London Hydro

2017
Substation Assessment Report

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Introduction

This report provides an assessment of the condition of assets at London Hydro's transformer stations up to the middle of 2017. This report will review the priority categories from the previous report (2013) and highlight the work that has been completed since that time including status updates for each station. Recommendations for ongoing and future work will also be included, as will special notes for any substations with unique and persistent issues. Identify in the report ATC replacement and Porcelain insulator replacement. Switching stations like Galleria, One London Place, Decade, and Old Oak will be included.

Objectives of the Previous Report (2013)

Priorities identified in the previous report include:

1. Equipment status updating
2. Ongoing improvement capital programs, such as
    a. Replacing vintage DC systems
    b. Replacing vintage relays
    c. Installing new or upgrading telemetry (SCADA)
    d. Replacing depreciated T1-L switches and updating switchgear
3. Transformer testing and monitoring
4. Yard improvements

Method of Evaluation

For this report substations were evaluated based on information from the following sources collected over the last five years (2013-2017):

- Site visits;
- Substation Maintenance Department maintenance records, 2013 to 2016 inclusive;
- Substation Assessment 2017

The substations are reviewed individually to provide the clearest update and the details of the individual substation assessments are captured in Table 1.

Report Highlights

Work Completed in Last 5 Years

Highlights of the work completed at London Hydro substations in the last five years include:

- The elimination of substations 1 (4kV), 2 (4kV), Sub 4 Network and Non Network switchgear (13kV), Sub 5 (13kV) and 28 (13kV)
- The replacement of T1-L switches at substations 22 and 27 (leaving two remaining in the system at Sub 36 and 37)
- The replacement of substation DC systems (batteries and/or chargers) at substations 17, 24, 25, 93, 96

- The replacement of protection relays at substations 18, 22, 24, 27, 29, 36, 39, 49
- The replacement of Remote Terminal Units (RTUs) at substations 18, 24, 27, 29, 36, 37, 39 and 49
- ATC control at One London Place, Decade, Galleria, and Old Oak

Work Recommended to be completed in 2017

- The replacement of DC systems (batteries and/or chargers) at substation 27
- The replacement of protection relays at substation 52
- The rebuild of substation 4 for 27.6kV distribution system

Work Recommended to be completed in Next 5 Years

- The replacement of DC systems (batteries and/or chargers) at substation 37
- Complete the rebuild of substation 4 (tied to Carling St. re-build)
- New program – change all structure insulators from Porcelain pin style to Polymer where feasible on a case-by-case basis
- The replacement of protection relays at substations

4kV Conversion Plan

Substations 1, 2, 28 in Zone A of the 4kV conversion project were eliminated. Zone B of the 4kV conversion plan includes substations 18, 29, 48, 54, and 92. Significant conversion due to silicone injection has occurred in substations 96 and 93 areas. Substation 50 in Wonderland TS was also eliminated. The 4kV plan is being reviewed to re-evaluate the timing for the elimination of these stations. Conversion of the entire 4kV system could take 20 years and maintenance will have to continue, but with consideration for the expected life of the asset.

Substation Assessments and Equipment Status Summary - Update and Recommendations

Sub	kV	Location	Assessment	Recommendation	Special Notes
1	4kV/ 13.8kV	Horton and Ridout	• New Service installed to supply 120/240V • 4kV switchgear and 13.8 to 4kV station transformers removed as part of Zone A conversion • All pilot wire protected feeders blocked except 1K3 to Labatt • Rantech RTU • Electromechanical relays • No grounds on fence	• Continue to maintain. No planned upgrade or capital expenditure • 13kV switchgear to be eliminate once conversion of Non-Network is completed (2020)	13.8kV substation in poor condition
2	4kV/ 13.8kV	Kitchener and Cabell	• 4kV switchgear and 13.8 to 4kV station transformers removed as part of Zone A 4kV conversion • 2F2E1 oil switch removed as part of Zone A conversion • 2K2 protections changed to block instantaneous • 2K15 feeder re-routed using old 2K3 riser cable to feed out • New service installed to supply 120/208V to remaining 13.8 switchgear • 2K13 feeder removed going to Nelson • All pilot wire protected feeders blocked • Electromechanical relays • Rantech RTU • Abandoned cement product needs to be removed	• Continue to maintain with no planned upgrade or capital expenditure • 13kV switchgear to be eliminated once conversion of Non-Network is complete • 2K15 can remain as needed	13.8kV substation in poor condition (same vintage as Nelson TS)
4	13.8kV	Carling Street	• Substation removed as part of Non Network 13.8kV conversion • LC7770 (13M3) removed as part of emptying site for future rebuild	• Continue with capital expenditure to upgrade substation to 27.6kV	
5	13.8kV/ 600V	111 Horton	• Substation removed as part of Non Network 13.8kV conversion		
6	13kV	Central Ave	• All pilot wire protected feeder blocked • Rantech RTU • New sign needed for gate and back door needs painting	• Continue to maintain with no planned upgrade or capital expenditure • Substation to be eliminated once conversion of Non Network is completed • A-Bus should be eliminated as first priority	Substation one of the oldest with oil circuit breaker
7	Network Oil Switches 13kV	York Street	• Structural repair completed on support beam and east wall	• Continue to maintain with no planned upgrade or capital expenditure • Eliminate switches as part of the Network conversion plan	

Sub	kV	Location	Assessment	Recommendation	Special Notes
8	13kV	Anne Street	• All pilot wire protected feeders blocked • Yard needs weed removal and new gravel • Yard needs abandoned cement product cleaned up • Rantech RTU	• Continue to maintain with no planned upgrade or capital expenditure • Eliminate as part of the Non Network conversion plan	Potential location for backup 27.6-13.8kV transformer for Non Network system
9	4kV	McCormick Blvd	• Failed PT changed out • Rantech RTU • Electromechanical relays	• Continue to maintain with no capital expenditure • Substation will be eliminated through future 4kV Zone conversion once completed	Only F1 feeder left
10	27.6kV-13.8kV Ring	111 Horton Street	• 10F2 CB Visilink failure	• Continue to maintain with no planned upgrade or capital expenditure • Develop a new switching procedure to ground feeder cable before removing C links	
11	27.6kV-13.8kV Ring	Bathurst and Burwell	• No major changes to the station	• Continue to maintain with no planned upgrade or capital expenditure	
12	27.6kV-13.8kV Ring	Talbot and Bathurst	• 12 SS moved to new source	• Continue to maintain with no planned upgrade or capital expenditure	
15	27.6kV-4kV	Pond Mills	• This substation is identified in Zone C 4kV conversion • Lead clean up done in substation lunchroom area, need to clean up unused cable and structure and remove abandoned risers and associated equipment • Abandoned 4kV switchgear removed • Reclosers and T1-L needs painting • T1 overhead bus system	• Continue to maintain with no planned upgrade or capital expenditure • Substation to be eliminated once Zone C 4kV conversion is completed	
16	27.6kV-4kV	Baseline and Wellington	• No major changes to the station • Breather and filter set-up needed • T1-l needs paint • T1-L overhead bus style	• Continue to maintain with no planned upgrade or capital expenditure • Substation to be eliminated through future 4kV Zone conversion once completed	
17	27.6kV-4kV	Adelaide Street N	• New battery bank and changer installed as part of ongoing capital upgrade program • Lead clean up done in substation lunchroom area • T1-L overhead bus style	• Continue to maintain with no planned upgrade or capital expenditure • Substation to be eliminated through future 4kV Zone conversion once completed	

Sub	kV	Location	Assessment	Recommendation	Special Notes
18	27.6kV-4kV	Gore Rd	• Lead clean up done in substation lunchroom area • New protection relay installed as part of ongoing capital program • New RTU installed as part of ongoing capital program • Overhead bus to transformer replaced with Hendrix cable to mitigate future tracking issue • Gravel needed in yard	• Continue to maintain with no planned upgrade or capital expenditure • Substation to be eliminated through 4kV Zone B & C conversion once completed	
21	27.6kV-4kV	Weston Street	• 21F3 removed as part of 4kV Zone C conversion • Co-11 mechanical relays • Rantech RTU • Old battery charger • Gravel needed in yard	• Continue to maintain with no planned upgrade or capital expenditure • Substation will be eliminated through 4kV Zone C conversion once completed	
22	27.6kV-4kV	Duchess Street	• Protection relay replaced as part of ongoing capital program • T1-L replaced as part of ongoing capital program	• Continue to maintain with no planned upgrade or capital expenditure	
23	27.6kV-4kV	Southdale at Wellington	• This station is near Zone C 4kV conversion and is pad mount style • 23F3 removed from service as part of 4kV Zone C conversion • 23F2 CT's replaced • Electromechanical relays • Rantech RTU • Reclosing scheme blocked on 23F2	• Continue to maintain with no planned upgrade or capital expenditure • Prioritize in next 4kV conversion zones to eliminate the substation or upgrade protection relay to enable reclosing	Only one feeder left 23F2, reclosing scheme disabled on feeder
24	27.6kV-4kV	Oxford at Cherryhill	• New protection relays installed as part of ongoing capital program • New RTU installed as part of ongoing capital program • New transformer temperature gauge installed • 4kV metal clad- needs paint due to rust, considering exchanging with until from Sub 28 if it will fit on existing structure • Asbestos breakers	• Continue to maintain • Incoming T1-L riser should be fused	
25	27.6kV-4kV	Oxford at Sanatorium	• New battery bank installed as part of ongoing capital program • 25T1 retro-filled with new oil • Substation floor needs paint	• Continue to maintain with no planned upgrade or capital expenditure	
26	27.6kV-13.8kV	Kellogg's	• Theft occurred at substation	• Budget for the removal of remaining switchgear. Site to be cleaned up for re-use or possible sale	Site is still not cleaned up

Sub	kV	Location	Assessment	Recommendation	Special Notes
27	27.6kV-4kV	Adelaide and Huron	• Lead clean up done in substation lunchroom area • New T1-L installed as part of ongoing capital program • New protection relay installed as part of ongoing capital program • New RTU installed as part of ongoing capital program • Yard needs weeds removed and new gravel	• Continue to maintain with no planned upgrade or capital expenditure	
28	27.6kV-4kV	Nelson Street	• Substation removed from service as part of Zone A 4kV conversion	• Consider reconditioning metal clad switchgear for re-use elsewhere after conversion is complete (e.g. Sub 24)	
29	27.6kV-4kV	Second Street	• New protection relays installed as part of ongoing capital program • New RTU installed as part of ongoing capital program • 29F4 lead cable removed • Substation floor needs paint	• Continue to maintain with no planned upgrade or capital expenditure	
33	27.6kV-4kV	Sanford Street Mini Sub	• 33F1 CB changed out with a replacement and settings update • Yard needs weeds removed • Transformer and recloser need paint	• Continue to maintain with no planned upgrade or capital expenditure	
35	27.6kV-4kV	Baseline Rd Byron	• Bell insulator changed on fuse holder • Need FOB installed	• Continue to maintain • New program – change all structure insulators from porcelain	
36	27.6kV-4kV	Killaly	• New protection relays installed as part of ongoing capital program • New RTU installed as part of ongoing capital program • 36F1 and 36F3 abandoned as part of 4kV conversion • Yard in poor condition • T1-L shelf style (in good shape) • Fence post grounded but mesh and barbed wire are not, barbed wire needs repair	• Continue to maintain with no planned upgrade or capital expenditure • Accelerate 4kV conversion to eliminate the substation	

Sub	kV	Location	Assessment	Recommendation	Special Notes
37	27.6kV-4kV	Masonville	• New protection relay installed as part of ongoing capital program • New RTU installed as part of ongoing capital program • Yard needs weeds removed and new gravel • Paint needed outside of yard door • T1-L shelf style (in good shape)	• Continue to maintain with no planned upgrade or capital expenditure • New battery bank needed in next 5 years (unless conversion occurs first). Change out as part of ongoing capital upgrade program • Accelerate 4kV conversion to eliminate the substation • Consider installation of new T1-L if conversion delayed	
38	27.6kV-4kV	Wharncliffe Rd	• No major changes to the station • Low oil	• Continue to maintain with no planned upgrade or capital expenditure	
39	27.6kV-4kV	Wonderland Rd	• New protection relay installed at the 39F1 and 39F2 as part of ongoing capital upgrades • New RTU installed as part of ongoing capital program • Security FOB missing	• Continue to maintain with no planned upgrade or capital expenditure	
40	27.6kV-4kV	Chippendale Mini Sub	• This station is identified in Zone C 4kV conversion • 40T1 retro-filled with filtered oil. Was 20ppm now ND for PCB’s • Transformer and recloser need paint	• Continue to maintain with no planned upgrade or capital expenditure	
41	27.6kV-4kV	Oakside Mini Sub (pad mount)	• 41T1 retro-filled with filtered oil. Was 19ppm now ND for PCB’s • Oil filled recloser	• Continue to maintain • Update telemetry (SCADA)	
43	27.6kV-4kV	Springbank Mini Sub	• No major changes to the station • T1-L grounding cut • Yard needs weeds removed	• Continue to maintain with no planned upgrade or capital expenditure	
44	27.6kV-4kV	Riverside Mini Sub	• No major changes to the station • Fins leaking north side of transformer • Yard needs weeds removed	• Continue to maintain with no planned upgrade or capital expenditure • Investigate leaking fins, capital expenditure may be required to change transformer	
46	27.6kV-13.8kV	Highbury Ave	• Substation removed from service and transformer moved to Sub 2 for re-use		Station removed

Sub	kV	Location	Assessment	Recommendation	Special Notes
48	27.6kV-4kV	Trafalgar East	• This station is identified in Zone B 4kV conversion • Rantech RTU • Temporary charger in place – take old charger from Sub 27 and wire into Sub 48 DC bus	• Continue to maintain with no planned upgrade or capital expenditure • Substation to be eliminated once Zone B 4kV conversion is complete	
49	27.6kV-4kV	Clarke Rd	• New protection relays installed at the 49F2 and 49F3 as part of ongoing capital upgrades • New RTU installed as part of ongoing capital program • New EPR cable installed for the 49F2 and 49F3 • 49F1 removed from service • Replaced Bell insulator on structure	• Continue to maintain with no planned upgrade or capital expenditure • New capital program to change all structure porcelain insulators	
50	27.6kV-4kV	Wonderland TS	• Substation removed from service and transformer moved to Sub 93 as back-up		Station removed
51	27.6kV-4kV	Oxford Street West	• No major changes to the station • Yard needs weeds removed and new gravel	• Continue to maintain with no planned upgrade or capital expenditure	
52	27.6kV-4kV	Baseline and Ridout	• New protection relays installed at the 52F2 and 52F3 as part of ongoing capital upgrades • New RTU installed as part of ongoing capital upgrade program • 52F1 and 52F4 removed from service • Transformer needs paint • Breather and filter set-up needed	• Continue to maintain • Replace 27.6kV primary lead riser and install fuses at road	
54	27.6kV-4kV	Trafalgar	• 54 T1-L SF6 gas reclaimed and new installed	• Continue to maintain with no planned upgrade or capital expenditure	
55	27.6kV-4kV	Whiteoaks Side Rd	• No major changes to the station	• Continue to maintain with no planned upgrade or capital expenditure • Accelerate 4kV conversion to eliminate the substation	
83	27.6kV-4kV	Huron and Clarke	• 83T2 gassing issue. Repaired at Stein industries • 83-L SF6 gas reclaimed and new installed	• Continue to maintain with no planned upgrade or capital expenditure	

Sub	kV	Location	Assessment	Recommendation	Special Notes
92	27.6kV-4kV	Wavell and Clarke	• This station is identified in Zone B 4kV conversion • Rantech RTU and CO-11 relays • Oldest 4kV switchgear and has oil breakers	• Continue to maintain with no planned upgrade or capital expenditure • Substation to be eliminated once Zone B 4kV conversion is completed • New capital program to change all porcelain insulators (not needed if removed first)	
93	27.6kV-4kV	Topping Lane	• No major changes to the station • Spare transformer in yard needs paint	• Continue to maintain with no planned upgrade or capital expenditure	
96	27.6kV-4kV	Wharncliffe and Commiss	• New battery bank installed as part of ongoing capital program	• Continue to maintain with no planned upgrade or capital expenditure	
97	27.6kV-8kV	Colonel Talbot	• T1 secondary bushing replaced • T1 and T2 transformers painted • Backed up by overhead transformers	• Continue to maintain with no planned upgrade or capital expenditure • Continue with 8kV conversions. Substation to be eliminated once conversion is completed • Update telemetry (SCADA) • Replace structure insulators	
98	27.6kV-4kV	Dingman	• Transformer flushed and refilled with new oil • Antenna installed for future wireless telemetry communications	• Continue to maintain with no planned upgrade or capital expenditure • Update telemetry (SCADA) • Consider in future Zone conversion • Replace structure insulators • Remove T1 and install 2.5MV pad mounted units	Critical – consider 2 mini's to support load
100	27.6kV-600V	Convention Center	• No major changes to the station	• Continue to maintain with no planned upgrade or capital expenditure	
101	27.6kV-600V	Research Park	• No major changes to the station	• Continue to maintain with no planned upgrade or capital expenditure	
102 103	27.6kV-600V	St. Mary's Hospital	• Replace ATC control with latest SEL work order 2017	• Complete replacement of ATC control to latest SEL	
104	27.6kV-600V	Essex Hall	• No major changes to the station	• Continue to maintain with no planned upgrade or capital expenditure	

Sub	kV	Location	Assessment	Recommendation	Special Notes
106 107	27.6kV-4kV	Greenway Pollution Plant	• No major changes to the station	• Continue to maintain with no planned upgrade or capital expenditure	
108 109 110 111	27.6kV-600V	St. Joe's Hospital	• No major changes to the station	• Complete replacement of ATC control with latest SEL Future WO	
112	27.6kV-4kV	Highbury Pumping Station	• No major changes to the station	• Continue to maintain with no planned upgrade or capital expenditure	
113	27.6kV-4kV	392 South St. Victoria Hospital	• LHSC is planning to demolish this building 2017-18, coordinate for the removal of this substation • Remove transformer and install at Sub 98 or Sub 44	• Continue to maintain with no planned upgrade or capital expenditure until removal	

Summary

Ongoing Capital Programs

London Hydro has four current and ongoing programs, a fifth is recommended, as follows:

1. The replacement of vintage DC systems
2. The replacement of vintage relay systems
3. The replacement or installation of new telemetry (SCADA)
4. The replacement of depreciated T1-L switches and switchgear
5. The replacement of porcelain insulators

1. Replacing Vintage DC Systems

Substation batteries are used within a station to operate circuit breakers and power supervisory equipment. NiCad battery banks have a 15-20 year life span. Yearly reviews are completed recording the age of the bank, maintenance results and substation conversion/elimination plans to aid in choosing the bank`s replacement. Over the past five years, the DC systems (batteries and/or changers) have been replaced at substations 17, 24, 25, 27, 93 and 96. This program will continue with substation 37 in 2018. Special note the next youngest bank was installed in 2003 at substation 38, making the install 14 years old.

2. Replacing Vintage Relays

Escalating failure rates with old mechanical relays have become a reliability issue. If the timing relay cannot be properly calibrated or does not operate properly when needed, the reclosing feature on the distribution feeder circuits will not operate correctly, which can result in extended service interruptions rather than the expected momentary flicker. Also, an inoperable relay can pose a safety risk to the public if the relay doesn't open the feeder when required. Installing new electronic relays provides greater feeder protection and coordination, optimizes feeder operation, assists with faultfinding, mitigates unknown feeder operability risk and improves reliability. Breaker performance issues, maintenance results and zone conversion/elimination plans all factor into which stations will be scheduled for replacement.

Over the last five years, protection relays have been replaced at substations 18, 22, 27, 29, 36, 39 and 49. This program will continue in 2017 with the replacement of relays at substation 52.

3. Installing New or Upgrading Telemetry (SCADA)

Having SCADA telemetry at substations provides the Control Room operators with the real time status of all the feeders fed from the station. This information provides instant feedback that improves outage response time and reliability and will provide historical data on the station loads for planning purposes.

The priority list for substations requiring telemetry (SCADA) include 97, 98 and 41 (not done). These stations will continue to be evaluated based on system performance and zone conversions.

In the last five years, RTU's were placed in substations 18, 24, 27, 29, 36, 37, 39 and 49. In 2017, new RTU's will be installed at substation 52.

4. The Replacement of Depreciated T1-L Switches and Switchgear

The last report identified problems with depreciated switches and switchgear and recommended that their replacement be included in the Capital program. In the last five years T1-L switches have been replaced in substations 22 and 27 in accordance with the reported specific recommendations. Substations 36 and 37 T1-L switches have been identified as being in a depreciated state and should be replaced. T1-L switches at other substations will be reviewed based on maintenance records (2013-16 inclusive), Substation Assessment 2017 and zone conversions.

5. The Replacement of Porcelain Structure Insulators

Porcelain insulators used on the structures inside some of London Hydro's substations are prone to failure similar to known issues with the line post insulators used on the overhead distribution system. These insulators will be assessed and replaced to enhance reliability and safety.

The priority porcelain station insulators to be replaced based on the 2017 Substation Assessment are substations 35 and 49.

Maintenance Programs

Transformer Testing and Monitoring

On a yearly basis, oil samples are taken from all substations and sent to a lab for analysis. Results are compared to previous recordings and to published standards. If readings fall outside of acceptable levels, steps are taken to address the underlying issue. This program has been successful in identifying problems, and in the last five years issues were discovered at substations 25 and 98. At both stations T1 was refilled with new oil. Low level PCB oil was also removed from substations 40 and 41.

It is recommended that we continue with the established annual program.

Yard Improvements

Substation assessments completed in 2017 along with monthly inspections have identified issues with the yard, fence and buildings. Although not as critical as the electrical infrastructure, improvement opportunities are identified. It is recommended that this program continue.

4kV Conversion

In 2011, the "4.16kV Aging Infrastructure System Planning Report" recommended the systematic replacement of all 4kV infrastructures over a 25 year period, with the initial phase addressing three zones (A, B and C) which represent some of the older and more complicated areas of the city. These zone conversions are expected to result in the avoidance of expensive rebuilds. The scope of this work is new to London Hydro and as such presented a challenge in terms of determining the requirements for completion. While zone conversions are currently slightly behind the predicted schedule, due to other priorities that emerged, they are progressing well and are being completed at a steady pace.

It is recommended that these conversions continue and include the elimination/reduction of substations in the area. When the first three zones are completed, it will be important to continue the momentum by identifying new zones for conversion.

Recommendations

1. The Ongoing Capital Programs should continue with plans to complete the following in 2017:
    a. Replace the vintage DC systems at substation 37
    b. Replace the vintage relays at substation 52
    c. Install new or upgraded telemetry (SCADA) for substations 97, 98 and 41 based on system considerations and install new RTU's at substations 18, 24 and 27
    d. Monitor remaining T1-L's at substations 36 and 37
2. Continue transformer testing and monitoring
3. Continue yard improvements
4. Replace or remove ATC controls no longer supported. This relates to substations 102 and 103 in 2017 followed by substations 108, 109, 110, 111 and LC 5764 (GM diesel automated switchgear)
5. Replacement of porcelain pin type insulators at substations 35, 49, 92, 97, and 98

In addition, it is recommended that London Hydro continue with 4kV conversions in Zones B and C. Once those are completed, it is recommended that the program continue with identification of new areas for conversion.

Appendix A: Substation Matrix

Substation	Location	Substation Type	Interrupting Type	Number of Feeders	High Voltage (kV)	Low Voltage (kV)	Transformer (T1)	Transformer (T2)	Transformer (T3)	Transformer style	Station Capacity (MVA)	Battery Voltage (V)	Battery Make and Type	Battery Amp Hours (Ah)	Last Test Date	Date Installed	Battery Charger Make and Number of Cells	Charger Replacement Date	2017 Maintenance Assessment Recommendations
Sub	Address	Equipment		Station Information								Batteries							Recommendation
1 (13.8kV)	Horton & Ridout	Metal Clad	Magnetic Air	9	13.8	13.8	-	-	-	-	-	129	Varta-RM 55	55	Feb.2013	2007	SAFT - 90	2007	• Continue to maintain. No planned upgrade or capital expenditure • 13kV switchgear to be eliminate once conversion of Non-Network is completed (2020)
2 (13.8 kV)	Cabell & Kitchener	Metal Clad	Magnetic Air/Oil	7	13.8	13.8	-	-	-	-	-	129	MTI-KL 65P	65		2009	MTI - 92	2009	• Continue to maintain with no planned upgrade or capital expenditure • 13kV switchgear to be eliminated once conversion of Non-Network is complete • 2K15 can remain as needed • 13.8kV substation in poor condition (same vintage as Nelson TS)
2 (27.6 kV)	Cabell & Kitchener	Padmount	Vaccum in Oil-Pad	1	27.6	13.8			1999	Sealed	7.5								
4	Carling	Switchgear	Air Switches/ Vacuum in Solid-LC	8	13.8	13.8					N/A								• Continue with capital expenditure to upgrade substation to 27.6kV
5	111 Horton St.	Switchgear	Air Switches	1	13.8	600v	-	-	-	Indoor Sealed	0.5+0.5								• Substation has been eliminated
6 (13.8 kV)	Central Ave.	Cottage Style	Oil	4	13.8	13.8	-	-	-	-	-	129	GAZ-KL80-P	80	Jan.2013	2003	MTI - 96	2003	• Continue to maintain with no planned upgrade or capital expenditure • Substation to be eliminated once conversion of Non Network is completed • A-Bus should be eliminated as first priority • Substation one of the oldest with oil circuit breaker
7 (13.8kV)	York	Switchgear	Oil Switch	1	13.8	13.8	-	-	-	-	-								• Continue to maintain with no planned upgrade or capital expenditure • Eliminate as part of the Network conversion plan
8 (13.8 kV)	Ann St.	Metal Clad	Magnetic Air	4	13.8	13.8	-	-	-	-	-	129	VARTA-RM 55	55	Jan.2013	2010	PRIMAX	2010	• Continue to maintain with no planned upgrade or capital expenditure • Eliminate as part of the Non Network conversion plan • Potential location for backup 27.6-13.8kV transformer for Non Network system
9	McCormick Blvd	Metal Clad	Magnetic Air	2	27.6	4.16	1984	1960		Sealed	6+spare	48	Varta-RM 55	40	Apr.2014	2007	SAB NIFE - 36	Original	• Continue to maintain with no capital expenditure • Only F1 feeder left
10	London Hydro Parking Lot	Padmount Swgr	Vacuum Interrupter	2	27.6	13.8						24	Alcad-MC165P	165	Feb.2015	2010	18		• Continue to maintain with no planned upgrade or capital expenditure • Develop a new switching procedure to ground feeder cable before removing C links
11	Bathurst & Burwell	Padmount Swgr	Vacuum Interrupter	4	27.6	13.8						24	Alcad-MC165P	165	Feb.2015	2010	18		• Continue to maintain with no planned upgrade or capital expenditure
12	Bathurst & Talbot	Padmount Swgr	Vacuum Interrupter	4	27.6	13.8						24	Alcad-MC165P	165	Feb.2015	2010	18		• Continue to maintain with no planned upgrade or capital expenditure
15	Deveron & Pondmills	Padmount	Vacuum in Oil-Pad	1	27.6	4.16	1992	1960		Conservator	6+5								• Continue to maintain with no planned upgrade or capital expenditure • Substation to be eliminated once Zone C 4kV conversion is completed

Substation	Location	Substation Type	Interrupting Type	Number of Feeders	High Voltage (kV)	Low Voltage (kV)	Transformer (T1)	Transformer (T2)	Transformer (T3)	Transformer style	Station Capacity (MVA)	Battery Voltage (V)	Battery Make and Type	Battery Amp Hours (Ah)	Last Test Date	Date Installed	Battery Charger Make and Number of Cells	Charger Replacement Date	2017 Maintenance Assessment Recommendations
Sub	**Address**	**Equipment**		**Station Information**								**Batteries**							**Recommendation**
16	**Baseline & Wellington**	Cottage Style	Magnetic Air	2	27.6	4.16	1960			Conservator	5	48	Gaz-KM40P	40	Mar.2014	2008	MTI - 36	2008	• Continue to maintain with no planned upgrade or capital expenditure
17	**Mapledale & Adelaide**	Cottage Style	Magnetic Air	3	27.6	4.16	1960			Conservator	5	48	Powersafe-RM 40	40		2015	PRIMAX - 36	2015	• Continue to maintain with no planned upgrade or capital expenditure
18	**Gore & Montebello**	Cottage Style	Magnetic Air	3	27.6	4.16	1964			Conservator	6	48	Gaz-KM40P	40	Jan.2013	2008	MTI - 36	2008	• Replace 27.6 primary lead riser and install fuses at road
21	**Fairview & Weston**	Metal Clad	Magnetic Air	2	27.6	4.16	1965	1959		Conservator	6+spare	48	Varta-RM 40	40	May.2012	2007	POWERTRONIC - 36	Original	• Continue to maintain with no planned upgrade or capital expenditure • Substation will be eliminated through 4kV Zone C conversion once completed
22	**Dutchess & Wharncliff**	Metal Clad	Magnetic Air	3	27.6	4.16	1965			Conservator	6	48	Hoppecke-FNC 203H	35	Mar.2015	2006	POWERTRONIC - 36	Original	• Continue to maintain with no planned upgrade or capital expenditure
23	**Southdale & Montgomery**	Cottage Style	Magnetci Air	1	27.6	4.16	1965			Conservator	6	48	Hoppecke-FNC 203H	35	Jan.2013	2006	ACE-NIFE - 36	Original	• Continue to maintain with no planned upgrade or capital expenditure • Prioritize in next 4kV conversion zones to eliminate the substation or upgrade protection relay to enable reclosing • Only one feeder left 23F2, reclosing scheme disabled on feeder
24	**Oxford & Cherryhill**	Metal Clad	Magnetic Air	2	27.6	41.6	1963	1962		Conservator	6+5	48	Powersafe-RM 40	40	New 2013	2013	PRIMAX - 36	2013	• Continue to maintain • Incoming T1-L riser should be fused
25	**Oxford and Sanatorium**	Cottage Style	Magnetci Air	2	27.6	4.16	1962			Conservator	5	48	Powersafe-RM 40	40	New 2016	2016	PRIMAX - 36	2016	• Continue to maintain
27	**Huron & Adelaide**	Cottage Style	Magnetic Air	3	27.6	4.16	1963			Conservator	6	48	Powersafe-RM 40	40	New 2017	2017	C-CAN - 36	2017	• Continue to maintain • New battery bank needed. To be changed out in 2018 as part of ongoing capital upgrade program
28	**Nelson & Maitland**	Metal Clad	Magnetic Air									48	Hoppecke-FNC 203H	35	Feb.2013	2005	POWERTRONIC - 37	Original	• Transformers removed • Consider reconditioning metal clad switchgear for re-use elsewhere after conversion is complete (e.g. Sub 24)
29	**Second & Dundas**	Cottage Style	Magnetic Air	3	27.6	4.16	1965			Conservator	6	48	Hoppecke-FNC 203H	35	Aug.2018	2004	STATICON - 37	2004	• Continue to maintain
33	**Sandford & Huron**	Padmount	Vacuum in Oil-Pad	1	27.6	4.16	1995			Sealed	2.5								• Continue to maintain with no planned upgrade or capital expenditure
35	**Baseline & Boler**	Metal Clad	Magnetic Air	2	27.6	4.16	1973			Conservator	6	48	SAFT-NIFE - SBM30-2	30	Jan.2013	2004	POWERTRONIC - 36	2004	• New program – change all structure insulators from porcelain
36	**Kilally & Highbury**	Cottage Style	Magnetic Air	2	27.6	4.16	1965			Conservator	6	48	Hoppecke-FNC 203H	35	Mar.2014	2006	POWERTRONIC - 36	2006	• Continue to maintain with no planned upgrade or capital expenditure • Accelerate 4kV conversion to eliminate the substation
37	**Fanshawe & Richmond**	Cottage Style	Magnetic Air	1	27.6	4.16	1967	1960		Conservator	6+spare	48	Powersafe-RM 40	40	New 2018	2018	C-CAN - 36	2018	• Continue to maintain with no planned upgrade or capital expenditure • New battery bank needed in next 5 years (unless conversion occurs first). Change out as part of ongoing capital upgrade program • Accelerate 4kV conversion to eliminate the substation • Consider installation of new T1-L if conversion delayed
38	**Riverside & Wharncliff**	Cottage Style	Magnetic Air	3	27.6	4.16	1992			Conservator	6	48	NIFE JUNGER-GAZ	55	Aug.2018	2003	MTI - 40	2003	• Continue to maintain with no planned upgrade or capital expenditure

Sub	Address	Equipment		Station Information								Batteries							Recommendation
Substation	Location	Substation Type	Interrupting Type	Number of Feeders	High Voltage (kV)	Low Voltage (kV)	Transformer (T1)	Transformer (T2)	Transformer (T3)	Transformer style	Station Capacity (MVA)	Battery Voltage (V)	Battery Make and Type	Battery Amp Hours (Ah)	Last Test Date	Date Installed	Battery Charger Make and Number of Cells	Charger Replacement Date	2017 Maintenance Assessment Recommendations
39	**Riverside & Wonderland**	Metal Clad	Magnetic Air	2	27.6	4.16	1967			Conservator	6	48	Hoppecke-FNC 203H	35	Jul.2013	2005	SAB NIFE - 37	2005	• Continue to maintain with no planned upgrade or capital expenditure
40	**Chippendale & King Edward**	Padmount	Vacuum in Oil-Pad	1	27.6	4.16	1973			Sealed	2.5								• Continue to maintain with no planned upgrade or capital expenditure
41	**Oxford & Oakside**	Padmount	Oil Recloser	1	27.6	4.16	1973			Sealed	2.5								• Continue to maintain with no planned upgrade or capital expenditure • Update telemetry (SCADA)
43	**Springbank & Kernohan**	Padmount	Vacuum in Solid-Viper	1	27.6	4.16	1981			Sealed	2.5								• Continue to maintain with no planned upgrade or capital expenditure
44	**Riverside & Everglade**	Padmount	Oil Recloser	1	27.6	4.16	1987			Sealed	2.5								• Continue to maintain with no planned upgrade or capital expenditure • Investigate leaking fins, capital expenditure may be required to change transformer
48	**Trafalgar & Clarke**	Cottage Style	Magnetic Air	2	27.6	4.16	1981			Sealed	**5**	48	Varta-RM 40	40	Mar.2014	2008	ACE-NIFE - 36	Original	• Continue to maintain with no planned upgrade or capital expenditure • Substation to be eliminated once Zone B 4kV conversion is complete
49	**Clarke & Culver**	Metal Clad	Magnetic Air	3	27.6	4.16	1966			Conservator	6	48	Gaz-KM40P	40	May.2012	2008	MTI - 36	2008	• Continue to maintain with no planned upgrade or capital expenditure • New capital program to change all structure porcelain insulators
51	**Oxford & Oakridge**	Padmount	Vacuum in SF6-Pad	2	27.6	4.16	2003			Sealed	6								• Continue to maintain with no planned upgrade or capital expenditure
52	**Baseline & Ridout**	Cottage Style	Magnetic Air	3	27.6	4.16	1966			Conservator	6	48	Hoppecke-FNC 203H	36	Aug.2018	2004	STATICON - 37	2004	• Replace 27.6kV primary lead riser and install fuses at road • Continue to maintain
54	**Trafalgar & Thorne**	Padmount	Vacuum in Oil-Pad	3	27.6	4.16	2000	2000		Sealed	2.5+2.5								• Continue to maintain with no planned upgrade or capital expenditure
55	**White Oak & Southdale**	Padmount	Oil Recloser	1	27.6	4.16	1995			Sealed	2.5								• Continue to maintain with no planned upgrade or capital expenditure • Accelerate 4kV conversion to eliminate the substation
83	**Huron & Clarke**	Padmount	Vacuum in Oil-Pad	3	27.6	4.16	2001	2001		Sealed	2.5+2.5								• Continue to maintain with no planned upgrade or capital expenditure
92	**Wavell & Clarke**	Cottage Style	Oil	2	27.6	4.16	1958			Conservator	5	48	Hoppecke-FNC 35H	36	Nov.2011	2006	STATICON - 36	Original	• Continue to maintain with no planned upgrade or capital expenditure • Substation to be eliminated once Zone B 4kV conversion is completed • New capital program to change all porcelain insulators (not needed if removed first)
93	**Topping & Commissioners**	Metal Clad	Magnetic Air	3	27.6	4.16	1984			Sealed	6	48	Varta-RM 40	40		2012	PRIMAX - 36	2012	• Continue to maintain with no planned upgrade or capital expenditure
96	**Wharncliff & Commissioners**	Metal Clad	Magnetic Air	3	27.6	4.16	2003			Sealed	6	48	Powersafe-RM 40	40		2014	NEW-PRIMAX P4500 - 36	2014	• Continue to maintain

Substation	Location	Substation Type	Interrupting Type	Number of Feeders	High Voltage (kV)	Low Voltage (kV)	Transformer (T1)	Transformer (T2)	Transformer (T3)	Transformer style	Station Capacity (MVA)	Battery Voltage (V)	Battery Make and Type	Battery Amp Hours (Ah)	Last Test Date	Date Installed	Battery Charger Make and Number of Cells	Charger Replacement Date	2017 Maintenance Assessment Recommendations
Sub	**Address**	**Equipment**		**Station Information**								**Batteries**							**Recommendation**
97	**Scottsville & Hwy 402**	Outdoor	Oil Recloser	1	27.6	8	1951	1949		Conservator	2+2								• Continue to maintain with no planned upgrade or capital expenditure • Continue with 8kV conversions. Substation to be eliminated once conversion is completed • Update telemetry (SCADA) • Replace structure insulators
98	**White Oak & Dingman**	Outdoor	Air Switches	3	27.6	4.16	1954	2001		Cons/ Sealed	5+2.5								• Continue to maintain with no planned upgrade or capital expenditure • Update telemetry (SCADA) • Consider in future Zone conversion • Replace structure insulators • Remove T1 and install 2.5MV pad mounted units • Critical – consider 2 mini's to support load
100	**Convention Center**	Indoor SF6	SF6 Switches and wallmount fuses		27.6	0.6	-	-	-	-	-	-	-	-	-	-	-	-	• Continue to maintain with no planned upgrade or capital expenditure
101	**Research Park**	Indoor SF6	SF6 Switches and wallmount fuses		27.6	0.6	-	-	-	-	-	-	-	-	-	-	-	-	• Continue to maintain with no planned upgrade or capital expenditure
102, 103	**St. Mary's Hospital**	Indoor SF6	SF6 Switches and wallmount fuses		27.6	0.6	-	-	-	-	-	-	-	-	-	-	-	-	• Complete replacement of ATC control to latest SEL
104	**Essex Hall**	Indoor SF6	SF6 Switches and wallmount fuses		27.6	0.6	-	-	-	-	-	-	-	-	-	-	-	-	• Continue to maintain with no planned upgrade or capital expenditure
106, 107	**Greenway Pollution Plant**	Indoor SF6	SF6 Switches and wallmount fuses		27.6	4.16	-	-	-	-	-	-	-	-	-	-	-	-	• Continue to maintain with no planned upgrade or capital expenditure
108, 109, 110, 111	**St. Joe's Hospital**	Indoor SF6	SF6 Switches and wallmount fuses		27.6	0.6	-	-	-	-	-	-	-	-	-	-	-	-	• Complete replacement of ATC control with latest SEL Future WO
112	**Highbury Pumping Station**	Indoor	customer owned switchgear		27.6	4.16	-	-	-	-	-	-	-	-	-	-	-	-	• Continue to maintain with no planned upgrade or capital expenditure
113	**392 South St. Victoria Hospital**	Indoor	customer owned switchgear		27.6	4.16	-	-	-	-	-	-	-	-	-	-	-	-	• Continue to maintain with no planned upgrade or capital expenditure until removal

London Hydro

High Voltage Design Report for Dundas Flex Street

December 2017

Acknowledgements:

This report was developed with input and collaboration received from the following members of the Planning, Design, and Standards departments.

