London Hydro Inc

System Planning Report SP03-01

Annual Energy Delivery Efficiency Performance for Year 2002

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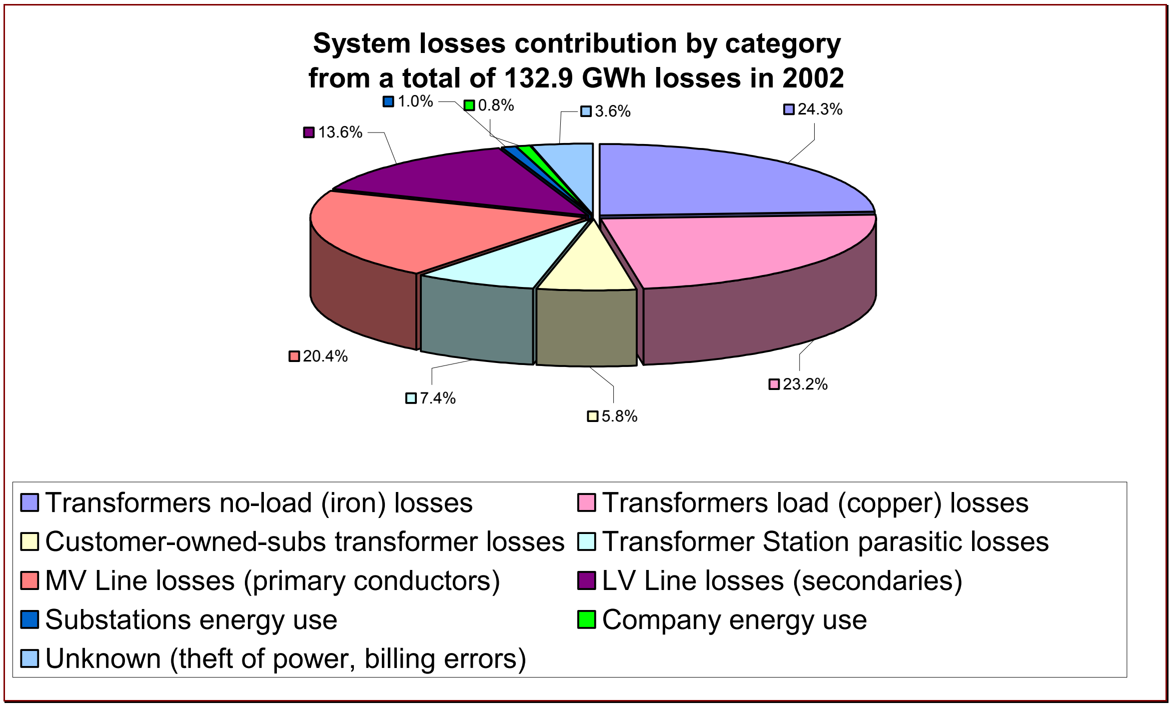
Executive Summary

London Hydro's distribution system is not inefficient, in the sense that the system is poorly designed or operated, rather the transmission of electricity though any electrical device incurs a certain amount of electrical loss. Transformers consume a small portion of the power fed into them to establish the magnetic fields needed to operate; the flow of electricity through the internal resistance of a conductor or cable causes internal heating, another form of loss; and there are energy conversion losses associated with our substation battery chargers. These losses are a result of inviolable laws of nature. They can be measured, assessed, and minimized through proper engineering, but never eliminated completely.

A clear understanding on the magnitude of technical and commercial losses is the first step in the direction of reducing losses. Indeed, the primary purpose of this report is to characterize the various loss components, compare our delivery efficiency performance to historical performance, and ultimately to extend the comparison to other benchmarks (e.g. similar distribution utilities and so-called *best of breed* utilities). It also helps to identify areas where improvement is cost-effective, prioritize where to devote energies and resources, and documents accomplishments.

Analysis of London Hydro's distribution system losses (both qualitatively and quantitatively) has revealed the percentage breakdown of the total system energy losses in year 2002 as illustrated below.



This subdivision of overall system losses into categories represents the best good faith approximations available at this time based on the combination of rigorous analysis and assumptions.

Maximizing the energy delivery performance (i.e. minimizing system losses) of an electrical distribution system is an undertaking that requires great persistence. At the outset it is fairly easy to find and implement the so-called *low-hanging fruit*; efficiency improvement opportunities that provide tangible rewards significantly greater than their implementation costs and efforts. As time progresses, extracting further efficiency gains becomes increasingly more challenging (i.e. the benefit / cost ratio decreases).

This report has identified a number of initiatives that minimize system losses through the use of sophisticated and data intensive engineering systems capable of modeling and analyzing the distribution circuitry. These initiatives include:

- ☐ Re-arranging some of the single-phase loads on our distribution system to achieve greater phase balance, with associated savings from reduced system losses on the order of $10K;
- ☐ Adjusting the configuration of three-phase distribution circuits by adjusting the location of tie switches between adjacent feeder circuits, with associated savings from reduced system losses on the order of $120K; and
- ☐ Pursuing the installation of capacitor banks on selected feeder circuits, with associated savings from reduced system losses on the order of $25K – with payback on the investment in capacitor banks likely within five years.

On a different front, the report has recommended that London Hydro adopt a more proactive and attentive approach to the matter of energy theft associated with illegal indoor marijuana grow operations. It is reasonable to believe that the energy theft associated with this type of operation represents as much as $350K annually. It isn't likely that such theft can be eliminated, but it can certainly be greatly reduced.

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1 INTRODUCTION

1.1 Background

Within its established franchise service territory, London Hydro is responsible for the construction, operation and maintenance of the electrical distribution system that interconnects the end-use consumer with the provincial transmission grid. However, responsibility does not end here; it also extends to managing the availability, performance, and integrity of the distribution system infrastructure, and to providing satisfactory service levels (as gauged by the end user).

One metric of *performance,* and indeed the subject of this report, is *delivery system efficiency*. The delivery system efficiency, generally expressed as a percentage, is the ratio of "energy delivered to the end-use customers" to the "energy procured from the combination of the provincial transmission grid and embedded generators"; the difference being the so-called *electric distribution system losses*.

Electric distribution system losses are the amount of electricity lost in the distribution system. In general, losses consist of transmission, transformation, and distribution losses between supply sources and delivery points. Loss of electric energy is primarily a result of heating in transmission and distribution elements.

Minimizing the system losses contributes to London Hydro's ability to create and sustain measurable business value (by both maintaining reasonable distribution tariffs and added profitability to the corporation).

The time-tested adage "*The essence of management is that one cannot manage that which one cannot measure*[1]" definitely applies to London Hydro's approach to managing the efficiency (i.e. energy delivery performance) of its electric distribution system. Measurement is also a management tool to ensure that positive progress is made toward achieving goals and objectives.

Coincidentally, with the opening of the energy marketplace by the provincial *Electricity Competition Act, 1998*, the subject of losses has gained importance as it has a bearing on the determination of London Hydro's electricity tariff and due to its visibility as a line item (Total Loss Factor) on the customer's monthly power invoice.

In fact, licensed distribution utilities are compelled to report their line losses on an annual basis to the Ontario Energy Board. The following excerpts from Ontario Energy Board's regulatory publication *Electricity Distribution Rate Handbook* (March 9, 2000 Edition), Chapter 12, *Filing Requirements*, have been replicated below for convenience of reference:

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[1] *Planning and Measurement in Your Organization of the Future*; by D. Scott Sink and Thomas C. Tuttle; Industrial Engineering and Management Press, 1989.

12.4.3 Energy Delivery Information

The distribution utilities must provide wholesale and retail demand and energy data…. In addition, the utilities should provide the monthly wholesale kW and kWh billing amounts and annual line losses.

12.4.4 PBR Related Information

The utilities need to file data to enable the Board to research and monitor industry trends in input prices and productivity.

The information to be filed is presented in Table 12-9. The year-end data of the previous year must be filed with the evidence for initial rates in year 1, and by February 1 of 2002 and 2003 for year 2 and year 3 rates.

Table 12-9
PBR Related Information

Cost Category	***Item***
Miscellaneous	*Line Losses*

One of the difficulties in benchmarking London Hydro's system loss performance pre- and post-market opening will be related to the accounting practices for administrative building operating and maintenance expenses such as telephone, water, heating and specifically electricity. Prior to market opening, the electric service to London Hydro's administrative buildings were unmetered, and hence considered a system loss. This practice was not unique to London Hydro. Now, the electric service to the building is metered and the electricity consumption is universally recorded throughout the province within the classification *Office Supplies and Expenses* or *Miscellaneous General Expenses*.

There are other inconsistencies (e.g. the allocation of unbilled energy arising from a favourable dispute resolution, etc.) that will make benchmarking London Hydro's system loss performance against both our own earlier performance and the performance indicators of other utilities somewhat of a challenge.

1.2 Scope

This report firstly defines the magnitude of London Hydro's electrical distribution system in terms of the overall length of medium-voltage distribution circuitry, the accumulated amount of transformation connected to this circuitry, the number of supplied customers, and the overall energy delivered to these customers.

A number of electrical performance parameters that are commonly used by the electricity distribution sector are presented. These parameters are then compared against London Hydro's historical performance. As any market system will reward efficiency directly and in the short term, there should be steady improvement in these performance parameters.

Next, the report describes the sources of energy losses that pertain to London Hydro's electric distribution system, and attempts to quantify the extent or magnitude of each type of loss. The subdivision of overall system losses into categories represents the best good faith approximations available at this time based on the combination of rigorous analysis and assumptions.

Finally, the report examines methods and programs that can improve the energy delivery efficiency of London Hydro's distribution system by minimizing such losses.

1.3 Purpose

London Hydro's distribution system is not inefficient, in the sense that the system is poorly designed or operated, rather the transmission of electricity though any electrical device incurs a certain amount of electrical loss. Transformers consume a small portion of the power fed into them to establish the magnetic fields needed to operate; the flow of electricity through the internal resistance of a conductor or cable causes internal heating, another form of loss; and there are energy conversion losses associated with our substation battery chargers. These losses are a result of inviolable laws of nature. They can be measured, assessed, and minimized through proper engineering, but never eliminated completely.

A clear understanding on the magnitude of technical and commercial losses is the first step in the direction of reducing losses. Indeed, the primary purpose of this report is to characterize the various loss components, compare our delivery efficiency performance to historical performance, and ultimately to extend the comparison to other benchmarks (e.g. similar distribution utilities and so-called *best of breed* utilities). It also helps to identify areas where improvement is cost-effective, prioritize where to devote energies and resources, and documents accomplishments.

A secondary purpose of this System Planning report is as a supporting reference document to accompany London Hydro's annual submission of Performance Based Regulation (PBR) information to the Ontario Energy Board.

1.4 Terminology and Abbreviations

1.4.1 Glossary of Terms

The following definitions are not intended to embrace all legitimate meanings of the terms.

Distribution losses means electrical energy losses incurred in distributing electricity over a distribution network.

