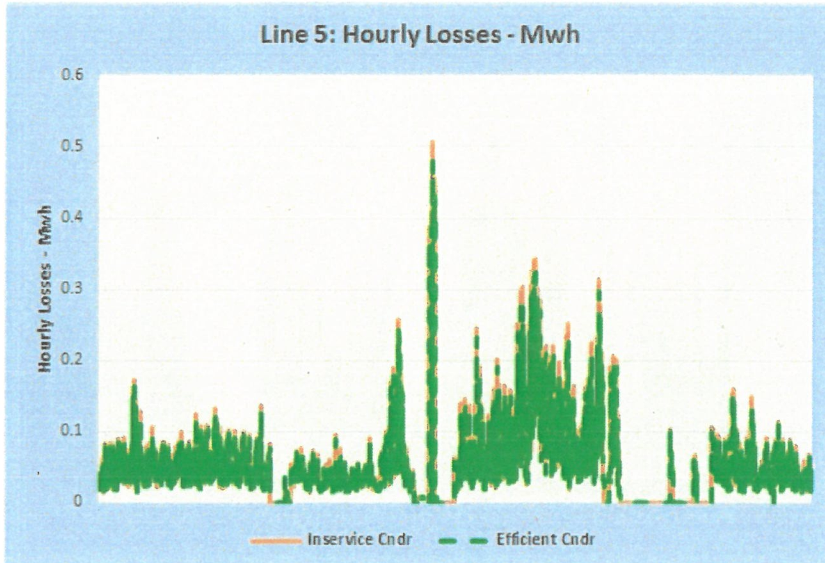


Figure A-6
Line 5 Loading and Loss Comparison

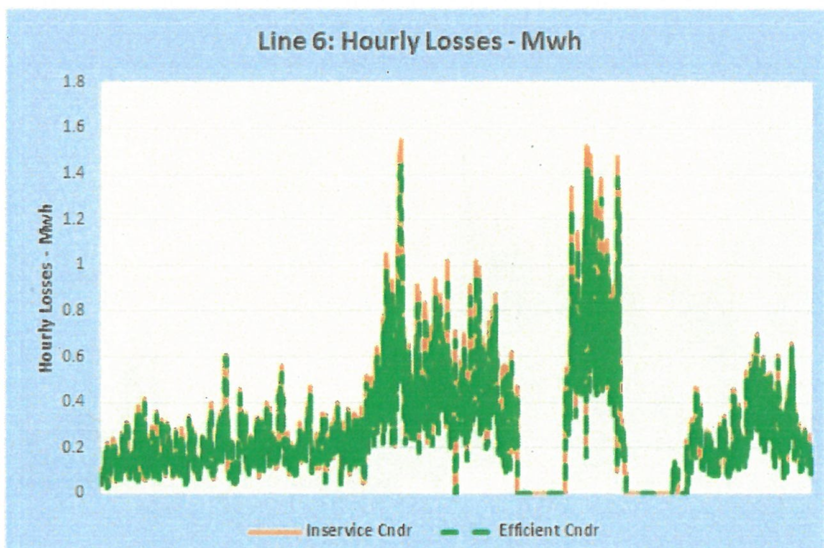


Figure A-7
Line 6 Loading and Loss Comparison

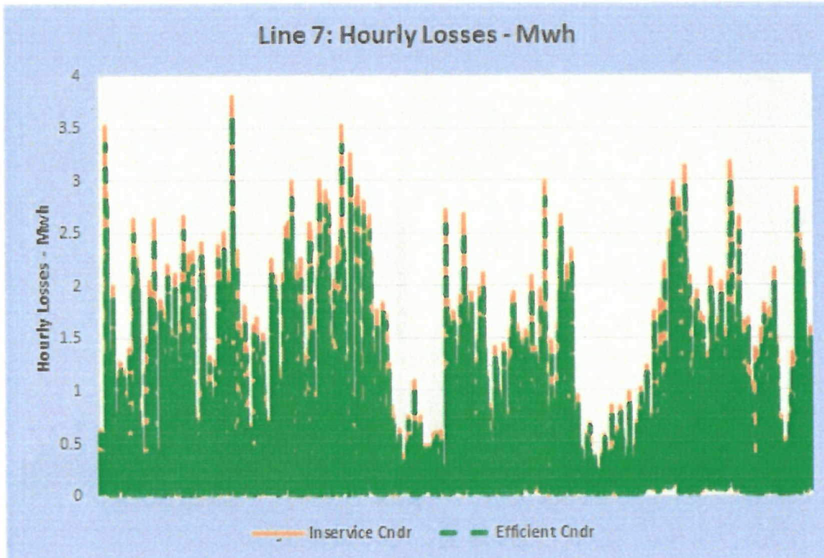


Figure A-8
Line 7 Loading and Loss Comparison

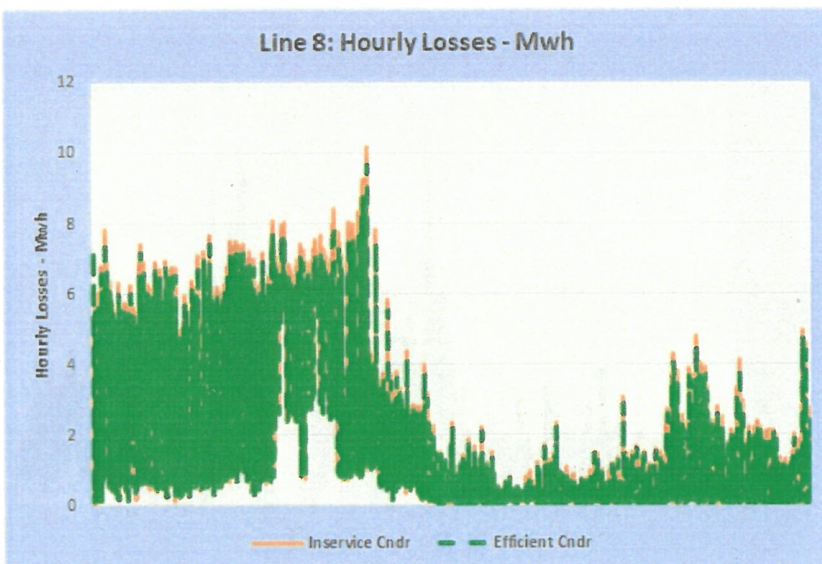


Figure A-9
Line 8 Loading and Loss Comparison

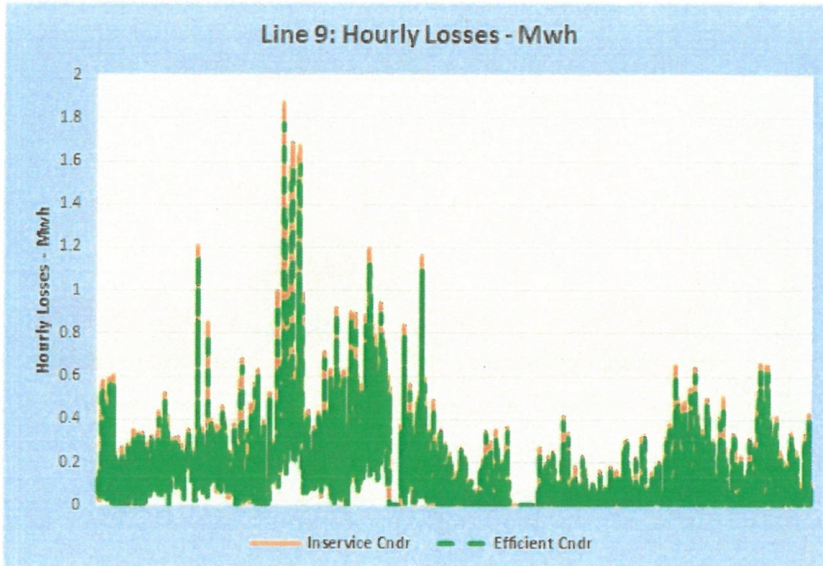


Figure A-10
Line 9 Loading and Loss Comparison

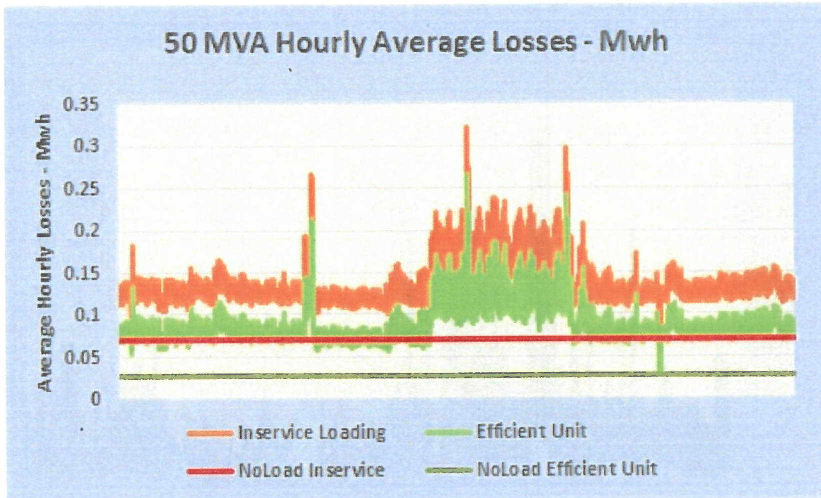


Figure A-11
50 MVA Transformer Loading and Loss Comparison

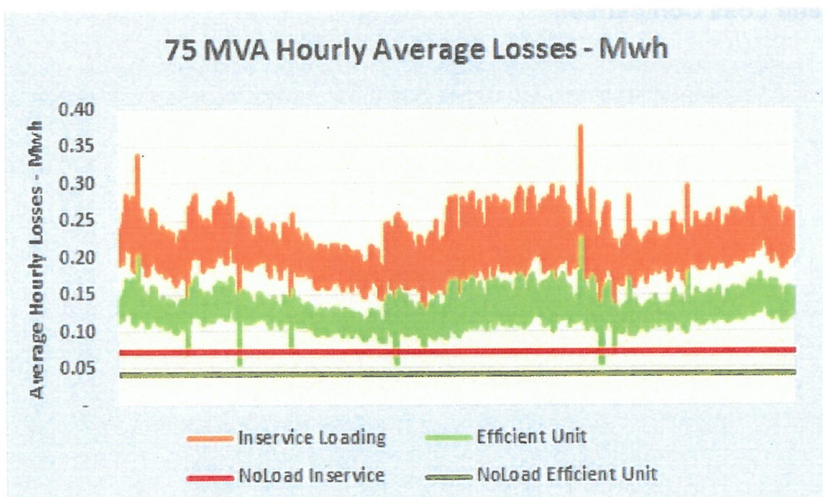


Figure A-12
75 MVA Transformer Loading and Loss Comparison