Contributors	**Department**	**Role**
Ismail Sheikh, P.Eng.	Systems Engineering	Planning and Report
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Many staff in multiple departments including Operations, Design, and Substation Maintenance provided valuable input along the way.

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Executive Summary

Subsequent to the high level feasibility assessment of partitioning the existing secondary grid network by London Hydro and evaluation of the Plan by METSCO, this report details the high voltage design requirements of the new 27.6kV supplied minigrid networks and the ensuing modifications required to the existing system.

A long term vision of the system configuration post Dundas Flex Street was developed taking into account other capital programs such as the conversion of 13.8kV non-network customers and second contingency designs for the North and South grid networks. "Enabler" plans were developed in order to eliminate 13.8kV circuitry along Dundas where possible via circuit reconfigurations to minimize impact during the 2018-2019 construction period.

The planning objectives associated with the High Voltage design for Dundas Flex Street are as follows:

- Update the aging distribution infrastructure on Dundas Street in tandem with the city's project.
- Effectively convert the Dundas St. corridor primary supply from 13.8kV to 27.6kV.
- Implement a secondary network consisting of six minigrid networks ("zones").
- Reconfigure the primary radial feeders to the North and South grid networks to ensure an N-2 design.
- Offload Sub 10 to allow for the utilization of hard to convert 13.8kV non-network customers.

The 13.8kV supplied secondary network currently services the downtown core via substations 10, 11, and 12. The existing secondary network is to be split into three sections: North, South, and Centre. This is done to achieve better operability, less complexity, and increased reliability. The North and South sections will remain on the 13.8kV system and were reconfigured to maintain an N-2 design criteria.

The configuration of the 27.6kV supplied minigrid networks was established to meet an N-1 design criteria. The transformers supplying the minigrid networks have been customized by London Hydro by incorporating dual loadbreak switches to mimic "switchable" padmounted transformers for improved reliability and operational flexibility.

The existing 13.8kV network transformers windings are delta-wye-grounded, whereas the new 27.6kV network transformers will be wye-grounded-wye-grounded. The advantages and disadvantages of the two configurations were analyzed considering ferroresonance, protective relay operations, harmonics, primary feeders off a combination feeder (i.e. non-dedicated supply feeder).

The network protector is the key to automatic isolation and continued operation. In addition, the Dundas minigrid networks will be equipped with the latest technology to permit monitoring and control of the network transformers via SCADA. Eaton's VaultGard Gateway will be deployed to track vital network protector performance metrics.

1 Introduction

A combination of aging infrastructure and new development (i.e. Dundas Place) has compelled London Hydro to optimize its distribution system supplying the downtown core. A high level feasibility assessment of partitioning the existing grid network into three sections was performed in 2016 and this was validated by METSCO consultants under their design evaluation. The North and South grid networks would remain on an existing 13.8kV primary supply, pending conversion to 27.6kV as per London Hydro's vision for a single distribution system voltage where feasible. The Centre grid network will be located along the Dundas Flex Street corridor between Ridout Street and Wellington Street (a.k.a. Dundas Place). This report will provide a more in depth analysis of the high voltage design for the Dundas Flex Street minigrid networks, as well as the impacts its implementation will have on the distribution supply in the downtown core.

2 Objectives

To avoid coordination challenges between the City's contractor and London Hydro's construction staff that could potentially impact the schedule and cost of the Dundas Flex Street project, the bulk of London Hydro's work will be tendered as part of the City's contract utilizing contractors approved by London Hydro. This means the design, and hence planning, for years 2018 and 2019 would need to be included in the tendered package. The implication is an aggressive project timeline that has expedited London Hydro's planning and design activities for not only 2018 & 2019, but rather the years 2017-2020.

A long term vision of the system configuration post Dundas Flex Street, considering other capital programs such as the 13.8kV non-network conversion, was necessary to develop overall efficient plans for downtown distribution system. Additional steps were taken to limit the extent of high voltage work required within Dundas Street by carrying out "enabler" works that involved eliminating 13.8kV circuitry along Dundas where possible via circuit reconfigurations. These circuit reconfiguration plans considered the need to redesign the supply to the North and South grid networks for an N-2 contingency; and offloading the Sub 10 feeders to free up the stepdown 27.6kV-13.8kV transformation for use on the 13.8kV non-network system for difficult to convert customers.

The planning objectives associated with the High Voltage design for Dundas Flex Street are as follows:

1. Update the aging distribution infrastructure on Dundas Street in tandem with the city's project.
2. Effectively convert the Dundas St. corridor primary supply from 13.8kV to 27.6kV.
3. Implement a secondary network consisting of six minigrid networks ("zones").
4. Reconfigure the primary radial feeders to the North and South grid networks to ensure an N-2 design.
5. Offload Sub 10 to allow for the utilization of hard to convert 13.8kV non-network customers.

3 27.6kV High Voltage Design for Secondary Network

3.1 Topology and Architecture

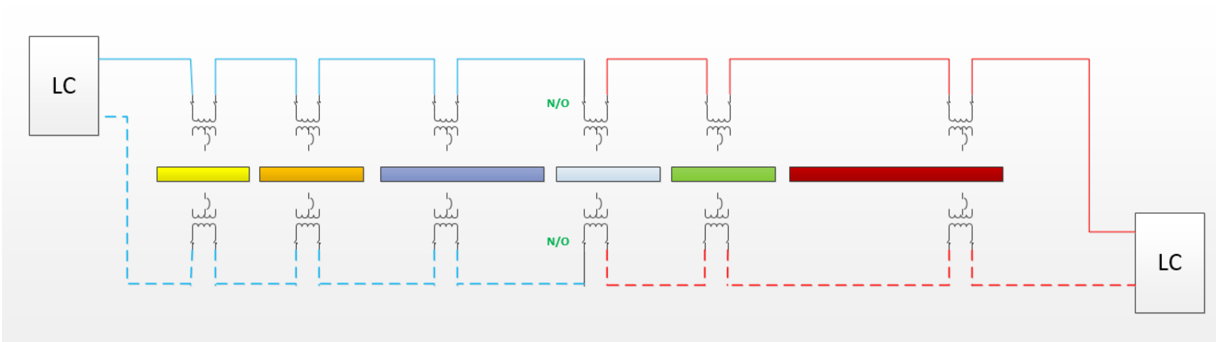

Figure 1: Schematic of the 27.6kV supplied Secondary Network

A high level depiction of the 27.6kV supplied minigrid networks on Dundas St. is shown in Figure 1.

Each LC (load centre) represents an S&C Vista Switchgear as the source of the 27.6kV feeders. The design topology is based on looped primary feeders supplying pairs of network transformers that form independent miniature secondary grid networks (or extended spot networks). Under normal system configuration, the LC located inside Sub 4 (left) will supply zones 1, 2, and 3, while the LC located at King and Wellington (right) will the remaining zones 4, 5, and 6.

Networks are normally fed by feeders originating from one substation bus (as was the case for the Nelson BQ bus). Having one source reduces circulating current and gives better load division and distribution among circuits. It also reduces the chance that network protectors stay open under light load (circulating current can trip the protectors). Although difficult, it is still possible to feed secondary networks from different substations or electrically separate busses. The architecture for the Dundas Flex Street minigrids is based on one bus supplying the minigrids. Hence, the two feeders originating from either LC will always be off the same bus, though both LCs may not necessarily be off the same supply. This subtlety is attempted to be shown in Figure 1 with the solid blue and dashed blue feeders coming off the same bus of Source 1 and solid red and dashed red coming off a difference bus of Source 2.

The planned routes for these 27.6kV feeders are depicted in Figure 2. All primary runs will use a triplexed, 2/0 copper cable with 200 amp capacity utilizing one duct. The configuration of the 27.6kV supplied minigrid networks was established to meet an N-1 design criteria. The routes of the feeders were selected to minimize single-point contingencies, such as manhole events; however, there is one instance where both feeders are in the same vault or cross the same manhole.

For each zone (minigrid), the primary voltage will be stepped down from 27.6kV to 120/208V by a pair of 750kVA network transformers. These transformers have been customized by London Hydro by incorporating dual loadbreak switches to mimic “switchable” padmounted transformers. These switches may be used to quickly isolate faulted cables or isolate transformers for maintenance for improved reliability and operational flexibility.

Figure 2 Routing of 27.6kV Primary Network Feeders

3.2 Network Transformer

The existing 13.8kV network transformers windings are delta-wye-grounded, whereas the new 27.6kV network transformers will be wye-grounded-wye-grounded. The advantages and disadvantages of the two configurations were analysed considering ferroresonance, protective relay operations, harmonics, primary feeders off a combination feeder (i.e. non-dedicated supply feeder). T.A. Short summarizes these points well in his Electrical Power Distribution Handbook (2nd edition):

> *Most network transformers are connected delta-grounded wye. While there are advantages to this type of transformer configuration in terms of blocking zero sequence currents and harmonics, a major disadvantage of this connection is with combination feeders – those that feed network loads as well as radial loads. For a primary line-to-ground fault, the feeder breaker opens, but the network transformers will continue to backfeed the fault until all of the network protectors operate (and some may stick). Now, the network transformers backfeed the primary feeder as an ungrounded circuit. An ungrounded circuit with a single line-to-ground fault on one phase causes a neutral shift that raises the line-to-neutral voltage on the unfaulted phases to line-to-line voltage. The non-network load connected phase-to-neutral is subjected to this overvoltage.*
>
> *Some networks use grounded-wye-grounded-wye connections. This connection fits better for combination feeders. For a primary line to ground fault, the feeder breaker opens. Backfeeds to the primary through the network still have a grounding reference with the wye-wye connection so chances of overvoltages are limited. The grounded-wye-grounded-wye*

connection also reduces the change of ferroresonance in cases where a transformer has single-pole switching.[1]

For ease of transitioning between two system voltage classes, the new network transformers have been designed with dual-voltage primary winding 13.8kV delta and 27.6kV wye-grounded (Figure 3). As discussed earlier, a 27.6kV wye-grounded primary configuration was selected as this is ideal for combination feeders where the primary feeder is not dedicated to supplying a secondary network system. The transformers were standardized at 750kVA capacity for an N-1 design such that one transformer is able to supply the associated minigrid.

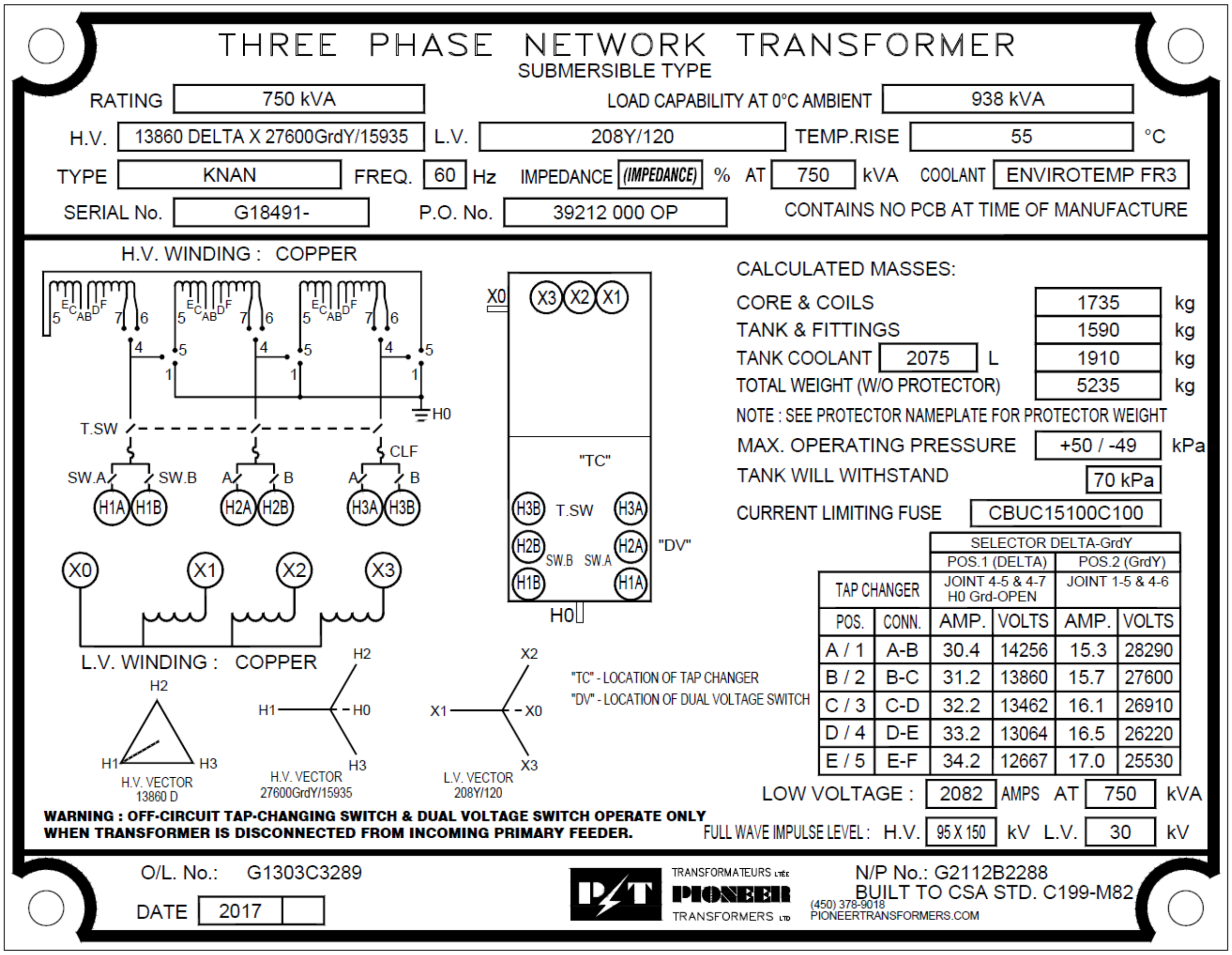

Figure 3: New Network Transformer Name Plate

The transformer is designed with a five-legged core which is typical for a wye-grounded-wye-grounded configuration. This reduces the problem of tank heating as the extra leg provides an iron path for zero-sequence flux, so none travels into the tank. The problem with a three-legged core

[1] T.A. Short, Electric Power Distribution Handbook, 2nd ed. (Florida: CRC Press, 2014), 243.

construction is that when there is unbalanced secondary loading and voltage unbalance on the primary system, the zero-sequence flux has no iron-core return path, so it must return via a high-reactance path through the air gap and partially through the transformer tank.2

The outline drawing and customized internal switching arrangement for the new network transformers are shown in Figure 4 and Figure 5. The switches were designed such that personnel will be able to perform operations using a hot stick on grade level without a need to enter the vault.

[2] T.A. Short, Electric Power Distribution Handbook, 2nd ed. (Florida: CRC Press, 2014), 223.

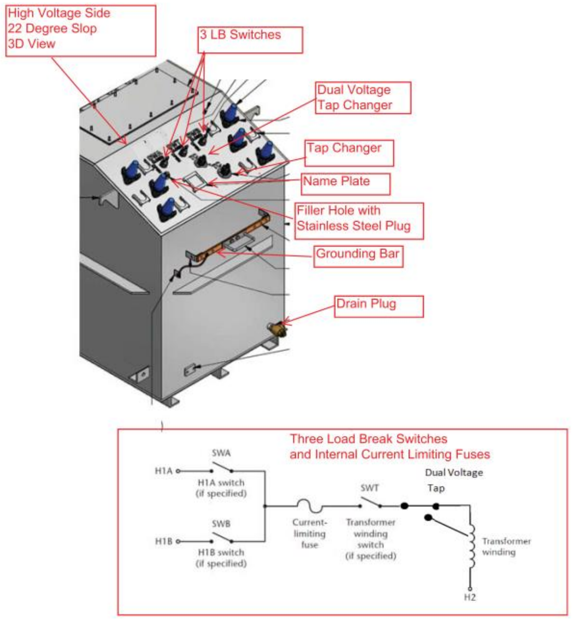

Figure 5: Conceptual Arrangement of the Innovative Design for the Dundas Street NTs

3.3 Network Protector Settings and Protection Coordination

A network protector is a three-phase low-voltage circuit breaker with controls and relaying that will open when there is reverse power through it. When a fault occurs on a primary circuit, fault current backfeeds from the secondary network to the fault. When this occurs, the network protector will trip on reverse power. The network protector does not have forward-looking protection. The network protector is the key to automatic isolation and continued operation.

They are maximum current rated devices. Therefore, they should not be applied outside their nameplate ratings. The transformers for Dundas Flex Street have been standardized at 750kVA, hence the Network Protector is 2500 amp rated. Note that the rated current of the secondary side of a 750kVA network transformer is 2080 amps. The network protector has been designed to permit 20% overloading of the transformer.

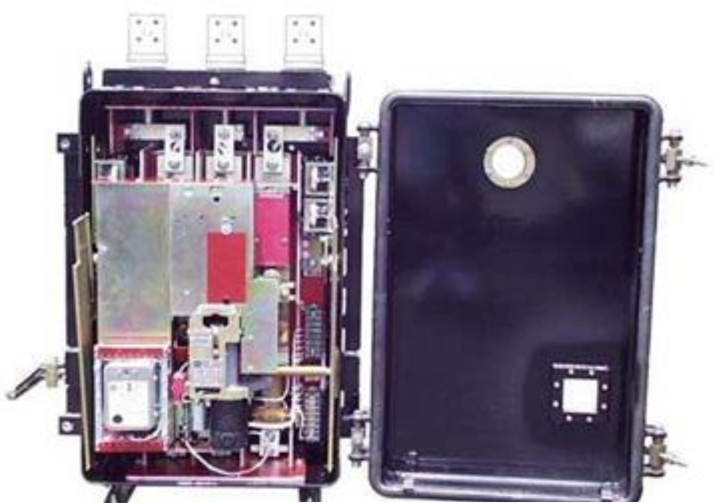

Figure 6: Network Protector

London Hydro's approved products for the Network Protector are the Cutler-Hammer Type CM-22 and the Richards Manufacturing Type 313-NP. Secondary Network protectors are designed to the ANSI/IEEE Standard C57.12.44, IEEE Standard Requirements for Secondary Network Protectors.

The existing network protector settings based on the 13.8kV-208/120V transformers were reviewed in light of the new 27.6kV/13.8kV-208/120V transformers. The transformer manufacturer's test data for the 5 transformers received are shown in the Table below:

Table 1: New Network Transformer Manufacturer's Test Data

Transformer SN #	Excitation Current %	Excitation Current amps at 208V	No Load Loss	Full Load Loss	Impedance Z%	X/R
G18491-1	0.16	3.33	998	5130	4.71	6.8
G18491-2	0.18	3.75	1054	5070	4.66	6.8
G18491-3	0.17	3.54	1039	4966	4.66	7.0
G18491-4	0.16	3.34	1001	5136	4.79	6.9
G18491-5	0.16	3.34	992	5142	4.68	6.8

The typical settings used historically for the 13.8kV transformers and the recommended settings for the new 27.6kV transformers are shown in the Table below.

Table 2: Network Protector Settings

	Typical Settings for 13.8kV Transformers	Recommended Settings for 27.6kV Transformers
Closing Characteristic		
Closing Curve	Straight Line	Straight Line
Master Line Volts	1.2	1.2
Phasing Line	-5 degrees	-5 degrees
Tripping Characteristic		
Tripping Curve	Reverse Trip – Sensitive	Reverse Trip – Sensitive
Trip Level	0.15%	**0.13%**
Time Delay	0	0

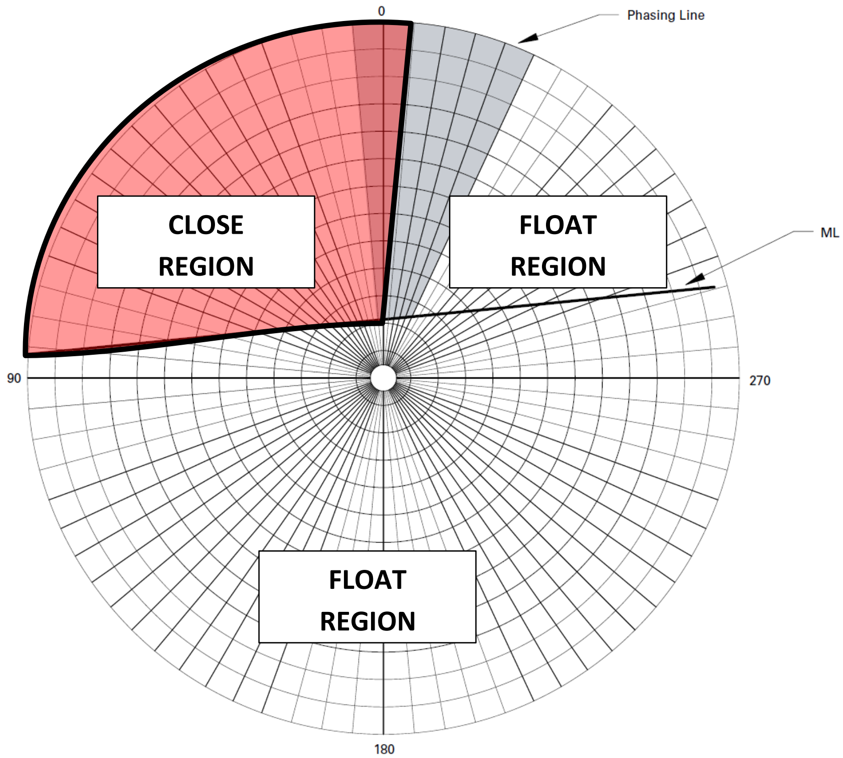

Figure 7: Typical Network Protector Relay Straight Line Closing Curve

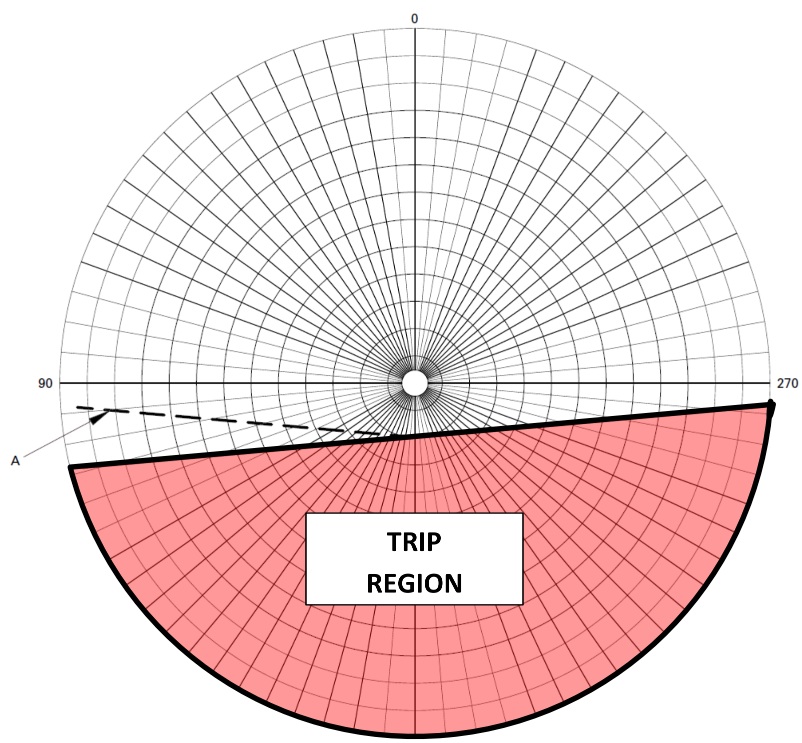

Figure 8: Typical Network Protector Relay Sensitive Trip Curve

3.4 Smart Grid Technology

The Dundas minigrid networks will be equipped with the latest technology to permit monitoring and control of the network transformers via SCADA. Eaton's VaultGard Gateway will be deployed to track vital network protector performance metrics such as:

- Device address including status and MPCV relay reason codes
- Breaker position and alarms
- Phase Currents
- Network, Transformer, and Phasing voltages
- Operations counter
- Power metrics: Real (Kilowatts), Reactive (VAR), Power factor
- Positive sequence angle and positive sequence voltage
- Sensor input: captures wireless current sensor and temperature data
- Real time MPCV vector graphic display

The VaultGard Gateway also offers alarms, logging of captured relay data, and set point control. MPCV data can be viewed through a series of phasor plots that illustrate real-time load data along with set point trip and close boundary characteristics. These plots automatically adjust to reflect the current relay state and curves, and can be used to detect errors, send alerts, and show where problems exist within the network.

4 13.8kV Supplied Secondary Network Re-Design

The 13.8kV supplied secondary network currently services the downtown core via substations 10, 11, and 12. Each substation is fed from Talbot TS (26M48 feeder) at 27.6kV. As previously mentioned, the existing secondary network is to be split into three sections: North, South, and Centre. This is done to achieve better operability, less complexity, and increased reliability. The North and South sections will remain on the 13.8kV system.

The existing secondary grid network has a N-2 design criteria. The North grid which reaches as far north as Kent St. and the South grid which reaches as far south as York St. were reviewed to ensure the N-2 design criteria would still be applicable post Dundas Flex Street. Upon review, it was determined that dissecting the Dundas minigrids out of the wider secondary grid network would impact the N-2 design criteria and primary feeder modifications would be necessary to ensure the network components would not be stressed under a second contingency.

These feeder modifications were performed in conjunction with 'enabler' works to vacate 13.8kV feeders from Dundas Street to facilitate the upcoming rebuild. Since the conversion of Dundas St. to 27.6kV would yield an excess of transformation capacity on the 13.8kV network, the primary feeder modifications were planned to offload substation 10 for the purpose of leveraging it as part of the 13.8kV non-network customer conversion program. Figure 10 details the substation connections post conversion (2020). A larger version of this figure can be found in the Appendix along with year-over-year modifications of the primary network feeders.

The end goal for the North and South grid networks is that it will be supplied by Substation 11 and 12, two feeders from each substation, four feeders in total. This would allocate a total of 16MVA transformation capacity from the Substations, 8 MVA from each Sub. In an N-2 scenario with the loss of 2 feeders from either the North or South Grid, the remaining 8MVA of capacity is sufficient to supply the load under peak conditions without stressing the step-down transformers at Sub 11 and 12. N-2 design was also reviewed at the local area of the network transformers and modifications were made to ensure sufficient redundancy and in the supply to these transformers.

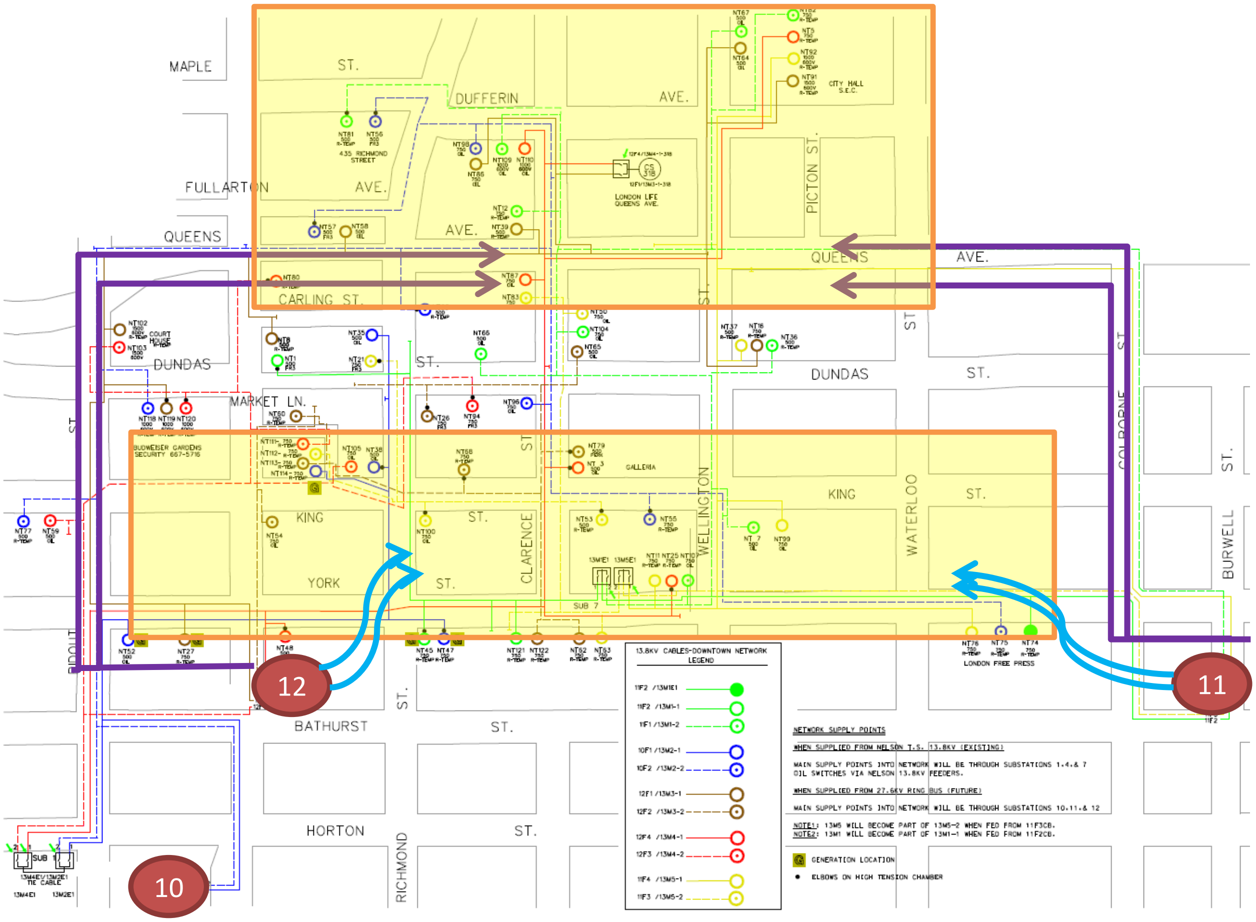

Figure 9: 13.8kV Supply to North and South Grids Plan Drawing

Figure 9 provides a simple view of the plan to resupply the remaining North and South Grid networks. The four feeders supplying the North Grid are routed on the fringes of the downtown core, thereby allowing better cable management and the congestion in the core. Figure 10 provides a one-line diagram schematic of the planned supply to the network transformers post all ‘enabler’ modifications and offloading Sub 10 by year 2020.

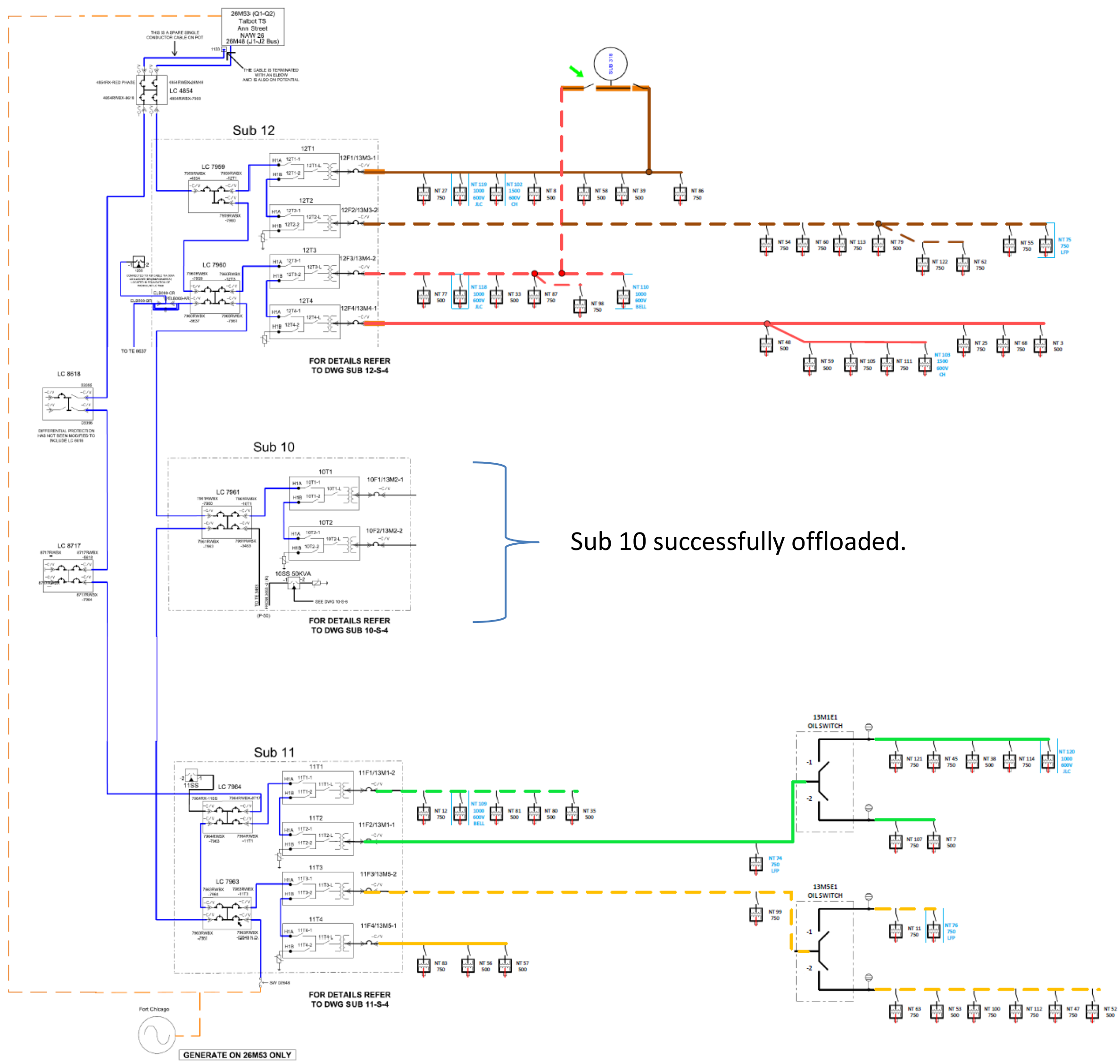

Figure 10: 13.8kV Supply to North and South Grids Plan Schematic – with Sub 10 Offloaded

4kV Conversion Plan – 2018 Update

Plan for Rear Lot to Front Lot Conversion

September 2018

Acknowledgements:

This report was developed with input and collaboration received from the following members of the System Engineering & Design Engineering Departments. Valuable input was also received from the Supervisor of the System Operating Centre, Rolf Reiners, and the Supervisor of the Electrical Maintenance & Stations Department, Steve Legan.

Contributors	**Department**	**Role**
Ismail Sheikh, P.Eng.	Systems Engineering	System planning & report
Jagoda Borovickic, P.Eng.	Design Engineering	Design evaluation of rear lot to front lot conversion & report
Gelber Vargas, E.I.T.	Systems Engineering	Reliability evaluation & Geomedia plots and statistics
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Rolf Reiners	System Operating Centre	Feedback on Operational Challenges

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Executive Summary

London Hydro has upgraded significant portions of the 4.16kV system over the past 20 years to 27.6kV. The 4.16kV infrastructure is gradually being phased out due to its limited capacity, inability to serve load growth, and the high system losses associated with it. London Hydro has thirty-three (33) 4.16 kV substations remaining in-service throughout the City.

The 10-year 4kV system plan developed in 2011 identified three priority zones based on a coordinated approach using multiple evaluation factors such as age and condition of assets, reliability and system performance, and operational flexibility.

This 2018 report is intended to provide an update on the status of the priority Zones A, B, and C, provide direction for the next conversion Zone, and evaluate design options for rear lot to front lot conversions.

Update

Zone A: The scope of Zone A includes the conversion of substations 1, 2, and 28 service territories and portions of their associated backup feeders. Conversion of Zone A is complete.

Zone B: The scope of Zone B includes the conversion of substations 18, 48, 54 and 92 service territories. Overall more than 50% of Zone B has been converted, primarily within subdivisions which are more difficult and resource intensive compared to conversions on arterial roads. Conversions on the arterial roads and decommissioning of the substations remains to be completed. A plan has been developed to address the remaining areas in the next 2-3 years subject to rate of Capital investments in this area.

Zone C: The scope for Zone C includes the conversion of substations 15 and 40 service territories and portions of backup feeders from Subs 16 and 21. Overall nearly 60% of Zone C has been converted. There is a plan in place to convert the remaining subdivisions and decommission substations 15, 21 and 40 within 3-4 years subject to rate of Capital investments in this area.

Recommendations for New Zone of Conversion

Recent reliability data, substation assessments, and Operations staff feedback was considered in identifying the next Zone of conversion. In selecting the new Zone for conversion, it is recognized that multiple zones may need to be constructed in parallel due to developments in reliability, performance degradation, and balancing available construction resources efficiently.

Zone D has been selected as the Oakridge region bounded by Oxford St, Wonderland Rd, Springbank Dr, Commissioners Rd, and Sanatorium Rd. This zone has been subdivided into four areas to be prioritized based on reliability performance. Within this zone there is a mixture of front lot and rear lot 4kV construction. Area 1, known as the Oak Park subdivision, is recommended to be prioritized due to poor reliability performance. This area is bounded by Oxford Street on the north, Sifton Bog on the east, Plymouth Ave on the South, and Sanatorium Rd on the west. One of the 4kV circuits in this neighbourhood runs through the Sifton Bog which is a conservatory area with very large trees both City and Customer owned that overhang or are adjacent to the 4kV circuit.