Distribution loss factor means a factor assigned to a distribution network to impute the level of energy losses incurred in the *distribution network*.

Distribution network means the network used to transport electricity from the high-voltage provincial transmission grid to customers.

Local distribution company means the distribution business conducting the *wires business* to whose *distribution network* the customer is connected.

Network losses – see Distribution losses.

Site-specific loss adjustment means a factor applied to revenue meter readings in cases where the actual meter point is not at the point of sale. Such factors are commonly applied at transformer stations wherein the point of sale is the 115 kV or 230 kV transmission circuit and the revenue metering is installed on the low-voltage winding (i.e. at 13.8 or 27.6Y kV) of the power transformers. The purpose of the loss adjustment is to account for the no-load and load losses of the power transformers.

Substation means a facility used for switching and/or changing or regulating the voltage of electricity. Service equipment, line transformer installations, or minor distribution or transmission equipment are not classified as substations.

Wires business means the component of a distribution business that distributes (transports) electricity from the provincial transmission grid to customers across a *distribution network*. A wires business is operated under a distribution license.

2 CHARACTERIZING LONDON HYDRO'S DISTRIBUTION SYSTEM

2.1 Length of Medium-Voltage Distribution Circuitry

Within London Hydro's franchise service territory, the following distribution voltages are maintained: 16/27.6Y kV, 8/13.8Y kV, 13.8Δ kV, 4.8/8.32Y kV, and 2.4/4.16Y kV. The overall length of distribution circuitry and subdivision into overhead and underground electric lines is:

- Overall system length: ....2,459 circuit-kilometres
- Length of overhead electric lines:..................1,261 circuit-kilometres
- Length of underground electric lines:............1,198 circuit-kilometres

A breakdown of the circuit lengths by voltage class is included as Table 3-1 (see page 11 herein).

Note: Some of the underground distribution circuitry in the core area of the city is not completely represented in our electronic Geographic Information System (GIS). As a consequence the circuitry lengths given above are understated. This shortcoming will be addressed in the reporting for future years.

2.2 Total Transformer Capacity

2.2.1 Municipal Substations

Municipal substations convert what was formerly a sub-transmission voltage (27.6 kV) to a lower three-phase four-wire 4.8/8.32Y or 2.4/4.16Y kV distribution voltage. At the end of 2002, there were 40 utility-owned municipal substations in operation within London Hydro's franchise service territory totalling a number of 46 power transformers in service.

Table 2-1, Installed Municipal Substations by Voltage Class (as of December 2002)

Substation Transformer Voltage Rating	Total Number of Municipal Substations	Total Installed Transformer Capacity
27600-8320Y/4800 V	1	4,000 kVA
27600-4160Y/2400 V	32	162,500 kVA
13860-4160Y/2400 V	7	33,100 kVA
Total:	40	199,600 kVA

Within London Hydro's service territory there are a number of lines built and energized at a lower distribution voltage where it was impractical or simply not economical to convert to a higher voltage when a conversion project took place. Also, some of these lines were annexed in 1998 from Hydro One and are located at the outer fringes of the city. These lower voltage radial lines are currently fed from the distribution system via a total of 56 step-down transformers from either the 27.6 kV or 13.8 kV to either 8.32 kV or 4.16 kV.

Table 2-2, Installed Step-down Transformers by Voltage Class (as of December 2002)

Step-down Transformer Voltage Rating	Total Number of Step-down Transformers	Total Installed Transformer Capacity
27600-8320Y/4800 V	21	5,250 kVA
27600-4160Y/2400 V	29	3,250 kVA
13860-4160Y/2400 V	6	900 kVA
Total:	56	9,400 kVA

2.2.2 Distribution Transformers

Distribution transformers convert high-voltage electricity to lower voltage levels acceptable for use in homes and businesses. At the end of 2002, there were 13,876 utility-owned distribution transformers in use within London Hydro's franchise service territory. This figure excludes substation transformers, step-down transformers between 27.6Y / 13.8Y kV and 8.32Y / 4.16Y kV and those privately owned.

Table 2-3, Installed Distribution Transformers by Voltage Class (as of December 2002)

Distribution System Voltage	Total Number of Transformers Installed	Total Installed Transformer Capacity
2.4/4.16Y kV	3,895	215,690 kVA
4.8/8.32Y kV	852	24,806 kVA
8/13.8Y kV	443	49,878 kVA
13.8 kV	88	61,050 kVA
16/27.6Y kV	8,598	799,018 kVA
Total:	13,876	1,150,442 kVA

The above tabulation refers to number of individual units, either single- or poly-phase distribution transformers installed on the overhead and the underground systems. Most often, for commercial smaller size services (i.e., under 500 kVA), an installation is comprised of three single-phase pole-mounted units installed in a delta or wye configuration and designated as one transformer bank (i.e., T-8643). Therefore, a comparable size utility that has different practices may count a far less number of units for the same total kVA installed.

Note: To illustrate this final point, whereas London Hydro may service a 75 kVA three-phase customer load via a transformer bank consisting of three (3) – single-phase pole-mounted distribution transformers, each rated 25 kVA, another LDC with differing design and procurement practices may elect to service this same load with one (1) – three-phase pole-mounted distribution transformer with a 75 kVA rating. In both cases, 75 kVA of transformation has been installed, but London Hydro has used three transformers whereas another LDC will use one transformer.

2.2.3 Customer-Owned Electric Power Substations

Customer-owned electric power substations convert high-voltage electricity to lower voltage levels acceptable for use in businesses. At the end of 2002, there were 168 privately owned substations in operation within London Hydro's franchise service territory.

Table 2-4, Installed Customer-Owned Substations by Voltage Class (as of December 2002)

Supply Voltage	Total Number of Privately Owned Substations Installed	Total Installed Transformer Capacity
2.4/4.16Y kV	7	4,470 kVA
4.8/8.32Y kV	--	--
8/13.8Y kV	29	87,350 kVA
13.8 kV	--	--
16/27.6Y kV	132	435,978 kVA
Total:	168	527,798 kVA

Of this total, 84 of the customer-owned substation installations have associated high-voltage revenue metering systems, and the remaining 84 installations have low-voltage revenue metering systems. The significance of this subdivision will become more apparent later in the report.

2.3 Amount of Energy Delivered

London Hydro receives supply from the provincial transmission grid via six (6) transformer stations (see Figure 4-6 on page 18 for the locations of these stations). London Hydro also receives supply from five (5) embedded retail generators (Fanshawe Dam, Labatts, Casco, London Health Sciences, and Core Energy) located within the franchise service territory. The overall energy delivered throughout 2002 was:

Maximum system demand:	670,874 kW
Total electricity entering the system (before losses of electricity):	3,396,514,660 kW·h
The total amount of electricity supplied from the system (after losses of electricity):	3,263,528,822 kW·h

A breakdown of the delivered energy by transformer station is included as Table 4-1 (see page 20 herein).

2.4 Number of Customers

In general, a customer is an individual, partnership, organization, corporation, institution or business that is receiving electrical energy (as measured by a revenue meter) from London Hydro. The number of customers, by supply voltage, is given in Table 2-5 below.

Table 2-5, Number of Customers by Supply Voltage (as of December 2002)

Supply Voltage	Number of Customers
Low voltage [2]	132,433
2.4/4.16Y kV	8
4.8/8.32Y kV	--
8/13.8Y kV	33
13.8 kV	--
16/27.6Y kV	131
Total:	132,605

The number of customers tabulated above does not include unmetered supplies to roadway lighting systems, Bell and CATV amplifiers, bus shelters, traffic signals, emergency fire pump services, and certain billboards.

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[2] Most customers receive a low-voltage single- or three-phase supply (at 120/240 V, 120/208Y V, 240/416Y V, or 347/600Y V) from London Hydro transformers. The remaining customers receive supply directly at one of the available distribution voltages.

3 ENERGY DELIVERY EFFICIENCY PERFORMANCE MEASURES

3.1 General

The losses in any system depend on the pattern of energy use, intensity of load demand, load density, and capability and configuration of the distribution system that varies for various system elements.

3.2 Load Factor

Load factor is the amount of electricity (in kilowatt hours) entering the system during the financial year divided by, the maximum demand multiplied by the total number of hours in the financial year, expressed as a percentage.

2002 Load Factor = 52.4%

Load factor is calculated in accordance with the following formula:

$$\frac{\mathrm{a}}{\mathrm{b}\,x\,\mathrm{c}}\,x\,\frac{100}{1}$$

Where —

a is the amount of electricity (in kilowatt hours) entering the system during the financial year; and

b is maximum demand; and

c is the total number of hours in the financial year.

Local distribution companies (LDC's) with higher load factors compared with like LDC's, other things being equal, are better at utilizing their line investment. Load factor is not something over which an LDC has much control; rather it is a reflection of the customer's usage patterns.

3.3 Loss Ratio

Loss ratio is losses of electricity (expressed in kilowatt hours) divided by, the amount of electricity (in kilowatt hours) entering the system during the financial year, expressed as a percentage.

2002 Loss Ratio = 3.92%

Loss ratio is calculated in accordance with the following formula:

$$\frac{a}{b} x \frac{100}{1}$$

Where —

a is losses of electricity (expressed in kilowatt hours); and

b is the amount of electricity (in kilowatt hours) entering the system during the financial year.

Loss ratios lower than another local distribution company (LDC), other things being equal, signifies a more technically efficient line. However, such factors as the relative mix of underground and aerial line and cable and the overall investment would also need to be taken into account.

3.4 Capacity Utilization

Capacity utilization is maximum demand divided by, transformer capacity (in kilovolt amperes), expressed as a percentage.

2002 Capacity Utilization = 35.5%

Capacity utilisation is calculated in accordance with the following formula:

$$\frac{a}{b} x \frac{100}{1}$$

Where —

a is maximum demand; and

b is transformer capacity (in kilovolt amperes).

Utilisation higher than a like local distribution company (LDC), suggests a closer matching of the ability of the system to meet peak demand and thus a higher level of effectiveness.

Note: For all the customer-owned substations a separate capacity utilization factor can be calculated. It is obtained from totalizing their individual peak demands coincident with the time of London Hydro’s system peak demand and divided by the total installed transformer capacity (as given in Section 2.2.3). This factor is calculated to be 22% for the year 2002. It can be inferred from this considerably lower utilization value that the designs for customer-owned substations are considerably more conservative in nature that London Hydro’s practices, and hence reduce the overall capacity utilization factor that would be calculated considering only London Hydro’s distribution assets.

3.5 Comparison with Historical Performance

The following tabulation is intended to provide a comparison of London Hydro's year 2002 performance with that of the preceding four years.