Loss Calculation Comparison

Based on the analysis and comparison for the transmission lines and transformers, the comparative losses and reductions are shown in Table A-2. Only two of the transmission lines showed significant savings from using a more efficient conductor to reduce losses. The other seven lines ranged from a 3 to 5% reduction. The analysis of the two transformers showed that more efficient transformer designs available on the market today efficiently reduce losses by 30-40%.

Table A-2

Loss Comparison Results

Asset	Voltage (kV)	Section Length (km)	Average Loadflow	In-service Approx Annual Losses (Mwh)	Efficient Approx Annual Losses (Mwh)	% Loss Reduction
1	230	7.3	38%	1,987	1,922	3%
2	500	208.7	19%	63,185	48,772	23%
3	115	6.9	39%	1,567	1,510	4%
4	115	40.0	23%	3,000	2,617	13%
5	230	12.1	13%	451	428	5%
6	230	12.0	31%	2,438	2,311	5%
7	230	168.3	11%	3,785	3,589	5%
8	230	116.8	24%	14,442	13,752	5%
9	230	30.4	14%	1,225	1,161	5%
50 MVA	121/28	50 MVA	60%	1,230	815	34%
75 MVA	244/44	75 MVA	60%	1,887	1,134	40%

The line losses estimated from the loading information provided by Hydro One are a very small portion of the losses if estimated based on the rating of the transmission element. This is especially true in the case of the line losses.