Evaluation of Options for Overhead Rear Lot to Front Lot Conversion

There are several existing areas within London Hydro service territory that are supplied from the rear lot overhead 4kV system. Many operating, safety, reliability and customer service issues are associated with the rear lot supply. London Hydro retained an external consulting firm (Tetra Tech) to evaluate various conversion options to address those issues and to recommend the most cost effective conversion option. This part of the report summarizes the inventory, condition, concerns, recommended conversion option, and high level cost for implementation. It was recommended that the existing rear lot overhead supply system be converted to the front lot underground supply system.

1 Introduction

London Hydro has converted significant portions of the 4.16kV system over the past 20 years. The 4.16kV infrastructure is gradually being phased out due to its limited capacity, inability to serve load growth, and the high system losses associated with it. A majority of the assets on the 4.16kV system are old and approaching the end of their useful service life. The goal is to continue the 4.16kV to 27.6kV conversions where feasible.

The 10-year 4kV system plan[1] developed in 2011 identified three priority zones based on a coordinated approach using multiple evaluation factors such as age and condition of assets, reliability and system performance, and operational flexibility.

London Hydro has thirty-three (33) 4.16 kV substations remaining in-service throughout the City. The asset replacement resulting from the 4.16kV conversion program is expected to have a number of positive impacts on future O&M costs such as:

- reduction in frequency of pole failure and the costs associated with outage response and reactive replacement when newer poles are installed as part of the voltage conversion;
- lower labour-intensive program of inspection and corrective maintenance[2];
- lower line losses; and
- improved overall system reliability, resulting in lower costs associated with outage response.

This 2018 report is intended to provide an update on the status of the priority Zones A, B, and C, provide direction for the next conversion Zone, and evaluate design options for rear lot to front lot conversions.

[1] A report entitled '4.16kV Aging Infrastructure System Planning Report – 2011' was released in October – 2011
[2] As compared to the periodic preventive maintenance required for legacy assets such as transformers and switches, which can no longer be economically maintained.

2 Zones A, B, and C Conversion Status Update

Capital Projects for the years 2012-2018 targeted the priority zones recommended in the '4.16kV Aging Infrastructure System Planning Report – 2011'. The report recommended Zone A to be addressed in the years 2012-2013, Zone B to be addressed in the years 2014-2016, and Zone C to be addressed in the years 2017-2019. The Planning Report recognized that urgent situations could arise that impact investments into the 4kV system upgrades and hence rate of converting the 4kV system. The Planning Report also recognized that the prioritization within the plan could change due to ongoing assessments and reliability evaluations.

The following tables and maps provide a brief summary of work completed to date. Overall, the plan outlined in the 2011 report has proceeded as indicated. At times, in lieu of work within the priority zones, upgrading and silicone injection of subdivisions with depreciated (i.e. beyond expected useful service life) underground infrastructure was necessary for reliability improvements.

Refer to the Appendix 1 for comprehensive maps.

2.1 Zone A Status Update

Conversion of Zone A is 100% complete. Details as follows:

- 4.16kV Substations 1, 2, and 28 within Zone boundary were decommissioned and associated circuits converted to 27.6kV.
- Other 4.16kV backup feeders originating from Substations 16, 21, 22, and 52 were addressed as follows:
  - Substation16
    - Portions of the 16F1 and 16F2 have been removed
  - Substation 21
    - Feeder 21F3 and portions of the 21F2 have been removed
  - Substation 22
    - Minimal removal of 4.16kV infrastructure served by this station
  - Substation 52
    - Portions of the 52F1 and 52F4 have been removed

Table 1: Zone A Status Update

Station	2011 Rank	Overall Completion (%)	Circuit Conversions (%)	Transformers Converted (%)	4kV Station Decommissioned?
Sub 1	4	100 %	100 %	100 %	Yes
Sub 2	1	100 %	100 %	100 %	Yes
Sub 28	2	100 %	100 %	100 %	Yes

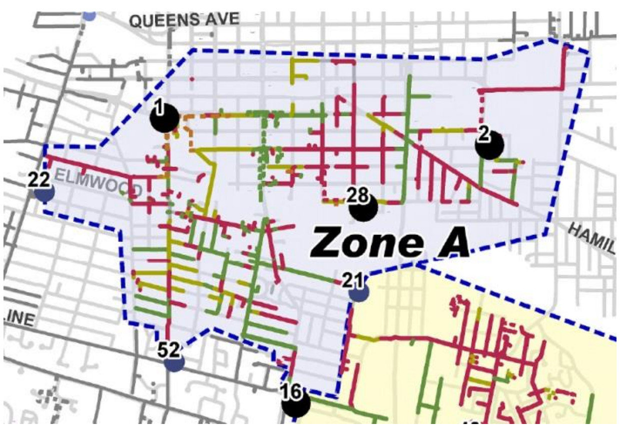

Figure 1: 4.16kV Map of Zone A in the 2011 Report

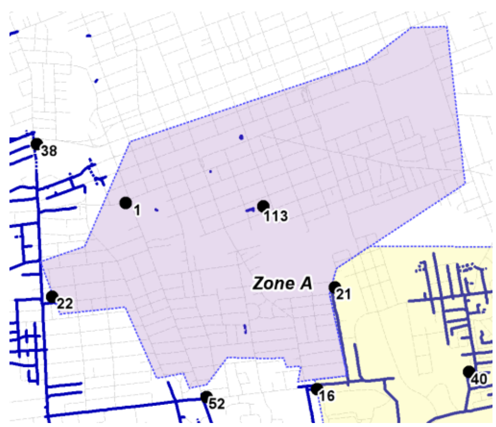

Figure 2: 4.16kV Map of Zone A as of August 2018

2.2 Zone B Status Update

Conversion of Zone B is partially complete (45%). Details as follows:

- 4.16kV Substations 18, 48, 54, and 92 within Zone boundary are still in service
- Extensive conversion of 4.16kV circuits in subdivisions within Zone boundary has been completed
- 4.16kV circuits along arterial roads remain to be completed
- Other 4.16kV backup feeders originating from Substations 29 and 15:
  - Substation 29
    - 29F1 backup to 54F2 circuit was disconnected at Dundas and Saskatoon St. as part of the conversion of 4kV along Dundas St.

Table 2: Zone B Status Update

Station	2011 Rank	Overall Completion (%)	Circuit Conversions (%)	Transformers Converted (%)	4kV Station Decommissioned?
Sub 18	10	45 %	47 %	42 %	No
Sub 48	36	6 %	1 %	11 %	No
Sub 54	25	52 %	48 %	55 %	No
Sub 92	3	78 %	78 %	79 %	No
ZONE B Overall		55%	53%	57%	

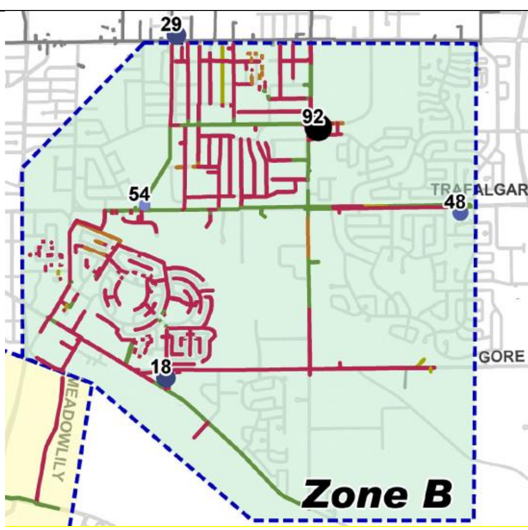

Figure 3: 4.16kV Map of Zone B in the 2011 Report

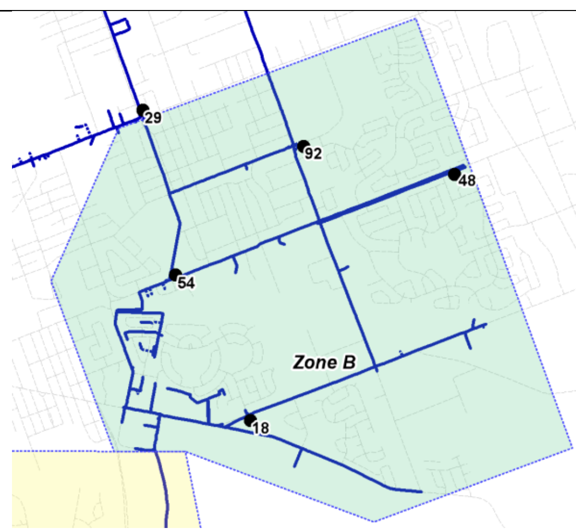

Figure 4: 4.16kV Map of Zone B as of August 2018

Continued conversion of Zone B is recommended to address the remaining 4kV infrastructure. This will offload substations 48, 92, 54, and 18 to a point where they can be decommissioned. Substation 92 transformers are 1958 vintage and the associated switchgear is the oldest in the system (oil filled breakers). The following plan is proposed for the continued conversion of Zone B:

Table 3: Proposed conversion to complete Zone B (Refer to Figure 5)

Steps	Description	Outcome
1 and 2	Convert Saskatoon St from Dundas St to Trafalgar, and convert Wavell St from Clarke Rd to Saskatoon St	Partial conversion of 29F1 and full conversion of 54F2 and 92F2 feeders
3 and 4	Convert Clarke Rd. from Atlantic court to Dundas St, to Wavell Rd, and to Trafalgar St	Partial conversion of 49F2 and full conversion of 92F3 feeder. *Now can decommission Sub 92*
5 and 6	Convert Trafalgar St from Thorne Ave to Clarke Rd to Lem Gardens. *48F2 tie to 18F3 is required until 18F3 is fully converted.*	Full conversion of 54F1, 48F1 and 48F2.
7 and 8	Convert Clarke Rd from Trafalgar St to Gore Rd and convert Gore Rd from Marconi Gate to Montebello Dr.	Full conversion of 18F3. *Now can decommission Sub 48.*
9 and 10	Convert Hale St. from Trafalgar St to Hamilton Rd and Hamilton Rd from Hale to Meadowlily Rd. Convert Hamilton Rd from Gore Rd to Clarke Rd. *18F1 tie to 15F3 is required until 15F3 is fully converted.*	Full conversion of 54F3 and partial conversion of 18F1. *Now can decommission Sub 54.*

Note Sub 54 transformers are of a relatively newer vintage (2 x 2.5MVA units of 2000 vintage) and can be reclaimed to replace older transformers in the 4kV system that will not be converted within 5 years.

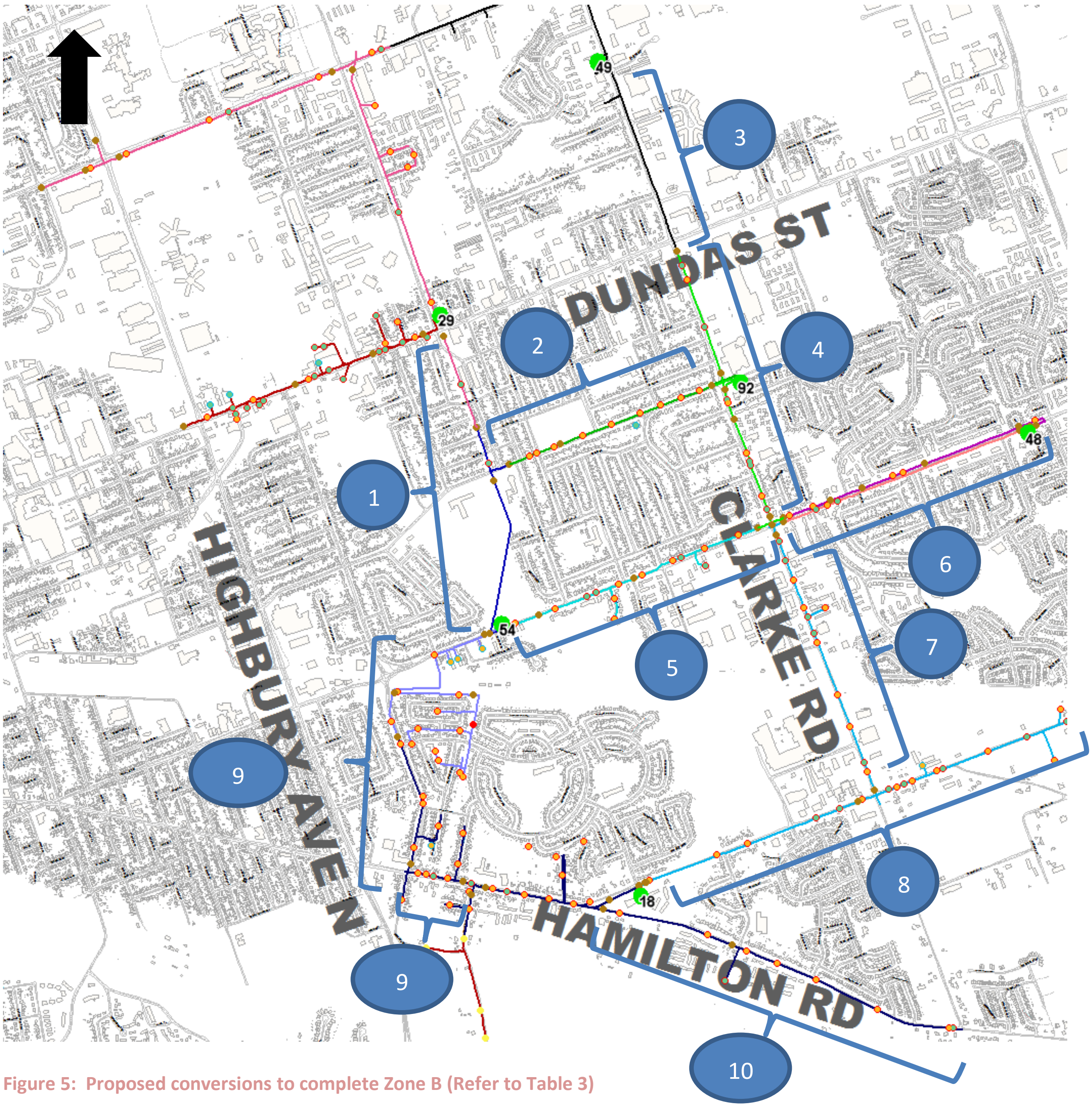

Figure 5: Proposed conversions to complete Zone B (Refer to Table 3)

2.3 Zone C Status Update

Conversion of Zone C is partially complete (60%). Details as follows:

- 4.16kV Substations 15 and 40 within Zone boundary are still in service
- Conversions within this zone north of Commissioners have started this year along Thompson Road.
- Pond Mills subdivision underground has been upgraded to 27.6kV as part of the SPOORE underground subdivision program
- Approximately 0.5km of 15F3 underground cable has been removed
- Other 4.16kV backup feeders originating from Substations 16 and 21:
    - Substation 16
        - 29F1 backup to 54F2 circuit was disconnected at Dundas and Saskatoon St. as part of the conversion of 4kV along Dundas St.
    - Substation 21 - Portions of the 21F2 and 21F3 have been removed

Table 4: Zone C Status Update

Station	2011 Rank	Overall Completion (%)	Circuit Conversions (%)	Transformers Converted (%)	4kV Station Decommissioned?
Sub 15	6	36%	35%	37%	No
Sub 16	5	69%	64%	75%	No
Sub 21	17	85%	71%	98%	No
Sub 40	32	45%	31%	58%	No
ZONE C Overall		58%	51%	66%	

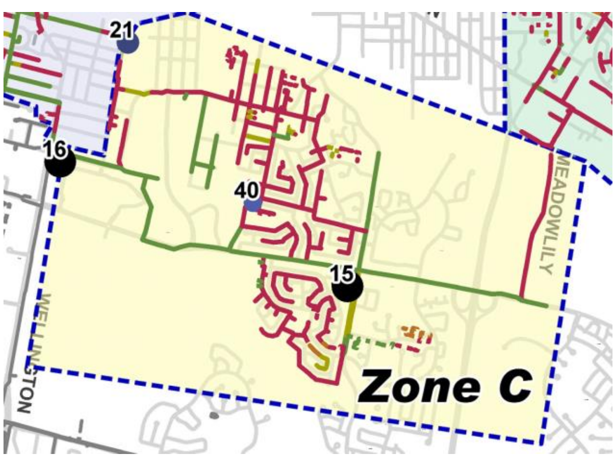

Figure 6: 4.16kV Map of Zone C in the 2011 Report

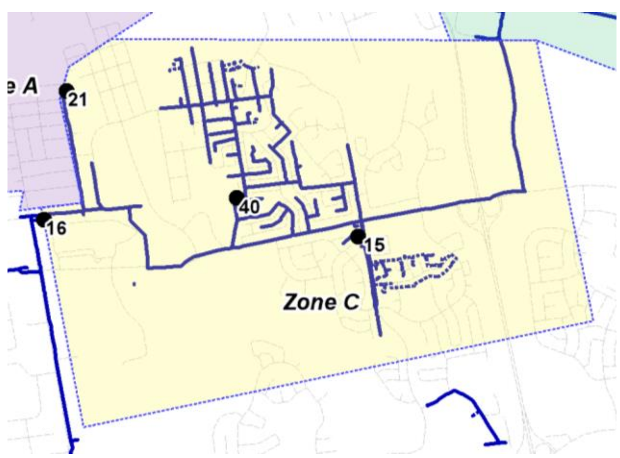

Figure 7: 4.16kV Map of Zone C as of August 2018

Continued conversion of Zone C is recommended to address old 4kV infrastructure. This will offload substations 40 and 15 to a point where they can be decommissioned. As well, Substation 18 can be decommissioned once 15F3 is fully converted. The following plan is proposed for the continued conversion of Zone C:

Table 5: Proposed conversions to complete Zone C (Refer to Figure 8)

Steps	Description	Outcome
1	Convert remaining Glen Cairn neighbourhood. *40F1 tie to 16F3 is required until 16F3 is fully converted.*	Full conversion of 40F1 and partial conversion of 15F3 and 16F3
2	Convert Hamilton Rd from Gore Rd to Meadowlily Rd and convert Meadowlily Rd from Gore Rd to Commissioners Rd. At Meadowlily and Norlan Ave, it is recommended to use a step-down transformer to soft convert the six single phase transformers south of the river to Commissioners Road. The area is a defined as a Tree Protection Area by the City of London and there development to warrant a 3-phase 27.6kV build is not expected in the foreseeable future. There are a number of poles on Meadowlily that are greater than 55 years old. Pole condition should be reviewed at the time of soft conversion to determine if these poles should be replaced.	Full conversion of 18F1 and partial conversion of 15F3. *Now can decommission Sub 18.*
3	Convert Commissioners Rd from Meadowlily Rd to Pond Mills Rd.	Partial conversion of 15F3
4	Convert Pond Mills Rd from Commissioners Rd to south of Deveron Crescent including the Pond Mills subdivision.	Full conversion of 15F3. *Now can decommission Sub 15.*
5	Convert Commissioners Rd from Pond Mills Rd to Adelaide St. *The 21F2 circuit along Fairview Ave is an express circuit to back up the 16F3. No conversion is required along Fairview Ave.*	Partial conversion of 16F3.
6 and 7	Convert Base Line Rd from Wellington St to Westminster Ave. *The 21F2 circuit along Fairview Ave is an express circuit to back up the 16F3. No conversion is required along Fairview Ave.*	Full conversion of 16F3. *Now can decommission Sub 21.*

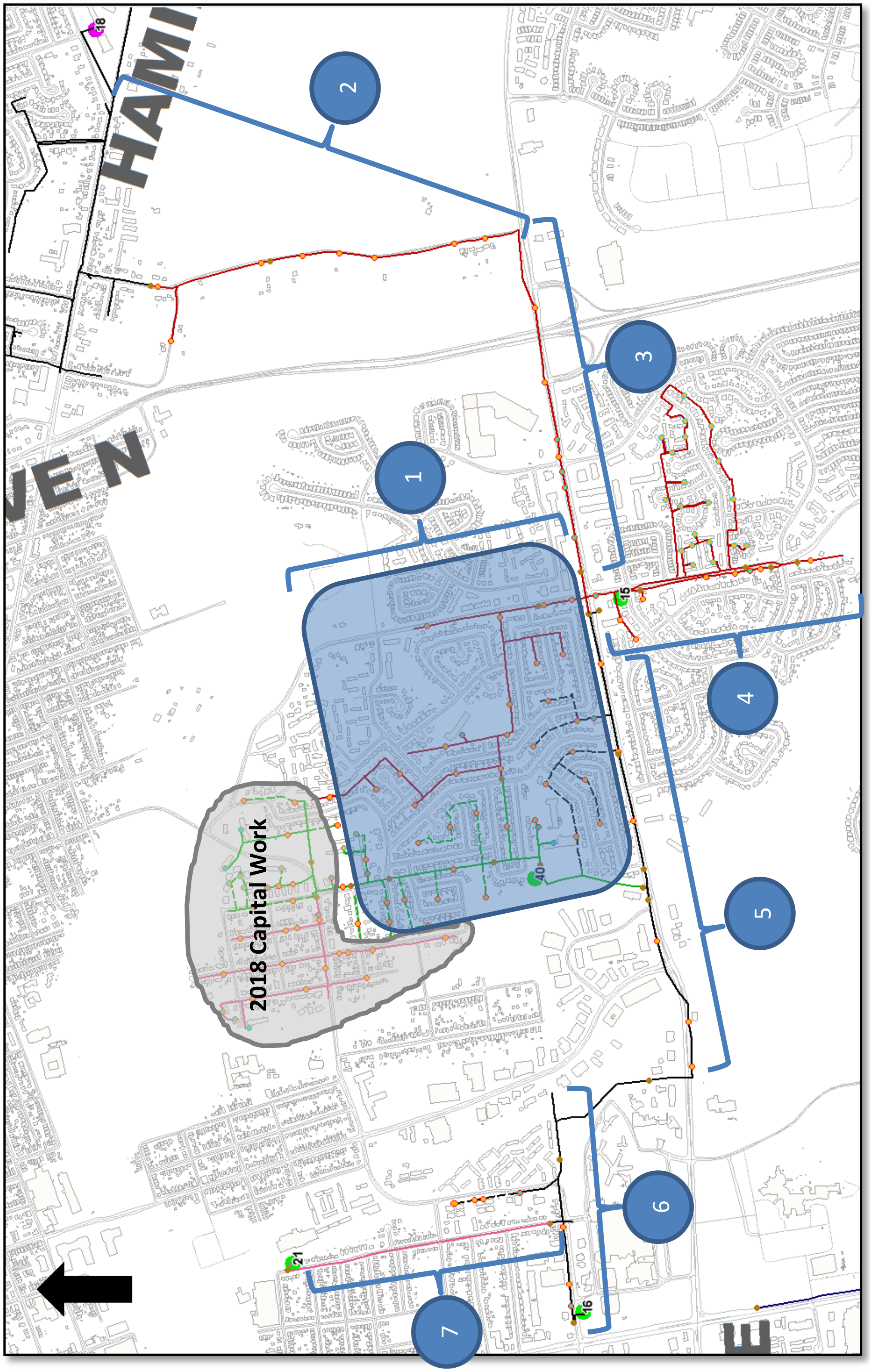

Figure 8: Proposed conversions to complete Zone C (Refer to Table 5)

2.4 Summary of Investments into 4.16 kV System Upgrades

The table below summarizes capital project investments made into converting the 4.16kV system to 27.6kV.

Table 6: Summary of 4.16kV Capital Project Investments

Year	Cost	YTD Total
2011	$2,558,385	$2,558,385
2012	$5,896,787	$8,455,171
2013	$3,963,659	$12,418,831
2014	$3,590,500	$16,009,331
2015	$3,005,745	$19,015,077
2016	$2,528,883	$21,543,960
2017	$2,590,219	$24,134,179
2018[3]	$1,881,419	$26,015,598

[3] These 2018 values are based on YTD costs, at the time of writing this report, with estimated projections for end-of-year expenditures.

3 New Conversion Zones

3.1 Criteria

The 2011 4kV planning report identified various areas where the infrastructure was depreciated[4] in 2011 and would be depreciated in the years 2016 and 2021. Although the relative age of the 4kV system may be the same in various parts of the City, the performance of the 4kV feeders in terms of reliability and operational flexibility varies from one part of the City to another. Furthermore, the recent reliability performance of rear lot construction is generally poorer in comparison to front lot construction. This can be explained by considering the environmental conditions in backyards with greater tree related outages and longer repair times due to accessibility challenges which are further exacerbated by customer installations of pools, sheds, etc.

Recent reliability data, substation assessments, and Operation staff feedback was considered in identifying the next Zone of conversion. In selecting the new Zone for conversion, it is recognized that multiple zones may need to be constructed in parallel due to developments in reliability, performance degradation, and balancing available construction resources efficiently. For example, Zone D below encompasses areas that have both front lot and rear lot construction, were the rear lot area is recommended to be prioritized in 2019 due to poor reliability performance. This rear lot design and construction will require more underground design/construction staff resources as opposed to overhead design/construction staff resources. Conversely, the remaining areas of Zone B, C and D will require predominantly overhead design/construction staff resources. Therefore, Zone B and C can be addressed in parallel with the design/construction of the rear lot area in Zone D.

3.1.1 Reliability

The performance of the 4kV feeders was evaluated based on outage data from 2013 to 2018 YTD. Scheduled outages were excluded from the dataset in order to focus on unplanned outages under London Hydro's control (loss of supply due to Hydro One was excluded).

The number of customers interrupted and the duration in minutes of interruption per feeder were merged to get reliability indicators for Feeder Average Interruption Duration Index (FAIDI) and Feeder Average Interruption Frequency Index (FAIFI). In order to classify the performance of the feeder based on FAIFI and FAIDI, the indicators were weighted as 70% and 30% respectively[5].

Similarly, the Substations supplying the 4kV feeders were ranked based on the reliability of its feeders. That is, the aggregated FAIFIDI performance indicator ratings determined the performance of the respective substation.

[4] The term "depreciated" used in this report denotes infrastructure that is aged and operating beyond expected useful service life.

[5] The frequency of interruptions was considered as having a higher impact to customer as opposed to the duration of the interruption. In addition, the FAIFI trend was steadier whereas the FAIDI trend fluctuated significantly.

Figure 9 below shows the 4kV feeders in service and their reliability performance ranked relative to each other from least performing to best performing.

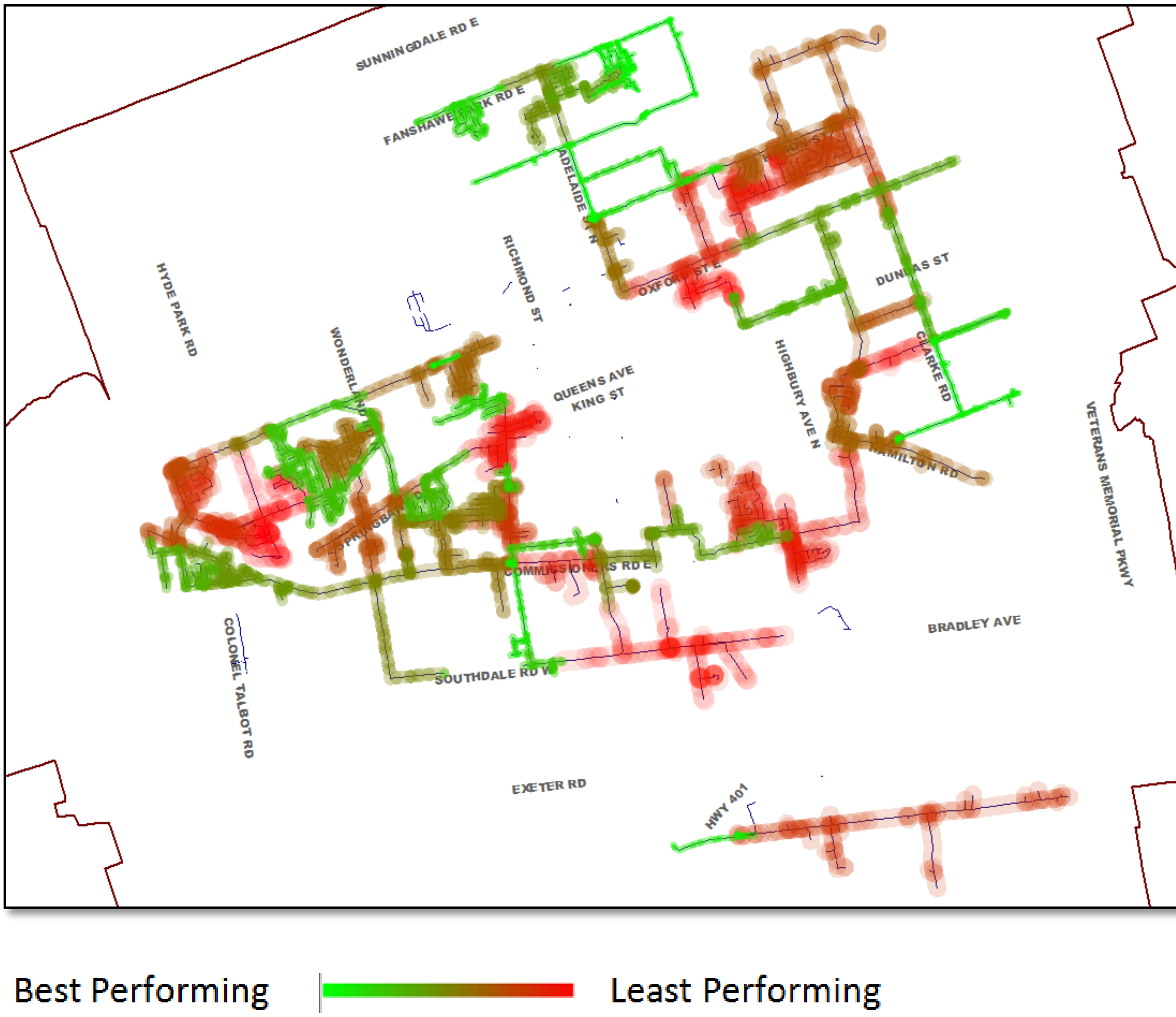

Figure 9: 4kV feeder reliability performance

Correspondingly, Figure 10 shows the aggregation of feeder performance allocated to the respective Substation.

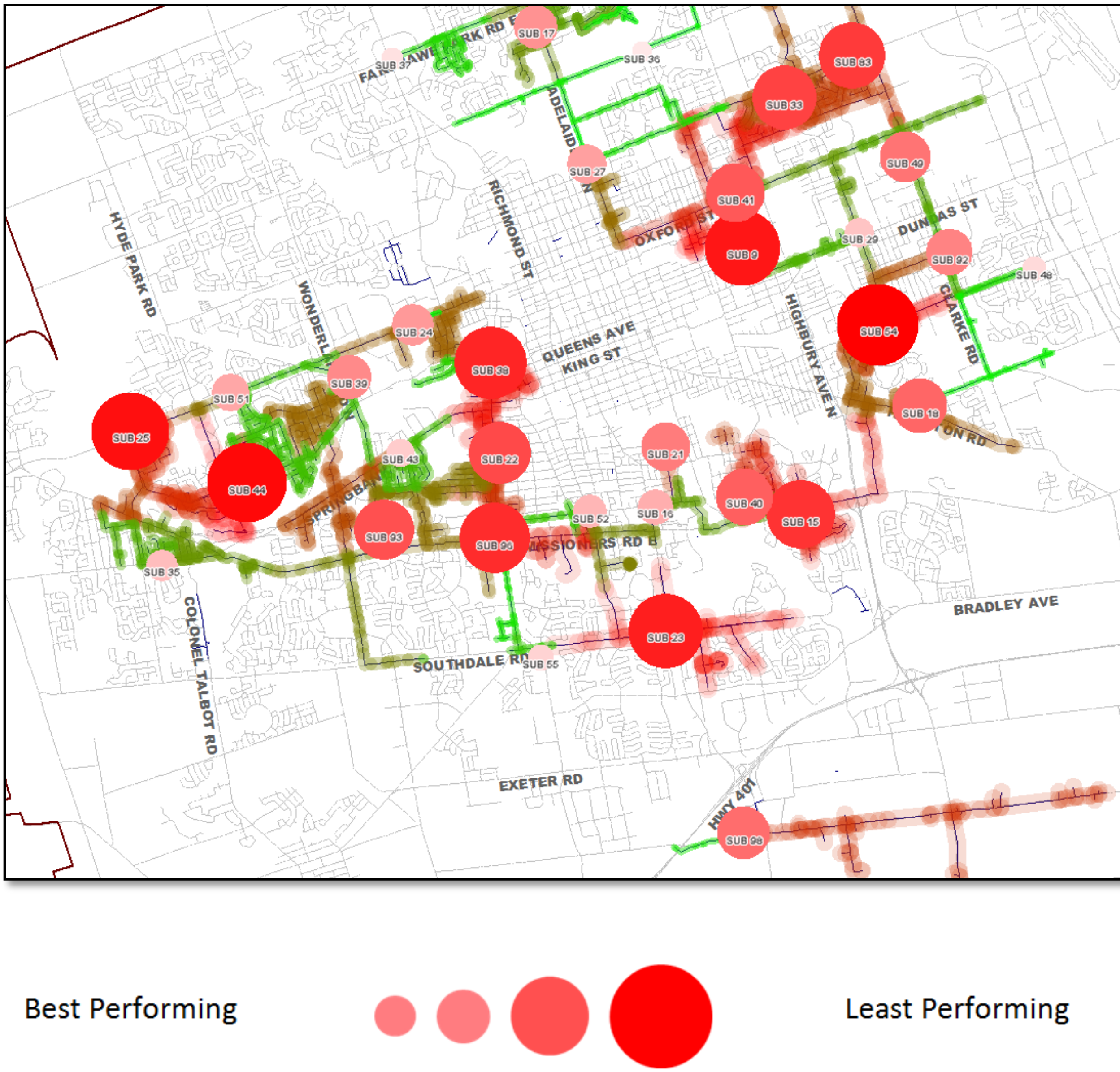

Figure 10: 4kV substation reliability performance

3.1.2 Asset Management

The 2015 Asset Sustainment Plan evaluated the rate of replacement of overhead circuits, including poles. Poles are tested on an annual basis to ensure public safety and worker safety, and the test results are a main driver for developing the capital replacement plan. Based on London Hydro's empirical data over a six year period, the average estimated life span of a pole is 55 years. The ASP determined that on average 686 poles per year would need to be replaced (including third party poles) in order to address all poles that were greater than 55 years of age in 2015 or will reach 55 years of age over the next 15 years.

The Figure below illustrates poles older than 55 years on the 4kV system (including third party poles) as of August 2018. There are 2,277 poles older than 55 years on the 4kV system.[6] In total, there are 3,571 poles older than 55 years in the entire system. As expected, the 4kV system is an older system and as such 64% of depreciated poles (>= 55 years of age) support 4kV infrastructure. Targeting investments into 4kV conversions zones is a cost effective means to upgrade a legacy distribution system while satisfying the commitments in the ASP.

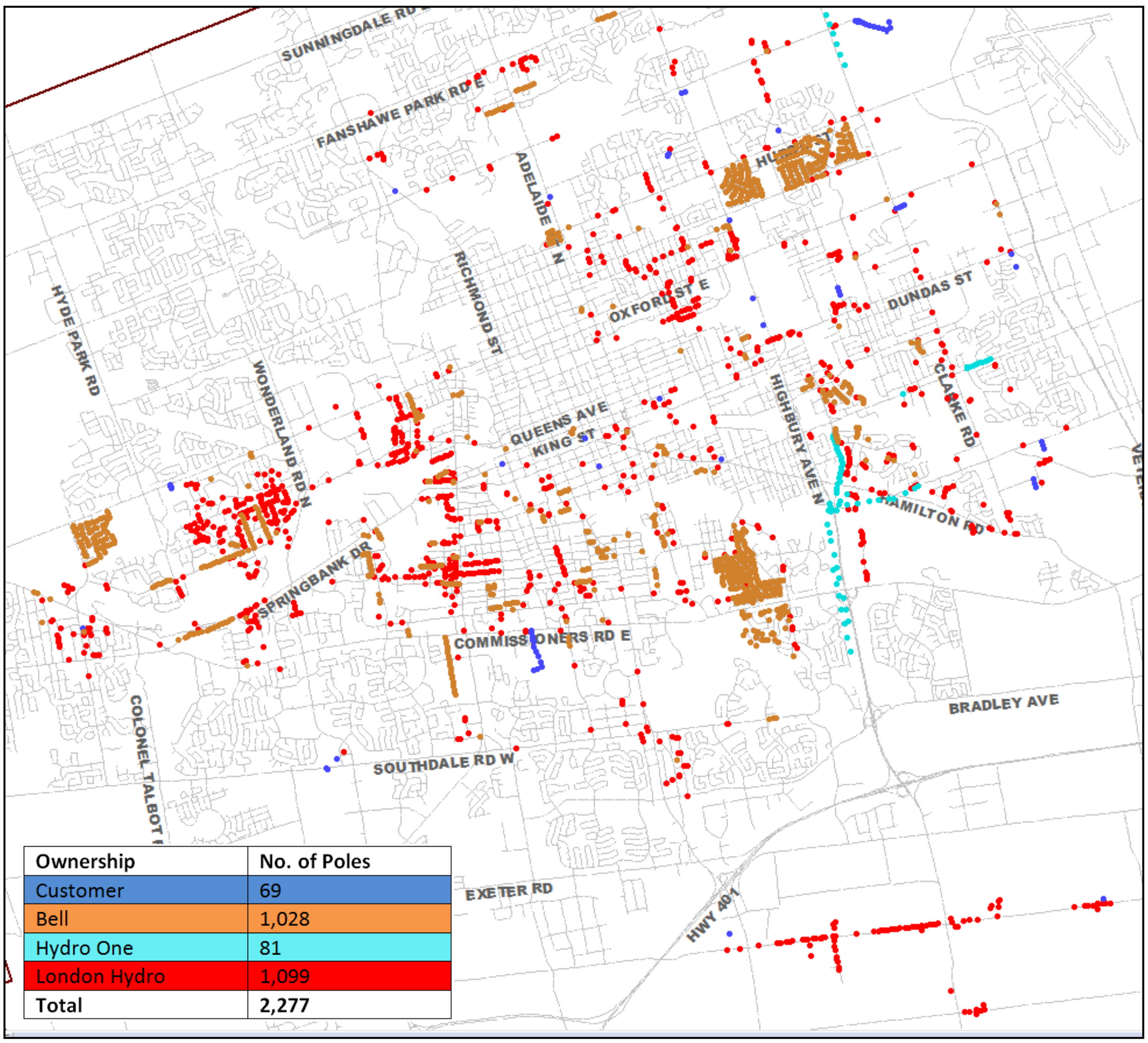

Figure 11: Depreciated poles (>55 years, beyond expected useful service life) of on the 4kV System.