Table 3-1, Energy Delivery Efficiency Performance Comparison

		2002	2001	2000	1999	1998
1.	**Energy Delivery Efficiency Performance Measures:**					
(a)	Load Factor	52.4%	55%	57.8%	53.6%	--
(b)	Loss Ratio	3.92%	3.24%	3.84%	3.29%	3.11%
(c)	Capacity Utilization	35.5%	--	--	--	--
2.	**Statistics:**					
(a)	System Length Breakdown in Kilometres					**kms**
	16/27.6Y kV (1ϕ + 3ϕ)	1,495	1,472	1,245	1,173	
	8/13.8Y kV (1ϕ + 3ϕ)	161	161	161	124	
	13.8Δ kV (3ϕ)	--				
	4.8/8.32Y kV (1ϕ + 3ϕ)	235	245	183	183	
	2.4/4.16Y kV (1ϕ + 3ϕ)	568	585	624	753	
	Total	2,459	2,463	2,213	2,233	
(b)	Transformer Capacity, MVA	1,887.2				
(c)	Maximum Demand, MW	670.8	680.4	590.6	652.4	593.3
(d)	Total Electricity Supplied from the System in MW·h	3,263,528,822	3,160,817,427	3,087,899,141	3,108,654,339	2,921,609,220
(e)	Total Customers	132,605	129,319	129,259	128,789	123,931

Note: With respect to item 2(b), there are no records systems available from which the system-wide transformer capacity can be determined with an acceptable degree of accuracy.

Note: The loss ratios for year 2002 and beyond are not necessarily comparable to the loss ratios for earlier years due to changes resulting from the provincial *Electricity Competition Act, 1998*. Post market opening, LDC's are responsible for the power transformer losses and parasitic loads within transformer stations, and the treatment of administrative building loads has changed for some LDC's.

Certainly one of the intriguing patterns in Table 3-1 is the loss ratio (depicted as line item 1b). Whereas one might expect that the loss ratio would remain relatively static or perhaps decay slightly over time (reflecting improvements associated with voltage conversion projects, a greater penetration of low-loss distribution transformers, etc.), London Hydro's loss ratio seems to be almost cyclic in nature.

It will be recalled that the loss ratio is calculated based on the difference between the total energy entering the system and the total energy sales to the customers. The total energy entering the system is explicitly known on 15-minute intervals from the revenue meters installed within transformer stations and within embedded generator plants. There is an element of uncertainty related to the manner in which energy sales are estimated at the crossover from one calendar year to the next. If a revenue meter is read say on the 10th of December and again on the 10th of January, the subdivision of overall consumption into the two calendar years is based on simple prorating, i.e. no consideration is given to the influences of ambient temperature and holidays in this period. The estimated energy sales can therefore be over-estimated in one year and under-estimated in the next, or vice versa.

It is therefore believed that certainly one contributing factor towards this unexpected pattern may be related to inaccuracy in the estimation of annual energy sales. This entire subject area is certainly one that deserves to be looked at in greater detail.

4 COMPONENTS OF DISTRIBUTION SYSTEM LOSSES

4.1 General

Losses are usually divided into two categories: technical, and non-technical (or commercial) losses.

The technical losses are due to the physical characteristics of the power system, and consist mainly of energy dissipated in the conductors and the equipment used for transformation, sub-transmission, and distribution of power. These technical losses are inherent in a system and can be reduced to an optimal level.

The non-technical or commercial losses are caused by theft of service, defective revenue metering systems, errors in meter reading, estimating un-metered supply of energy, customers lost in the billing system, etc.

4.2 Technical Losses

Technical losses are those that are contributed by equipment and hardware in the transmission and distribution system.

Excessive losses (and voltage drop) in these circuits are often due to line conductors and transformers being too small, and feeders being too long for the demand. However, when a transformer is overloaded, it saturates and produces harmonics in the system that contributes to energy losses in addition to the transformer inherent losses. The transformer output voltage is also lowered when it is overloaded.

Another source for energy loss is what is called the 'reactive component' of the load. This should really be kept to an optimal level, otherwise excessive voltage drop and energy losses result.

These factors and others (highly imbalanced loads on the 3-phase distribution system for instance) are good indicators that technical losses are a significant portion of the total amount of losses.

4.2.1 Transformer Losses

Transformers consist of two primary components; a core made of magnetically permeable material; and conductors, or windings, typically made of low resistance material such as aluminum or copper. The copper or aluminum conductors are wound around the magnetic core to transform current from one voltage to another (see Figure 4-1 and Figure 4-2 below).

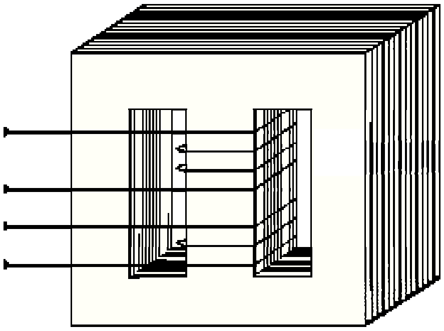

Figure 4-1, Internal Magnetic Circuit for Single-Phase Transformer

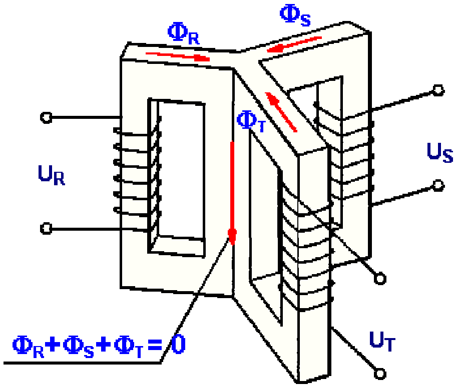

Figure 4-2, Internal Magnetic Circuit for Three-Phase Transformer

There are losses associated with both the primary elements of a transformer. Core losses occur continuously due to the need to keep the transformer energized and ready to serve demand. Conversely, winding losses depend solely upon transformer load and result from resistance in the windings. Core losses are constant while winding losses increase exponentially with the electricity load.

Advances in transformer design have produced substantial efficiency improvements over the past 20 years. The most significant improvements have been made in core technologies with the use of high-efficiency silicon-steel and amorphous metal. Efficiency gains have also been achieved with windings by using materials with lower resistivity or greater diameters.

4.2.1.1 Transformer Core Losses

The core losses in the magnetic material of the transformer core comprise two quite separate components: the magnetic hysteresis loss and the eddy current loss. Although both produce heat in the core material they do this in quite different ways. Hysteresis loss is a magnetic loss process whereas eddy current loss is an electrical loss process.

4.2.1.2 Transformer Winding Losses

The other form of losses that occur in transformers and act to limit their efficiency are ohmic heating losses in the conductor material of the windings. They are commonly called *copper losses*.

These are generated by the heating effect in the conductor resistance of the load current passing through the windings. As ohmic heating (I^2R) losses they scale as the square of the current or load level supplied by the transformer.

4.2.1.3 Transformer Loss Allowances for Private Substations with Primary Metering

Although London Hydro's distribution system normally includes the step-down transformation necessary to provide utilization voltage (i.e. 120/240 V to residential dwellings, and 120/208Y V or 347/600Y V to commercial, institutional and small industrial customers) to the customers, some customer elect to, or are required to, construct their own electric power substation for a variety of reasons that include:

- Plant loads in excess of the apparent power rating (kVA) of transformers that London Hydro provides;
- Plant loads requiring a voltage level that is considered non-standard in Ontario;
- Plant loads that produce harmonics in excess of the design limitations of standard distribution transformers, thereby requiring a specialty transformer; and
- Customer insistence that the transformer be installed in a location that is considered inaccessible to London Hydro or beyond the capabilities of available equipment (e.g. in the penthouse of a high-rise building).

For technical reasons, some customer-owned substations will have revenue metering systems installed on the secondary side of the transformer (to measure electrical consumption at utilization voltage), whereas the balance will have revenue metering systems installed on the primary (or source) side of the transformer. From the perspective of losses, the first case would be similar to London Hydro supplied transformation – the inherent core and winding losses contribute to overall system losses. In the latter case, where the revenue metering system is actually measuring the customer's electrical consumption as well as the internal losses of the transformer, a 1% transformer loss adjustment factor (i.e. reduction) is applied to the demand and energy readings to account for the transformer losses.

Appendix A herein lists the customer-owned substations (by operating designation, e.g. SUB-284) with high-voltage revenue metering systems. For each such substation, its respective annual energy consumption (for year 2002) is tabulated along with the transformer loss credit that was applied (i.e. the second column in the tabulation represents the annual energy consumption that was registered by the revenue metering system, and the third column represents the energy credit that was applied for substation transformer losses).

4.2.2 Line Losses on Medium-Voltage Distribution Circuits

London Hydro's distribution circuitry consists in feeder circuits emanating out of six transformer stations and forty municipal substations energized at different voltage levels: 16/27.6Y kV, 8/13.8Y kV, 13.8Δ kV, 4.8/8.32Y kV, and 2.4/4.16Y kV. Line losses are inherent characteristics from transporting the electrical energy over the electric lines due to the internal resistance of a conductor or electric cable. The major contributor to the line losses in a distribution system is current squared loss through the resistance and it constitutes load dependant losses. Therefore, the level of line losses on the medium-voltage distribution circuits will be proportional to the level of current through each segment of line squared times the resistance of the line. Larger conductors generally result in lower resistance to minimize losses.

London Hydro's electrical distribution primary system is modeled with an electrical analysis software package. This package is capable of importing data from London Hydro's Geographic Information System (GIS). Within the electrical model, average summer and winter loads for all the distribution transformers are imported from London Hydro's *Customer Information System* (CIS). Analysis of the electrical model has indicated that the line losses on the medium-voltage distribution circuits amount to only 1.3% of the total system power demand on a typical summer day (when the system reaches its peak, i.e. at 16:00 hours).

4.2.3 Line Losses on Low-Voltage Bus and Service Cables

Line losses on the low-voltage bus and service cables form another category of line losses (secondary line losses), also proportional to the amount of power transferred through a line or conductor, energized at the rated voltages of 120/208Y V or 347/600Y V. As it is expected, for the same level of power transferred over the conductors or cables but at a much lower voltage level, currents are expected to be higher.

One would tend to believe the secondary losses exceed the losses in the primary conductors by a large extent. In fact, a closer examination of some generic models reveals that the total line losses in the secondary cables are somewhat smaller than in the primary circuitry. This can be explained considering the much higher total length of the primary circuits in the city compared to the total length of secondary conductors and cables. Also, the provincial Electrical Safety Code, which dictates the size of most secondary cable systems, is inherently conservative in nature (i.e. the low-voltage network cables are thus generally largely oversized, especially the privately-owned cables of large services). Therefore larger size conductors having smaller resistances result in overall smaller losses in the secondary lines.

The line losses attributed to secondary services are comprised of losses pertaining to various supply service types that can be briefly categorized as below:

- Residential underground service, normally supplied from a single-phase pad-mounted transformer;
- Residential overhead service, normally supplied from a single-phase pole-mounted transformer;
- General overhead service, normally supplied from a three-phase bank of single-phase transformers running an aerial 120/208Y V or 347/600Y V bus;
- General underground service, normally supplied from a three-phase transformer running a privately-owned secondary cable;
- General service supplied from a bank of three single-phase vault units located sometimes in an apartment building vault.