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI members represent 90% of the electric utility revenue in the United States with international participation in 35 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

Together...Shaping the Future of Electricity

© 2018 Electric Power Research Institute (EPRI), Inc. All rights reserved. Electric Power Research Institute, EPRI, and TOGETHER...SHAPING THE FUTURE OF ELECTRICITY are registered service marks of the Electric Power Research Institute, Inc.

3002012721

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

ED INTERROGATORY 10

Issue 5.4: What is the status of the IESO's transmission losses study?

Interrogatory No. 5.4-ED-10

INTERROGATORY

Reference: Exhibit C-1-1, p. 3

Preamble: In the 2017/2018 Hydro One transmission rates case reads, the Board made the following order:

> *"The OEB finds that, given the magnitude of line losses, Hydro One should work jointly with the IESO to explore cost effective opportunities for line loss reduction. Hydro One should also explore, as part of its investment decision process, opportunities for economically reducing line losses. The OEB requires Hydro One to report on these initiatives as part of its next rate application."*

In its decision on the issues list in this proceeding, the Board stated as follows:

> *"The OEB has added a new issue, issue 5.4, on the status of the transmission losses study. This issue will allow ED and others to appropriately examine the IESO's response to the OEB's direction in its 2017 fee application with respect to transmission losses."*

Interrogatory:

a) Please indicate when the IESO and Hydro One's study regarding transmission losses will be complete.

b) Please describe the scope of the work and/or research being undertaken by the IESO and Hydro One pursuant to the Board's direction in the IESO's 2017 fee application with respect to transmission losses. If the scope is described in any internal documents (e.g. presentations, draft reports, etc.), please provide those documents.

RESPONSE

a) and (b) Please see the response to ED Interrogatory 9 at Exhibit I, Tab 5.4, Schedule 5.09.

DRAFT / CONFIDENTIAL

Page Intentionally Blank

ED INTERROGATORY 11

Issue 5.4: What is the status of the IESO's transmission losses study?

Interrogatory No. 5.4-ED-11

INTERROGATORY

Reference: Exhibit C-1-1, p. 3

Preamble: In the 2017/2018 Hydro One transmission rates case reads, the Board made the following order:

> *"The OEB finds that, given the magnitude of line losses, Hydro One should work jointly with the IESO to explore cost effective opportunities for line loss reduction. Hydro One should also explore, as part of its investment decision process, opportunities for economically reducing line losses. The OEB requires Hydro One to report on these initiatives as part of its next rate application."*

In its decision on the issues list in this proceeding, the Board stated as follows:

> *"The OEB has added a new issue, issue 5.4, on the status of the transmission losses study. This issue will allow ED and others to appropriately examine the IESO's response to the OEB's direction in its 2017 fee application with respect to transmission losses."*

Interrogatory:

Will the transmission losses study include each of the following elements:

a) A methodology for calculating transmission losses;

b) A methodology for calculating the cost of transmission losses to electricity consumers;

c) A methodology for assessing the cost-effectiveness of various kinds of incremental capital investments intended in whole or in part to reduce transmission losses;

d) A methodology for assessing the cost-effectiveness of various kinds of operational measures aimed at reducing transmission losses;

e) A financial model that recognises that transmission loss volumes are highest when the cost of electricity is the highest (i.e. at peak electricity demand);

f) Avoided cost figures for transmission loss reductions (e.g. to determine whether loss reduction measures or investments are cost-effective);

g) A clear division of responsibilities between the IESO and Hydro One for seeking out, identifying, and assessing the various kinds of measures to cost-effectively reduce transmission losses;

DRAFT / CONFIDENTIAL

h) A recommendation regarding regular transmission loss reductions planning and reporting;

i) An assessment of the transmission losses planning and reporting tools used by the System Operator in the United Kingdom, National Grid UK[1];

j) An assessment of best practices in transmission loss reduction measures in leading jurisdictions, including regulatory, planning, and reporting practices?

If any of the above items will not be addressed in the study, please explain why.

<u>RESPONSE</u>

a) to j) Please see the response to ED Interrogatory 9 at Exhibit I, Tab 5.4, Schedule 5.09.