[6] These are poles that either have 4 kV circuits only, or a combination of 4kV and 27.6kV circuits.

Figure 12 below presents a map of the overhead and underground 4.16kV primary conductors based on Age. The red colouring denotes depreciated (i.e. beyond expected useful service life) infrastructure.

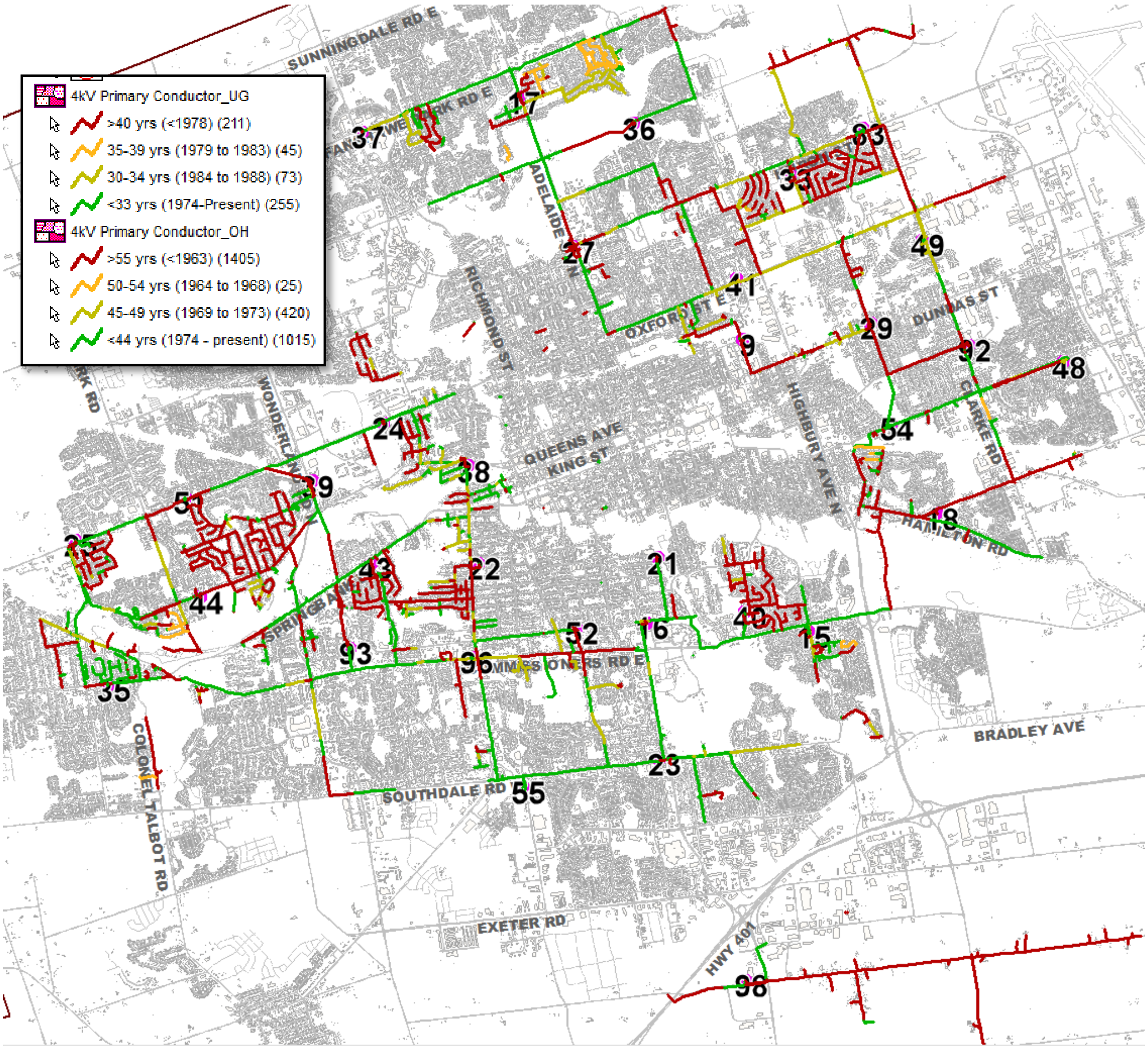

Figure 12: 4.16kV Map of overhead and underground primary conductors as of August 2018 based on age.

3.2 Zone D

Zone D, shown in Figure 13, is defined as the region bounded by Oxford St, Wonderland Rd, Springbank Dr, Commissioners Rd, and Sanatorium Rd. This zone has been subdivided into four areas to be prioritized based on reliability performance. Within this zone there is a mixture of front lot and rear lot 4kV construction as shown in Figure 14 and Figure 15.

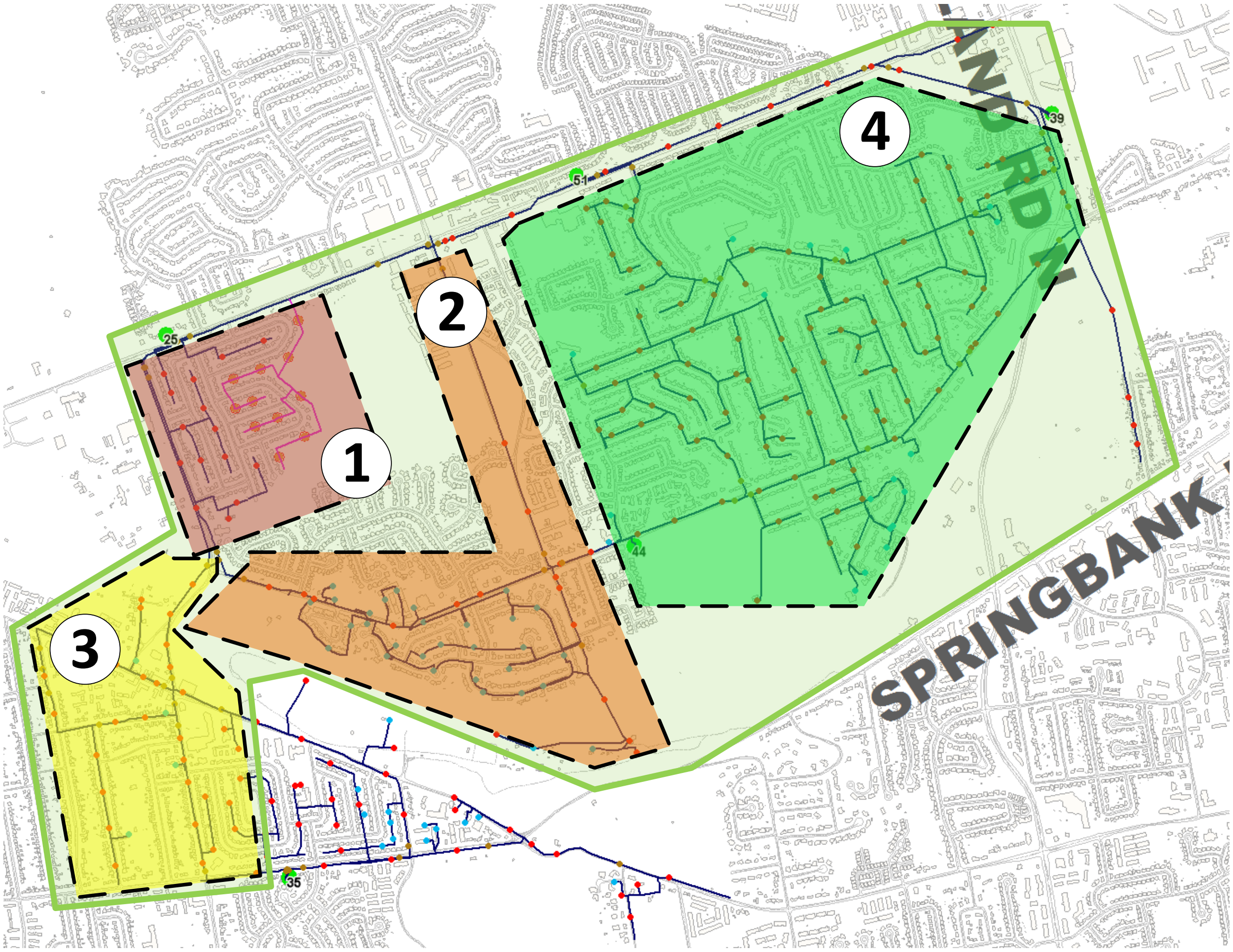

Figure 13: Zone D - Oak Ridge with prioritized areas

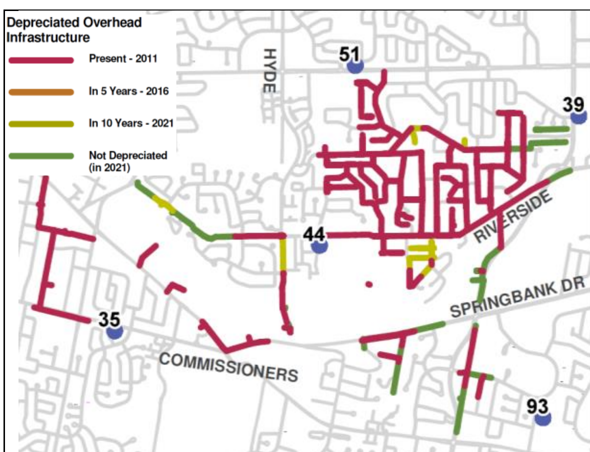

Figure 14: Zone D – Oakridge Front Lot circuits

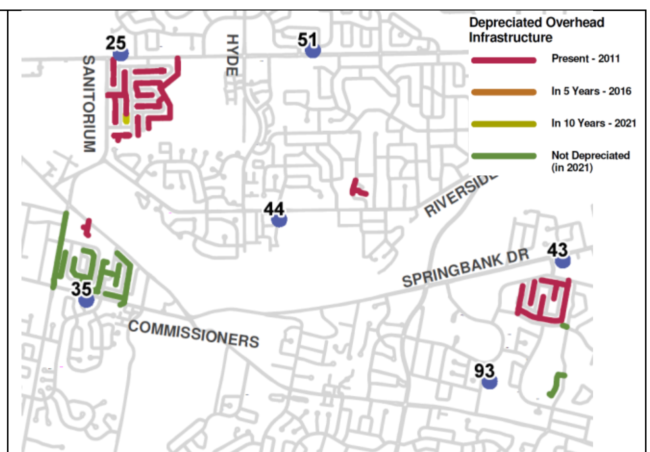

Figure 15: Zone D – Oakridge Rear Lot circuits

The substations and associated feeders of concern in Zone D are tabulated in the table below. As conversion within the Areas identified in Zone D progresses, the loads at the substations will be reduced to a point where it would make it viable to eliminate and decommission the substations. A decommissioning strategy similar to that provided for Zone B and Zone C will need to be developed in the future. For example, to decommission Sub 25, the following would be required:

1. full conversion of 25F1 and partial conversion of supporting feeders 44F1 (south-west region of circuit bounded by Hyde Park RD and Riverside Dr.)
2. full conversion of 25F3 and full conversion of supporting feeder 35F2 and partial conversion of supporting feeder 35F1 (north-west region of circuit bounded by Commissioners Rd, North St, and Byron Baseline Rd).

Table 7 Zone D Substations 25, 39, 44, 51, 35

STN	Decom. STN	FDR	Supported Feeders											
			25 F1	25 F3	39 F1	39 F2	44 F1	51 F1	51 F2	35 F1	35 F2	24 F3	93 F1	93 F3
Sub 25	Y	25F1		✓			✓							
		25F3	✓					✓		✓	✓			
Sub 39	Y	39F1					✓		✓			✓		✓
		39F2												
Sub 44	Y	44F1	✓		✓			✓	✓					
Sub 51	Y	51F1		✓			✓							
		51F2			✓	✓	✓							
Sub 35	N	35F1		✓							✓		✓	
		35F2		✓						✓				

It is recognized that Sub 35 will be required to be in-service beyond the completion of Zone D to support 4kV load pockets south of Commissioners and Springbank Dr. A decommissioning strategy for Sub 35 would be developed in the future as part of a new Zone targeting conversion in the South of Commissioners/Springbank region.

Estimated cost for Zone D is ~$11M with Oak Park rebuilt to an underground supply.

3.2.1 Zone D – Area 1, Oak Park Subdivision

Area 1, known as the Oak Park subdivision, is recommended to be prioritized due to poor reliability performance. This area is bounded by Oxford Street on the north, Sifton Bog on the east, Plymouth Ave on the South, and Sanatorium Rd on the west. One of the 4kV circuits in this neighbourhood runs through the Sifton Bog which is a conservatory area with very large trees both City and Customer owned that overhang or are adjacent to the 4kV circuit. Though London Hydro has a registered easement along the rear lots, access to London Hydro's infrastructure can be a challenge. Over the years many large trees have been planted in proximity to the lines along with other structures on the easement (e.g. sheds). Combination of wind storms, tree density, soil quality, and accessibility challenges have caused this neighbourhood to suffer from below average reliability performance.

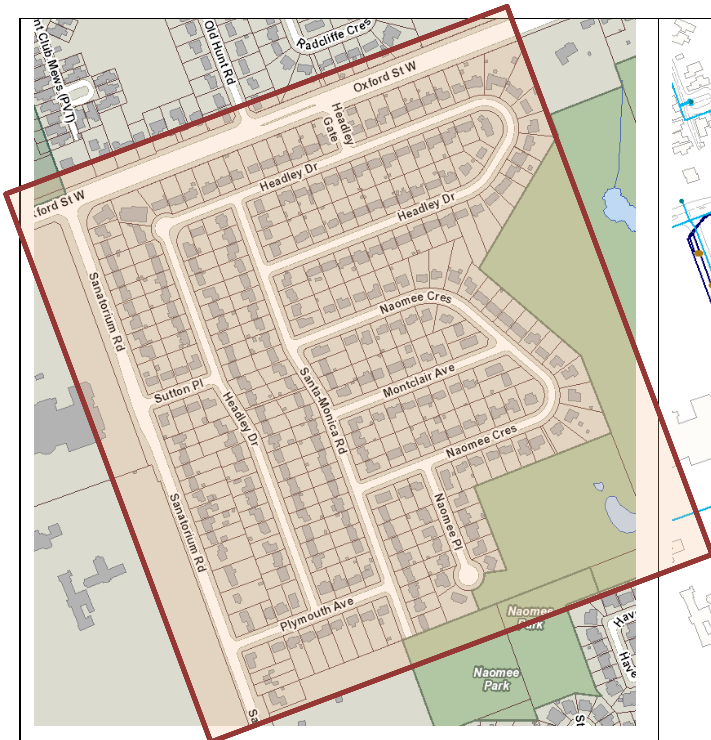

Figure 16: Area 1 - Oakpark Subdivision Map

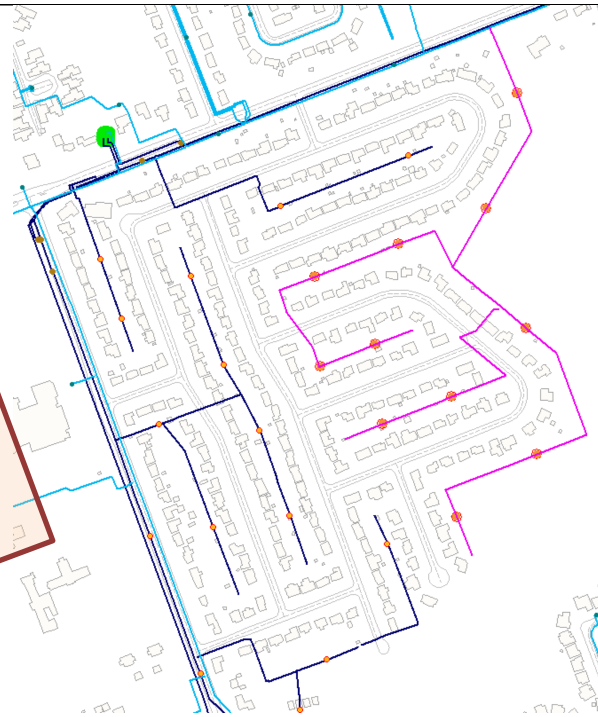

Figure 17: Area 1 - Oakpark Subdivision Circuit Distribution

Primary sources of supply to this division are:

- 26M54 via 27.6kV-4.16kV polemounted step-down transformer off Oxford St. adjacent to the Sifton Bog
- 25F1 and 25F3 off Oxford St. and Sanatorium Rd.

All supplies into the neighbourhood are single phase.

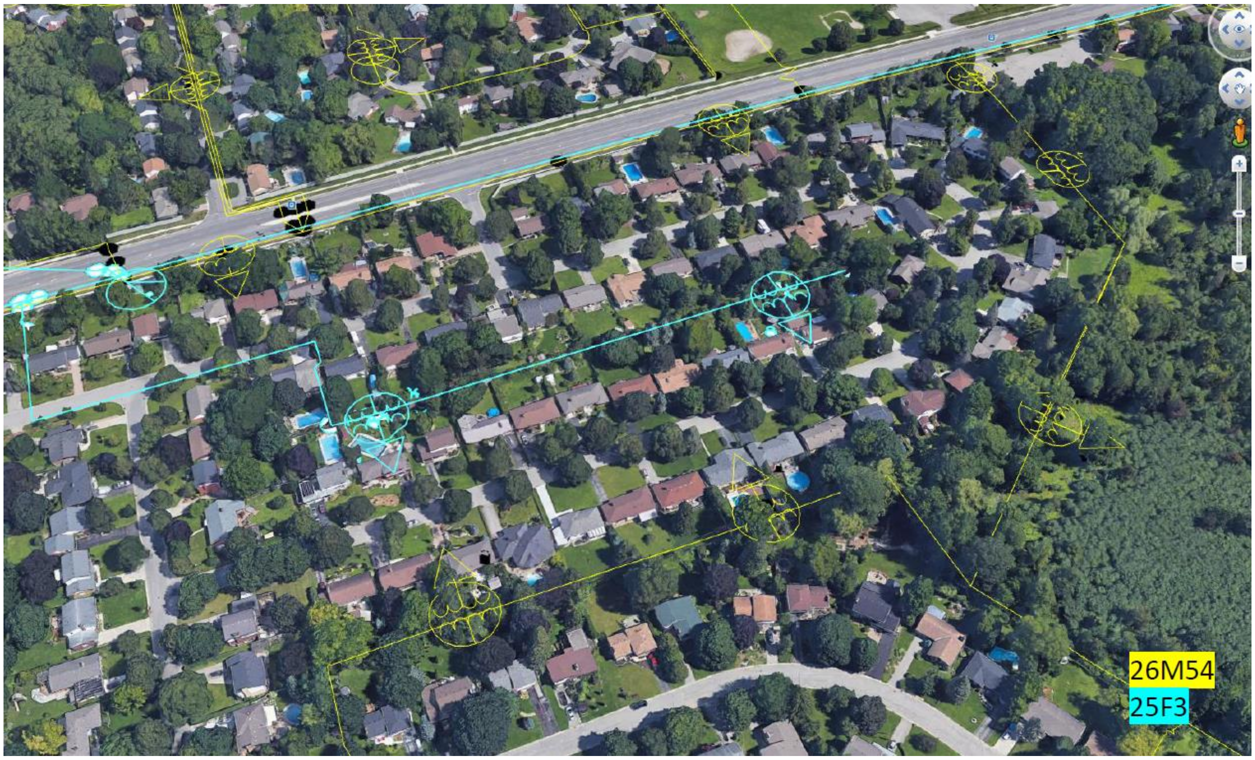

Figure 18: Area 1 - Oak Park aerial view

All poles in the rear lot of Area 1, with the exception of one pole supporting London Hydro's voltage regulator, is owned by Bell. However, all of these poles are depreciated and their replacement or removal would aid in the fulfillment of London Hydro's Pole Asset Sustainment Plan recommendation of replacing/addressing 686 poles on average per year.

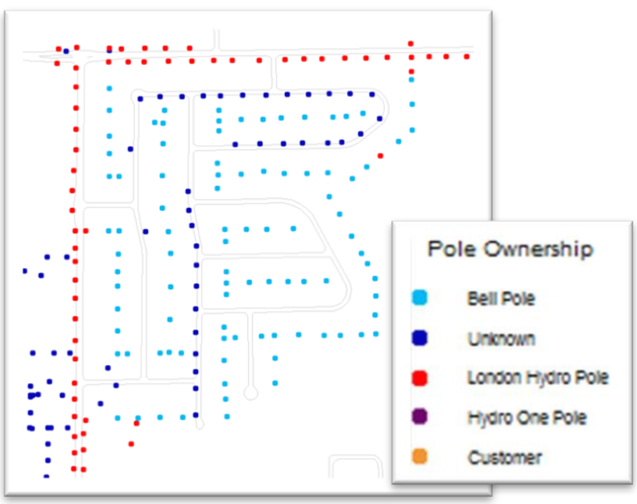

Figure 19 Area 1 – Pole Ownership in Oakpark Subdivision

The approximate number of poles, transformers, and customers in Zone D is as follows:

Area	No. of Poles	No. of Transformers	No. of Customers
Area 1	120	26	264
Area 2	113	45	310
Area 3	232	35	382
Area 4	665	121	1118
Total	1130	227	2074

Recommendation for Conversion

The overhead 4kV supply adjacent to the Sifton Bog (shown in pink in the Figure 17) experiences a significantly poorer level of reliability due to the environmental conditions at the Sifton Bog and hence conversion of this area is recommended to be prioritized in 2019.

To prevent future occurrences of outages due to tree contacts from the Sifton bog which is an environmentally protected area, it is recommended that the overhead rear lot circuit be converted to front lot and designed as a full underground system for both primary and secondary circuits.

Options for new 27.6kV source

The 26M54 overhead circuit runs along Oxford St and Sanatorium Rd. A primary loop design can be completed through this subdivision with riser connections to both Oxford and Sanatorium.

3.3 Future Zones for Consideration

Sub 98 is located near White oaks and Dingman area is a 4kV island with no backups. Sub 98 has an original 1954 transformer, which is the oldest transformer in-service in the 4kV system, and a backup transformer 1979 vintage.

Figure 20: Future Zone – Sub 98 Area Map

Substation assessment reports indicate 98-T1 is in poor condition and may require replacement in 3-5 years. Several options exist which require further evaluation in the future:

1. Area 1 consists of 4.16kV transformers with 27.6kV overbuilt on non-depreciated poles. This area can easily be converted leveraging the existing 27.6kV overbuilt circuit and removing the 4.16kV lines.
2. Area 2 consists of only 4.16kV circuitry on majority depreciated poles but not in very poor condition. This area is ideally suited for a pole-mounted step-down transformer as a backup to 98T2 in the event 98T1 is removed due to deteriorating conditions before the completion of Zone B and Zone C. After completing Zone B and C, it is recommended that Sub 98 area be evaluated as the next Zone E.

Table 8: Future Zone - Sub 98 Area

Zone	Transformers	Customers	Poles
Area 1	7	9	
Area 2	44	89	
Total	51	98	260

4 Design Evaluation of Rear Lot to Front Lot Conversion

4.1 History and Extent of Existing Rear Lot Supply System

London Hydro has a number of pockets of customers being supplied by rear lot OH distribution infrastructure installed in the 1950's and 1960's on customers private properties in rear lot, within the easements obtained by London Hydro. These customers are located in 6 rear lot geographic areas. Maps of those remaining areas are attached under Appendix 3.

Figure 21: Rear Lot Supplied Areas

In general, the rear lot areas are older neighbourhoods, the electrical supply systems are ageing and deteriorating and are difficult to access and repair.   The rear lot supply system poses many reliability, operations, safety, and customer service concerns. Based on the age and condition, this is expected that this equipment will continue aging beyond their useful service lives creating safety risk, greater reliability concerns and higher repair costs. Pictures below illustrate general rear lot asset condition.

Figure 22: Rear Lot Plant Condition

The following table shows locations, number of customers, average asset age, and characteristics of existing rear lot systems.[7]

Table 9: Remaining Rear Lot Supply and Inventory

Rear Lot Supply							
Area	Intersection	Installation Year	Number of Customers	Number of Poles: London Hydro	Number of Poles: Bell	Number of Transformers	Length of Primary Circuitry (M)
1	Oxford/Sanatorium	1960	256	3	92	24	3925
2	Commissioners Rd W/North St.	1956	284	99	1	24	3033
3	Ridgewood Cres/Southcresr Dr.	1994	189	2	80	14	3266
4	Highbury Ave N/Cheapside St	1950	352	1	109	32	3217
5	Sandford/Cheapside	1960	693	31	121	44	6804
6	Commissioners Rd E/Pond Mills Rd.	1960	986	54	222	65	10063
		Total	**2760**	**190**	**625**	**203**	**30308**
				815			

Below is summary of remaining rear lot system showing how it compares to London Hydro's overall overhead distribution system:

- 2760 customers supplied by rear lot systems. This accounts for about 1.8% of the total number of 150,000 customers.
- total of 815 poles supporting rear lot supply; 190 poles that are owned by London Hydro accounts for about 0.7% of the total number of 28,000 poles; 625 poles are owned by Bell Canada

[7] Two rear lot areas have been converted to hybrid system configuration (primary system underground in front lot and secondary overhead in rear lot).

- 203 overhead transformers in rear lot systems. This accounts for about 2.6% of the total number of 7,893 overhead transformers.
- 30.3 km of the primary circuitry represents about 2.24% of the overall 1,350km of overhead circuity
- the average installation year of all rear lot supply is 1962 (57 years old) prorated by number of customers supplied and overall circuit length.

4.2 Issues Associated with Maintaining Rear Lot Construction

There are many operating, safety, reliability and customer service issues related to maintaining the existing aging rear lot systems. An overview of the issues and disadvantages associated with the rear lot systems, which are not associated with the front lot systems, are outlined below.

4.2.1 Accessibility

Due to obstructions along pathways such as trees, gates, vehicles and customer construction (patios, sheds, pool), crews cannot gain access, bring in service vehicles and equipment, and create a safe working space in the rear lot, as illustrated in Figure 19. Many tasks are completed manually or by special rental equipment at high rental cost. Generally, the rear lot customers have to wait longer for the crews to restore power during an outage than the front lot customers.

Figure 23: Accessibility issue caused by fence and vegetation

4.2.2 Vegetation Management and Animal Contact

Vegetation that has grown over the time in the rear lots adversely affects London Hydro's system. The impact is especially high during storms and other adverse weather conditions when the wind and snow accumulation brings branches or whole tree over the wires. The growth of vegetation also increases the risk of animals (e.g. squirrels) coming into contact with electrical equipment.

Before responding to an outage, very frequently the crew needs to trim the trees to provide access and/or clearance for safe work, as illustrated in Figure 24.

Figure 24: Excessive vegetation in close proximity of distribution equipment

4.2.3 Safety Risk to Public

Safety Risk to Public associated with presence of the rear lot distribution system are related to the aged distribution plan condition and close proximity of the equipment to the buildings and other structures. Although the easement terms specify that placement of any structures and trees is not permitted along the granted easement, there are cases that customers do not follow the specified conditions and install facilities (patios, swimming pools, sheds, house extensions, landscapes…) on the easement and too close to power line, as illustrated in Figure 21. This encroachment creates a safety hazard for both customers and crews.

Figure 25: Close proximity of the equipment to the buildings

4.2.4 Safety Risk to London Hydro Crews

Safety Risk to London Hydro Crews is associated with reduced clearances due to outdated construction standards (as depicted in Figure 22) or encroachment of power line to the structures and vegetation (as depicted in Figure 21). The risk level increases when restoring power in storm or other adverse weather condition and during the night. In addition, the lack of road access requires that many tasks are carried out manually (e.g. crew staff carrying poles and transformers to the back yard) and may negatively impact crew staff's health. Due to the rear lot pole condition climbing the poles is another safety concern since the majority or the poles are in depreciated state. In addition, dogs may also be a safety hazard to the crews.

Figure 26: Reduced safe work clearances due to an outdated construction standard

4.2.5 Customers Service and Reliability

Due to the aged plant condition and the tree and animal contacts, the customers supplied by the rear lot distribution system experience more frequent outages than the front lot supplied customers. They also experience longer outage restoration time than the front lot supplied customers due to difficult accessibility to the rear lot for London Hydro crews. Both, the higher outage frequency and longer outage restoration time have negative impact on customer service and London Hydro system reliability.

In addition, restriction on use of customers' property due to potential interference between the rear lot distribution assets and certain aspects of their properties, such as landscape, fences, gates, sheds, and pools causes inconvenience to the rear lot supplied customers.

4.3 Challenges Associated with Rebuilding Rear Lot Construction

As a part of the 4 kV conversion program London Hydro has converted two large rear lot supplied areas. In order to mitigate vulnerability of the primary supply and improve reliability, those areas were converted by installing primary cable and transformers at the front lot underground and rebuilding the existing poles and secondary system at rear lot (hybrid option).

While rebuilding pole lines in the rear lots the crews were facing various challenges due to accessibility issues and not being able to easily gain access and bring in service vehicles and equipment. In some cases the temporary access roads were built and, where it was not feasible, the tasks were handled manually or by renting special equipment at high rental cost. Those issues contributed to approximately 40% higher actual cost of the overhead portion of work than estimated. Pictures illustrating some of the challenges on the previous Hybrid rear lot rebuild projects are shown under Figure 23.

Figure 27: Accessibility issue while rebuilding rear lot construction

By relocating primary system to the front lot and leaving secondary system at the rear lot some issues described under Section 4.2 *Issues Associated with Maintaining Rear Lot Construction* are addressed, however safety aspect of climbing the poles, and also reliability aspect of limited accessibility and secondary system exposure to falling trees in storm and the other adverse weather condition, still exist.

In some instances we are challenged by Bell Canada on our pole replacement criteria. Due to higher safety criteria for distribution system plant than communication plant Bell does not always agrees that poles are fully depreciated and needing replacement, and negotiations sometimes put project completion timeline to jeopardy.

4.4 Review of Rear Lot Rebuild Options

London Hydro has retained a consulting firm, Tetra Tech to review London Hydro's rear lot distribution system with objective of completing the risk/benefits analysis and cost analysis to determine the most cost-effective option for construction, operation, maintenance and non-tangible benefits (improved system reliability, safety to London Hydro crews/public, customer acceptance and satisfaction, streetscape aesthetics). Tetra Tech completed the review and submitted the final report "Rear Lot Conversion Feasibility Study" (attached to this report under Appendix 5).

Three options were evaluated to address the rear lot issue:

1. **Hybrid** – This option considers the relocation of primary conductors from existing overhead rear lot distribution to underground front lot distribution and while secondary distribution system continues to remain in rear lot
2. **Full Front Lot Underground (with customer services connected directly to transformers)** - This option considers the relocation of complete primary and secondary distribution system from existing overhead rear lot to underground front lot. The customer secondary services will be installed underground and connected directly from transformers to customer meter base
3. **Full Front Lot Underground (with customer services connected through secondary Pedestal/Tap box)** - This option considers the relocation of complete primary and secondary distribution system from existing overhead rear lot to underground front lot. The secondary bus cables will be installed underground from transformer to secondary pedestals boxes and the customer service cables will be installed underground from secondary pedestals to customer meter base.

Option of rebuilding overhead primary distribution in rear lot has not been considered in the study due to proximity of high voltage primary conductors to residential structures and back yard activities. This type of construction would not address the present safety concerns to public and London Hydro crews.

Also, option of replacing rear lot overhead distribution system with front lot overhead distribution system has not been considered as a viable option due to expected public and political backlash against new overhead plant in an area where overhead plant did not exist. In addition, installation of new poles and wires would require extensive trimming of the existing mature trees that would not be acceptable by the City.

4.5 Evaluation of Rebuild Options

4.5.1 Risks/Benefits Analysis

Based on the Risks/Benefits Analysis, the two underground options (Option 2 and 3) provide greatest benefits in regards to:

- Safety to public
- Safety to London Hydro crews
- Reliability
- Constructability
- Vegetation Management
- Esthetics

Summary comparison of the tree analyzed options based on 12 selected criteria is shown in Table 10.

Table 10: Summary comparison of the three options considered for rear lot conversion

Criteria	Option 1: Hybrid	Option 2: UG (services connected directly to transformers)	Option 3: UG (services connected to secondary pedestals)
Safety to Public	Least Favourable	Highly Favourable	Highly Favourable
Safety to Worker	Least Favourable	Favourable	Highly Favourable
Constructability	Least Favourable	Highly Favourable	Highly Favourable
Service Connections	Highly Favourable	Least Favourable	Least Favourable
Reliability	Least Favourable	Highly Favourable	Highly Favourable
Operation and Maintena	Least Favourable	Favourable	Highly Favourable
Vegetation Management	Least Favourable	Highly Favourable	Highly Favourable
Area Aesthetics	Least Favourable	Highly Favourable	Favourable
Customer Acceptance	Favourable	Favourable	Favourable
Initial Construction Cost	Highly Favourable	Least Favourable	Least Favourable
Life time asset carrying c	Highly Favourable	Favourable	Least Favourable
City Approvals	Favourable	Least Favourable	Least Favourable

4.5.2 Cost Analysis

Based on the cost analysis, the underground options have approximately two times higher initial installation cost than hybrid option, however the total cost of ownership is around 35% higher. Between two underground options, Option 2 has lower installation cost and also lower total cost of ownership than Option 3.

Comparison of the initial installation cost and the total cost of ownership of three evaluated options are summarized in table below:

Table 11: Initial installation cost and the total cost of ownership

Description of Work	OPTION 1 -Hybrid	OPTION 2 – UG with secondary services connected directly to Padmounted transformers	OPTION 3 – UG with secondary bus to Pedestal /Tap box and secondary services connected to Pedestal /Tap box
Total Estimated Rebuild Cost (selected area)	$716,729	$1,562,501	$1,629,476
Number of Services	158	158	158
Total Estimated Rebuild Cost per Service	$4,536	$9,889	$10,313
Total Cost of Ownership (selected area)	$2,743,574	$3,699,649	$3,858,230
Total Cost of Ownership per Servcie	$17,364	$23,416	$24,419

4.5.3 Recommendation

Based on risks/benefits analysis and cost analysis, Tetra Tech recommended Option 2 - Full Front Lot Underground (with customer services connected directly to transformers) as the best option to consider for rear lot rebuild.

This recommendation is in line with some larger Ontario utilities' approach in addressing their rear lot supply. Toronto Hydro is converting all their rear lot overhead distribution system to front lot underground since 2010. PowerStream converts their rear lot with either hybrid or full front lot underground and decision is made on project basis.

5 Conclusion

The conversion of Zones A, B, and C is generally proceeding on track with some delays due to higher priorities that had arisen that required redirecting capital investments. Due to recent reliability degradation in certain areas of rear lot construction, the simultaneous design/construction within multiple zones is recommended to address those areas experiencing a significantly poorer level of reliability.

Overall, the plan outlined in the 2011 report has proceeded as indicated. At times, in lieu of work within the priority zones, upgrading and silicone injection of subdivisions with depreciated underground infrastructure was necessary for reliability improvements.

The next Zone of conversion has been defined as the Oakridge Area. Within the Oakridge Area, Oak Park neighbourhood is prioritized to be rebuilt from a rear lot overhead supply to a front lot underground supply system as a pilot project. This will enable London Hydro to develop design and construction experience with this type of rebuild. As well, it will enable London Hydro to develop a better understanding of costs for this type of rebuild to aid in future evaluation and decisions.

Oak Park is expected to take 3-4 years to rebuild and possibly an additional 3 years for the remaining Zone D areas. Estimated cost for Zone D is ~$11M with Oak Park rebuilt to an underground supply.

North West Supply Capacity Study

September 2018

Acknowledgements:

This report was developed with input and collaboration received from the following members of the Engineering & Operations Team.

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Executive Summary

The City of London conducts a 20 year growth forecast every 5 years; the most recent study was completed in February of 2018 that contributed to our future feeder build/reconfiguration plans.

London Hydro has a total of fifty-two (52) 27.6kV feeders in-service and the potential for two (2) future feeders, 26M23 and 26M43. Also, there are five (5) feeders that are Hydro One owned and leveraged for contingency needs when London Hydro feeders are not an option.

Utilizing a 10 year outlook, and a linear extrapolation, based on City of London's economic development projections, we anticipate 79.9 MW total ten (10) year growth, or approximately 8 MW growth per year for the entire system. The largest growth, or 42% of the total growth, is projected in the North West, which is sourced by Talbot TS. This translates to 33.4 MW total ten (10) year growth, or approximately 3 MW growth per year for Talbot TS only.

All 27.6kV feeders' coincident peaks were determined, and the three (3) highest loaded feeders, 26M54, 26M56 and 26M21, all originate from Talbot TS, and supply the North West. Two (2) of the feeders, 26M54 and 26M56, may be considered at or near capacity, >25 MW, which challenges Operation's to backup these feeders during peak and/or contingency/maintenance activities.

Generation adds a unique challenge too, as many of our feeders that are lightly loaded do not accept generation. Although our philosophy is not to build and/or reconfigure feeders only to accommodate generation, the planning study had to account for existing generation and ensure that these generators can generate on the feeders reconfigured due to high loading. Generation is not centralized so it will continue to be a feeder design/planning dynamic that needs to be carefully considered. The proposed changes had an ancillary benefit for XXXX Wastewater Treatment Plant (WWTP), as it enabled London Hydro to provide a feeder that could accept generation and hence support the City's waste-heat recovery project.

The report focused on the North West feeders only, more specifically 26M54, 26M56, 26M13, 26M42, 26M22 and 26M14. 26M23 is recommended to be built in 2019, for source diversity and load balancing, along a route that will utilize spare circuit positions and/or aging infrastructure near end of life, ideal for 4kV conversion. The key roadways proposed for the new feeder was Wharncliffe Rd and Riverside Rd, to tie into 26M13 near Hyde Park Rd.

Assuming forecasts trend as presented 26M21 will be in an overloaded state by 2021. Therefore, further investigation will be needed on this feeder to best address in the near future; 26M43, future feeder, most likely will assist along with leveraging other existing lightly loaded feeders.

1 Existing Conditions

1.1 27.6kV Feeders Overview

The general feeder design philosophy for 27.6kV feeders, is to target 17-20 MW of load with a minimum of 3 tie-points for 1/3 contingency backup and/or supply, and not to exceed 30MW; greater than 25 MW may be considered an overloaded state and should be prioritized to address at earliest opportunity.

As a result of many contributing variables such as city expansion, large development projects, city rezoning and/or conversion projects, the load on many feeders have increased beyond target levels. These levels are monitored to ensure safe and reliable operation, and to determine reconfiguration and timing for new feeder(s) builds.