Losses on the low-voltage downtown network grid (the secondaries of all network transformers interconnected together) have not been considered in this classification but they also partake in the overall line losses contribution to the total system loss.

Note: The low-voltage network grid cable circuitry in the core area of the city is not represented in our Geographic Information System, and as such they weren't included in the engineering analysis program model. This shortcoming should be addressed in the reporting for future years.

4.2.4 Municipal Substation Parasitic Losses

Municipal substations are equipped with a station service transformer that provides a supply to the local (or parasitic) loads within the substation that are required for the proper functioning of the substation equipment. Such parasitic loads include, but are not necessarily limited to:

- Thermostatically-controlled electric strip heaters in each cable termination compartment
- Thermostatically-controlled electric space heater in the main aisle of the metalclad switchgear or bungalow
- Task lighting (that is only switched on when maintenance or operating staff are in the metalclad switchgear or bungalow)
- Battery chargers, to maintain the station batteries in a state of charge and to recharge the batteries after circuit breaker operations – see Figure 4-4 below.
- Telecontrol equipment required for transmitting status, alarm, and telemetry information to London Hydro's central control room
- The closing motor circuits for feeder circuit breakers (which are activated only briefly when the circuit breaker is automatically closed or reclosed).

These loads aren't constant in nature; rather they fluctuate considerably depending on ambient temperature, substation occupancy, and circuit breaker operations.

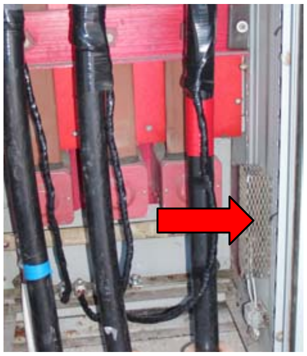

Figure 4-3, Compartment Heating Element

Figure 4-4, Battery & Charger Subsystem

Figure 4-5, Typical Supervisory RTU

Electronic recording ammeters (ERA) were installed in a subset of municipal substations to monitor the power consumption and demand during wintertime. It is believed that the parasitic losses originating from heating and lighting are the largest component from the ones listed above. By extrapolation of the measurements performed, the parasitic losses of the municipal substations contribute with about 1% to the total system losses.

4.2.5 Transformer Station Parasitic Losses

The six transformer stations that form the interconnection point between the provincial transmission grid and London Hydro's distribution network are owned, operated and maintained by Hydro One Networks. Their locations are depicted in Figure 4-6 below.

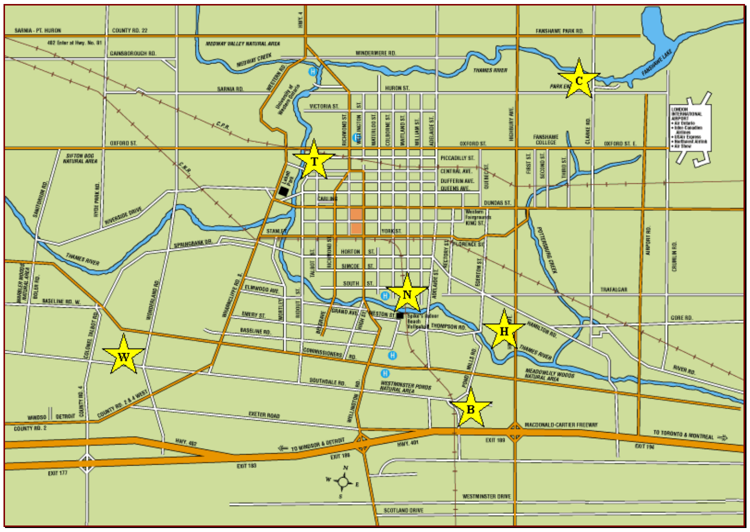

Figure 4-6, Locations of Hydro One Networks' Transformer Stations

A typical transformer station is depicted in Figure 4-7 below. Also shown is one of the power transformers with a rating of 50/83.3 MVA and 215.5-28 kV.

Figure 4-7, Wonderland Transformer Station

Figure 4-8, Wonderland T.S. Power Transformers

The *Energy Competition Act, 1998* resulted in profound changes in the structure of the electric utility sector within the Province. The so-called Market Rules stipulate that all energy transactions occur at the connection point to the provincial transmission system (as compared to the historical practice of measuring downstream of the secondary winding of the station power transformers). The side effect of this change is that (as of market opening in May 2002), utilities are now burdened with the following transformer station losses:

- The core and winding losses of the station power transformers;
- The parasitic losses of the station that are supplied from the station service transformer; and
- The dielectric losses of shunt capacitor banks (where installed).

Wholesale revenue metering systems are generally installed on the low-voltage winding of the power transformers as depicted in Figure 4-9 for both economic and historic reasons. With knowledge of each power transformer's electrical performance characteristics (i.e. no-load and full load losses), the electrical power flows as measured at the wholesale metering installations can be converted to equivalent electrical power flows at the transmission connection point, the difference being the losses incurred by the pair of power transformers. The calculation method for doing such a conversion has been coined the *Site Specific Loss Adjustment* (or SSLA) by the provincial Independent Electricity Market Operator.

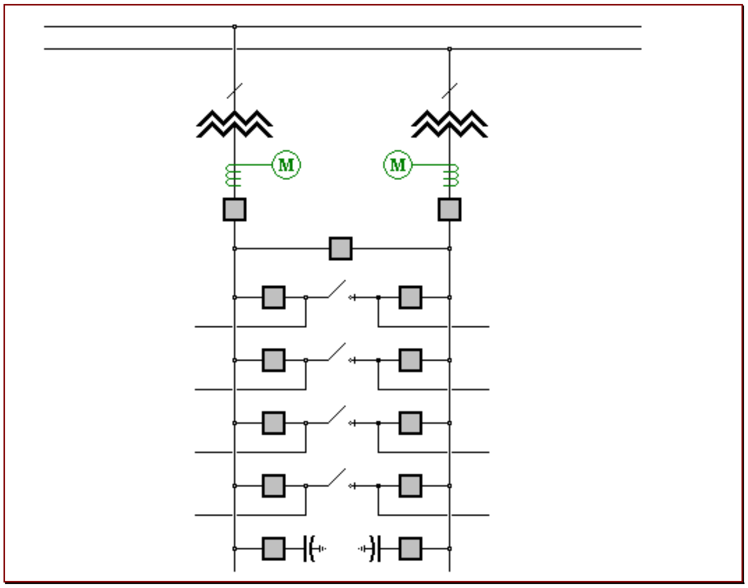

Figure 4-9, Single-Line of Typical Jones-Style DESN Transformer Station

Since certified test reports that provide explicit loss performance information are not available for the power transformers installed in many vintage transformer stations, *typical* data is presently used for the adjustments.

For each of the supply transformer stations, the *unadjusted* energy procurements (as recorded by the wholesale revenue metering systems installed on the secondary winding of the power transformer) are shown in Column 2 of Table 4-1. The transformer's core losses (constant) and winding losses (that vary with transformer loading) that are derived from the SSLA calculation are indicated in Columns 3 and 4 respectively of Table 4-1. The summation of columns 3 and 4 are the power transformer losses, the cost of which is now borne by the LDC (in this case London Hydro).

Table 4-1, Calculated Power Transformer Losses & Measured Station Service Loads

Delivery Point	Unadjusted Annual Energy Procurements, MW·h ① ③	Power Transformer Core Losses, MW·h	Power Transformer Winding Losses, MW·h	Station Service Consumption, kW·h ② ③
(Col 1)	(Col 2)	(Col 3)	(Col 4)	(Col 5)
Buchanan TS [3]	343,586.882	10.777	40.790	41,904
Clarke TS	394,832.036	334.080	1,629.481	N/A
Highbury TS	298,793.878	806.400	735.383	62,313
Nelson TS	266,232.575	921.600	953.113	N/A
Talbot TS	613,173.491	564.480	2,131.000	379,958
Wonderland TS	374,056.505	334.080	1,250.455	N/A
Edgeware TS	1,876.842	N/A	N/A	--
	Total (MWh):	2,971.417	6,740.222	484,175

Notes:

① The unadjusted annual energy procurement is the energy consumption measured on the low-voltage winding of the transformer station power transformers. It is this quantity that will be reflected to the primary winding of the power transformers using established engineering principles of adjusting for the transformers' core and winding losses to arrive at transmission procurement quantities.

② The station service (used to power the transformer station's ancillary equipment such as relays, lighting, battery chargers, etc.) has a revenue metering system installed to directly measure consumption. For entries that read "N/A", the service consumption exists but cannot be retrieved electronically since an interval-style revenue metering system is not yet installed.

③ These readings cover only the eight-month period from Market opening in May 2002 to December 2002.

For transformer stations that are shared between neighbouring LDC's, the metered station service consumption is allocated in to the various LDC's in proportion to the number of feeder circuit breakers allocated to each LDC (e.g. an LDC with 10 out of 12 in-service feeder positions would be assigned 10/12 of the measured station service consumption). In Table 4-1 above, Column 5 represents London Hydro's share of the overall station service consumption. Again, this is only for the eight-month period from Market opening in May 2002 to year-end.

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[3] Buchanan TS indicates a very small amount of energy losses in the power transformers. It is as resulted from the IMO calculation of uplifting the unadjusted energy procurements to the transmission connection point. This energy loss is inconsistent with losses from similarly sized power transformers.

Since May 2002, the so-called *site-specific losses* cumulated from all seven delivery points (six transformer stations and one HONI-owned 27.6 kV feeder at Edgeware) accounted for approximately 0.5% of the wholesale energy data with a corresponding effect on increased system losses compared to previous years. In the years to come it is expected that the system losses contribution from transformer stations parasitic losses will increase another one or two percent from what it represents now as this energy loss will be accounted for throughout an entire year.

4.2.6 Distribution Automation Parasitic Losses

London Hydro has a number of automated switches and reclosers installed in the distribution system. These devices offer greater flexibility and improvement in switching times, number of customer affected from a fault on a feeder, temporary transferring load, etc. They are connected to the 27.6 kV system on a selection of main feeders totalling seventy (70) distribution automation switches and so far only two (2) in-service reclosers (with another five to be in-service at the end of this year) that communicate with the SCADA master station at the central control room.

Figure 4-10, Typical Pole-Mounted Automatic Circuit Recloser

Figure 4-11, Typical Distribution Automation Switch

Figure 4-12, Typical Distribution Automation Padmounted Sectionalizing Switchgear

There is an inherent power consumption associated with their controls that are normally supplied from a 120 V service. It is estimated that while approximately 1 kW of <u>connected</u> load is associated with each switch, each unit draws only a few watts on a continuous basis. For the number of automated interrupting devices currently installed, this load along with identified parasitic losses contribute with less than 0.5% to the total system losses.