---

[1] See e.g. https://www.nationalgrid.com/sites/default/files/documents/36718-Transmission%20Losses%20Strategy.pdf

ED INTERROGATORY 12

Issue 5.4: What is the status of the IESO's transmission losses study?

Interrogatory No. 5.4-ED-12

INTERROGATORY

Reference: Exhibit C-1-1, p. 3

Preamble: In its *CEER Report on Power Losses* (October 18, 2017), the Council of European Energy Regulators made the following recommendations (p. 34)[1]:

Overall:

1) Harmonise definitions for improved benchmarking
2) Make more data available, such as the availability of energy injected into distribution grids, which would permit the calculation of distribution system losses as a percentage of energy injected into distribution grids
3) Incentivise system operators to reduce losses instead of passing losses on to consumers
4) Employ a life cycle costing approach that includes losses when making investment decisions

Technical losses:

1) Increase voltage levels
2) Apply less transformational steps to deliver electricity to consumers
3) Utilise new and improved equipment
4) Employ distributed generation in a more efficient manner, including combining it with local storage
5) Optimise network flows – reduce peaking
6) In general, pursue network architecture and management that promote the highest efficiency

Non-Technical losses:

1) All countries should collect data on these types of losses

DRAFT / CONFIDENTIAL

[1] https://www.ceer.eu/documents/104400/-/-/09ecee88-e877-3305-6767-e75404637087

2) Focus on more accurate recording of electricity consumptions through improved metering and the use of smart meters
3) Reduce theft and other hidden losses

Interrogatory:

a) For each of the above recommendations, please indicate whether the applicable issue is being addressed by the ongoing transmission losses research by the IESO and Hydro One; and

b) For each of the above recommendations, please indicate whether the IESO agrees with the recommendation (if a decision has not yet been made, please indicate when a decision will be made).

RESPONSE

a) and b) Please see the responses to ED Interrogatory 9 at Exhibit I, Tab 5.4, Schedule 5.09.

ED INTERROGATORY 13

Issue 5.4: What is the status of the IESO's transmission losses study?

Interrogatory No. 5.4-ED-13

INTERROGATORY

Reference: Exhibit C-1-1, p. 3

Interrogatory: Please provide a list of the different kinds of incremental capital investments and operational measures that can be used to reduce transmission losses (e.g. voltage control, generation siting, dispatch, identification of incremental line or equipment investments, expansion of demand response, etc.). For each measure, please indicate whether the IESO or Hydro One is primarily responsible for (a) seeking, (b) identifying, and (c) assessing potential cost-effective measures to reduce transmission losses.

RESPONSE

Please see the response to ED Interrogatory 9 at Exhibit I, Tab 5.4, Schedule 5.09.

DRAFT / CONFIDENTIAL

Page Intentionally Blank

ED INTERROGATORY 14

Issue 5.4: What is the status of the IESO's transmission losses study?

Interrogatory No. 5.4-ED-14

INTERROGATORY

Reference: Exhibit C-1-1, p. 3

If the Board were to direct the IESO to measure and monitor the effectiveness of its efforts to optimize the level of transmission losses, please compare, rank, and discuss the appropriateness of the following metrics:

a) Annual transmission losses (TWh);

b) Annual transmission losses (TWh) as a percent of total annual transmission throughput volumes (TWh);

c) Total annual cost of transmission losses to consumers; and

d) Total annual cost of transmission losses to consumers per TWh of total annual transmission throughput volumes.

If the ongoing transmission losses analysis has not yet reached the point at which the IESO is comfortable responding to this interrogatory, please indicate when in the future the IESO would expect to be able to provide a response.

RESPONSE

As noted in the response to ED Interrogatory 14 at Exhibit 1, Tab 5.1, Schedule 4.14 (EB-2017-0150) as part of the IESO's 2017 revenue requirement proceedings:

> *The IESO is not in a position to comment on what metric the OEB would determine as most appropriate to measure and monitor the effectiveness of efforts to optimize the level of transmission losses, particularly given the IESO's limited control of electricity system characteristics that influence losses.*

In addition, please see the response to ED Interrogatory 9 at Exhibit I, Tab 5.4, Schedule 5.09.

DRAFT / CONFIDENTIAL

Page Intentionally Blank