Table 1 below summarizes London Hydro's 27.6kV feeders 2017 "true" coincident peak loads, which occurred June 12th, 2017 at 5:00 pm. The table included two (2) future feeders, 26M23 and 26M43, and five (5) Hydro One feeders. Of the fifty-seven (57) feeders, the four (4) highest loaded originate from Talbot TS, representing 15% of total system MW. And, the two (2) highest, 26M54 and 26M56, originate from DESN2-Q2 Bus, supplying approximately 6000 and 6400 customers, respectively.

"True" feeder peaks infers that "SCADA" and "Metering" data had been compared, in Tableau, to determine each feeders' peak demand under a normal configuration. Contingency events and/or data spikes have been manually corrected as results may be skewed from an automated report. The "True" feeder peak analysis did not include Nelson TS feeders, as the summary only considered 27.6kV feeders, but the loads would not be representative during the construction/offloading period either. In addition, the "True" feeder analysis process introduced a margin of non-coincidence, related to the extrapolation process. Therefore, in total it is estimated a margin of error, as compared to previously reported system peaks, to be 5 to 10%. This margin is conservative and within acceptable margins for planning needs.

Total 27.kV LH Demand (Less HO): 682 MW	Total 27kV Demand (Incl. HO): 714 MW

TS_STN Name	TS_STN Bus	TS_STN Feeder	Date of Peak [DD-MMM-YY]	Time of Peak [HH:MM]	Power [MW]
Talbot TS	Q2	26M54	12-Jun-17	17:00	31.508
Talbot TS	Q2	26M56	12-Jun-17	17:00	26.070
Talbot TS	B	26M21	12-Jun-17	17:00	23.660
Talbot TS	J2	26M41	12-Jun-17	17:00	21.780
Buchanan TS	B	19M25	12-Jun-17	17:00	21.650
Buchanan TS	B	19M37	12-Jun-17	17:00	20.900
Talbot TS	Q2	26M55	12-Jun-17	17:00	20.790
Talbot TS	J1	26M47	12-Jun-17	17:00	20.237
Clarke TS	B	70M3	12-Jun-17	17:00	19.840
Talbot TS	J1	26M46	12-Jun-17	17:00	19.646
Talbot TS	Y	26M11	12-Jun-17	17:00	19.030
Talbot TS	B	26M25	12-Jun-17	17:00	18.580
Talbot TS	J2	26M42	12-Jun-17	17:00	18.230
Talbot TS	Q1	26M52	12-Jun-17	17:00	18.029
Wonderland TS	Y	32M8	12-Jun-17	17:00	17.660
Clarke TS	B	70M7	12-Jun-17	17:00	16.220
Buchanan TS	B	19M23	12-Jun-17	17:00	15.233
Talbot TS	Q1	26M53	12-Jun-17	17:00	15.150
Wonderland TS	B	32M5	12-Jun-17	17:00	15.140
Buchanan TS	B	19M29	12-Jun-17	17:00	15.046
Talbot TS	B	26M22	12-Jun-17	17:00	14.467
Talbot TS	J1	26M48	12-Jun-17	17:00	14.163
Talbot TS	Q1	26M51	12-Jun-17	17:00	13.966
Buchanan TS	Y	19M28	12-Jun-17	17:00	13.925
Clarke TS	Y	70M2	12-Jun-17	17:00	13.685
Highbury TS	Y	4M15	12-Jun-17	17:00	13.212
Buchanan TS	Y	19M38	12-Jun-17	17:00	12.864
Clarke TS	Y	70M8	12-Jun-17	17:00	12.695
Clarke TS	Y	70M4	12-Jun-17	17:00	12.500
Clarke TS	B	70M1	12-Jun-17	17:00	12.380
Highbury TS	J	4M14	12-Jun-17	17:00	11.832
Talbot TS	Y	26M13	12-Jun-17	17:00	11.420
Highbury TS	Y	4M13	12-Jun-17	17:00	11.252
Wonderland TS	B	32M7	12-Jun-17	17:00	11.169
Highbury TS	J	4M16	12-Jun-17	17:00	10.960
Wonderland TS	B	32M3	12-Jun-17	17:00	10.920
Buchanan TS	Y	19M26	12-Jun-17	17:00	10.849
Clarke TS	Y	70M6	12-Jun-17	17:00	10.314
Buchanan TS	Y	19M22	12-Jun-17	17:00	9.632
Wonderland TS	Y	32M6	12-Jun-17	17:00	8.239
Highbury TS	J	4M12	12-Jun-17	17:00	8.069
Wonderland TS	Y	32M2	12-Jun-17	17:00	7.638
Clarke TS	B	70M5	12-Jun-17	17:00	7.133
Talbot TS	Y	26M14	12-Jun-17	17:00	7.030
Buchanan TS	B	19M27	12-Jun-17	17:00	6.536
Wonderland TS	B	32M1	12-Jun-17	17:00	6.328
Buchanan TS	Y	19M24	12-Jun-17	17:00	6.195
Buchanan TS	B	19M21	12-Jun-17	17:00	5.860
Highbury TS	Y	4M17	12-Jun-17	17:00	5.602
Buchanan TS	Y	19M30	12-Jun-17	17:00	5.333
Highbury TS	Y	4M11	12-Jun-17	17:00	3.930
Wonderland TS	Y	32M4	12-Jun-17	17:00	3.681
Highbury TS	J	4M18	12-Jun-17	17:00	3.106
Talbot TS	Y	26M12	12-Jun-17	17:00	2.297
Talbot TS	B	26M23	12-Jun-17	17:00	
Talbot TS	J2	26M43	12-Jun-17	17:00	
Edgeware TS	Y	27M2	12-Jun-17	17:00	

Table 1: Summary of 27.6kV Feeders - 2017 "True" Feeder Coincident Peak[1]

[1] The MW delta, versus system reports (<10%), may be attributed to the analysis technique introducing a margin of non-coincidence, and not considering non-27.6kV feeders (Nelson TS).

For insight to system capacity, Table 2 summarizes the Transmission stations namplate ratings. Comparing 2017's Coincident Peak, 715 MVA, including HO feeders and 0.98 PF applied[2], to the STN LTR, 930 MVA, the transmission stations are 77% utilized. The 33% balance indicates adequate growth potential, however, not all feeders may be treated equally due to proximity to loads and generation acceptance.

TS Name	TXFMR Nameplate Rating [MVA]	STN LTR [MVA]	% of System LTR
Buchanan TS	2 x 75/125	192	21%
Clarke TS	2 x 50/83	115	12%
Highbury TS	2 x 50/83	120	13%
Nelson TS	2 x 50/83	94	10%
Talbot TS	2 x 50/83, 2 x 75/125	304	33%
DESN 1	2 x 50/83	126	--
DESN 2	2 x 75/125	178	--
Wonderland TS	2 x 50/83	105	11%
Total TS STNs LTR (MVA):		930	

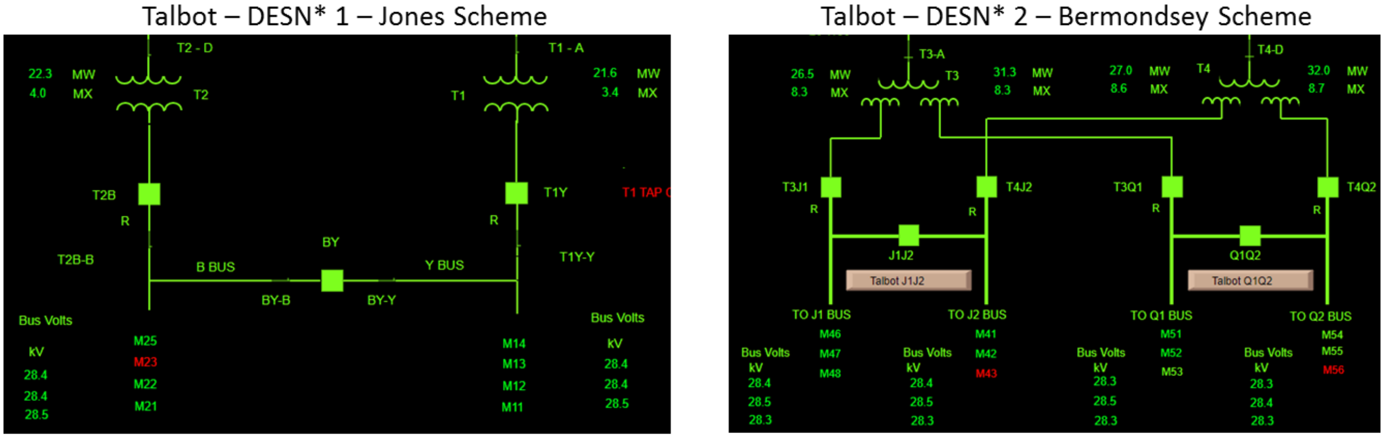
Table 2: Summary of TS Stations TXFMR Nameplate and LTR Ratings[3]

1.2 Existing Demand on Talbot TS Feeders

Table 3 summarizes Talbot TS's feeders 2017 Coincident Peak loads, 316 MW. Although the sum of the "True" feeder loads is 316 MW, the coincident peak recorded by the Wholesale meters at the TS for the same period was 272 MW, a delta of 14 %. The difference between the values may be explained by the non-coincidence that occurs between all the Talbot feeders within the hour. In addition, Table 3 highlights the existing unbalance between DESN 1 and DESN 2 buses. In general we target to have Bus deltas as near to zero as possible, for transformer efficiencies and voltage level maintenance. However, in practise 10 to 20% is more realistic. For reference, Figure 1 is Talbot's SLD that depict DESN 1, supply for BY Bus, and DESN 2, supply for JQ Bus.

Talbot – DESN* 1 – Jones Scheme

Talbot – DESN* 2 – Bermondsey Scheme



(*DESN = Dual Element Spot Network)

Figure 1: Talbot TS SLD depicting DESN 1 and DESN 2

[2] Average Power Factor (PF) per TS during system peak used to compare LTR MVA values to system MW demand
[3] The capacity for Nelson TS reflects that of the new 27.6kV station that is under construction

Sum of Row Labels	B	J1	J2	Q1	Q2	Y	[MW] Grand Total
Talbot TS	**56.71**	**54.05**	**40.01**	**47.15**	**78.37**	**39.78**	**316.05**
26M11						19.03	19.03
26M12						2.30	2.30
26M13						11.42	11.42
26M14						7.03	7.03
26M21	23.66						23.66
26M22	14.47						14.47
26M23							
26M25	18.58						18.58
26M41			21.78				21.78
26M42			18.23				18.23
26M43							
26M46		19.65					19.65
26M47		20.24					20.24
26M48		14.16					14.16
26M51				13.97			13.97
26M52				18.03			18.03
26M53				15.15			15.15
26M54					31.51		31.51
26M55					20.79		20.79
26M56					26.07		26.07
Grand Total	**56.71**	**54.05**	**40.01**	**47.15**	**78.37**	**39.78**	**316.05**

BUS Deltas: 30% 26% 40%

Table 3: Summary of Talbot TS Feeders 2017 Coincident Peak by Bus

1.3 Talbot Feeders of Interest with Ties

Table 4 lists the existing state of supplying North West feeders proposed to be modified. 26M54 is depicted to be overloaded and in need of reconfiguration to offload and provide more capacity for the developments occurring in the West near Westdel Bourne and Oxford, and in the North near Hyde Park Road and Sunningdale Road.

Feeder	DESN	BUS	Length [KM]	No. of Cust.	2017 CP [MW]	LEVEL 1 TIES
26M54	DESN2	Q2	13.0	6087	31.51	26M13, 26M14, 26M22, 26M42, 26M55, 26M56, 32M2, 32M5, 32M8
26M56	DESN2	Q2	13.0	6408	26.07	26M11, 26M14, 26M21, 26M42, 26M46, 26M47, 26M54, 26M55, 70M2
26M21	DESN1	B	8.6	4360	23.66	26M11, 26M12, 26M13, 26M14, 26M22, 26M46, 26M47, 26M56
26M42	DESN2	J2	8.2	3424	18.23	26M14, 26M25, 26M47, 26M54, 26M55, 26M56
26M55	DESN2	Q2	7.1	3246	20.79	26M12, 26M13, 26M14, 26M42, 26M46, 26M54, 26M56
26M13	DESN1	Y	7.5	1998	11.42	26M21, 26M22, 26M54, 26M55, 51F1
26M14	DESN1	Y	8.9	2009	7.03	26M21, 26M22, 26M25, 26M42, 26M46, 26M47, 26M54, 26M55, 26M56

Table 4: Summary of Talbot TS Feeders of Interest with Level 1 Ties

2 Future Development and Growth

2.1 City of London Growth Forecast

The City of London conducts a 20 year growth forecast every 5 years; the most recent study was completed in February of 2018, and we were provided shapefiles to conduct our spatial and analytical analysis.

The cities report considers population, employment, industrial and residential criteria all grouped by Traffic Zones (TAZ). In total there are 669 traffic zones in London's municipal boundary but for the purposes of this report the North West territory was of most interest, which contained 315 Traffic Zones.

To simplify the presentment and analysis we considered a 10 year projection, 2019 to 2029, and only the total projected increase of Industrial Commercial and Institutional (ICI) square-meter and number of residential units. The ICI square-meter (m^2) and number of Low/Medium/High (L/M/H) Density residential data was converted to MW per Traffic Zone. The final result was consolidated to depict the total MW addition, of both ICI and Residential types, by Traffic Zone by year 2029.

Table 5 below summarizes typical demand constants and coincident factors applied to convert City of London's per unit growth data to MW. The ICI constants were based on the Ontario Electric Saftey Code's (OESC) base load, Section 8-204, with a 30% ancillary load factor and a 60% coincident factor applied to account for loads not peaking at the same time.[4] And, Residential constants were based on actual meter data and an 87% coincident factor applied to account for loads not peaking at the same time.

Building Type	Sub Building Type	OESC Basic Load Constant W/m^2	Ancillary Connection Load Factor (%)	Extended Load Constant W/m^2	Typical per Unit (kW)	Coincident Factor (%)
Industrial Commercial Institutional (ICI)	Industrial	25.00	30%	32.50	--	--
Industrial Commercial Institutional (ICI)	Office	50.00	30%	65.00	--	--
Industrial Commercial Institutional (ICI)	Retail	30.00	30%	39.00	--	--
Industrial Commercial Institutional (ICI)	Institutional	50.00	30%	65.00	--	--
Residential	Low Density (LD)				2.9384	--
Residential	Medium Density (MD)				2.3509	--
Residential	High Density (HD)				2.0788	--
ICI - Coincident Factor	--	--	--	--	--	60%
Residential - Coincident Factor	--	--	--	--	--	86.66%

Table 5: Summary of typical demand conversion constants and coincident factors

The following two (2) figures, Figure 2 and Figure 3, spatially depict the total MW by colour shading. Figure 2 is of the entire municipality, including approximate Transmission Station feeder boundaries, and Figure 3 is of the North West area only. For explanation of the shaded colours, reference the embedded legend for MW ranges by Traffic Zone by year 2029; this is the total forecasted MW in 10 years, or by year 2029.

[4] London Hydro's experience is that the OESC is very conservative with respect to electrical demand at a facility, hence only the base load was accounted for and a fraction of the demand for ancillary loads.

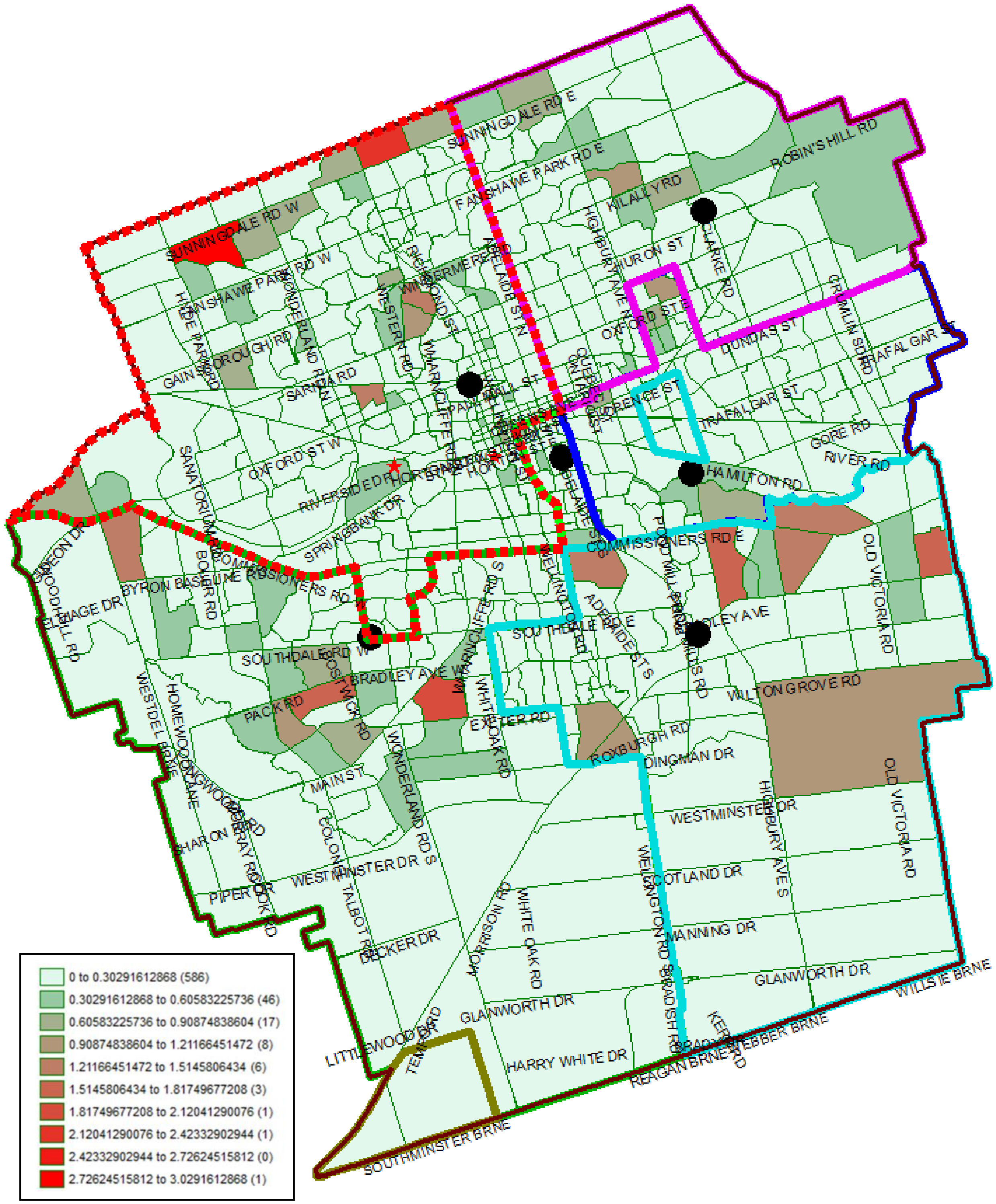


Figure 2: City of London's 10 Year, 2019 to 2029, Projected MW Growth by Traffic Zone

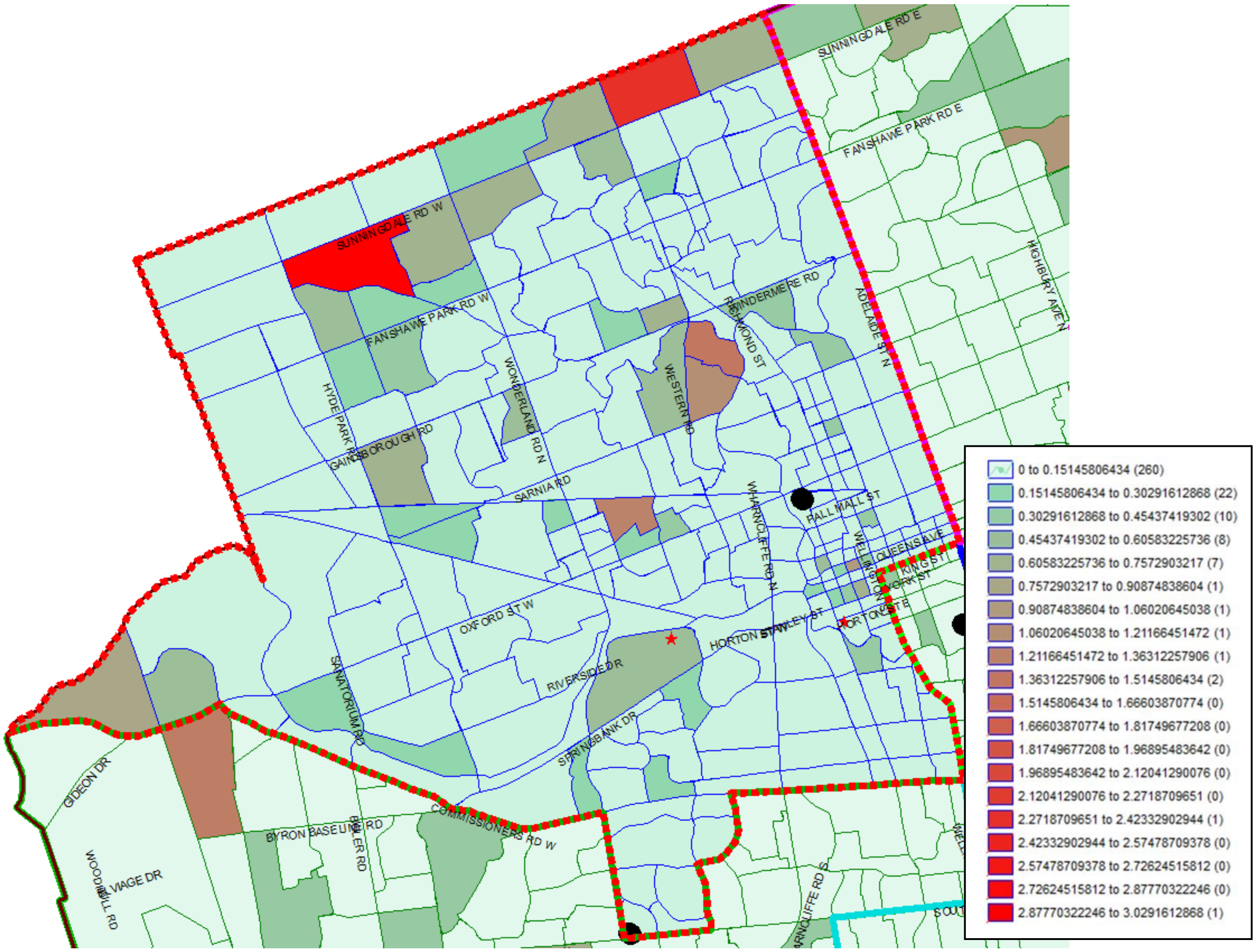


Figure 3: North West 10 Year, 2019-2029, Projected MW Growth by Traffic Zone

In general the highest growth is observed in North West area, predominantly along Sunningdale Road's West corridor, bookended from Hyde Park Road to Adelaide Street North.

Table 6 summaries the total new projected MW, by type of development, for both the entire municipality and North West territory.

Feeder	ICI All BLDG Types	Residential LD/MD/HD	ICI & Residential Total	ICI & Residential North West Only
Peak TAZ [MW]	1.61	2.73	3.03	3.03
Summary [MW]	31.7	48.3	79.9	33.5
% of Total Demand	40%	60%	--	--
% of NW to Total MW	--	--	--	42%

Table 6: Summary ICI and Residential MW demand by 2029

Table 7 below summarizes the total MW forecasted for all the Transmission Stations servicing London Hydro. The minor discrepancy between Table 6 and Table 7 may be attributed to TAZs that do not have transformers for mapping to a feeder.

For further understanding of each of the columns in Table 7, and how results were derived, below aids to explain:

Max TAZ MW by 2029 – The maximum MW Traffic Zone (TAZ) that is serviced by respective TS.

Sum of Bank KVA Namplates – The total Transformer KVAs installed in the field by respective TS.

Sum of MW based on TXFMR TAZ Mapping - Transformers have primary feeder associations that enabled a spatial point query for determining total banked KVA by TAZ; this allowed estimating the percentage each transformer contributed per feeder and TAZ, and in turn used this to estimate a projected MW growth per feeder; this table rolled it up to TS level.

10 Year Yearly MW Linear Extrapolation – To simplify analysis the total 10 year forecast was divided by 10 for a linear extrapolation.

HO Transmission Station	Max TAZ MW by 2029	Sum of Bank KVA Nameplates	Sum of MW based on TXFMR TAZ Mapping	10 Year Yearly MW Linear Extrapolation
Buchanan	1.9559	199,282	17.5722	1.7572
Clarke	0.9837	172,269	6.3041	0.6304
Highbury	0.9837	89744	2.8330	0.2833
Talbot	3.0292	392,646	32.5212	3.2521
Wonderland	1.9559	119,241	14.4779	1.4478
Grand Total	3.0292	973,182	73.7085	7.3708

Table 7: Summary of New MW by TS by 2029

Reviewing the total 10 year projected MW, across the entire municipality, Talbot TS accounts for 44%, or approximately 33 MW. This new growth is well within the stations capacity but clearly depicts the unbalanced growth between TS's.

Table 8 below continues the above transformer mapping approach, but focuses only on the North West feeders to summarize the 10 year projected feeder loads. In addition, a conditional formatting was applied; reference Table 9 for the legend to understand shading and the year when feeder attention is anticipated and/or prioritized.

NW Feeder	Total 10yr Growth [MW]	10yr Linearly Extrapolated Yrly Growth [MW]	2017_2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	%_Yrly_Growth	%_10yr_Growth
26M54	3.4456	0.3446	31.5077	31.8523	32.1968	32.5414	32.8859	33.2305	33.5751	33.9196	34.2642	34.6088	34.9533	35.2979	1.09%	12.03%
26M56	4.8209	0.4821	26.0700	26.5521	27.0342	27.5163	27.9984	28.4805	28.9626	29.4446	29.9267	30.4088	30.8909	31.3730	1.85%	20.34%
26M21	4.7335	0.4734	23.6600	24.1334	24.6067	25.0801	25.5534	26.0268	26.5001	26.9735	27.4468	27.9202	28.3935	28.8669	2.00%	22.01%
26M41	0.6253	0.0625	21.7800	21.8425	21.9051	21.9676	22.0301	22.0927	22.1552	22.2177	22.2803	22.3428	22.4053	22.4679	0.29%	3.16%
26M55	1.7883	0.1788	20.7900	20.9688	21.1477	21.3265	21.5053	21.6841	21.8630	22.0418	22.2206	22.3994	22.5783	22.7571	0.86%	9.46%
26M47	1.3406	0.1341	20.2370	20.3711	20.5051	20.6392	20.7733	20.9073	21.0414	21.1754	21.3095	21.4436	21.5776	21.7117	0.66%	7.29%
26M46	1.3796	0.1380	19.6460	19.7840	19.9219	20.0599	20.1978	20.3358	20.4738	20.6117	20.7497	20.8876	21.0256	21.1636	0.70%	7.72%
26M11	0.6415	0.0642	19.0300	19.0942	19.1583	19.2225	19.2866	19.3508	19.4149	19.4791	19.5432	19.6074	19.6715	19.7357	0.34%	3.71%
26M25	0.7854	0.0785	18.5800	18.6585	18.7371	18.8156	18.8942	18.9727	19.0513	19.1298	19.2083	19.2869	19.3654	19.4440	0.42%	4.65%
26M42	0.7686	0.0769	18.2300	18.3069	18.3837	18.4606	18.5374	18.6143	18.6912	18.7680	18.8449	18.9217	18.9986	19.0755	0.42%	4.64%
26M52	0.4771	0.0477	18.0290	18.0767	18.1244	18.1721	18.2198	18.2675	18.3153	18.3630	18.4107	18.4584	18.5061	18.5538	0.26%	2.91%
32M8	0.0027	0.0003	17.6600	17.6603	17.6605	17.6608	17.6611	17.6613	17.6616	17.6619	17.6621	17.6624	17.6627	17.6629	0.00%	0.02%
70M7	0.0071	0.0007	16.2200	16.2207	16.2214	16.2221	16.2229	16.2236	16.2243	16.2250	16.2257	16.2264	16.2271	16.2279	0.00%	0.05%
26M53	0.3157	0.0316	15.1500	15.1816	15.2131	15.2447	15.2763	15.3078	15.3394	15.3710	15.4026	15.4341	15.4657	15.4973	0.21%	2.29%
32M5	1.2842	0.1284	15.1400	15.2684	15.3968	15.5253	15.6537	15.7821	15.9105	16.0389	16.1673	16.2958	16.4242	16.5526	0.85%	9.33%
26M22	1.3562	0.1356	14.4670	14.6026	14.7382	14.8739	15.0095	15.1451	15.2807	15.4164	15.5520	15.6876	15.8232	15.9589	0.94%	10.31%
26M48	0.5075	0.0507	14.1630	14.2137	14.2645	14.3152	14.3660	14.4167	14.4675	14.5182	14.5690	14.6197	14.6705	14.7212	0.36%	3.94%
26M51	1.8936	0.1894	13.9660	14.1554	14.3447	14.5341	14.7234	14.9128	15.1022	15.2915	15.4809	15.6702	15.8596	16.0490	1.36%	14.91%
19M38	0.0008	0.0001	12.8640	12.8641	12.8642	12.8642	12.8643	12.8644	12.8645	12.8646	12.8646	12.8647	12.8648	12.8649	0.00%	0.01%
26M13	1.6488	0.1649	11.4200	11.5849	11.7498	11.9146	12.0795	12.2444	12.4093	12.5741	12.7390	12.9039	13.0688	13.2337	1.44%	15.88%
32M7	0.0387	0.0039	11.1690	11.1729	11.1767	11.1806	11.1845	11.1884	11.1922	11.1961	11.2000	11.2038	11.2077	11.2116	0.03%	0.38%
32M3	0.0781	0.0078	10.9200	10.9278	10.9356	10.9434	10.9512	10.9590	10.9669	10.9747	10.9825	10.9903	10.9981	11.0059	0.07%	0.79%
26M14	0.7156	0.0716	7.0298	7.1013	7.1729	7.2444	7.3160	7.3875	7.4591	7.5307	7.6022	7.6738	7.7453	7.8169	1.02%	11.20%
19M24	0.0455	0.0046	6.1950	6.1996	6.2041	6.2087	6.2132	6.2178	6.2223	6.2269	6.2314	6.2360	6.2405	6.2451	0.07%	0.81%
26M12	0.0148	0.0015	2.2970	2.2985	2.3000	2.3014	2.3029	2.3044	2.3059	2.3073	2.3088	2.3103	2.3118	2.3133	0.06%	0.71%

Table 8: Summary of North West Feeders MW Linearly Projected to 2029

	Greater than 28 MW
	Between 25 to 28 MW
	Between 21 to 25 MW
	Between 17 to 21 MW

Table 9: Conditional Formatting Legend for Table 8

The two (2) feeders with the highest loading, 26M54 and 26M56, was the primary focus; later sections summarize proposed reconfigurations to bring loads within target MW levels.

Talbot TS has future provisions for two (2) new feeders, 26M23 and 26M43. It is recommended 26M23 be built first; this will bring diversity to the North West, since the two main feeders, 26M54 and 26M56 are supplied by the same DESN2 Q2 Bus. The only caveat is generation is not accepted on 26M23, so this needed to be taken into consideration. More details on the build/reconfiguration will be expanded on in later sections.

26M43 is not a priority at this time, but recommend building common sections where construction efficiencies may be found, such as river-crossings.

Further investigation will be required for 26M21 in 2019 for options to bring load within ideal MW levels. Preliminary investigations reveal that the 26M12 could be leveraged through a feeder expansion North on Adelaide St. via spare positions on existing pole lines.

3 Distributed Energy Resources (DER)

3.1 Complexities with Generation

Generation can be found throughout our municipality. Not all feeders accept generation, as specified by Hydro One due to short circuit current contributions beyond accepted levels. Although TS's can be upgraded to allow generation, in most cases, typically by adding bus-tie reactor(s), however, such cost would be at the expense of the requestor; unless, it can be coordinated with other station upgrades.

For reference, Hydro One had provided a $3M indicative number, in 2018, to construct a tie-bus reactor so Talbot TS's BY Bus may accept generation.

If all feeders cannot be treated equally, due to generation acceptance, the challenge to monitor and balance feeders will persist. Considerable cost is involved to reconfigure and balance feeders load while considering diversity and reliability factors. However, the costs of reconfigurations need to be compared to upgrading a station's bus to accept generation to determine if a business case exists for investment.

In general, it is London Hydro's policy not to reserve and/or reconfigure the system to accommodate generation customers. The operation of the system is paramount and, in times of contingency and/or maintenance, generation is shed at our control to allow teams to perform their role/service reliably and safely.

For reference, Table 10 summarizes Talbot TS's feeders and generation acceptance.

Feeder Number	HO_Txmfr Stn Name	TS_BUS	TS_DESN Number	Generation Allowed	TS_Primary Voltage [kV]	TS_Secondary Voltage [kV]	Notes
26M11	Talbot TS	Y	DESN1	N	230	27.6	
26M12	Talbot TS	Y	DESN1	N	230	27.6	
26M13	Talbot TS	Y	DESN1	N	230	27.6	
26M14	Talbot TS	Y	DESN1	N	230	27.6	
26M21	Talbot TS	B	DESN1	N	230	27.6	
26M22	Talbot TS	B	DESN1	N	230	27.6	
26M23	Talbot TS	B	DESN1	N	230	27.6	Future
26M25	Talbot TS	B	DESN1	N	230	27.6	
26M41	Talbot TS	J2	DESN2	Y	230	27.6	
26M42	Talbot TS	J2	DESN2	Y	230	27.6	
26M43	Talbot TS	J2	DESN2	Y	230	27.6	Future
26M46	Talbot TS	J1	DESN2	Y	230	27.6	
26M47	Talbot TS	J1	DESN2	Y	230	27.6	
26M48	Talbot TS	J1	DESN2	Y	230	27.6	
26M51	Talbot TS	Q1	DESN2	Y	230	27.6	
26M52	Talbot TS	Q1	DESN2	Y	230	27.6	
26M53	Talbot TS	Q1	DESN2	Y	230	27.6	
26M54	Talbot TS	Q2	DESN2	Y	230	27.6	
26M55	Talbot TS	Q2	DESN2	Y	230	27.6	
26M56	Talbot TS	Q2	DESN2	Y	230	27.6	

Table 10: Summary of Talbot TS feeders and generation acceptance

Figure 4 and Figure 5 depict generation locations throughout our municipality. Figure 4 is of the entire municipality, with Transmission Station boundaries, and Figure 5 is of the North West area only. For explanation of the spot colours reference the embedded legends:

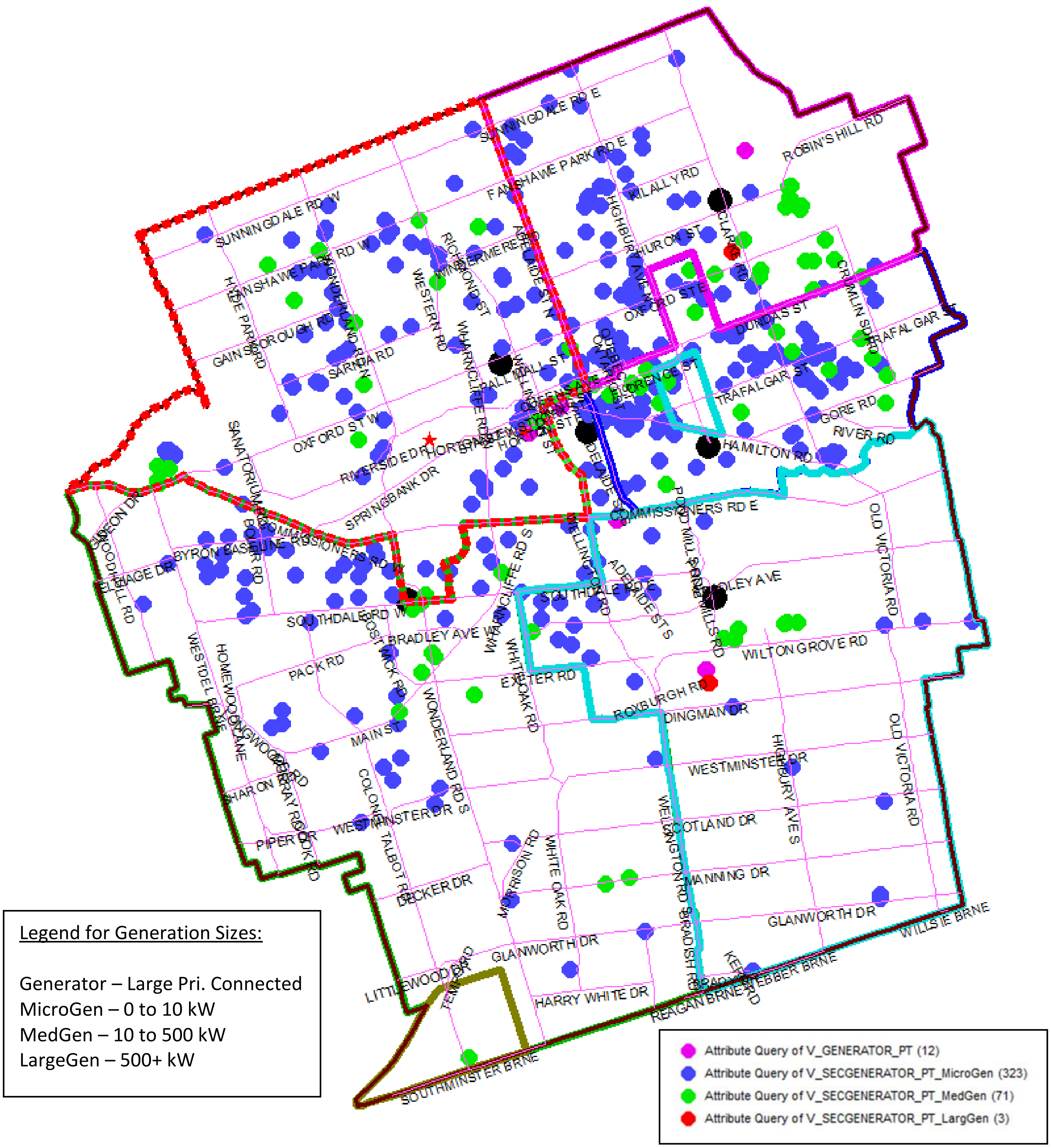


Figure 4: City of London's Generation Locations

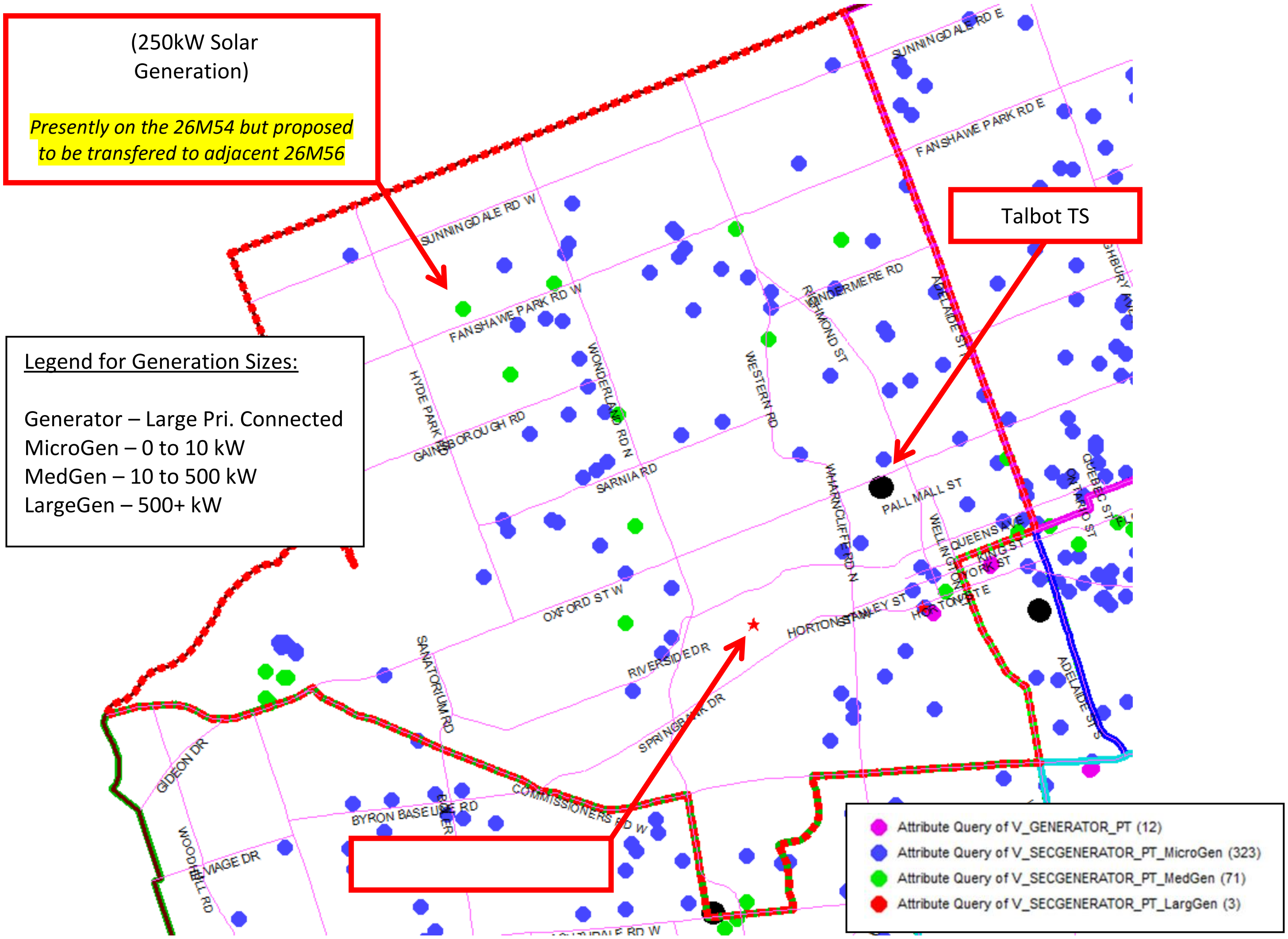


Figure 5: North West London's Generation Locations

4 Primary Feeder Modifications

This section describes the feeder modifications required over a two (2) year period, 2018 to 2019, to address the supply needs in the Northwest.