4.2.7 Energy Consumption by London Hydro's Administrative Building

Prior to May 2002, the energy consumed by London Hydro's administrative building located at 111 Horton Street was unmetered and considered a system loss. In the future, this electricity consumption will be measured and paid for by the utility, therefore not accounted for as a system loss component.

4.3 Non-Technical and Administrative Losses

4.3.1 Theft of Energy

Theft of electric power is a problem experienced in varying degrees by all electric utilities. The impact of theft is not limited to loss of revenue; it can also affect power quality resulting in low voltage and voltage dips.

According to research carried out by the Canadian Electrical Association[4], theft and pilferage account for part of the distribution losses. Some of the modes for illegal abstraction or consumption of electricity are given below:

- Bypassing the meter – see Figure 4-13[5] below.
- Making unauthorized load connections upstream of the revenue meter – see Figure 4-14 and Figure 4-15 below.
- Tampering with the revenue meter by disturbing the disk rotation with foreign matter.
- Changing the sequence of terminal wiring
- Changing the instrument transformer ratio thereby reducing the recording.

Figure 4-13, Jumpers Installed in Meter Socket

Figure 4-14, Illegal Tap at Service Mast

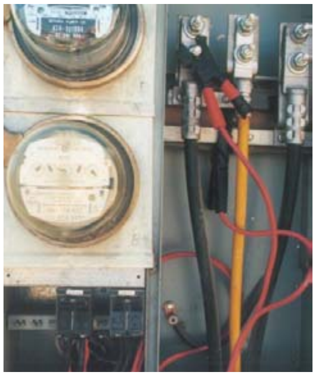

Figure 4-15, Illegal Tap in Service Entrance Panel

In recent years, there has been an alarming increase in the number of power theft incidents due to the proliferation of illegal indoor marijuana grow operations[6]. House interiors in suburban neighbourhoods are dismantled and reassembled to support illegal farm operations, and oft times the electricity meter is bypassed. Although

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[4] Canadian Electrical Association Report 9231-U-964, *The Extent of Energy Diversion on Customer Premises for Canadian Utilities*; April 1997.

[5] Photographs courtesy of International Utility Revenue Protection Association (IURPA).

[6] *EDA Board Adopts Position on Theft of Power Issue – Proliferation of Marijuana Grow Operations Prompts Industry Action*; Electricity Distributors Association Publication: The Distributor; April / May 2003 Edition; pages 6-7.

difficult to confirm, estimates from police place the number of grow houses within London Hydro's service territory at about 1000 of various sizes (i.e. a small operation would grow 20 to 50 plants, whereas a large operation would grow 200 to 500 plants). For the large grow operations, which are estimated to be about 75 in number, the revenue meter will certainly be bypassed or tampered with in another fashion.

Statistics show that grow operators steal an average of $1,500 of electricity per month to run their operations – that represents almost 300 kWh per day or 10 times the average electricity consumption.[7, 8] With each grow cycle lasting 3 – 4 months, and 3 harvests per year, the amount of energy stolen each year from these types of operations within London Hydro's service territory can be estimated as:

$$\text{Diverted energy } \approx 75 \text{ farms} \times \frac{3 \text{ harvests}}{\text{year}} \times \frac{3\text{-}1/2 \text{ months}}{\text{crop}} \times \frac{365 \text{ days}}{12 \text{ months}} \times \frac{300 \text{ kWh}}{\text{day}}$$

$$\approx 7{,}186{,}000 \text{ kWh/year}$$

If it were also considered that police forces have some success in discovering and closing down the large-scale operations, perhaps it would be more realistic to assign a 2/3 factor (i.e. the *average* farm harvests two crops before the operation is detected and closed down) to the above calculation. As such, the suspected magnitude of diverted energy attributable to illegal grow houses is estimated to be on the order of 4,790,000 kWh/year.

4.3.2 Defective Revenue Metering Systems

Every year a small number of in-service revenue metering systems are rendered inoperable for a variety of reasons, including lightning damage, vandalism, etc. When discovered, the metering system is remedied and the customer is invoiced on the basis of an estimated consumption over the time period in question. There is never any way of truly knowing if the estimate is an accurate depiction of actual usage.

4.3.3 Errors in Meter Reading, Billing, and Customers Lost in the Billing System

Computer-based billing systems have necessarily increased in complexity over the past few years both to respond to industry change (e.g. the demands of the provincial Electricity Competition Act, changes in service territory boundaries, amalgamations,

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[7] *Electricity Distributors Association (EDA) and Local Electricity Distribution Companies Join with Regional Police Force in "Operation York Connection";* EDA News Release; June 4, 2003.

[8] Although this passage is widely quoted in various EDA literatures, the monetary impact is believed to be erroneous. The 300 kWh/day statistic coincides with London Hydro's own assessment (i.e. 20 to 25 lamps rated at 1000 W each plus fans and blowers for ventilation; with the lamps on for 8 to 15 hours per day depending on the time within the grow cycle). With an average 2002 energy cost of 7½¢ per kWh, the quoted $1500 would correspond to the average value of the stolen energy over a two-month billing cycle (as opposed to the one month quoted).

etc.) and to the needs of customers. Almost every utility has had to replace or significantly upgrade their customer information / billing systems at the very time when there is less time and fewer resources for planning and implementing new processes. In some cases, the overall need can't be addressed with a single system or process, but rather two or three decoupled or loosely coupled systems. The focus on building / revamping systems often overshadows the need for appropriate controls.

London Hydro is certainly no different in this regard, and these changes increase the opportunity for so-called revenue leakage. Examples might include customers incorrectly receiving a transformer loss allowance due to a data conversion error, customers transferred to London Hydro from annexation for which there is no corresponding record in the billing system, incorrect multipliers recorded for so-called transformer-rated services, etc.

The contribution of this type of errors and oversights to system losses is unknown. In time, however, many of these anomalies will work themselves out of the system.

This entire subject area is certainly one that deserves to be looked at again in future if for no other reason than to quantify the magnitude of some of the contributors.

4.3.4 Estimating Un-metered Supply of Energy

Throughout London Hydro's franchise supply territory, there are a number of electric services that are provided either to the City of London or other business, which are considered un-metered supply of energy (no metering installation exists at the various locations where power is provided). The electricity charges are calculated simply by estimating the consumption for these services. Some of the types of un-metered supply of energy are identified below:

- Roadway lighting
- Bell and CATV amplifiers
- Traffic signals
- Sign connections
- Cathodic protection systems for steel pipelines (used for water distribution)
- Services to emergency fire pump systems.

Undoubtedly, the estimating of the energy consumption in any of these services can be either higher or lower than the actual unknown kWh delivered so the contribution to the system losses remains unknown.

5 MEASURES TO IMPROVE DELIVERY EFFICIENCY PERFORMANCE

5.1 Measures to Reduce Technical Losses

Technical measures that can be employed to optimize distribution system losses include, but are not necessarily limited to the following:

- Low loss transformers
- Re-conductor overhead lines with larger cross-sectional area conductors, or alternatively use of lower resistance conductors
- Installation of cables having larger conductor sizes
- The use of higher sub-transmission voltages further into the network
- Reactive power compensation (in practice, the installation of fixed or switched shunt capacitor banks, either at substations or on the network)
- Tariffs with maximum demand and / or power factor clauses
- Reconfiguration (normally open points) of feeders to reduce system losses, commensurate with other operational requirements
- Balancing of load between phases on feeders
- Load shifting – reduction of maximum demand through the off-peak tariffs.

Many of these concepts will be discussed in the subsections that follow.

5.1.1 Procurement of Low Loss Transformers by London Hydro

In the mid-1980's most distribution utilities throughout the province started buying transformers in accordance with a loss evaluation formula established by the Municipal Electric Association[9]. Transformer manufactures responded by optimizing the design of transformers to provide the most competitive combination of price (i.e. capital investment cost) and efficiency (the present value of future internal transformer losses). Although the weightings have changed over the years to reflect forecasts of future inflation rates, interest rates, transformer loading, and energy costs, the loss evaluation formulas remain in widespread use.

The two bar charts below depict the age distribution of London Hydro's in-service transformers by voltage class and vintage. Figure 5-1 shows simply the number of in-service transformers that were manufactured over each defined time period.

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[9] Municipal Electric Association Report ED-RD-1, *Distribution Transformer Loss Formula*; August 1987.

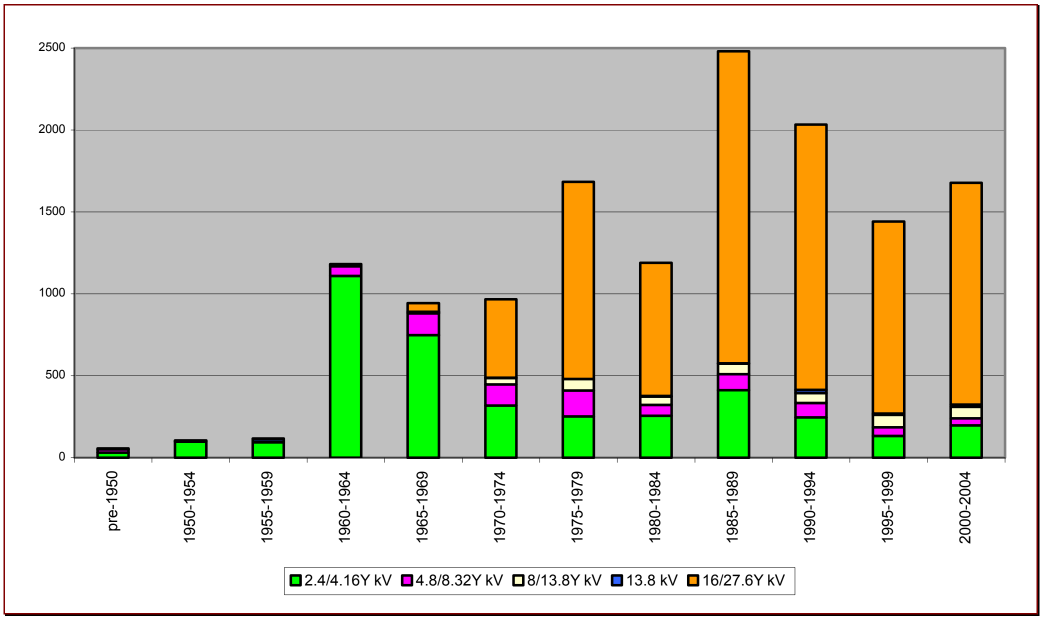

Figure 5-1, Transformer Population by Voltage Class and Vintage

For example, the chart shows that there are 2,033 in-service transformers manufactured over the time period 1990 to 1994; with a voltage class breakdown as follows: 246 connected to the 2.4/4.16Y kV distribution system, 88 connected to the 4.8/8.32Y kV system, 60 connected to the 8/13.8Y kV system, 21 connected to the 13.8 kV network system, and finally 1,618 connected to the 16/27.6Y kV distribution system.

Figure 5-2 shows the combined capacity of in-service transformers that were manufactured over each defined time period.

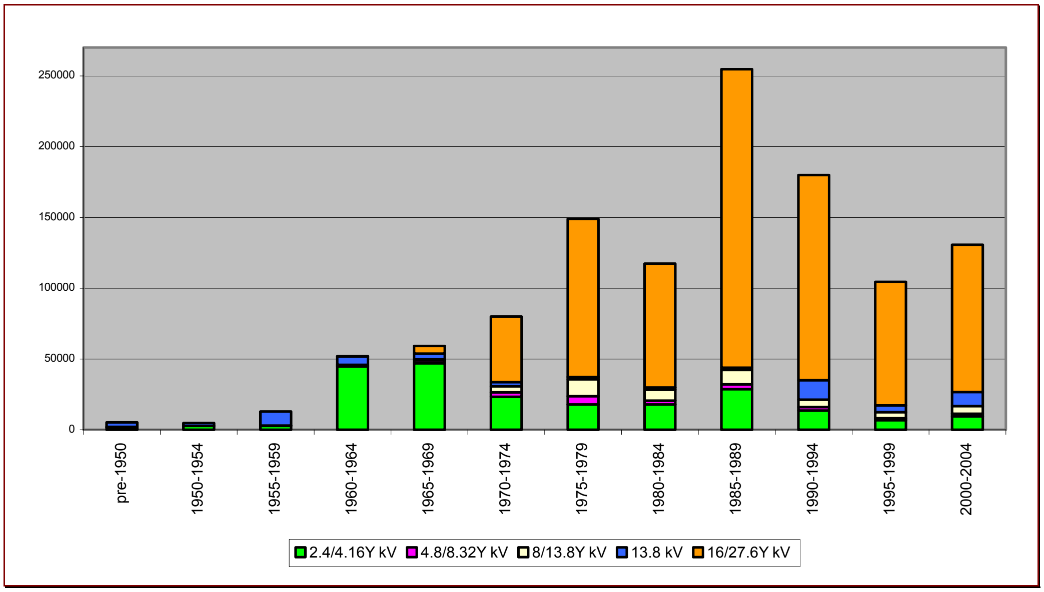

Figure 5-2, Transformer Capacity by Voltage Class and Vintage

For example, the chart shows that the combined capacity of in-service transformers manufactured over the time period 1990 to 1994 is 180,009 kVA; with a voltage class breakdown as follows: 13,609 kVA connected to the 2.4/4.16Y kV distribution system, 2,382 kVA connected to the 4.8/8.32Y kV system, 5,142 kVA connected to the 8/13.8Y kV system, 13,750 kVA connected to the 13.8 kV network system, and finally 145,126 kVA connected to the 16/27.6Y kV distribution system.

From the two charts it can be observed that about 45% of the transformer population comes from transformers purchased prior to the introduction of the formal loss evaluation formula, whereas the remaining 55% were purchased post formal loss evaluation formula. Similarly, 42% of the kVA installed comes from transformers purchased pre formal loss evaluation formula and the other 58% of installed kVA has been manufactured after that time.

There is no apparent distortion between the two graphs in terms of how many transformers contribute to how much percentage of the installed kVA. The larger percentage of kVA installed (58%) after the formal loss evaluation formula compared to the share in the total population of transformers (55%) can be an indication that perhaps larger transformers were manufactured with good efficiencies to replace a larger number of smaller transformers for the same total kVA. In other words, 60 – 100 kVA rated transformers is the same as 80 – 75 kVA rated units in kVA installed but not in number of units.

Also, from the ages of all in-service transformers and the number of units manufactured in a single year, the median age for all the distribution transformers was calculated as 17 years of age. This is basically a measure of saying that half of the in-service transformers are younger than 17 years and the other half are transformers older than 17 years.

As time passes and renewal projects for London Hydro's aging infrastructure are completed (i.e. vintage transformers are replaced with modern low-loss units), one can expect a commensurate improvement in overall system transformer loss performance.

5.1.2 Procurement of Energy Efficient Transformers for Private Substations

Historically, with privately owned substations, developers tend to focus on the initial capital costs and not the running costs of the power supply. The cheapest transformers available that fulfill the Canadian Electrical Code requirements tend not to be energy efficient.

In recent years, London Hydro has instituted a policy whereby privately owned substations will only be eligible for lower-cost secondary revenue metering installation if the transformer meets the requirements of CSA Standard C802, *Maximum Losses for Distribution, Power, and Dry-Type Transformers*.

Furthermore, with the advanced revenue metering systems now prevalent in the marketplace, London Hydro no longer needs to provide the traditional 1% loss allowance to customers with high-voltage revenue metering systems.

5.1.3 Load Balancing on Three-Phase Circuits for Optimal Performance

When electric power travels from a generator (source) to a load (consumer), the current needs a return path back to the source. In the case of perfectly symmetrical three-phase systems, the currents in the three phases are always equal, so the resultant return current equals zero[10]. In other words, no return current exists in a symmetrical three-phase system and no return line is needed. On this principle the three-phase three-wire delta (Δ) systems are formed to supply only perfectly balanced loads (three-phase loads).

Distribution systems are normally designed so that overall the three phases are essentially balanced[11]. However, in reality a distribution system serves a large variety of single-phase loads (domestic loads, lighting, small motors, etc.) in a Wye (Y) connection from a three-phase four-wire system that may result in an overall less balanced system. In this case, the fourth wire provides the return path to the source (i.e., generator, transformer station, power transformer). It is not uncommon to have as much as 50% difference in magnitude between the highest and lowest loaded phases. The higher the unbalance in the system, the more current will flow through the return (neutral) wire, thus increasing the line losses. Balancing reduces feeder losses because any phase peak reduction affects the losses for the phases as the square of the current magnitude.

For optimal performance in the operation of a three-phase four-wire electrical system at any distribution voltage (27.6Y kV, 13.8Y kV, 4.16Y kV or 8.32Y kV), load balancing of the three phases is a main factor in reducing line losses in conductors and cables. According to an engineering study[12] carried out by Acres International on London Hydro distribution system, the potential recurring savings from load balancing achievable on London Hydro's system are on the order of $20,000 per year.

Once the Electrical database of the network is imported from the Geographic Information System (GIS) into an Electrical Engineering Analysis platform, the resulting network model can be subjected to various analysis runs for carrying out studies that will be of interest to a distribution engineer.

The electrical distribution system data and connectivity information was extracted electronically from the GIS database of London Hydro and imported into the

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[10] *Electric Energy Systems Theory – An Introduction*, Second Edition, Olle I. Elgerd, Tata McGraw Publishing Company, 1982

[11] *Elements of Power System Analysis*, Fourth Edition, William D. Stevenson Jr., McGraw-Hill International Editions, Electrical & Electronic Engineering Series, 1982

[12] System Infrastructure Assessment and Optimization Plan (Phase 2), October 2001.

engineering analysis program along with distribution transformer loading information from CIS (*Customer Information System*) and MV-90 to develop an electrical model of the system in London. Loads were assigned to a specific load category (residential, industrial, commercial, etc.) and time period (summer and winter, weekday and weekend). From SCADA measurements, four generic load profiles (two seasons and two day types) for each load category were developed with the summer peak load determined to be at 4PM and the winter peak load to be at 6PM for a weekday. Based on these generic profiles, the load categories curves were adjusted to match the generic SCADA resulted profiles for all four day types (summer and winter, weekday and weekend).

Within this model, load-balancing analysis was run mostly for the 4 kV feeders exhibiting large unbalance (higher than 15%) and higher loads such as to benefit the system of the highest loss reduction possible for the least number of changes to be made in a feeder's configuration and loads' connection. Very often, the loads on each phase of a feeder can be brought in fairly good balance by switching around four or five single-phase loads (either overhead transformers or an entire single-phase taps feeding a string of transformers). However, in many of these instances only a better voltage regulation is attained along the feeder whereas the kilowatts savings even at peak loads (summer, 4PM weekday) are very small, therefore not justifying the cost to change the phase connectivity for a division of single-phase transformers and single-phase braches. It is realistic to assume that the benefits in improved use of feeder capacity and improved voltage quality are of more significance than the value of loss reduction.

The load balancing analysis run on London Hydro system yielded to changes on a selection of 4 kV feeders that can only improve the total line losses in the conductors with almost 1% reduction at peak times. However, consistent with Acres' study and recommendations, the annual savings achieved from load balancing the selected feeders in the system are on the order of $10,000 annually.

5.1.4 Circuit Reconfiguration for Optimal Performance

On the same electrical model an optimization analysis of the five transformer station territories (operating at 16/27.6Y kV) was carried out for the scope of reducing line losses. These five transformer stations (Buchanan, Clarke, Highbury, Talbot and Wonderland) have eight feeders each (with one exception Talbot that has 12 feeders) that are in a network configuration but radially operated. The purpose of the optimization is to identify the open points on the feeders to reduce line losses and improve the voltage condition.

Based on the power analysis software recommendation, each region supplied by a transformer station was optimized independently, and afterwards, the complete system was optimized as a whole by reconfiguring some of the open points between transformer stations. The impact on the system in terms of feeder and stations loading and system losses with each reconfiguration was verified in the program through a load flow analysis. The best practical open points were applied to the system and the optimization analysis was run until the program suggested no further change recommendation.

The benefit of the optimization process from simply reconfiguring some of the open points in the system was quantified to deliver approximately an 8% reduction in the line losses (on the 16/27.6Y kV and the 2.4/4.16Y kV systems) at system peak load, for an estimated dollar saving value on the order of $105,000 annually.

By combining the benefits of the two measures of reducing the line losses (as described in sections 5.1.3 and 5.1.4) the line losses on medium-voltage distribution circuits (4-wire feeders) can be reduced from 1.3% to 1.2% of the system peak demand, which also quantifies in over $120,000 of annual savings of losses at an average electricity price of 7½¢ per kWh for the year 2002.

5.1.5 Reactive Power Compensation

Fixed capacitors are often used in distribution networks to supply some of the reactive power demand at optimal locations along a feeder and to compensate for the reactive power losses due to the line impedance. The use of such capacitors results in improved voltage profiles but is limited by the increase in voltage at light loads.

If greater improvements either in line losses or voltage condition are desired, an option to consider is adding switched capacitors. These capacitors would be switched in and out of the network by controlling one of several parameters: time of switching, reactive power flow in the branch at the location of the bank, voltage at the capacitor node, etc. Time delay elements are present to eliminate spurious switching for transient events. The concern with switched capacitors is that any load increase to the feeder (due to either load growth or feeder reconfiguration) can necessitate resetting of the control parameters.