4.1 Primary Feeder Modifications – Phase 1 (2018)

Table 11 below summarizes the proposed feeder MW load changes for Phase 1, described in more detail in consecutive sections. Option 3, highlighted in blue is a load pocket West of Hyde Park Rd, on 26M54 which will be best addressed during the 4 kV conversions, so it is not included in final MW changes.

Feeder	Summer Coincident Peak June 12, 2017 @ 5pm [MW]	# 1 Gains/Hyde [MW]	# 2 Oxford/Sarnia [MW]	# 3 Furture Conversion [MW]	# 4 GWPP [MW]	# 5 M56 to M14 @ Fanshawe PKRD [MW]	Phase 1 Proposed New Load [MW]	% Delta
26M54	31.5	-3.2	-3.7	-2.8	3.0		27.6	-12%
26M56	26.0					-7.8	18.2	-30%
26M55	20.8							
26M42	18.2	3.2					21.4	18%
32M8	17.7							
32M5	15.1							
26M22	14.5				-3.0		11.5	-21%
26M13	11.4		3.7	2.8			15.1	32%
32M2	7.6							
26M14	7.0					7.8	14.8	111%
26M25	18.6							
26M23								

Table 11: Summary of Primary Feeder Modifications – Phase 1 (2018)

4.1.1 Option #1 – 26M54 – Gainsborough & Hyde Park – Offload to 26M42

26M54 has two (2) load pockets West and East, at the corner of Gainsborough and Hyde Park Rd, that may be transferred to 26M42.

Option A – West of Hyde Park Road

Figure 9's blue trace depicts a load pocket of 0.9 MW and 94 customers. Since this section of line is connected to the main trunk via mid-span taps, and it was not much benefit compared to cost, it was recommended to keep this on the 26M54 and only do option B, East of Hyde Park Rd, reference next section.

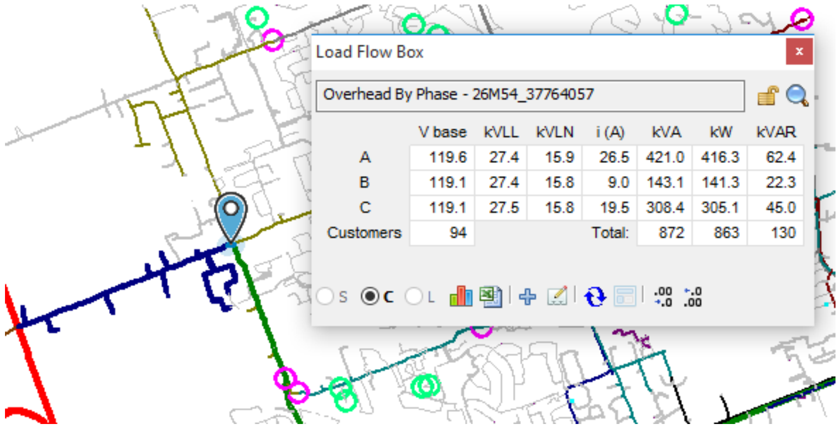


Figure 9: 26M54 Load Pocket West of Hyde Park Rd on Gainsbourgh Rd.

<u>Option B – East of Hyde Park Road</u>

This load pocket is 3.2 MW and 1531 customers in size. We propose segmenting 26M54 just east of the intersection by adding a Recloser to create a new tie point to 26M42; this Recloser will provide operational flexibility and coordinate well with the existing Recloser S54R-1, which will need updating to be N/C, so 26M42 may be extended. Note the conductor along the Gainsborough corridor is an older installation and 3/0 ACSR, <u>not</u> 556 AL.

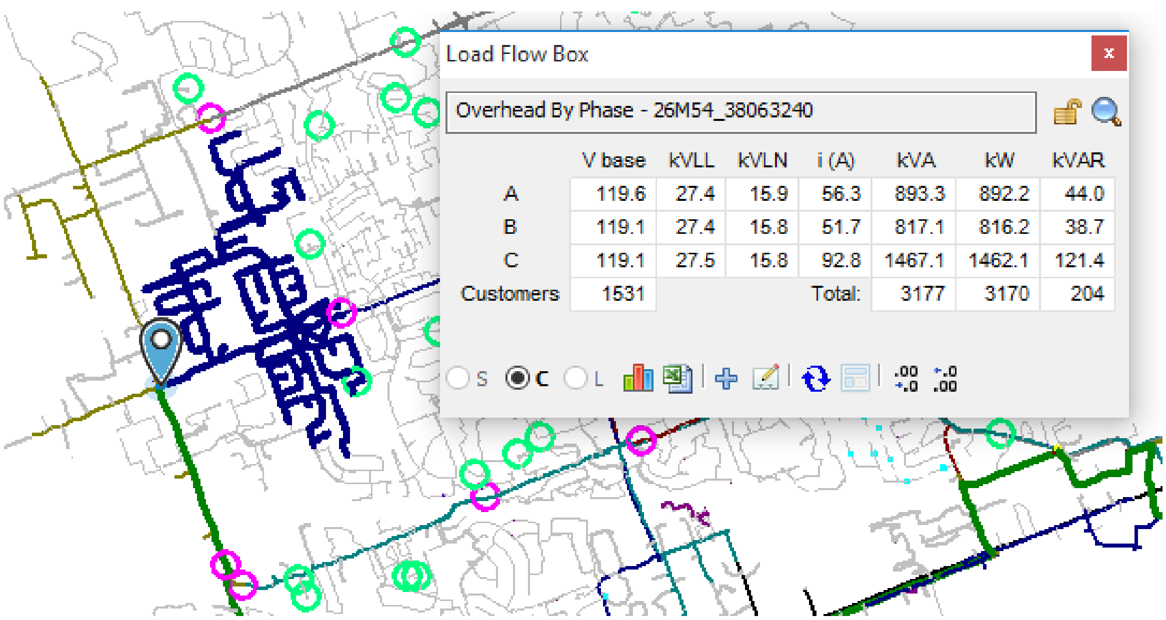


Figure 10: 26M54 Load Pocket East of Hyde Park Rd on Gainsbourgh Rd.

4.1.2 Option #2 – 26M54 – Oxford to Sarnia – Offload to 26M13

This load pocket is 3.7 MW and 1038 customers in size. We propose this area of 26M54 be overtaken by 26M13. It will entail some feeder reconfiguration such as, but not limited to, existing tie, Recloser Q55R-5, will need to be updated to N/C, and 26M54 will need to be expressed through to Sarnia, approx. 1 kM.

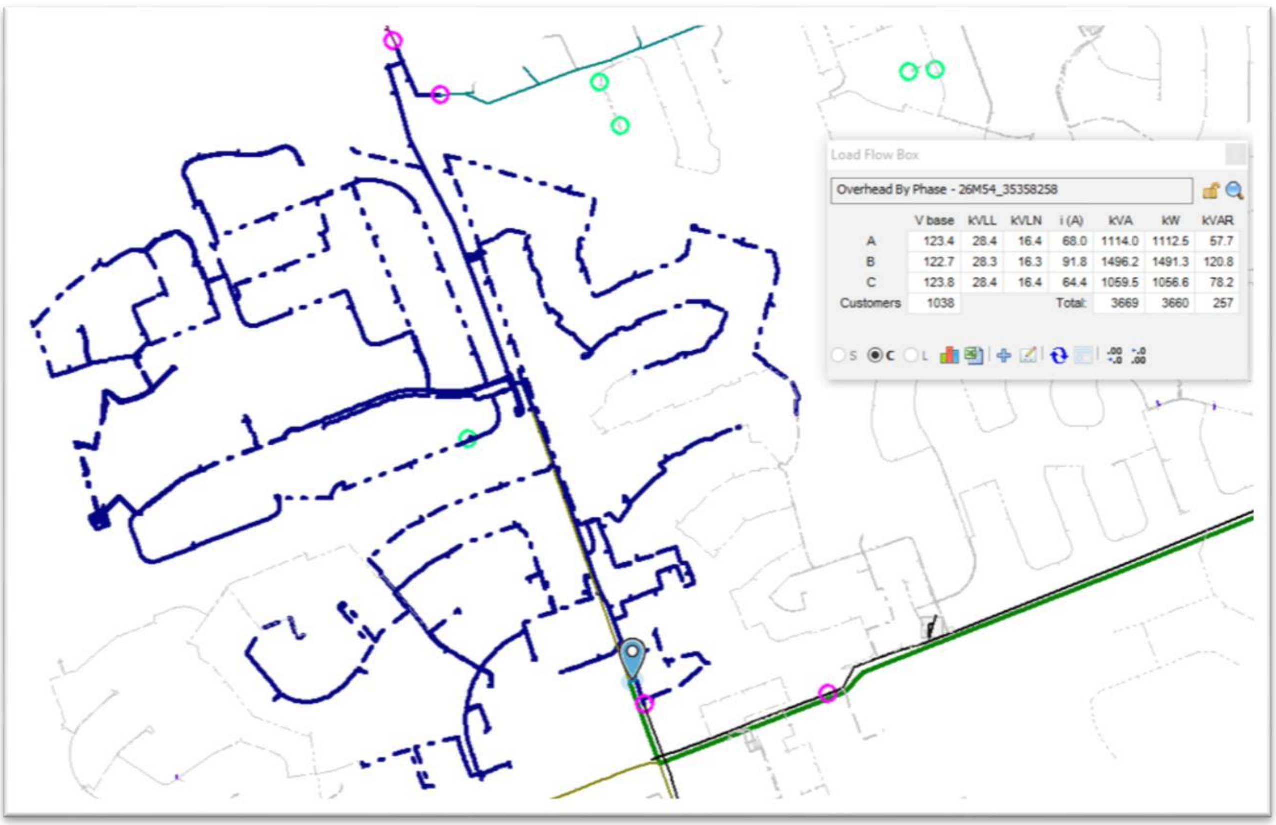


Figure 11: 26M54 Load Pocket East of Hyde Park Rd on Gainsbourgh Rd.

4.2 Primary Feeder Modifications – Phase 2 (2018-2019)

Table 12 below summarizes the feeder MW load changes for Phase 2, further explained in the sequential sections.

Feeder	Summer Coincident Peak June 12, 2017 @ 5pm [MW]	#6 New 26M23 TRSFR 2 load pockets from 26M13 [MW]	#7 M13 overtake M54 North of Oxford [MW]	#8 M13 Offloading Misc [MW]	Phase 2 Proposed Load [MW]	Phase 2 % Delta	Final Load [MW}	Total % Delta
26M54	31.5		-12.1	2.0	17.5	-37%	17.50	-44%
26M56	26.0						18.20	-30%
26M55	20.8	-4.8					16.00	-23%
26M42	18.2						21.40	18%
32M8	17.7						17.70	0%
32M5	15.1						15.10	0%
26M22	14.5						11.50	-21%
26M13	11.4	-7.2	12.1	-2.0	18.0	19%	18.00	58%
32M2	7.6						7.60	0%
26M14	7.0						14.80	111%
26M25	18.6						18.60	0%
26M23		12.0			12.0	N/A	12.00	N/A

Table 12: Summary of Primary Feeder Modifications – Phase 2

4.2.1 Option #6 – 26M23 – New Feeder Build – Offload 26M13 and 26M55

Two new feeders have already been provisioned at Talbot TS, 26M23 and 26M43. It is recommended to buildout the 26M23 and provision for the 26M43 egress at the same time for cost opportunities.

The initial feeder build beyond the river is proposed to be 26M23 to provide additional load diversity from a different DESN, DESN 1, considering that 26M54 and 26M56 are both servicing the North West from the same Bus at DESN 2.

The egress from the station is one of the first challenges, and based on existing feeder egresses and where the final target destination is, North West, the river crossing along Ann Street is most favourable. Note there are two (2) existing Overhead feeders along this route, 26M42 and 26M41, but do not envision this to be a concern.

Figure 13 depicts the two (2) new feeder routes, where the two yellow highlighted Overhead feeders are 26M42 and 26M41 for reference.

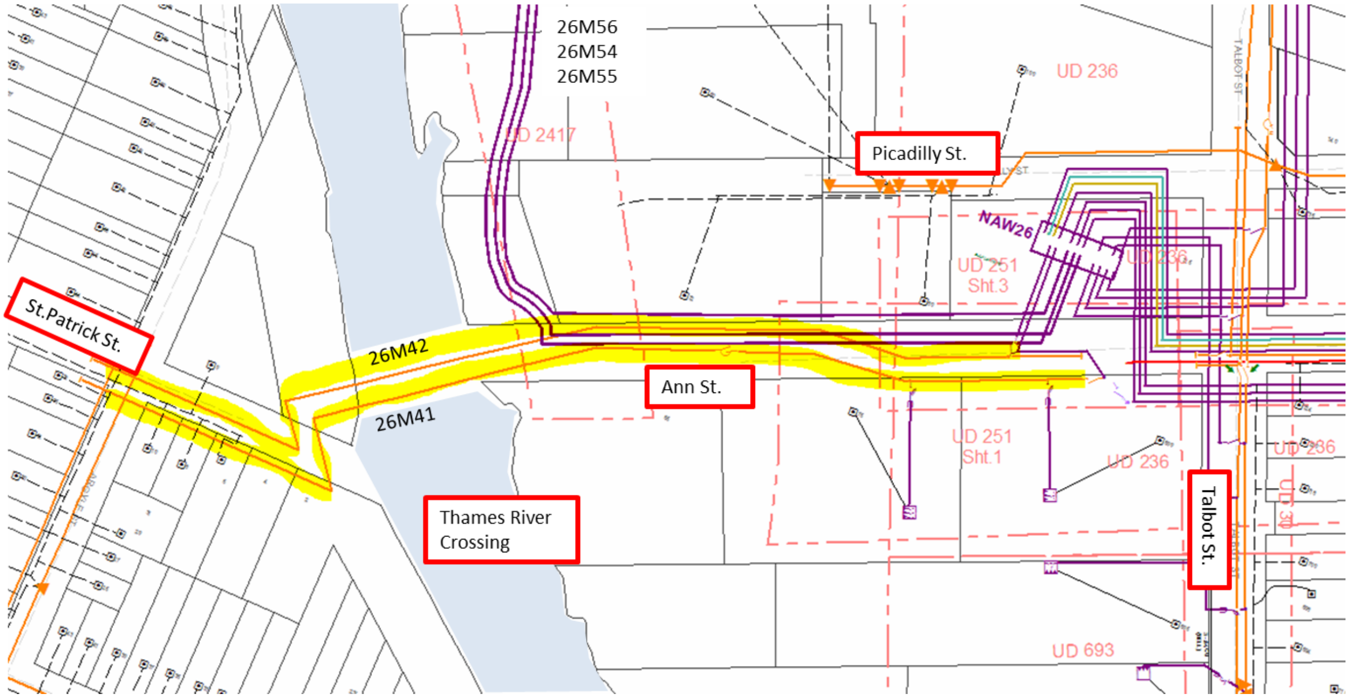


Figure 13: Proposed Talbot TS Egress via Ann St. & Water Crossing

Design of the 26M23 and provisioning of the 26M43 feeder egresses and river crossings at the same time will minimize mobilization and constructions costs.

Various new 26M23 feeder routes were considered. On a high-level, the following key routes were closely compared: (i) Oxford St to Wonderland Rd to Sarnia Rd, (ii) Western Rd to Sarnia to Hyde Park Rd, and (iii) Wharancliffe Rd to Riverside Rd to Hyde Park Rd. The challenge was to balance BRT interferences, minimizing disruption and/or visual impact of any new 27.6kV pole lines through established neighborhood's, utilizing natural and/or existing circuit paths, and considering reliability impacts along proposed routes. Reference Figure 14 for a high-level view of the various routes considered.

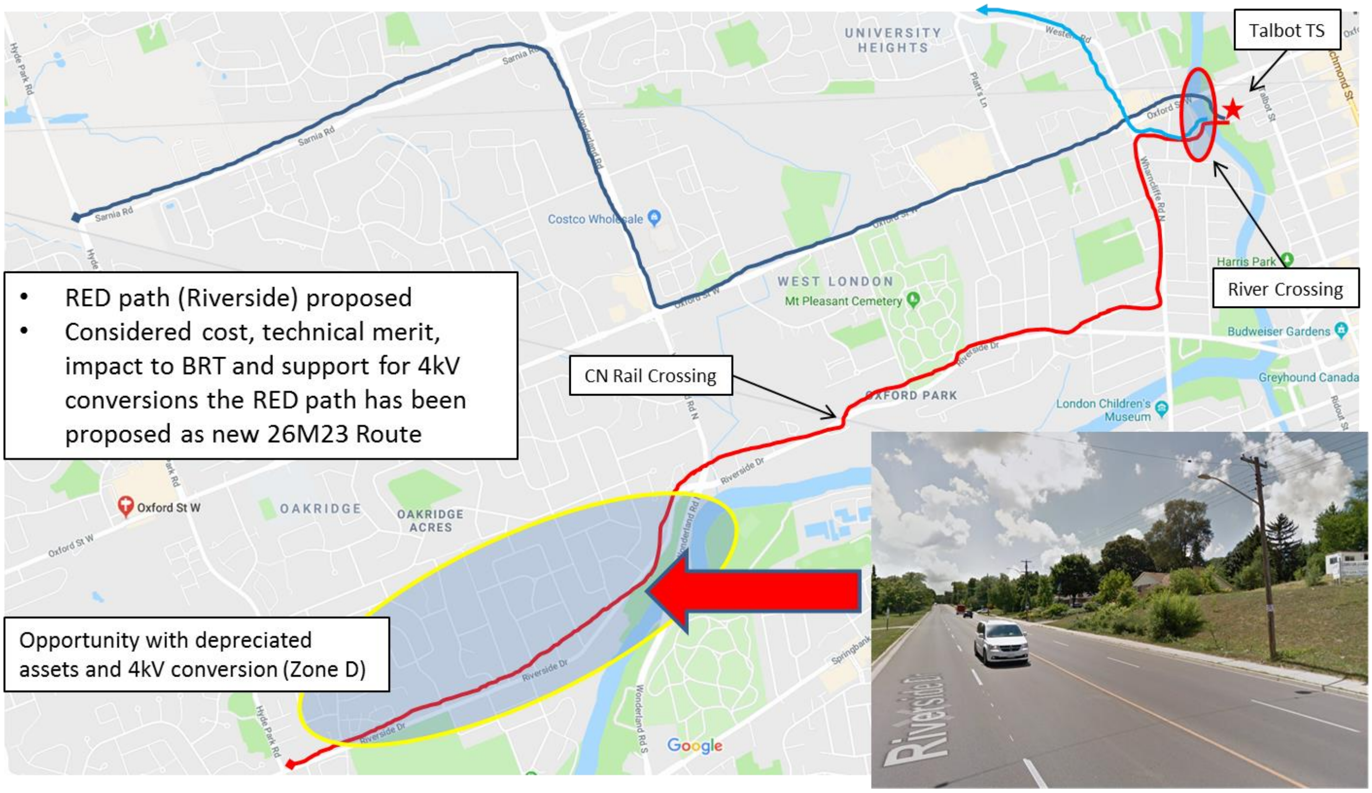


Figure 14: 26M23 Feeder Routes Considered

After deliberating the various options, the recommendation is Wharancliffe Rd to Riverside Drive to Hyde Park Rd as the proposed new 26M23 feeder route; this new path will also lend well to converting the 4kV Oakridge area as part of the 4.16kV ZONE D conversion program.

In addition, this route had an existing second circuit provision for most of corridor, including CN rail crossing, thereby minimizing reconfigurations/builds, and where new poles are required it will be upgrading older aged assets; older than 55 years.

The route along Riverside Drive, between Wharnacliffe Rd and Wonderland Rd was closely analyzed due to concern of the narrow road way, pole line proximity to the road, and the road having no curb in a small section. In review of reliability logs for the past 5 years, on 26M25, which is currently on the proposed pole line, there have been no incidents of car(s) hitting pole(s) in the corridor between Wharncliffe and Wonderland. There are incidents of vehicular pole contact, but none that recorded outages. The single outage incident logged in this corridor was from tree contact, in 2012, described in the logs as, “on riverside east of Wonderland”, but exact location not known; besides with a normal tree trimming regime and the new circuit to be road side, statistically we should have no concern. Figure 15 summarizes the reliability data on the 26M25 since 2011, which shows no statistical evidence depicting this route to be a high risk corridor.

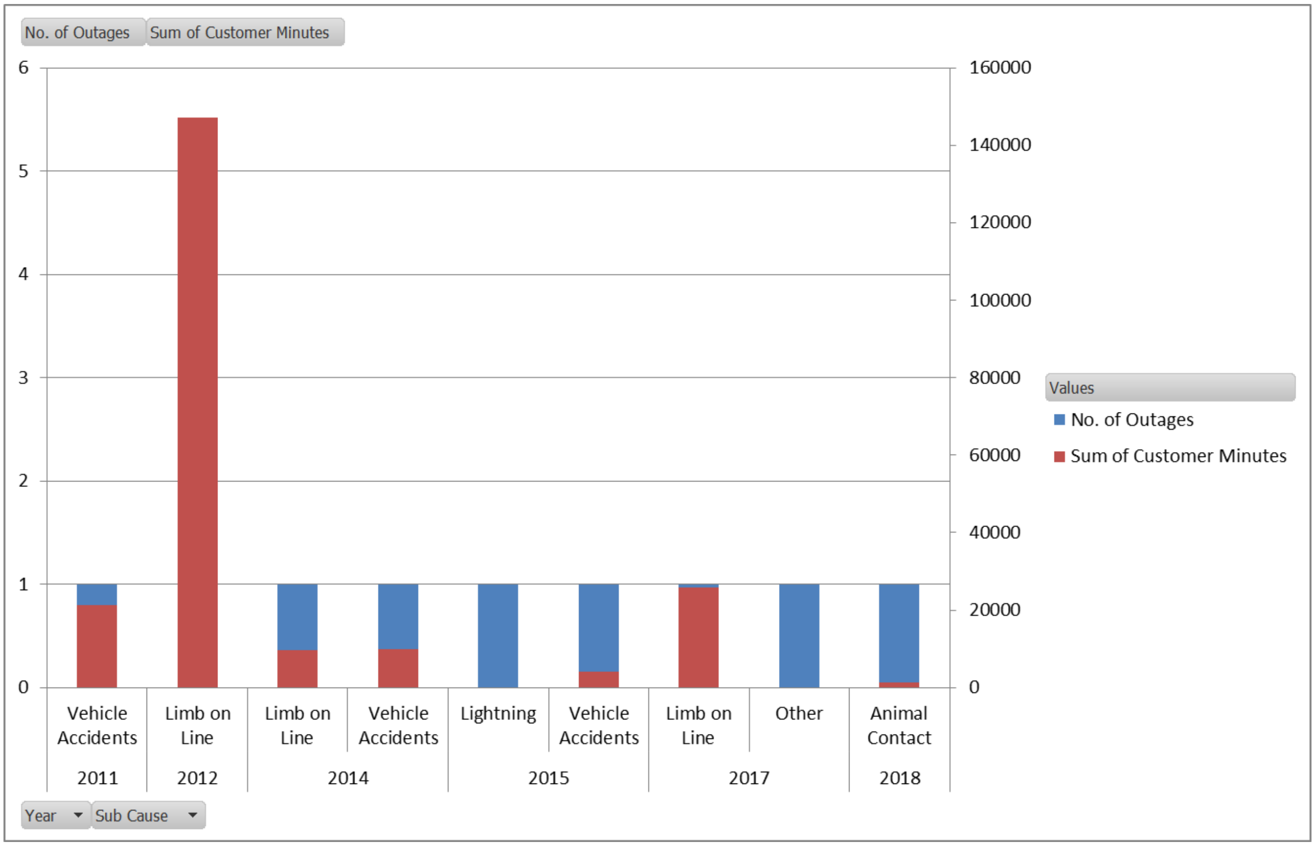


Figure 15: 26M25 – Reliability data – No Vehicular related incidents in Riverside Corridor

Further, there is one bollard that already exists in this corridor, reference Figure 16 below. And, if further protection is required, but statistics do not warrant, additional bollards in strategic locations may be considered.

Figure 16: 26M25 – Riverside Road depicting an existing Bollard

Figure 17 below depicts the new 26M23 route. Note near SUB 44 feeder 26M13 dead ends on Riverside Dr; the new 26M23 can overtake the 26M13 at this point. Due to the lengthy circuit exposure up to this point, a recloser is recommended near this location.

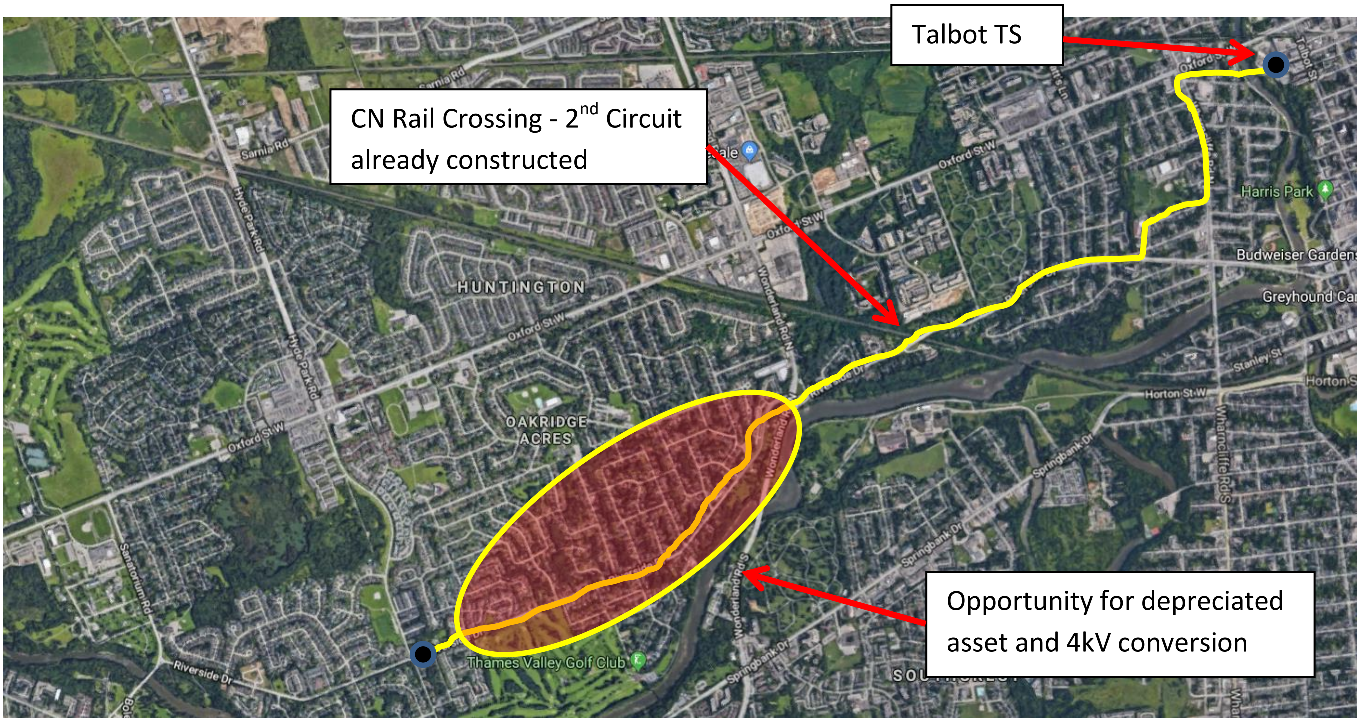


Figure 17: Proposed 26M23 Route Via Wharncliffe Rd and Riverside Rd.

Detailed design plans of the route is pending, however, for sequencing of work this new feeder, 26M23, will need to be constructed prior the proposed reconfigurations in the next section.

An indicative high-level Design Department estimate for the proposed 26M23 route is $1.5M, which includes materials, construction/design/engineer labour, TS egress and a river crossing.

4.2.2 Option #7 – 26M13 – Overtake 26M54 North of Oxford

For source diversity in the North West and to minimize construction, the 26M13 is proposed to overtake 26M54 North of Oxford and Hyde Park intersection. To achieve this 26M13 will be reconfigured at the Hyde Park and Oxford intersection to overtake 26M54 North of Oxford Street, and expressed up to Sarnia Road, by the construction done in phase 1.

To offload 26M13, and take advantage of the new feeder, 26M23 will overtake 26M13, from SUB 44, where the new tie was proposed, and along Hyde Park Rd to Sarnia Road.

Consideration should also be made to balance 26M55, by extending 26M23 across Hyde Park Rd to overtake a section of 26M55 on Sarnia road, via a new recloser for operational flexibility. The N/O R55R-2 recloser tie the 26M23 and 26M13, and the N/C R53R-8 will tie the 26M23 and 26M55; R53R-8 recloser will need to change from N/C to N/O. Figure 18 depicts the 26M55 section to be transferred to 26M23; the load pocket is 4.8 MW and has approximately 1207 customers.

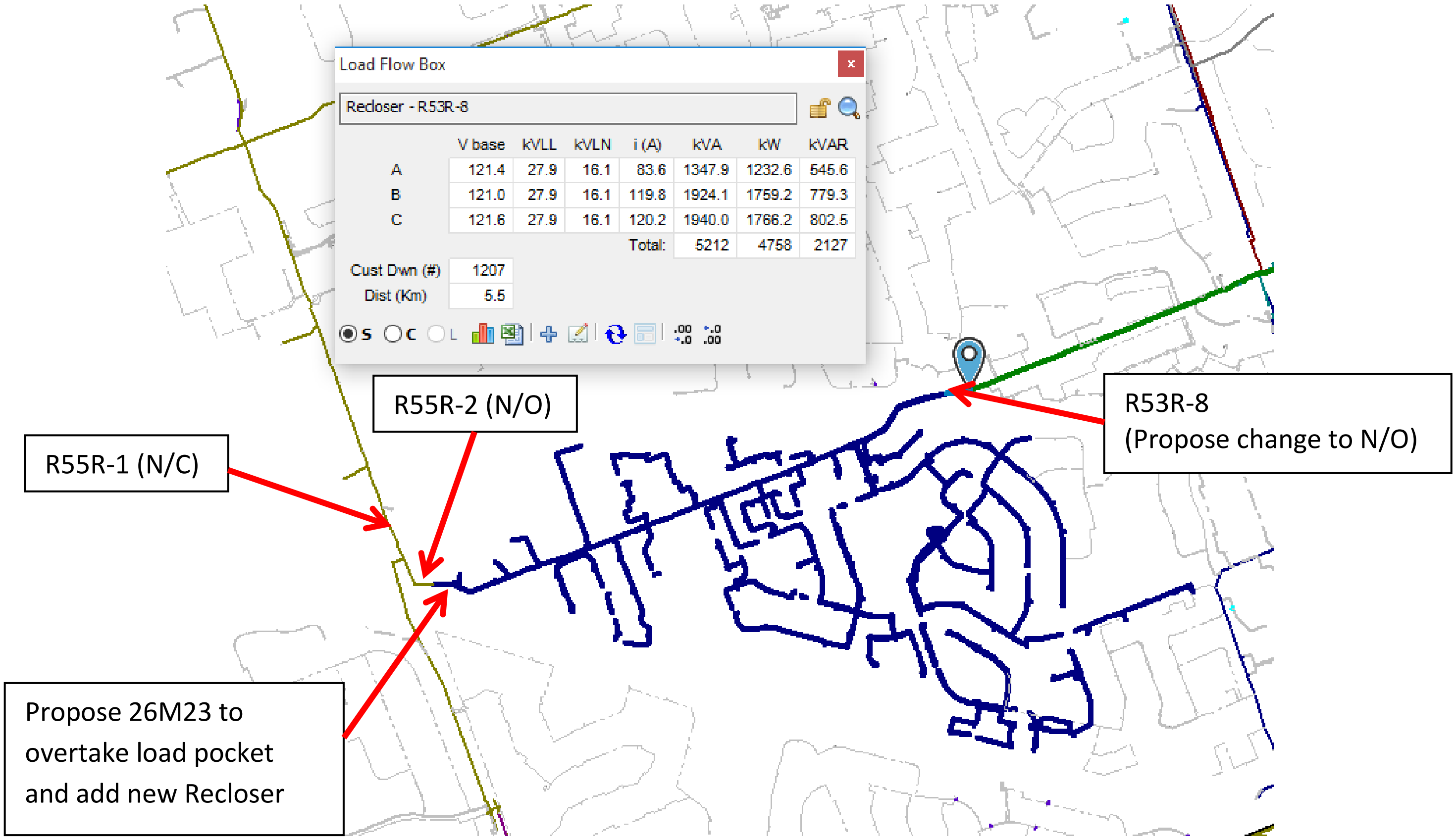


Figure 18: 26M55 Load Pocket proposed to be overtaken by 26M23

One issue is Talbot TS's BY bus does not allow generation. 26M13 originates from Y Bus, and, at time of writing this report there is one generation installation >10kW, 2727 Tokala Trail, 250kW (Saint André Bessette Catholic Secondary School). Note it is accepted practice to reconfigure generation installations that are <10kW onto feeders that do not accept generation. However, for generation >10kW the feeder must be able to accept generation and a CIA study must be conducted. Other protocols such as notification of Hydro One, transfer trip, and updating records are required and best handled by London Hydro's Standards and Generation department.

In the case of 2727 Tokala Trail's generation installation, it is reasonable to consider supplying from 26M56; it is on an underground looped supply so an open point may be placed for segmentation to allow feeding from two (2) feeders, 26M13 and 26M56, which will improve operational flexibility. Figure 19 depicts this proposed reconfiguration.

Lastly, there is a section of 26M54 that is 3/0 ACSR, which is not our standard 556 AL for trunk lines. Under normal configuration it is not an issue considering this is at the end of the feeder compared to if this was at the beginning. However, for operational flexibility under contingency conditions this should be standardized to 556 AL. The 26M54 3/0 ACSR section is found North of Gainsborough, and is majority, aside from newer sections that have been added recently.