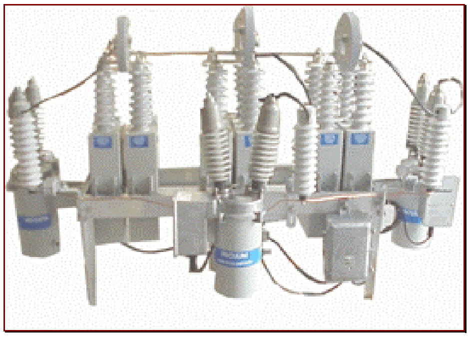

Figure 5-3, Typical Pole-Mounted Capacitor Bank

A typical pole-mounted capacitor bank installation (utilized on 3–phase overhead circuits) is depicted below. When installed on a main distribution feeder circuit, the position can be optimally located to maximize the benefits from voltage regulation and/or line loss reduction. Since distribution feeders are limited in length, and especially at 27.6 kV voltage level (where the currents are smaller for the same supplied load), voltage regulation is not of great concern (although inherently observed when applying a capacitor bank on a feeder). As such, the installation of capacitor banks is mainly considered for reactive power compensation with the scope of reducing line losses.

Computer applications are available to perform optimum capacitor placement on a distribution feeder. London Hydro uses its power system analysis package to perform such functions. The program applies the desired reactive power delivered by capacitors at various optimum locations along a distribution feeder. With the capacitors switched in the system, a load flow analysis is performed to evaluate the savings in line losses on various feeders. An in-depth economical analysis would then be needed to assess weather the dollar savings over a period of time justifies the initial investment needed with such installations.

It was observed from the electrical model of London Hydro that on 27.6 kV feeders, savings of up to 15% of the line losses on a main feeder are attainable when compensating for 60% of the reactive power demand at peak hour. In terms of savings, a reduction of 120 kW at system peak (equivalent to ¼ of the savings obtained from the system optimization) is achievable from compensating for the reactive power of three (3) distribution feeders with high losses for a total amount of 14.5 MVAr at a bulk price of $125K. Savings from this type of compensation would add up to over $25K annually.

Capacitors generate reactive power and have a significant impact in reducing feeder reactive power flows as described. Hence total feeder flows and line losses are reduced; at the same time conductor capacity is also released. Both consequences have economic benefits, the former in reducing the cost of losses and the latter in delaying the need for additional feeder capacity with load growth.

5.2 Measures to Reduce Non-Technical Losses

5.2.1 Revenue Protection Program

Revenue protection or revenue assurance, the most common names used to describe the activities related to (but not limited to) the detection, correction, prosecution and restitution of theft or fraud of all types from utilities, has been a concern to utilities for several decades.[13] Now, with performance based regulations in place there is even more concern, as many utilities race to protect the *bottom line* and become more efficient and competitive. At present, London Hydro does not have an aggressive approach to revenue protection; rather it tends to be restricted to providing support to law enforcement agencies when staff resources are available.

Unmetered use (or theft of energy) can equate to big dollars in an industry where profit margins will be minimal. As was previously described in Section 4.3.1 (see

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[13] Woody Woodward; *IURPA And The Internet: A Winning Combination*; Metering International Magazine (Issue 4: 1998); page 10.

page 22 herein), the energy thefts associated with illegal grow operations represents on the order of $350K annually.

London Hydro has taken a first step to become a member of the International Utilities Revenue Protection Association (IURPA), a network of revenue protection professionals dedicated to reducing revenue loss in the utility industry.

For this utility, revenue protection is one of the few remaining cases of the so-called *low hanging fruit*, i.e. the potential return greatly outweighs the investment.

5.2.2 In-Situ Inspections of Revenue Metering Installations

It is considered good practice to periodically field check the condition and accuracy of revenue metering installations. The frequency of such audits will be selected on the basis of striking a balance between cost and likelihood of uncovering incorrect or non-functioning metering installations.

London Hydro attempts to carry out installation inspections roughly six months after energization for new commercial, industrial, and institutional services, and therein after on a six year cycle (generally in conjunction with re-verification of the revenue meter pursuant to Measurement Canada regulations).

In future, London Hydro hopes to expand the scope of their Electric Metering Shop accreditation to include installation inspections. At that point in time, there will be records systems available for explicitly quantifying the benefit of periodic installation inspections.

6 SUMMARY

6.1 Conclusions

Analysis of the distribution system losses (both qualitatively and quantitatively) has revealed the percentage breakdown of the total system energy losses over a one-year period (2002) as illustrated in Figure 6-1 below.

It can be easily noticed that technical losses altogether account for more than 95% of the energy lost in the process of distributing electricity to the end-user. More than half of that portion of losses comes from transformers (both the constant and load-dependant losses) and is certainly reflected in a low level of utilization like London Hydro has.

The unknown portion of losses (non-technical or commercial losses) is significantly smaller (less than 5%) and it accounts for things like theft of energy, defective metering systems, estimating un-metered supply of energy, etc. As such, these losses are almost impossible to measure and/or optimize. Their annual level simply is derived as the difference between the total losses in the system and the technical losses estimated through engineering analysis and simplifying assumptions.

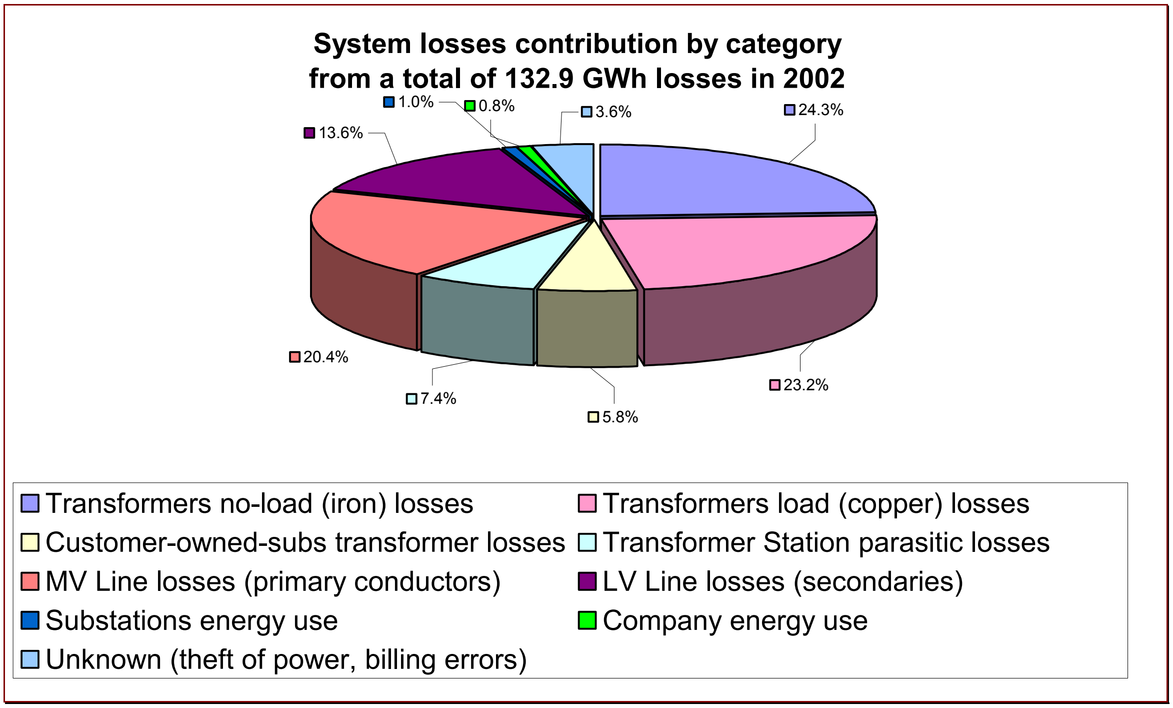

Figure 6-1, System Energy Losses Breakdown for Year 2002

The various programs or measures that London Hydro will continue to exercise for the scope of improving the system efficiency target some of the different categories of losses identified above (i.e. medium-voltage line losses optimization/reduction, low loss transformer procurement, energy efficient transformers required for private substations, etc.). Others remain as they are for the time being (transformer station parasitic losses) and their cost will continue to be borne by London Hydro in the future with a corresponding increasing effect on system losses.

6.2 Recommendations

Maximizing the energy delivery performance (i.e. minimizing system losses) of an electrical distribution system is an undertaking that requires great persistence. At the outset it is fairly easy to find and tackle the so-called *low-hanging fruit*; efficiency improvement opportunities that provide tangible rewards significantly greater than their implementation costs and efforts. As time progresses, extracting further efficiency gains becomes increasingly more challenging (i.e. the benefit / cost ratio decreases).

Being the first *Annual Energy Delivery Efficiency Performance* report, the recommendations presented below represent the *low-hanging fruit* that the underlying analyses carried out in conjunction with the preparation of this report have uncovered. Specific recommendations are:

[1] Balancing phase loadings on distribution feeders –

The use of advanced computer-based system modeling and analysis tools to balance the single-phase loads on medium-voltage distribution feeder circuits presents an opportunity for a reduction in system losses on the order of $10K – refer to Section 5.1.3 herein.

Note: Implementation of the analysis recommendations has not in fact awaited publication of this report; most circuit changes should in fact be complete by this date.

[2] Optimizing the configurations of distribution feeders –

The use of advanced computer-based system modeling and analysis tools to optimize the configuration (i.e. define the normally-open tie points) of medium-voltage distribution feeder circuits presents an opportunity for a reduction in system losses on the order of $120K – refer to Section 5.1.4 herein.

Note: Implementation of the analysis recommendations has not in fact awaited publication of this report; most circuit changes should in fact be complete by this date. One exception would be some feeder rearrangements within the service territory between Buchanan and Highbury transformer stations – this activity awaits construction of a minor tie circuit along Bradley Avenue and Jackson Road.

[3] Continue with feeder optimizations / phase balance on an annual basis -

The process of updating the model and running load flow analysis to identify further opportunities for balancing phase loading and adjusting feeder configurations should continue at least on an annual basis. The distribution system is not a static entity; rather it changes continuously with line extensions to service new load, changes in load patterns for existing customers, voltage conversion projects, and the construction of new circuits to reinforce the overall distribution system. As such, the optimal configuration of the distribution circuitry will be expected to change correspondingly. The potential gains from reconfiguration and load re-balancing in future years will not be nearly as appreciable but this doesn't mean the analysis isn't worthwhile.

[4] Become more proactive and attentive with revenue assurance –

Energy theft associated with illegal grow operations is believed to contribute on the order of $350K per year towards system losses – refer to Section 5.2.1 herein. The combination of not having quantified the extent and impact of energy theft, and resource limitations within the Electric Metering Department have contributed towards a laissez-faire attitude toward revenue assurance to date. It is readily apparent that if an additional employee could dedicate one-third to one-half their time pursuing energy theft and, in concert with law enforcement agencies, was effective at reducing the number of illegal grow operations by even half, there would be significant savings to London Hydro.

[5] Consider the installation of shunt-connected capacitor banks on selected feeder circuits –

The installation of shunt-connected capacitor banks on selected distribution feeders represents an opportunity worthy of further detailed engineering analysis and implementation – refer to Section 5.1.5 herein. Updates on the progress of this project will be reported in future *Annual Energy Delivery Efficiency Performance* reports.

As a concluding note, it was discovered when carrying out some of the background analyses necessary for this report that certain performance data (e.g. information on customer-owned substations, transformer loss data, models of the core area network grid, etc.) are incomplete or of uneven quality. Some of these matters are being remedied now, while others will be addressed in future. As time progresses and opportunities for system efficiency gains become increasingly difficult or more costly to achieve, there should be some consolation in the belief that any recommendations that are forthcoming will be based on better data and more precise analysis models.

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APPENDIX A

Transformer Loss Allowances
For
Customer-Owned Substation Transformers

This tabulation shows for each customer-owned substation (with a high-voltage revenue metering system) that was in-service in 2002, its operating designation (e.g. SUB-201), the annual energy consumption that was invoiced to the customer (i.e. the energy consumption measured by the revenue meter less the 1% transformer loss allowance), and finally the calculated annual loss allowance that was credited to the customer's invoices.

Substation Designation	Annual energy consumption (kWh)	kWh upaid for (1% of consumption)
SUB-200	0	0
SUB-201	5,644,967	56,450
SUB-202	5,412,070	54,121
SUB-203	929,586	9,296
SUB-205	108,411	1,084
SUB-206	2,456,294	24,563
SUB-216	1,161,935	11,619
SUB-218	21968571	219,686
SUB-221	1,189,045	11,890
SUB-224	25391130	253,911
SUB-225	0	0
SUB-226	45117284	451,173
SUB-229	2,685,301	26,853
SUB-230	4,999,190	49,992
SUB-231	4,357,634	43,576
SUB-232	28110099	281,101
SUB-234	17061562	170,616
SUB-235	49583837	495,838
SUB-240	906,818	9,068
SUB-241	367,917	3,679
SUB-242	560,207	5,602
SUB-243	2,595,615	25,956
SUB-244	3,723,552	37,236
SUB-246	2,288,881	22,889
SUB-247	2,381,703	23,817
SUB-249	4,492,026	44,920
SUB-251	27687483	276,875
SUB-252	4,257,955	42,580
SUB-253	1,207,504	12,075
SUB-254	0	0
SUB-255	669,980	6,700
SUB-256	227,432	2,274
SUB-257	2,298,893	22,989
SUB-260	0	0
SUB-262	557,823	5,578
SUB-264	0	0
SUB-265	1,683,636	16,836
SUB-267	4,096,694	40,967

SUB-268	4,538,094	45,381
SUB-269	3,299,575	32,996
SUB-270	4,518,292	45,183
SUB-271	1,245,911	12,459
SUB-273	960,877	9,609
SUB-274	3,398,954	33,990
SUB-275	1,213,555	12,136
SUB-276	267,140	2,671
SUB-278	433,228	4,332
SUB-284	3,719,721	37,197
SUB-286	6,742,846	67,428
SUB-287	3,938,340	39,383
SUB-288	2115059	21,151
SUB-291	4,545,355	45,454
SUB-295	417,498	4,175
SUB-297	204,345	2,043
SUB-298	0	0
SUB-300	575,218	5,752
SUB-307	3,825,301	38,253
SUB-308	0	0
SUB-310	0	0
SUB-313	0	0
SUB-314	4,696,090	46,961
SUB-317	3,875,034	38,750
SUB-318	1,408,925	14,089
SUB-322	7,418,678	74,187
SUB-341	1,158,919	11,589
SUB-349	111,544	1,115
SUB-355	6,327,612	63,276
SUB-360	5,040,364	50,404
SUB-361	1,663,047	16,630
SUB-366	18839854	188,399
SUB-369	6,725,817	67,258
SUB-373	0	0
SUB-375	1,822,105	18,221
SUB-377	1,110,268	11,103
SUB-378	864,001	8,640
SUB-379	615,850	6,159
SUB-380	116,201	1,162
SUB-381	1,531,077	15,311
SUB-382	3,204,222	32,042
SUB-384	1,956,677	19,567
SUB-385	992,807	9,928
SUB-389	974,115	9,741
SUB-392	812,288	8,123
SUB-394	2,785,105	27,851
	Total kWh unpaid for:	**3,961,909**

APPENDIX B

Transformer Losses
For
Customer-Owned Substation Transformers

This tabulation shows for each customer-owned substation (with a low-voltage revenue metering system) that was in-service in 2002, its operating designation (e.g. SUB-207), the transformer's apparent power rating and known or assumed performance characteristics (i.e. no-load and load losses), the average monthly peak demand recorded, and finally the calculated annual losses that were incurred by London Hydro as system losses.

Substation Designation	Total kVA installed	No-load losses (kW)	Load losses at full load (kW)	Peak load (kVA)	Load losses at peak loading (kW)	Losses unpaid for (kWh)
SUB-204	2000	2.9	13.8	353	0.43	26,506
SUB-207	6000	14.3	42.8	1,683	3.37	133,528
SUB-208	2000	4.3	13.0	403	0.53	39,150
SUB-209	1500	4.2	12.5	138	0.11	36,625
SUB-210	999	3.1	9.3	#N/A	0.84	29,303
SUB-211	1500	3.2	9.7	448	0.87	30,551
SUB-214	600	2.3	7.0	330	2.11	25,656
SUB-215	1000	3.1	9.3	643	3.85	36,914
SUB-220	9500	17.1	51.2	5,051	4.61	161,119
SUB-222	1000	3.1	9.3	#N/A	0.84	29,332
SUB-223	1000	3.8	11.5	1,249	17.92	78,650
SUB-227	1517.5	6.8	20.4	#N/A	1.84	64,344
SUB-228	9999	21.6	64.8	3,761	9.16	212,181
SUB-233	1200	5.7	17.1	424	2.13	55,199
SUB-236	5000	8.7	26.0	#N/A	2.34	81,703
SUB-237	2000	3.8	11.5	1,088	3.40	42,083
SUB-238	3000	5.2	15.6	367	0.23	46,079
SUB-245	1000	2.8	8.5	70	0.04	24,867
SUB-250	3000	5.2	15.6	126	0.03	45,560
SUB-258	6250	13.8	41.4	754	0.60	122,513
SUB-263	1500	3.8	11.3	#N/A	1.02	35,614
SUB-277	2000	3.8	11.5	#N/A	1.03	36,130
SUB-279	300	1.4	4.3	110	0.58	13,862
SUB-280	1000	2.6	7.9	482	1.85	27,812
SUB-282	1000	2.6	7.9	449	1.60	27,187
SUB-285	750	2.3	7.0	192	0.46	21,568
SUB-289	2000	4.5	13.4	1,602	8.60	60,808
SUB-290	750	2.7	8.1	528	4.02	33,794
SUB-294	3000	7.1	21.4	276	0.18	62,977
SUB-296	1500	3.4	10.1	394	0.69	31,108
SUB-299	1500	3.4	10.1	456	0.93	31,705
SUB-301	1500	4.8	14.5	436	1.22	45,292
SUB-302	1350	3.2	9.6	948	4.75	40,106
SUB-303	1500	3.4	10.1	122	0.07	29,533
SUB-304	1500	3.4	10.1	518	1.20	32,389
SUB-305	1500	3.4	10.1	778	2.70	36,170
SUB-309	5000	9.1	27.4	2,816	2.46	86,123
SUB-311	2750	6.3	19.0	287	0.21	55,934

SUB-315	750	2.0	5.9	289	0.88	19,595
SUB-316	1500	3.4	10.1	166	0.12	29,673
SUB-319	1500	4.2	12.5	297	0.49	37,590
SUB-320	750	2.2	6.7	233	0.65	21,342
SUB-321	1250	2.8	8.4	679	2.47	30,690
SUB-323	2500	4.6	13.7	1,385	4.20	50,539
SUB-324	2000	3.8	11.5	378	0.41	34,561
SUB-326	1250	2.8	8.4	720	2.78	31,472
SUB-327	1250	2.8	8.4	136	0.10	24,719
SUB-328	1000	2.2	6.7	180	0.22	20,123
SUB-331	500	1.9	5.8	204	0.97	19,387
SUB-332	2000	3.8	11.5	384	0.42	34,597
SUB-333	600	1.7	5.0	24	0.01	14,564
SUB-334	1000	2.2	6.7	35	0.60	21,096
SUB-336	2000	3.8	11.5	1,557	6.96	51,062
SUB-337	1000	2.2	6.7	58	0.02	19,632
SUB-338	2000	4.8	14.3	998	3.56	50,639
SUB-340	750	2.0	5.9	310	1.01	19,927
SUB-342	2750	7.4	22.1	232	0.16	64,893
SUB-343	2000	2.3	18.9	61	0.02	20,237
SUB-344	4000	4.6	37.2	427	0.42	41,145
SUB-345	2000	2.2	18.6	38	0.01	19,184
SUB-346	4000	4.6	37.6	661	1.02	42,858
SUB-348	1500	3.4	10.1	325	0.47	30,552
SUB-350	6000	10.4	31.2	1,442	1.80	95,513
SUB-352	1500	3.4	10.1	555	1.38	32,829
SUB-353	1500	3.4	10.1	528	1.25	32,506
SUB-354	1000	2.2	6.7	29	0.60	21,096
SUB-356	1000	2.2	6.7	158	0.17	19,998
SUB-357	2500	6.8	20.4	173	0.10	59,751
SUB-358	1250	2.8	8.4	670	2.41	30,534
SUB-359	1000	2.2	6.7	259	0.45	20,707
SUB-362	1500	3.4	10.1	908	3.68	38,645
SUB-365	1000	2.2	6.7	28	0.01	19,589
SUB-368	2000	3.8	11.5	2,247	11.48	62,446
SUB-370	1000	2.2	6.7	35	0.01	19,597
SUB-371	1500	3.4	10.1	404	0.73	31,199
SUB-372	3000	5.2	15.6	1,145	2.27	51,210
SUB-374	1500	4.2	12.5	6	0.00	36,361
SUB-376	1500	3.2	9.7	377	0.61	29,913
SUB-383	750	2.6	7.8	109	0.17	23,163
SUB-386	1000	2.6	7.9	149	0.18	23,606
SUB-388	15000	19.4	58.1	0	5.23	182,694
SUB-390	2000	3.8	11.5	264	0.20	34,032
SUB-391	2000	3.8	11.5	808	1.88	38,252
SUB-393	1500	3.2	9.7	628	1.70	32,655
					Total kWh unpaid for:	**3,716,350**

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As Distribution Planning Engineer, Cristina prepares spatial load forecasts (i.e. projections of the where, what, when and why of future demand for electric energy), develops macro-level distribution system expansion plans for transmitting electrical energy economically and reliably from generation centers to all load centers at an acceptable customer service quality and in the quantity desired (i.e. without overloading system components) through accepted corridors, improves the operating efficiency of the distribution system (by introducing system configurations, equipment, and other measures to reduce system losses), and finally addresses power quality concerns and, where appropriate, suggests emerging technologies to meet the power quality needs of customers.

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