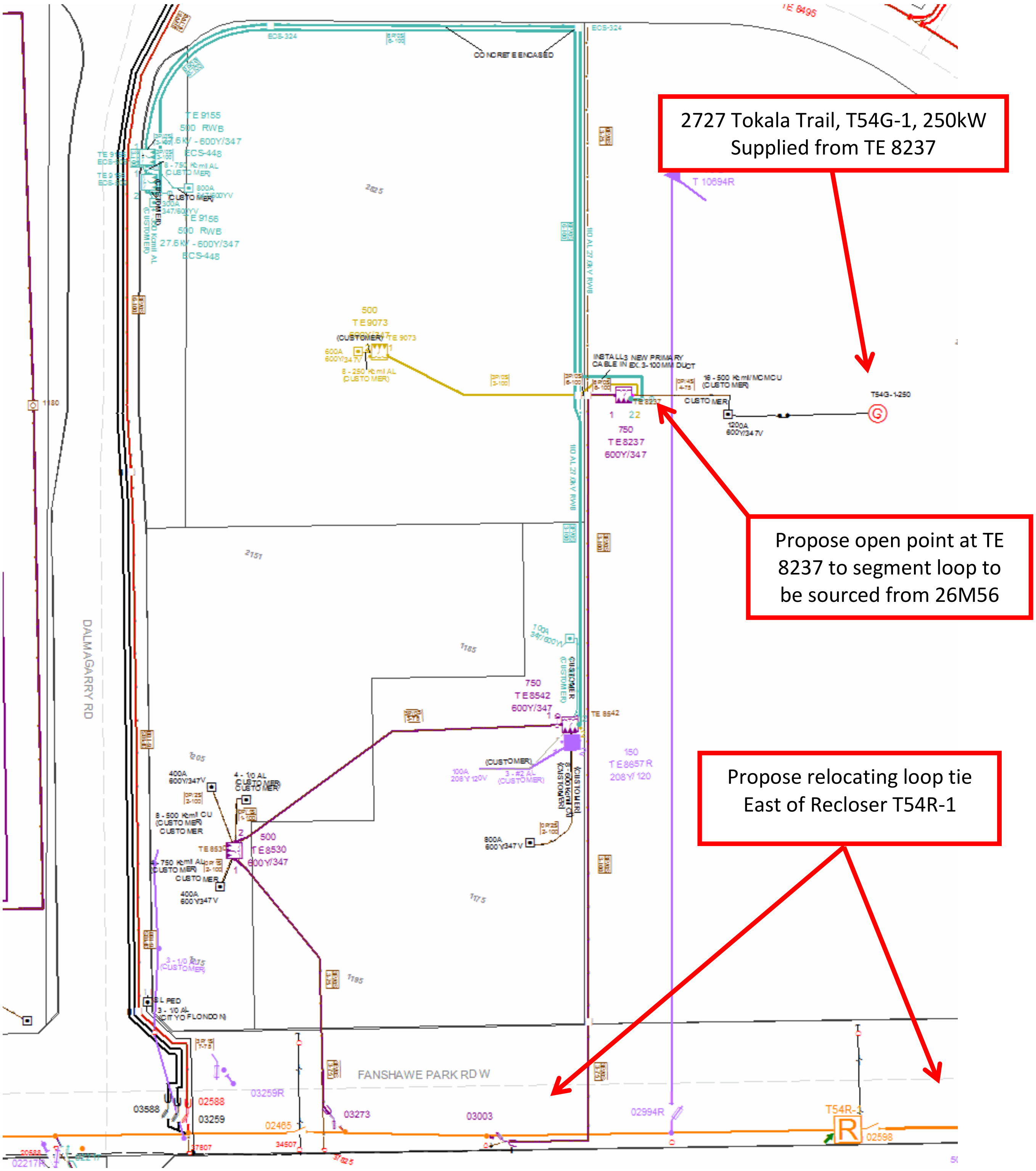


Figure 19: Propose 2727 Tokala Trail to be resupplied via 26M56

4.2.3 Option #8 – 26M13 – Oxford – Additional Offload to 26M54

To further balance 26M13 there is opportunity to offload to 26M54 along Oxford, where they share the same pole line. SUB 51 is a good candidate, as well as other 3 phase and 1 phase taps but these will need to be investigated further during the detail design stage. Conservatively approximately 2 MW could be offloaded from 26M13 to 26M54, bringing their load to 18 MW and 17.5 MW, respectively. Figure 20 depicts potential load pockets, where green shading is most likely and red is less likely.

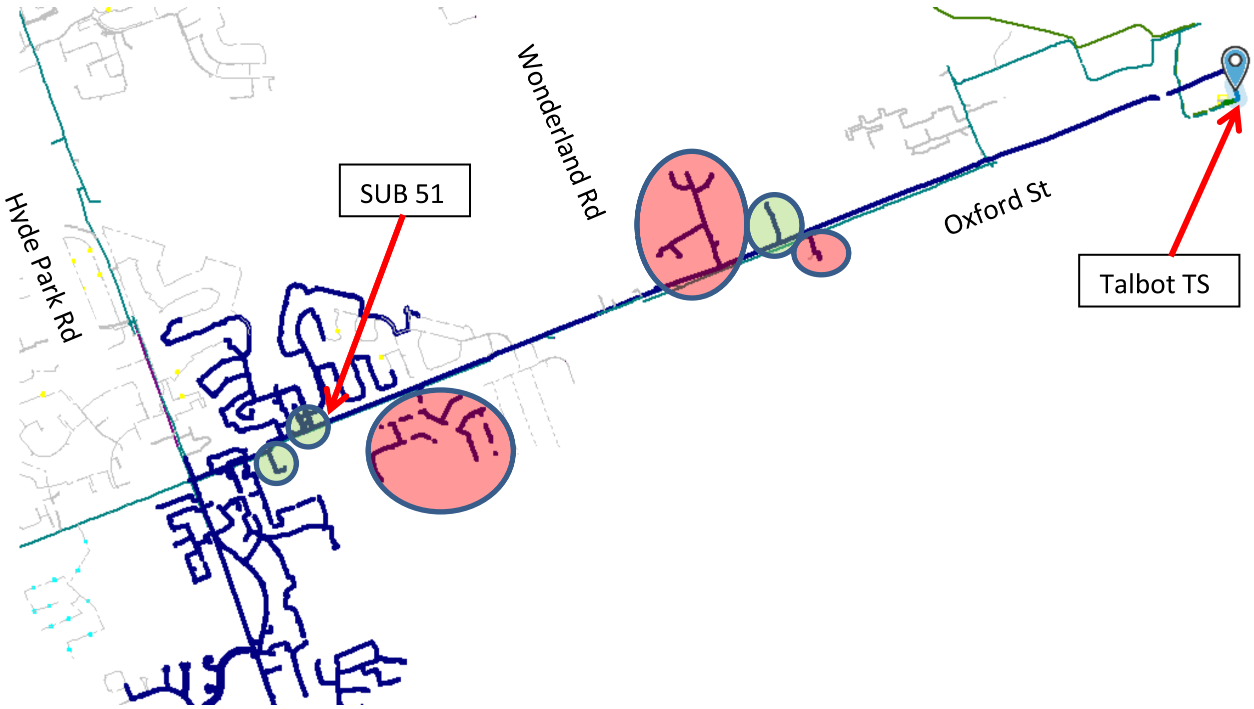


Figure 20: 26M13 – Potential Offload Load Pockets to 26M54

5 Summary

This report concentrated on the North West section of the city, to address the growth that London Hydro experienced over the past 5 years and consider the continued development occurring in the area.

The proposed changes will improve loading to address the immediate need of heavily loaded feeders, while freeing up capacity to accommodate forecasted developments.

The next feeder that is projected to be heavily loaded is 26M21. Preliminary analysis showed that the 26M12 which is lightly loaded could be leveraged to offload the 26M21. Further investigation is required.

The following tables, Table 13, Table 14, Table 15, and Table 16 summarize the feeders final configurations, assuming all proposed changes were applied.

Note the proposed final loadings, most notably 26M23, may increase, approximately 3 MW, as strategic 4 kV conversions along Riverside Drive, and/or other loads, are added to the feeder.

In addition a feeder contingency assessment was conducted to ensure adequate feeder tie capacity; Table 16 and Figure 21 assist to depict the Level 1 ties. In general, the feeders will have adequate back-up capacity post the reconfigurations, however, future assessment of the feeder automations, to ensure ½ or ⅓ feeder segmentation automation exists to provide operational flexibility. For insight to the process used to assess the feeder capacity, feeder ties were considered along with the Bus that the supply originated. Note only an N-1 bus failure scenario was considered.

Lastly, 26M23 is depicted as only having 2 feeder ties. Although this meets the N-1 requirement, however, it is expected when the feeder detailed design is in-progress opportunities with other feeders in close proximity, and expansion during the 4kV conversion activities, additional ties will be added.

Feeder	Summer Coincident Peak June 12, 2017 @ 5pm [MW]	Final Load (Expected Demand After Reconfigurations) [MW]	Total % Delta
26M54	31.5	17.50	-44%
26M56	26.0	18.20	-30%
26M55	20.8	16.00	-23%
26M42	18.2	21.40	18%
32M8	17.7	17.70	0%
32M5	15.1	15.10	0%
26M22	14.5	11.50	-21%
26M13	11.4	18.00	58%
32M2	7.6	7.60	0%
26M14	7.0	14.80	111%
26M25	18.6	18.60	0%
26M23		12.00	N/A

Table 13: Summary of Modified Feeders Final State

Sum of	Existing State						[MW]	Final State						[MW]	
Row Labels	Column Labels B	J1	J2	Q1	Q2	Y	Grand Total	B	J1	J2	Q1	Q2	Y	Grand Total	Delta
Talbot TS	56.71	54.05	40.01	47.15	78.37	39.78	316.05	65.707	54.05	43.21	47.15	51.77	54.18	316.05	
26M11						19.03	19.03						19.03	19.03	0%
26M12						2.30	2.30						2.30	2.30	0%
26M13						11.42	11.42						18.02	18.02	58%
26M14						7.03	7.03						14.83	14.83	111%
26M21	23.66						23.66	23.66						23.66	0%
26M22	14.47						14.47	11.467						11.47	-21%
26M23								12						12.00	NA
26M25	18.58						18.58	18.58						18.58	0%
26M41			21.78				21.78			21.78				21.78	0%
26M42			18.23				18.23			21.43				21.43	18%
26M43														0.00	NA
26M46		19.65					19.65		19.65					19.65	0%
26M47		20.24					20.24		20.24					20.24	0%
26M48		14.16					14.16		14.16					14.16	0%
26M51				13.97			13.97				13.97			13.97	0%
26M52				18.03			18.03				18.03			18.03	0%
26M53				15.15			15.15				15.15			15.15	0%
26M54					31.51		31.51					17.51		17.51	-44%
26M55					20.79		20.79					15.99		15.99	-23%
26M56					26.07		26.07					18.27		18.27	-30%
Grand Total	56.71	54.05	40.01	47.15	78.37	39.78	316.05	65.707	54.05	43.21	47.15	51.77	54.18	316.05	
BUS Deltas:	30%	26%		40%				18%	20%		9%				

Table 14: Summary of All Talbot TS Feeders Final State Including All Proposed Changes[5]

[5] Proposed changes improve Bus deltas to be within acceptable levels, < 20%

NW Feeder	Existing Total 10yr Growth [MW]	New Total 10yr Growth [MW]	10yr Linearly Extrapolated Yrly Growth [MW]	Existing 2017_2018	New 2017_2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	%_Yrly_Growth	%_10yr_Growth
26M54	3.4456	1.7000	0.1700	31.5077	17.5000	17.6700	17.8400	18.0100	18.1800	18.3500	18.5200	18.6900	18.8600	19.0300	19.2000	19.3700	0.97%	10.69%
26M56	4.8209	4.7209	0.4721	26.0700	18.2000	18.6721	19.1442	19.6163	20.0884	20.5605	21.0326	21.5046	21.9767	22.4488	22.9209	23.3930	2.59%	28.53%
26M21	4.7335	4.7335	0.4734	23.6600	23.6600	24.1334	24.6067	25.0801	25.5534	26.0268	26.5001	26.9735	27.4468	27.9202	28.3935	28.8669	2.00%	22.01%
26M41	0.6253	0.6253	0.0625	21.7800	21.7800	21.8425	21.9051	21.9676	22.0301	22.0927	22.1552	22.2177	22.2803	22.3428	22.4053	22.4679	0.29%	3.16%
26M55	1.7883	1.2709	0.1271	20.7900	16.0000	16.1271	16.2542	16.3813	16.5083	16.6354	16.7625	16.8896	17.0167	17.1438	17.2709	17.3980	0.79%	8.74%
26M47	1.3406	1.3406	0.1341	20.2370	20.2370	20.3711	20.5051	20.6392	20.7733	20.9073	21.0414	21.1754	21.3095	21.4436	21.5776	21.7117	0.66%	7.29%
26M46	1.3796	1.3796	0.1380	19.6460	19.6460	19.7840	19.9219	20.0599	20.1978	20.3358	20.4738	20.6117	20.7497	20.8876	21.0256	21.1636	0.70%	7.72%
26M11	0.6415	0.6415	0.0642	19.0300	19.0300	19.0942	19.1583	19.2225	19.2866	19.3508	19.4149	19.4791	19.5432	19.6074	19.6715	19.7357	0.34%	3.71%
26M25	0.7854	0.7854	0.0785	18.5800	18.5800	18.6585	18.7371	18.8156	18.8942	18.9727	19.0513	19.1298	19.2083	19.2869	19.3654	19.4440	0.42%	4.65%
26M42	0.7686	0.7986	0.0799	18.2300	21.4000	21.4799	21.5597	21.6396	21.7194	21.7993	21.8792	21.9590	22.0389	22.1187	22.1986	22.2785	0.37%	4.10%
26M52	0.4771	0.4771	0.0477	18.0290	18.0290	18.0767	18.1244	18.1721	18.2198	18.2675	18.3153	18.3630	18.4107	18.4584	18.5061	18.5538	0.26%	2.91%
32M8	0.0027	0.0027	0.0003	17.6600	17.6600	17.6603	17.6605	17.6608	17.6611	17.6613	17.6616	17.6619	17.6621	17.6624	17.6627	17.6629	0.00%	0.02%
70M7	0.0071	0.0071	0.0007	16.2200	16.2200	16.2207	16.2214	16.2221	16.2229	16.2236	16.2243	16.2250	16.2257	16.2264	16.2271	16.2279	0.00%	0.05%
26M53	0.3157	0.3157	0.0316	15.1500	15.1500	15.1816	15.2131	15.2447	15.2763	15.3078	15.3394	15.3710	15.4026	15.4341	15.4657	15.4973	0.21%	2.29%
32M5	1.2842	1.2842	0.1284	15.1400	15.1400	15.2684	15.3968	15.5253	15.6537	15.7821	15.9105	16.0389	16.1673	16.2958	16.4242	16.5526	0.85%	9.33%
26M22	1.3562	1.3562	0.1356	14.4670	11.5000	11.6356	11.7712	11.9069	12.0425	12.1781	12.3137	12.4494	12.5850	12.7206	12.8562	12.9919	1.18%	12.97%
26M48	0.5075	0.5075	0.0507	14.1630	14.1630	14.2137	14.2645	14.3152	14.3660	14.4167	14.4675	14.5182	14.5690	14.6197	14.6705	14.7212	0.36%	3.94%
26M51	1.8936	1.8936	0.1894	13.9660	13.9660	14.1554	14.3447	14.5341	14.7234	14.9128	15.1022	15.2915	15.4809	15.6702	15.8596	16.0490	1.36%	14.91%
19M38	0.0008	0.0008	0.0001	12.8640	12.8640	12.8641	12.8642	12.8642	12.8643	12.8644	12.8645	12.8646	12.8646	12.8647	12.8648	12.8649	0.00%	0.01%
26M13	1.6488	3.4456	0.3446	11.4200	18.0000	18.3446	18.6891	19.0337	19.3782	19.7228	20.0674	20.4119	20.7565	21.1011	21.4456	21.7902	1.91%	21.06%
32M7	0.0387	0.0387	0.0039	11.1690	11.1690	11.1729	11.1767	11.1806	11.1845	11.1884	11.1922	11.1961	11.2000	11.2038	11.2077	11.2116	0.03%	0.38%
32M3	0.0781	0.0781	0.0078	10.9200	10.9200	10.9278	10.9356	10.9434	10.9512	10.9590	10.9669	10.9747	10.9825	10.9903	10.9981	11.0059	0.07%	0.79%
26M14	0.7156	0.7217	0.0722	7.0298	14.8000	14.8722	14.9443	15.0165	15.0887	15.1608	15.2330	15.3052	15.3774	15.4495	15.5217	15.5939	0.49%	5.36%
19M24	0.0455	0.0455	0.0046	6.1950	6.1950	6.1996	6.2041	6.2087	6.2132	6.2178	6.2223	6.2269	6.2314	6.2360	6.2405	6.2451	0.07%	0.81%
26M12	0.0148	0.0148	0.0015	2.2970	2.2970	2.2985	2.3000	2.3014	2.3029	2.3044	2.3059	2.3073	2.3088	2.3103	2.3118	2.3133	0.06%	0.71%
26M23	#N/A	0.56	0.0560	N/A	12.0000	12.0560	12.1120	12.1680	12.2240	12.2800	12.3360	12.3920	12.4480	12.5040	12.5600	12.6160	0.47%	N/A

Table 15: Summary of NW Feeders, with Re-Configurations, MW Linearly Projected to 2029[6,7]

[6] 26M21 and 26M42 to be addressed in separate study in the near future

[7] 26M41 to be addressed with Nelson TS when construction is complete

	Present				New			
Feeder	Length [KM]	No. of Cust.	2017 CP [MW]	LEVEL 1 TIES	Length [KM]	No. of Cust.	2019 Est. [MW]	LEVEL 1 TIES
26M54	13.0	6087	31.51	26M13, 26M14, 26M22, 26M42, 26M55, 26M56, 32M2, 32M5, 32M8	10.6	2337	17.50	26M14, 26M22, 32M5, 32M8
26M56	13.0	6408	26.07	26M11, 26M14, 26M21, 26M42, 26M46, 26M47, 26M54, 26M55, 70M2	13.0	4412	18.20	26M11, 26M14, 26M42, 26M47, 26M55, 26M13, 70M2
26M42	8.2	3424	18.23	26M14, 26M25, 26M47, 26M54, 26M55, 26M56	9.3	4955	21.40	26M14, 26M25, 26M47, 26M55, 26M56, 26M13
26M55	7.1	3246	20.79	26M12, 26M13, 26M14, 26M42, 26M46, 26M54, 26M56	5.5	2039	16.00	26M12, 26M13, 26M14, 26M42, 26M46, 26M56, 26M23
26M13	7.5	1998	11.42	26M21, 26M22, 26M54, 26M55, 51F1	13.0	4945	18.00	26M21, 26M22, 26M55, 26M42, 26M56, 32M2, 26M23
26M14	8.9	2009	7.03	26M21, 26M22, 26M25, 26M42, 26M46, 26M47, 26M54, 26M55, 26M56	9.4	4005	14.80	26M21, 26M22, 26M25, 26M42, 26M46, 26M47, 26M54, 26M55, 26M56
26M22	8.6	2580	14.5	26M13, 26M14, 26M21, 26M25, 26M41, 26M54, 32M3, 32M6	8.6	2278	11.50	26M13, 26M14, 26M21, 26M25, 26M41, 26M54, 32M3, 32M6
26M23	--	--	--	--	10.8	3114	12.0	26M13, 26M55
26M43	--	--	--	--	--	--	--	--

Table 16: Summary of Modified Talbot TS Feeders Final State with Ties

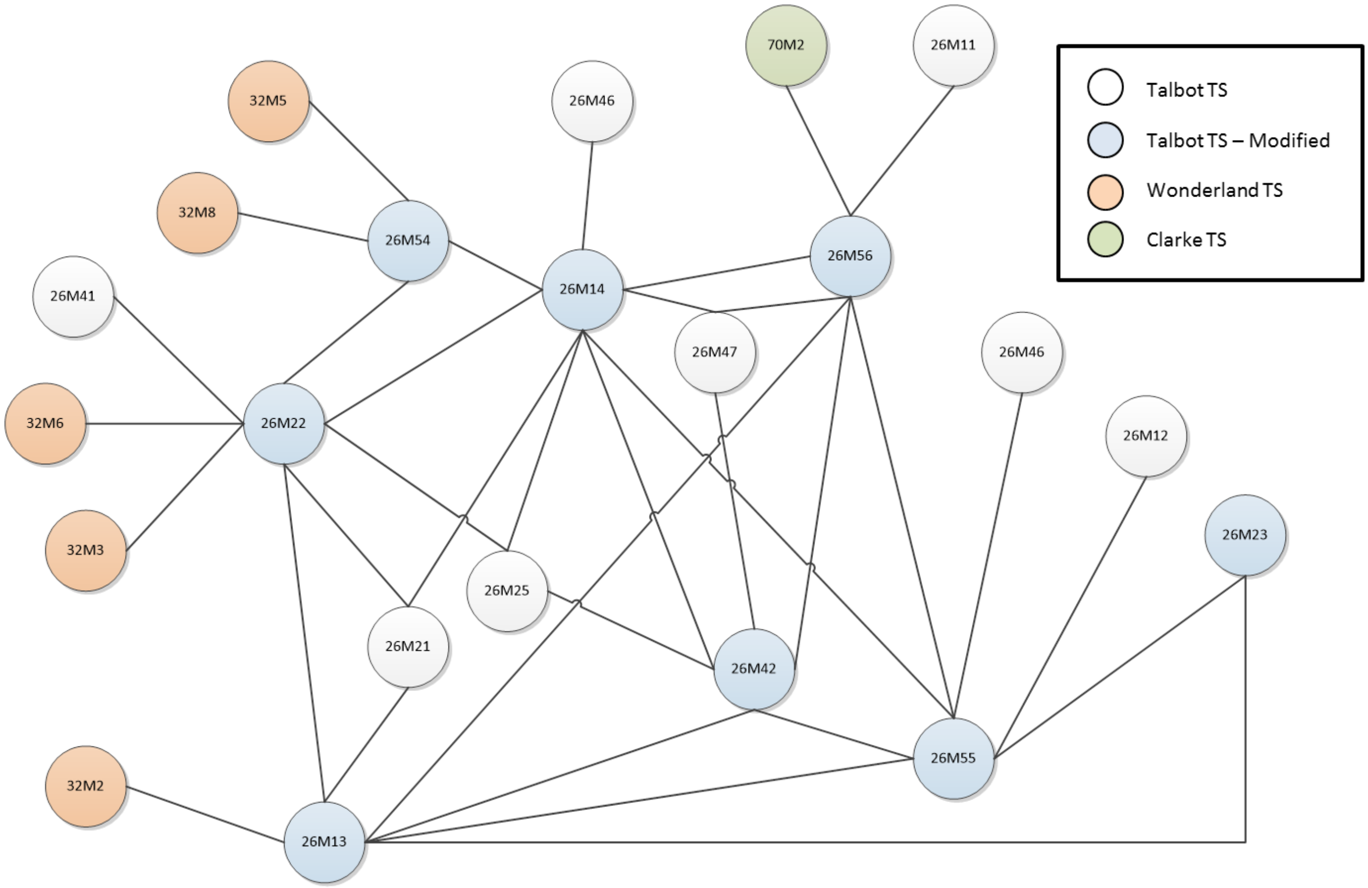


Figure 21: North West Feeders Level 1 Ties State Diagram[8]

[8] The state diagrams only depicts the Level 1 feeders associated with the proposed modified feeders as depicted by the blue shaded circles

Distribution System Planning Strategy

A Framework for 2020-2024

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Executive Summary

This Distribution System Planning Strategy (DSPS) report documents the strategic framework to guide Engineering and Operations' capital programs for the next five years (2020 to 2024). This report is intended to be a high level strategy and does not delve into the specifics of project development.

Section 1 of this report recognizes that the traditional electricity generation, transmission, and distribution (GT&D) system from the late 1800s is in the midst of disruption from multiple fronts (regulation, generation, customer demands, etc.). Utility engineers are faced with the challenges of addressing both the internal and external demands on the distribution system cost effectively with limited capital resources. There are observable market trends for incorporation of Distributed Energy Resources (DERs) that can be used as a guide to better position London Hydro for delivering electricity safely and reliably while being cost effective and provisioning for the distribution system of the next century.

It is also recognized that reliability is one of the key metrics that is at the forefront of our customers and the Ontario Energy Board as can be seen from the Scorecard that is published annually. The OEB considers it important for distributors to understand the reliability performance being delivered to the individual customer. Customers Experiencing Multiple Interruptions (CEMI) and/or Customers Experiencing Long Duration Interruptions (CELDI) were a couple of considerations for how to measure reliability at the customer level. Although there has not been further correspondence from the OEB on the topic of customer specific reliability reporting, London Hydro is well positioned to leverage the existing OMS system, with some improvements, to gain insight into reliability at the customer level.

Section 2 of this report provides an assessment of London Hydro's present situation with respect to reliability, increased level of City Works, and system capacity planning. The long term trend of reliability shows a declining SAIDI and SAIDI which is indicative of improving reliability, however, the near term five year trend shows that SAIFI is trending upwards which indicates the frequency of interruptions is increasing. As well, the number of major event days (MEDs) is trending upwards since 2014 as are the number of momentary interruptions. For a more granular analysis, a spatial reliability assessment was conducted to determine the relative SAIDI/SAIFI score for each transformer station. Assuming each TS was its own independent City, a reliability score was developed that considered only the customers supplied from that station. The score was based on a weighted sum of 70% SAIFI and 30% SAIDI. The assessment concluded that Buchanan TS, Talbot TS, and Wonderland TS have adversely poor performance in comparison to Clarke TS and Highbury TS.

In addition, the City has extensive plans for upgrading water, sewer, and transit infrastructure in the downtown core and outside of the core. Many of these projects impact London Hydro's infrastructure and requires coordination with the City. Furthermore, the residential, industrial, commercial and institutional development growth projected by the City was used to forecast the electrical demand at each station. This assessment shows that Talbot DESN1, Talbot DESN2, and Highbury TS will be exceeding LTR values in the near term (5 years) and Clarke TS LTR will be exceeded in the mid-term (10 years). After leveraging the available capacity at the new Nelson TS and planning for new feeder builds and balancing of feeder loads between stations, the adjusted projected electrical demand shows that there will be no excess at Talbot TS; however, the LTR at Clarke will continue to be exceeded in the mid-term. Highbury TS has abnormally low LTR threshold and London Hydro will be seeking to address this in the upcoming Regional Planning cycle starting in 2020.

Section 3 of this report sets forth the strategic direction considering the contextual background, challenges, and opportunities faced by London Hydro. The strategies were categorized into four areas:

- strategies by distribution system,
- opportunities for leveraging data and technology,
- distributed energy resources, and
- environmental and sustainability considerations

A number of strategies were recommended and these have been summarized in Section 4.

1 Introduction

1.1 Objective

The objective of this Distribution System Planning Strategy (DSPS) report is to document the strategic framework to guide Engineering and Operations' capital programs for the next five years (2020 to 2024). This report is intended to be a high level strategy and does not delve into the specifics of project development. In parallel with the development of this DSPS, Kinectrics has been retained by London Hydro to complete an Asset Condition Assessment (ACA) Study that is to be finalized by end-of-year 2019. The expectation is that a five-year plan of projects for the Asset Sustainment Plan (ASP) will be developed based on the findings of the ACA while following the principles of this strategic framework.

1.2 Strategic Context (Background)

The traditional electricity generation, transmission, and distribution (GT&D) system from the late 1800s was based on a top-down power delivery model with a unidirectional power flow. Although this model has served its purpose well historically, it is in the midst of disruption from multiple angles due to, among other things, changing regulation and policies, deployment of distributed energy resources by the 'traditional consumers', greater customer expectations. In addition to these external pressures, utility engineers are facing internal pressures due to aging / degrading infrastructure, diminishing reliability performance (i.e. increasing failures) due to degrading equipment and more frequent extreme weather conditions, and growth of the City requiring increased electrical demand or advanced refurbishment of infrastructure in conflict with City developments.

Utility engineers are faced with the challenges of addressing both the internal and external demands on the distribution system cost effectively with limited capital resources. While it is conceivable that the traditional distribution system would have naturally evolved to improve asset management and reliability by leveraging advancements in technological devices/solutions, the "ultimate" model for the electricity system of the next century that incorporates consumer based generation for bi-directional power flow and transactional energy is unclear at this time. There are observable market trends that can be used as a guide to better position London Hydro for delivering electricity safely and reliably while being cost effective and provisioning for the distribution system of the next century.

Reliability

The Ontario Energy Board (OEB) regulations have evolved over time with more stipulations on LDCs to assess their performance. Reliability reporting is one such stipulation as part of the OEB's Service Quality Requirements that is continually evolving. At the present time electrical utilities are benchmarked against their own historical performance. An electrical utility's rolling five-year system average number of interruptions (SAIFI) and system average duration of interruptions (SAIDI) are benchmarked against its own fixed five-year SAIFI and SAIDI prior to its Cost of Service filing. For example, London Hydro's performance at the end of 2019 would be based on the average performance of years 2015-2019 compared against the average performance of years 2012-2016 (the 5-years prior to Cost of Service approval).

Although there are no direct stipulations to monitor reliability at the individual customer level, the OEB considers it important for distributors to understand the reliability performance being delivered to the individual customer. In their December 7th 2015 Report of the Board, the OEB states:

> *The OEB has long recognized the need to explore reliability performance beyond the system wide level. The OEB is concerned with the extent to which specific customers may experience significantly below average reliability performance. A move towards customer specific reliability measures is essential to identifying those pockets of underserved customers. Therefore, the OEB will move forward with the introduction of customer specific system reliability measures, as soon as practical.*[1]

The OEB was considering a pilot project with a few utilities to monitor and report distribution outages in a manner that identifies the outages experienced at the individual customer level. Customers Experiencing Multiple Interruptions (CEMI) and/or Customers Experiencing Long Duration Interruptions (CELDI) were a couple of considerations. The OEB was open to suggestions on other ways that customer specific reliability could be measured and reported:

> *Whatever the approach, in light of the objectives of the OEB's renewed regulatory framework and its focus on the customer experience, the OEB considers it important for distributors to understand the reliability performance being delivered to the individual customer.*[1]

In response to the OEB's December Report, the OEB received ten written comments from stakeholders including electricity distributors and the Electricity Distributor's Association (EDA). There was overwhelmingly support for the OEB's initiative of monitoring customer specific reliability measures and to pursue a pilot project in this regard. Although the OEB was targeting an implementation date of 2018 for customer specific reliability reporting, the majority stakeholder feedback was that 2018 was potentially too aggressive and recommended to wait for the completion of the pilot project to determine next steps. The OEB's letter on May 3, 2016 was the last correspondence received on this topic where they noted that *"Issues relating to customer specific system reliability measures will be dealt through a separate process"*[2].

Although there has not been further correspondence from the OEB on the topic of customer specific reliability reporting, reliability is one of the key metrics that is at the forefront as can be seen from the Scorecard that is published annually. Further discussions on the topic of reliability is addressed in the report that will highlight the value of more granular reliability data

[1] OEB Report of the Board EB-2015-0182, December 7, 2015, pg. 3 and 22
https://www.oeb.ca/sites/default/files/uploads/Board_Report_MajorEvents_EB-2015-0182_20151207.pdf
[2] OEB Letter Re:EB-2015-0182, May 3, 2016, pg. 2
https://www.oeb.ca/oeb/_Documents/EB-2015-0182/Notice_Amendments_RRR_MajorEvents_20160503.pdf

Distributed Energy Resources (DERs)

Due to innovation and cost reductions, the requests / presence of Distributed Energy Resources (DERs) such as roof top photo-voltaic (PV) systems, battery energy storage systems (BESS), and micro-generation is increasing in the distribution system.

There is a rising interest in microgrids consisting of advanced control systems that integrates customer's loads, DERs such as PV and BESS, and coordinates with the distribution system. The perceived value of microgrids is that it provides improved reliability by sustaining the electrical load under a utility power outage and that it can reduce operational costs by reducing peak demand energy charges. Wide scale implementation of residential microgrids is likely to require further reduction in the cost of PV and battery technologies.[3]

London Hydro performed a situational analysis on factors relating to the EV industry and the adoption of EVs in 2017. At the time, the analysis showed increased government investment in this sector, increased investment from automakers, increased EV capabilities through improved technology (e.g. range, charging capacity), increased availability of smart charging tools and smart energy initiatives, and exponential growth in sales.[4] The new Conservative government of Ontario, sworn in on June 29, 2018, adopted a different policy to that of the Liberal government and canceled the cap-and-trade program which funded rebates for electric vehicles.[5] Since then, sales of EVs and hybrid vehicles have dropped more than 50% in Ontario over the past year. Electric Mobility Canada attributes at least part of this decline to the end of Ontario's Electric and Hydrogen Vehicle Incentive Program (EHVIP) in July 2018.[6]

[3] https://www.marsdd.com/wp-content/uploads/2019/03/Future-of-Microgrids-Residential.pdf

[4] Status of the EV Industry and London Hydro Grid Preparedness, A.V. Damme, June 2017. X:\Engineering\Engineering Reports\Special Projects\Electric Vehicles\2017 - Status of the EV Industry and London Hydro Grid Preparedness - London Hydro.pdf

[5] Bickis, Ian (July 13, 2018). "End of Ontario electric vehicle rebate program expected to hit sales". CTV News. The Canadian Press. https://www.ctvnews.ca/business/end-of-ontario-electric-vehicle-rebate-program-expected-to-hit-sales-1.4012761

[6] https://www.cbc.ca/news/canada/ottawa/electric-car-sales-ontario-drop-cancellation-rebates-1.5223071

2 Current State Assessment

2.1 Reliability

2.1.1 System Average Interruption Indices

The condition of London Hydro's distribution system can be inferred from the performance of its reliability indicators SAIFI and SAIDI.

Overall, the distribution system shows a remarkable progress in terms of SAIDI and SAIFI during the last 25 years. Both indicators have followed a downwards trend showing less interruptions with reduced duration. While in 1994 a customer, in average, experienced over 2 interruptions lasting over 1.5 hours, by the end of 2019, it is projected that a customer would experience just over 1 interruption lasting less than 1 hour.

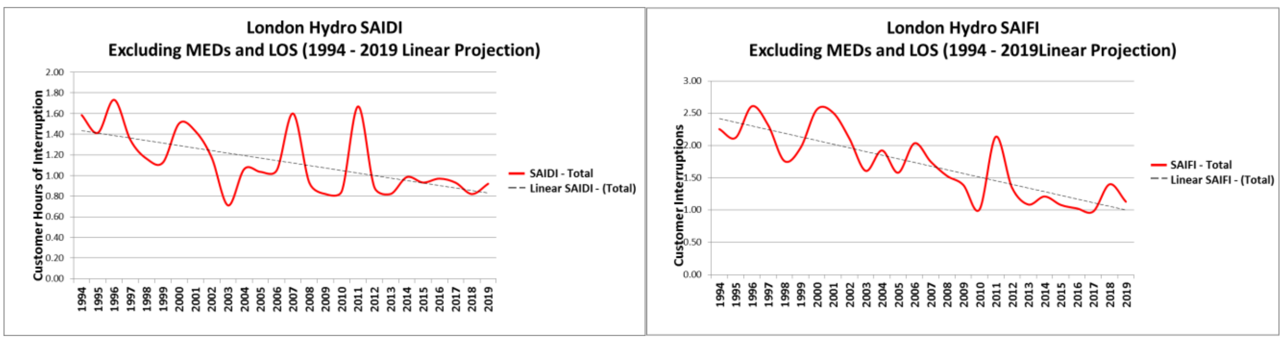

Figure 1: 25 Year SAIDI and SAIFI Performance

However, in order to get a better appreciation of the behavior of the system, it is necessary to look at the most recent years to capture the events that are impacting the current system. The SAIDI continues a decreasing trend while the SAIFI shows a slight increasing trend.

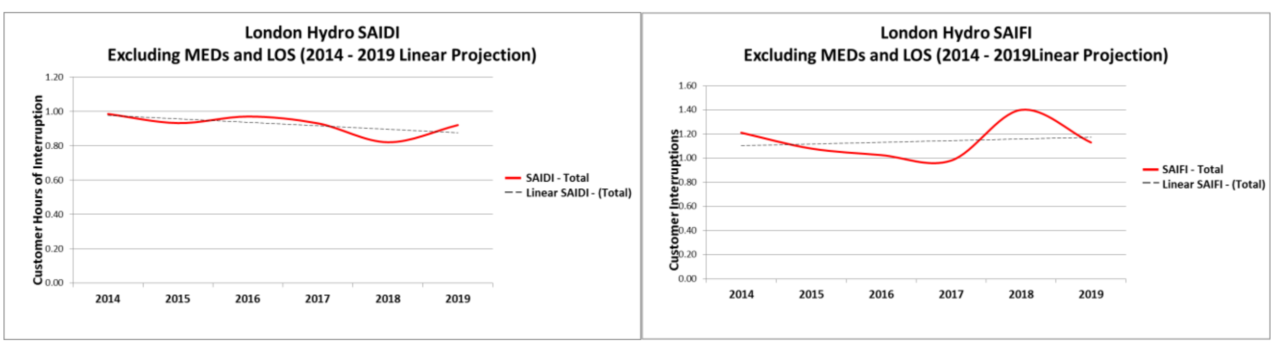

Figure 2: 5 Year SAIDI and SAIFI Performance

In regards to the SAIFI, the trend shows a slight increase. However, this trend is highly influenced by the 2018 indicator which peaked with 1.40 interruptions per customer on average. During 2018, equipment failure and foreign interference caused the largest interruptions after scheduled interruptions.

The SAIDI is following the linear trend closely. This indicates that the isolation and/or restoration procedures are effectively reducing the duration of the interruptions. Among the activities that have contributed to this positive outcome is the continued installation of automated devices (reclosers) and sectionalizing switches.

2.1.2 Major Events

The previous analysis excluded Major Event Days (MEDs) as these events are beyond the typical operation and control of the utility. A "Major Event" is defined as an event that is beyond the control of the distributor and is characterized as being unforeseeable, unpredictable, unpreventable, or unavoidable. MEDs are events that, due to their magnitude, extent and complexity, overpass the normal statistics of the utility. London Hydro has adopted the IEEE Standard 1366 – 2.5 Beta methodology in the determination of a MED.

Since 2014, London Hydro has experienced 10 MEDs. The most prominent causes of the MEDs have been weather related with seven events during the last six years as shown in Table 1.

Table 1: Major Event Days from 2014 to July 2019.

Year	Day	Cause	Customers Interrupted	Customer Minutes of Interruption
2014		No MED		
2015	23-Jun	Thunderstorm	21,500	1'000,000
2016		No MED		
2017	8-Mar	Windstorm	18,895	2'180,000
2017	24-Jun	Vehicle Accident	16,595	999,800
2017	10-Aug	Loss of Supply	16,911	1'256,757
2018	15-Apr	Freezing Rain	23,682	1'772,541
2018	4-May	Windstorm	20,890	2'240,373
2018	5-Jul	Adverse Weather	19,932	1'075,765
2019	13-Mar	Loss of Supply	29,692	1'267,134
2019	20-Jul	Thunderstorm	13,919	2'148,101
2019	21-Jul	Thunderstorm	16,855	1'180,609

It is important to note the increasing trend in terms of MEDs related to weather conditions as shown in Figure 3.

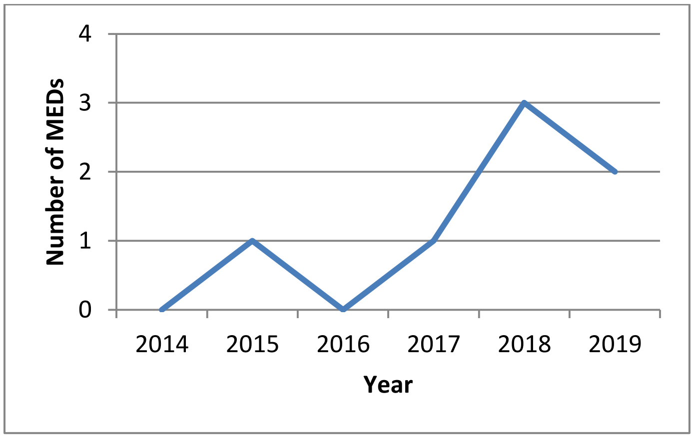

Figure 3: Weather Related MEDs per Year

2.1.3 Momentary Interruptions

Thus far, the discussions above have focused on sustained interruptions; however, momentary interruptions are an important consideration which is not forgotten. London Hydro employs a fuse saving scheme on its overhead feeders. The fuse saving scheme uses a low set instantaneous overcurrent element which will trip the feeder breaker before the fuse branch can blow, and the breaker is then immediately reclosed. The low set elements are automatically cut out of service after the first reclose, so that if the fault should persist, the inverse time elements will have to operate to trip the circuit breaker. This gives time for the branch circuit fuse of the faulty circuit to blow if the fault is beyond the fuse. In this way the cost of replacing blown branch circuit fuses is minimized, and at the same time the branch circuit outage is also minimized. One of the downsides of a fuse saving scheme is that all customers on the feeder are exposed to momentary outages.

When analyzing interruptions during the last three years, the data can be divided according to the involvement of a feeder breaker operation. The three cases considered are: 1) the breaker auto-recloses only, 2) the breaker auto-recloses and is followed by a sustained interruption downstream of a coordinating protection device, and 3) there is a sustained interruption either downstream of a coordinating protection device or due to a breaker lockout.

In regards to the first case scenario, on average, there were 144 breaker operations per year where only auto-reclosing took place. A breaker operation where only the auto-reclosing takes place indicates that the fuse saving scheme was successful and a sustained interruption was averted. A slight increasing trend is observed during the last three years as shown in Table 2.

In regards to the second case scenario of an auto-reclosure followed by a sustained interruption, on average there were 74 interruptions events. This scenario indicates that the fusing saving scheme was not successful due to a permanent fault that required a downstream protective device (or the circuit breaker) to operate to clear the fault. Similar to successful auto-reclosures, there is an increasing trend during the last three years.

The last category consists of interruption events where only sustained interruptions have been recorded (no auto-reclosures). The data does not discriminate between breaker lockout and downstream device operation (either fuse, interrupter or recloser). On average, there have been 918 sustained interruptions that have been recorded where auto-reclosing did not take place. The lack of an auto-reclosure operation may be due to numerous reasons such as: hold-off taken by control room operators, auto-reclosure not enabled on relay (i.e. U/G system), high impedance fault current seen on feeder which is below the low-set instantaneous pickup threshold, or mid-span tap failures).

Table 2: Sucessful vs Unsuccessful Auto-Reclosure Events.

Year	Number of Successful Auto-Reclosure Events	Number of Unsuccessful Auto-Reclosure Events	Number of non Auto-Reclosure Events
2017	134	50	915
2018	139	94	1016
2019	159	77	822
3-year average	144	74	918

2.1.4 Spatial Reliability

While the system average interruption indices provide a high level indication of overall reliability system wide, it does not serve well to indicate specific areas of the system that require improvement. In lieu of customer specific reliability indices, which are presently recognized as the ideal scenario to strive towards, we can apply the system wide indices at a TS level thereby providing an improved level of granularity.

Customer feedback states that frequency of interruptions is more disruptive than the duration of the interruption. Therefore, as a strategy to combine both $SAIFI_{TS}$ and $SAIDI_{TS}$ into a single score and to appreciate the impact of the frequency of interruption over the duration, the 27.6kv stations were ranked based on a 70% weight for SAIFI and 30% weight for SAIDI. The indicators were also normalized according to the customer count per station to stablish a baseline and be able to compare the stations' performance regardless their customer count. Thus a System Average Interruption Score ($SAIS_{TS}$) allowing a comparison of the relative reliability performance between Stations was derived.

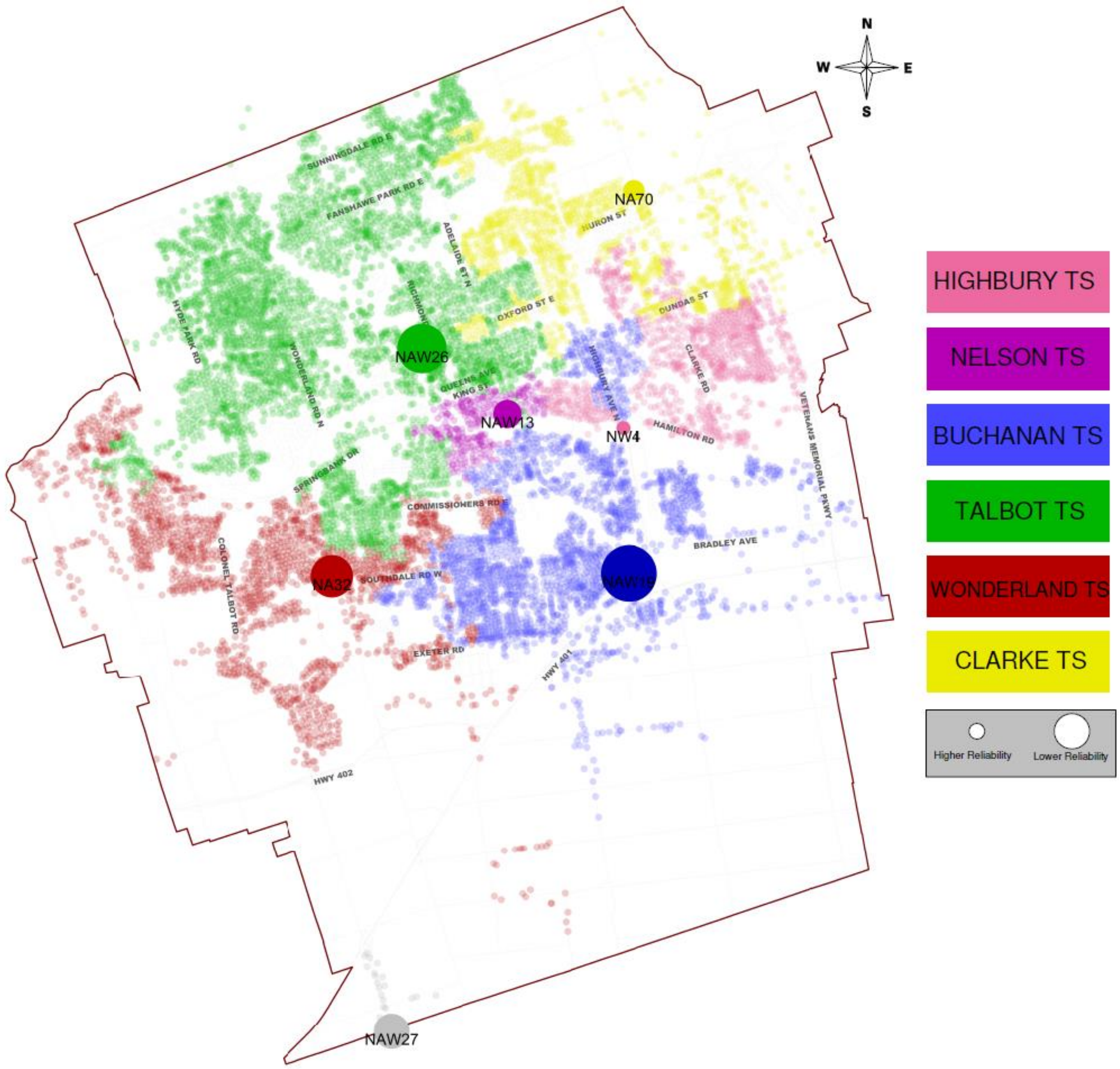

Figure 4: Transformer Station Reliability Performance based on Combined SAIFI (70%) and SAIDI (30%) Score

Figure 4 shows the service territory for each TS and the relative size of the circles indicate their performance $SAIS_{TS}$. Buchanan TS station has the lowest performance based on the highest $SAIS_{TS}$. Note the long reach and dispersion of their circuits. The weighted performance with emphasis on the frequency of interruptions provides value to improve the reliability and increase customer satisfaction. Figure 5 shows the contrast between the weighted/normalized Performance Score, SAIDI, and SAIFI per station.

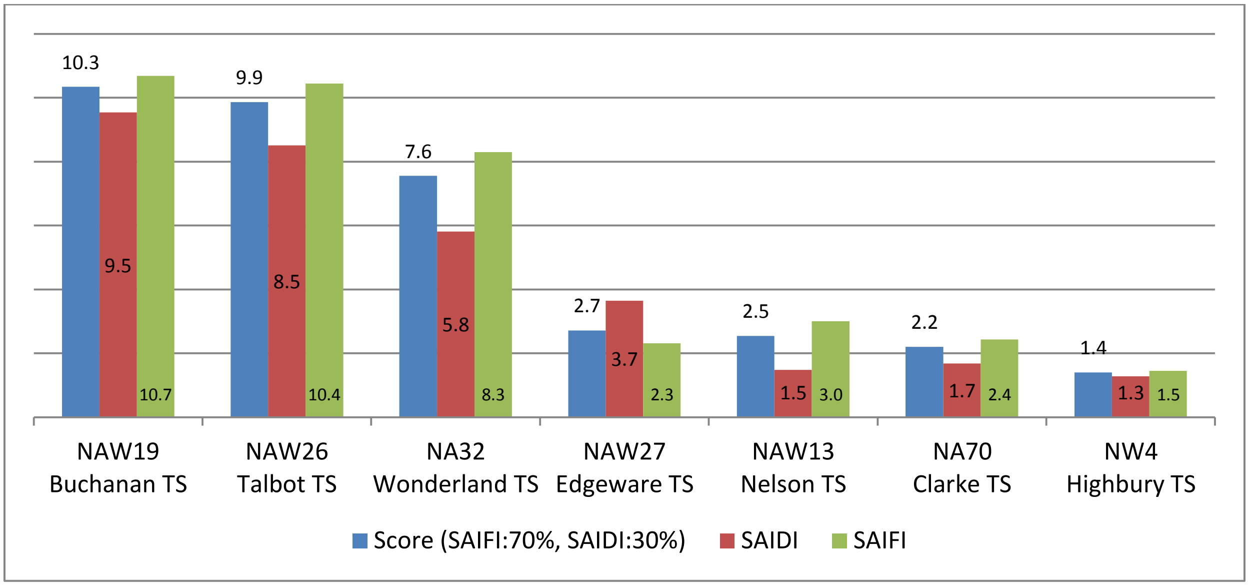

Figure 5: Weighted and normalized performance per station and average restoration (CAIDI)

Figure 6 provides an indication of the age of London Hydro's wood poles across the city. Note that replacement decisions are based on asset condition, but age is a general proxy for future replacement needs. As can be seen there is a significant quantity of assets approaching, or beyond, expected service life.

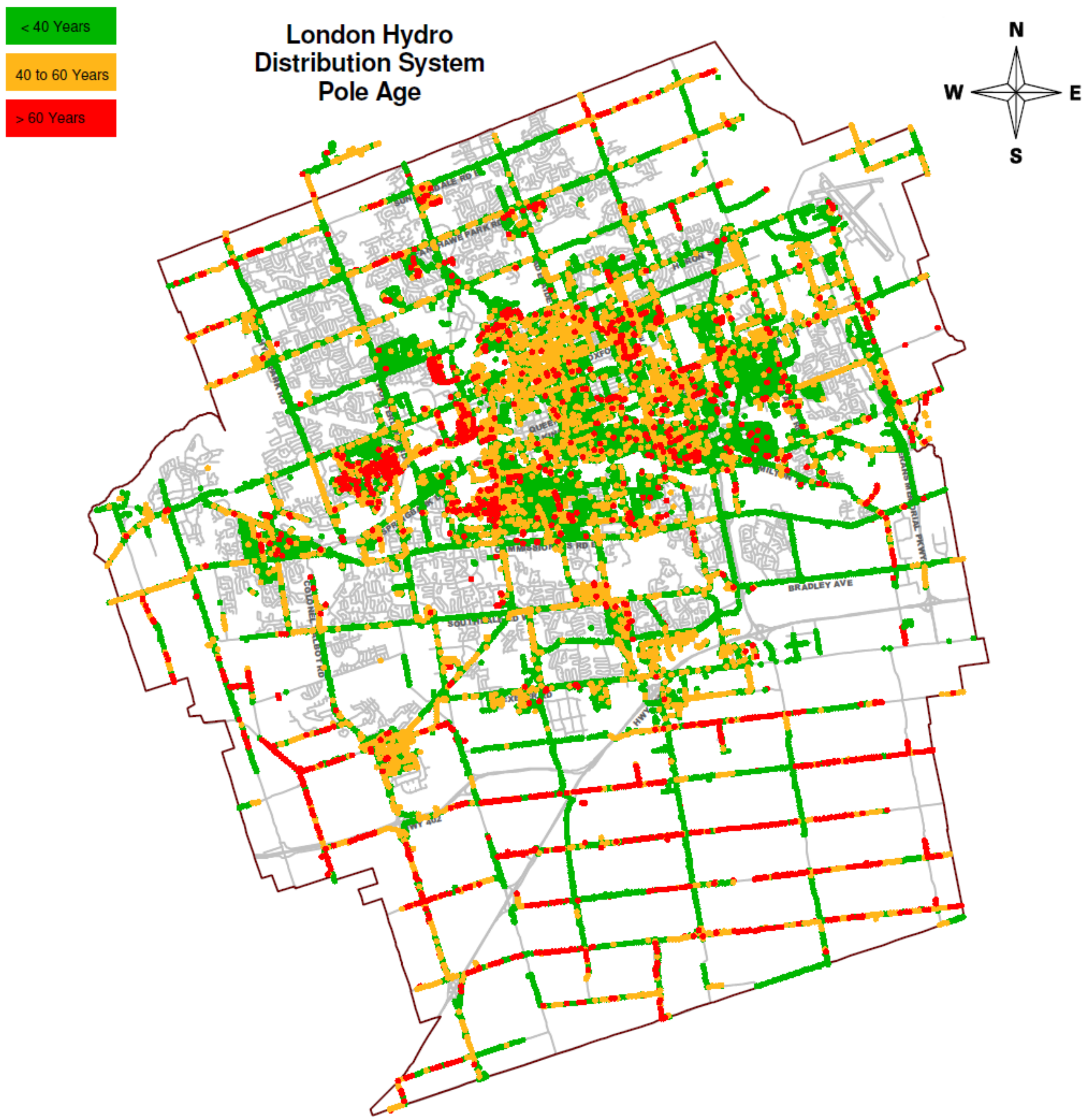

Figure 6: London Hydro Distribution System Pole Age Distribution

2.2 Increased Level of City Infrastructure Upgrades

Recently, the City of London has been performing an increased level of city infrastructure renewal projects. Such projects include road works and sewer/water upgrades that impact London Hydro's infrastructure. The largest project that is presently coming to an end by December 2019 is the Dundas Place project, shown in Figure 7, which was phased over a period of two years. The project scope extending from Ridout Street to Wellington Street involved the creation of a flexible street that is curbless and incorporates mid-block crossovers, allowing pedestrians to navigate from side to side with ease. It has been designed to accommodate both vehicles and pedestrians and would be closed to traffic for an event or activity to take place. In addition to the above-ground transformation, this project involved renewal of the storm sewer, sanitary sewer, and water main infrastructure. London Hydro rebuilt a significant amount cable/duct/maintenance hole infrastructure to renew the aging secondary network system downtown.

Figure 7: Dundas Place scope extended from Ridout St to Wellington St.

Concurrent with the Dundas Place project, the City was performing other renewal activities that is impacting London Hydro's infrastructure in many other parts of downtown such as York Street, Talbot Street and Richmond Street. Figure 8 shows an excerpt of the City of London's Infrastructure Projects for the year 2019. The rate and scale of City projects downtown is expected to continue in the near term planning horizon. This is likely to impact London Hydro's infrastructure and requires coordinated design / build activities with the City.

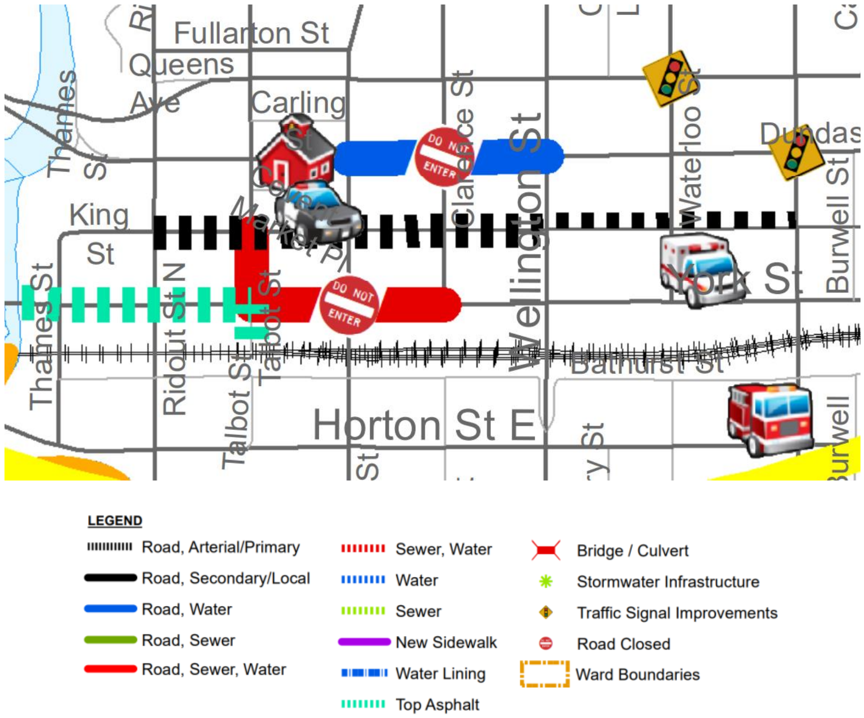

Figure 8: City of London's Infrastructure Renewal Projects Downtown

Subsequent to the City's Dundas Place project is the Bus Rapid Transit project which is more extensive (Figure 9). On August 23, 2019, the Government of Canada announced a $123-million funding commitment to support 10 transit and transit-supportive projects in London.[7] This contribution, combined with the Government of Ontario announcement on June 25, 2019 of a $103.5-million funding commitment is designed to help improve transit and transportation city-wide. The impacts of these projects are significant and will require many km of London Hydro's overhead circuitry to be rebuilt underground due to conflicts. There are many planning, design, and operational considerations that will need to be accounted for during and after the execution of the project.

[7] http://www.london.ca/residents/Roads-Transportation/TransitProjects/Pages/default.aspx

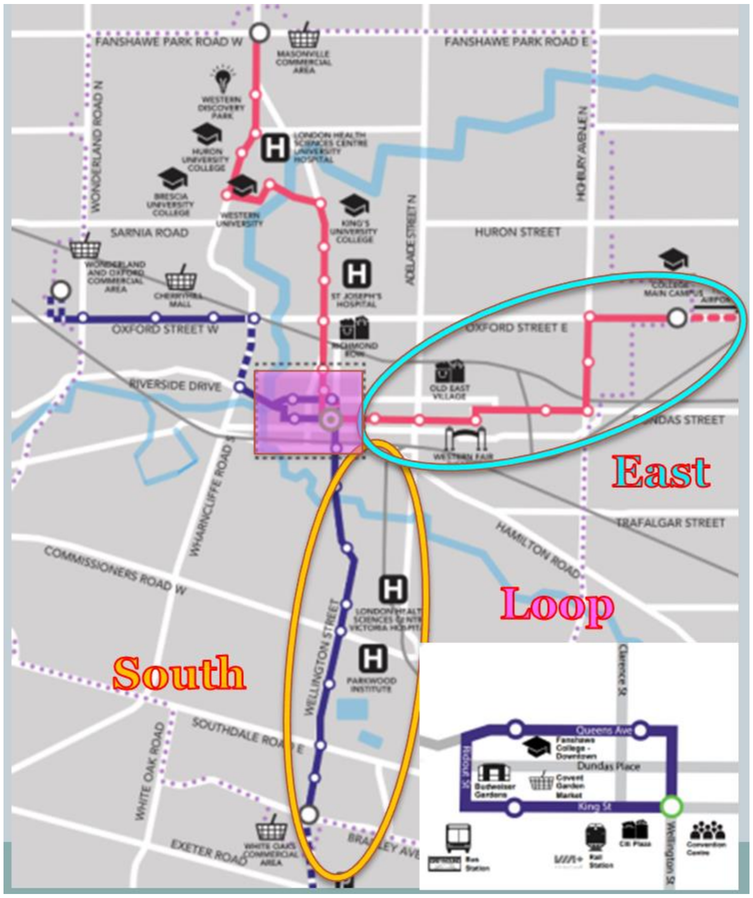

Figure 9: City of London's Bus Rapid Transit Project

2.3 System Capacity Planning

The aged 13.8kV Nelson Transformer Station was recently rebuilt to 27.6kV and put into service in December 2018. The bulk of Nelson's 13.8kV distribution system has been rebuilt to 27.6kV. There are a handful of large customers that remain to be converted and is planned to be addressed in 2020.

Hydro One has the following sustainment upgrade plans that fall within this planning horizon:

- Wonderland TS: replacement of all equipment with the exception of Transformer T5 and T6. T5 is a relatively new transformer as it has been replaced in 2019 (with a 2005 built unit) due to a failure. Planned in-service date for new station upgrades is Q3 2023.
- Clarke TS: Replacement T3 and T4 and replacement of HV disconnect switches, surge arresters, and DC station service. Q1 2025

The Normal Supply Capacity at Wonderland TS has increased from 105 MVA to 124 MVA due to the replacement of T5. This extra capacity provides the flexibility to load up the station to support growth in the South-West and support Talbot DESN 2 in the North-West.

The Normal Supply Capacity at Highbury TS is restricted to 1800 amps (88.5MVA) due to limitations of the bushings in the 4T3Y, 4T4J, and YJ breaker cubicles as well as the bus entrance bushings. This limitation is proving to be stressful to the operational flexibility of the system during peak demand conditions and prevents the full utilization of the transformers. Furthermore, the limitation is more pronounced when considering the 10-year demand forecast shown below in Figure 10.

Transformer Station Name	DESN ID (e.g. T1/T2)	Historical Data (MW) Net Load					Near Term Forecast (MW) Gross Peak Load Forecast					Medium Term Forecast (MW) Gross Peak Load Forecast				
		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Wonderland TS	T5/T6	100.00	95.51	87.31	95.00	90.97	92.79	94.62	96.44	98.27	100.10	101.92	103.75	105.57	107.40	109.23
Buchanan TS	T13/T14	118.0	139.1	123.2	140.0	132.0	122.2	129.2	132.2	135.3	138.3	141.3	143.0	144.6	146.3	148.0
Highbury TS	T3/T4	87.2	77.8	84.5	80.7	64.4	77.4	78.9	80.4	81.8	83.3	84.8	86.3	87.8	89.3	90.8
Clarke TS	T3/T4	79.5	106.9	94.6	111.1	85.3	86.7	88.1	89.5	90.8	92.2	93.6	95.0	96.4	97.8	99.1
Talbot TS (DESN 1)	T1Y/T2B	99.8	89.3	109.7	127.5	104.3	129.0	130.3	131.6	132.8	134.1	135.4	136.7	138.0	139.3	140.6
Talbot TS (DESN 2)	T3J1/T4J2 T3Q1/T4Q2	162.1	191.6	188.0	197.3	190.9	169.6	171.652	173.7	175.8	177.8	179.9	182.0	184.0	186.1	188.1
Nelson TS	T1/T2/T3/T4	34.6	15.5	11.9	11.6	37.8	38.2	38.5	38.9	39.3	39.7	40.1	40.5	40.9	41.3	41.7
Edgeware TS	27M2	0.84	0.55	0.53	0.53	0.58	0.58	0.59	0.59	0.59	0.59	0.60	0.60	0.60	0.61	0.61

Red fill, red text - Cells that are greater than Station LTR [MW]
No fill, green text - Cells that are greater than LH LTR [MW]

Figure 10: Un-adjusted 10-Year Non-Coincident Electrical Demand Forecast by TS

The second round of Regional System Planning is starting at the time of writing this report. Regional system planning ensures a reliable supply of electricity to Ontario's 21 electricity planning regions. Regional planning looks at the unique needs of each region, and considers conservation, generation, transmission and distribution, and innovative resources to meet these needs. The first round of Regional Planning started in 2015 with a Needs Assessment and ended in 2017 with the production of an Integrated Regional Resource Planning report. London Hydro is situated in the London Area Planning Region which included representatives from Entegrus Power Lines, Erie Thames Power Lines Corporation, St. Thomas Energy Inc., Tillsonburg Hydro Inc., Woodstock Hydro Services Inc., Hydro One Networks Inc. (distribution and transmission) and the IESO.

London Hydro has updated its load forecast in preparation for the Needs Assessment. The load forecast is built upon the City of London's growth and development forecast. The nature of the forecast is a spatial forecast that allows one to estimate the expected growth within a TS service boundary.

The un-adjusted forecast (Figure 10) highlights growth will exceed the Normal Supply Capacity (LTR) at various stations. Considering the interconnected nature of London Hydro distribution grid, the distribution system can be reconfigured to leverage the available capacity at lightly loaded Stations. Reconfiguration, which may require construction of some overhead infrastructure, supports those stations that are expected to exceed their Normal Supply Capacity thereby deferring the need to build a new TS.

The adjusted load forecast table which accounts for planned feeder builds and/or reconfigurations to leverage available capacity at various Stations to defer the need to construct a new TS is shown below (Figure 11).

Transformer Station Name	DESN ID	Historical Data (MW) Net Load					Near Term Forecast (MW) Gross Peak Load Forecast					Medium Term Forecast (MW) Gross Peak Load Forecast				
	(e.g. T1/T2)	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Wonderland TS	T5/T6	100.00	95.51	87.31	95.00	90.97	91.18	90.50	91.81	93.12	94.44	95.75	97.07	98.38	99.70	101.01
Buchanan TS	T13/T14	118.00	139.10	123.20	140.00	132.00	114.08	114.99	117.54	120.09	122.65	125.20	126.40	127.60	128.81	130.01
Highbury TS	T3/T4	87.20	77.80	84.50	80.70	64.38	76.97	78.04	79.11	80.18	81.25	82.32	83.38	84.45	85.52	86.59
Clarke TS	T3/T4	79.50	106.90	94.60	111.10	85.30	86.30	81.99	91.49	92.49	93.48	94.48	95.48	96.47	97.47	98.46
Talbot TS (DESN 1)	T1Y/T2B	99.80	89.30	109.70	127.50	104.30	121.73	119.95	112.38	113.31	114.23	115.16	116.09	117.01	117.94	118.87
Talbot TS (DESN 2)	T3J1/T4J2 T3Q1/T4Q2	162.10	191.60	188.00	197.30	190.93	169.01	161.40	145.68	147.17	148.65	150.13	151.62	153.10	154.59	156.07
Nelson TS	T1/T2/T3/T4	34.63	15.55	11.93	11.65	37.78	53.65	78.84	96.61	97.30	98.00	98.71	99.42	100.14	100.86	101.58
Edgeware TS	27M2	0.84	0.55	0.53	0.53	0.58	0.58	0.58	0.59	0.59	0.59	0.59	0.59	0.60	0.60	0.60

Red fill, red text - Cells that are greater than Station LTR [MW]
No fill, green text - Cells that are greater than LH LTR [MW]

Figure 11: Adjusted 10-Year Non-Coincident Electrical Demand Forecast by TS

It is important to note that DERs exceeding 10kW is restricting the flexibility of reconfiguring feeders and increasing the complexity of planning and assessments of the system.

Hydro One's planned station upgrades will naturally increase capacity at Wonderland TS, Clarke TS, and Highbury TS. Expected natural capacity increase is 19MVA, 9MVA, 36MVA, respectively, for a total of 64 MVA (or 61 MW @0.95 power factor). Only Wonderland TS capacity increase has been accounted for in the adjusted load forecast table since T5 has already been replaced.

The map below indicates potential areas of future growth based on the data provided by the City of London and was used to determine the associated electrical demand forecast.

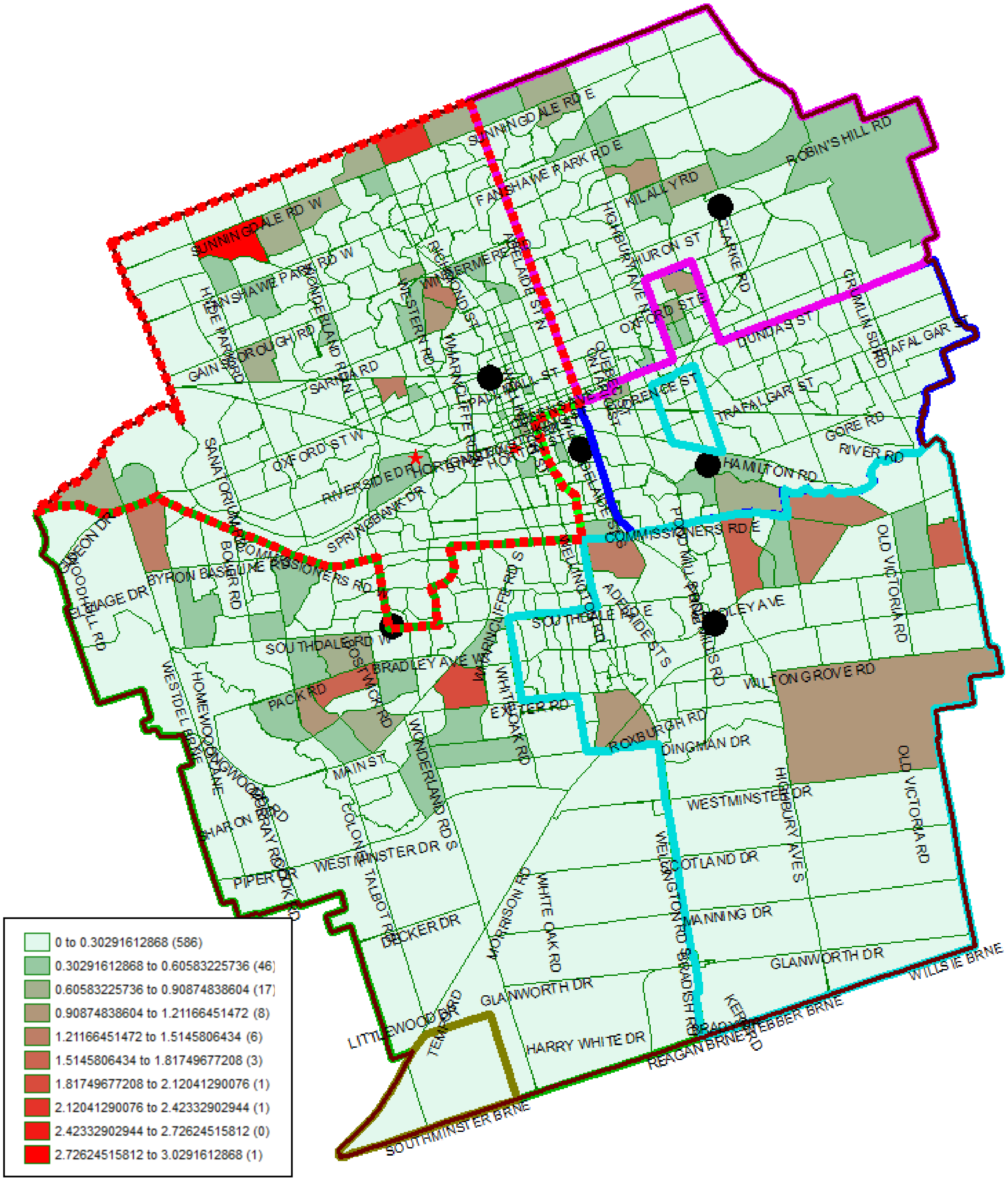

Figure 12: City of London's 10 Year, 2019 to 2029, Projected MW Growth by Traffic Zone

The 10 year load forecast (2020-2029) for each transformer station shows that in the near term (5-years) the Talbot DESNs will be operating above LTR levels. New developments in the north-west and the 13.8kV conversion of Nelson TS have contributed to the increased load seen at Talbot TS. The new Nelson 27.6kV DESN has capacity available and three feeders that can be built out to offload and support Talbot TS. Preliminary plans of feeder builds to leverage the available capacity at Nelson TS indicate that the demand at both Talbot DESNs can be reduced below LTR levels.

3 Strategic Direction

The strategic directions for the current planning horizon has been divided into four main categories

- Strategy by Distribution System
- Leveraging Data and Technology
- Distributed Energy Resources
- Environmental and Sustainability considerations

The topics discussed in the above sections *Strategic Context* and *Current State Assessment* have been considered in determining the distribution system planning strategy. Overarching objectives are to improve reliability, operational flexibility, alleviating capacity constraints at Stations due to load growth, and asset management improvements.

3.1 Strategy for Various Distribution Systems

London Hydro's primary distribution system can be divided in terms of voltage and architecture. The distribution system voltage varies depending on location in the City. As can be seen in the figure below, the standard distribution system voltages are 27.6kV, 8.32kV, and 4.16kV.

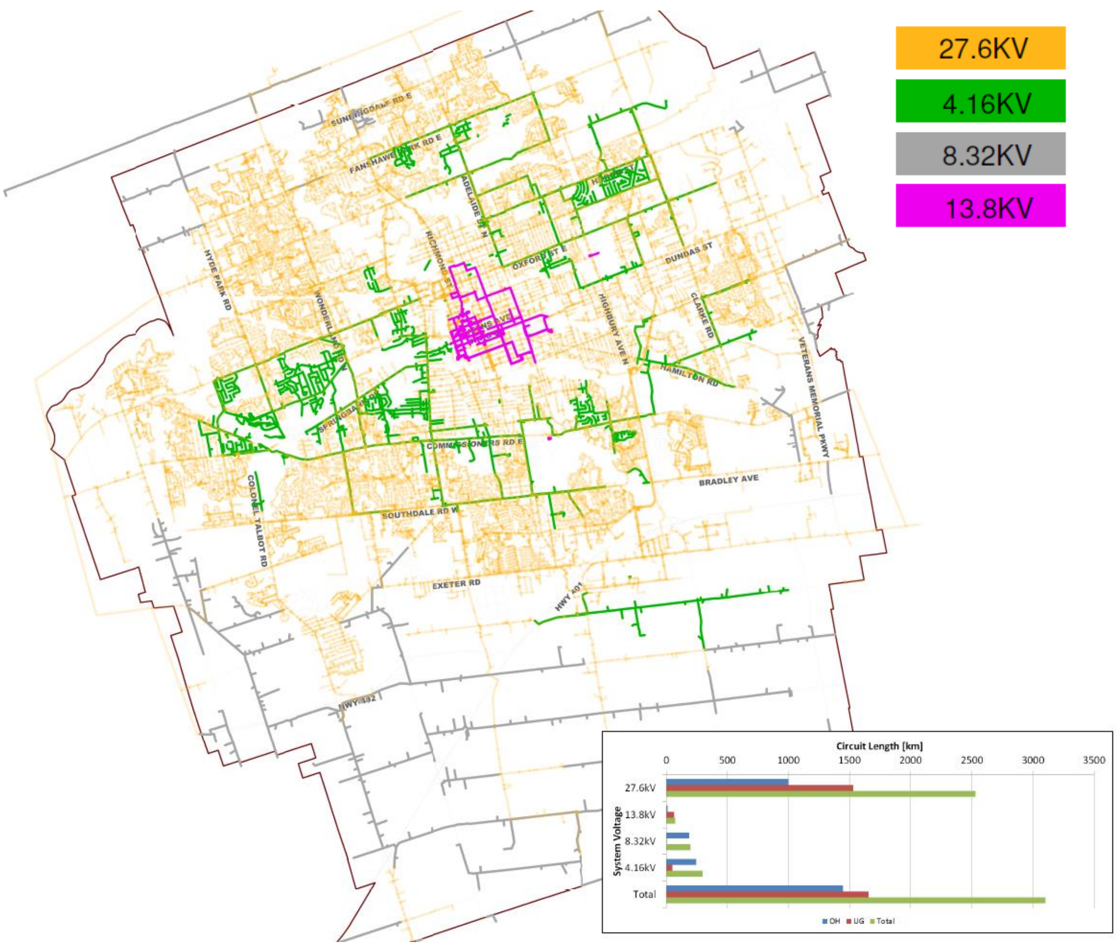

Figure 13: Primary Circuits by Distribution System Voltage

The 13.8kV distribution system is being phased out due to the decommissioning of the degraded 13.8kV Nelson DESN stations and is expected to no longer exist by end of December 2020. Needless to say, there will be 13.8kV distribution from London Hydro owned substations as will be discussed further below.

In addition, the architecture of the distribution system various depending on location

- looped design / radially operated: downtown, suburbs and subdivision
- parallel design / parallel operation: downtown Ring Bus
- radial design / Secondary network: downtown

The following sections discuss each distribution system and the vision / strategy for this planning horizon (2020-2024).

3.1.1 27.6 kV Overhead System

Purpose:

27.6kV is the main source of supply for the City of London and serves downtown and the urban developed areas. The 27.6kV overhead distribution system originates from all seven transformer stations[8] and serves the substations that convert down to 4.16kV as well as the step down pole-mounted transformers that convert down to 8.32kV. Large Industrial, Commercial, and Institutional loads are primarily supplied from this distribution system voltage.

Vision:

This Distribution System will continue to expand and grow to service new developed territories and re-supply rebuilt / converted 4.16kV areas and/or 8.32kV areas. Parts of the System are aging and will require replacement and Upgrade.

Strategy:

As the 27.6kV distribution system circuits expand to support new developments and resupply rebuilt 4.16kV and 8.32kV areas, it is expected that the increased service area will increase the exposure and likelihood of an outage due foreign interference (including animal contacts), adverse weather, and equipment failure. With an increased number of customers on a typical 27.6kV feeder, it is expected that an outage will have a greater impact on system reliability. *Hence, to mitigate against these adverse impacts, the level of automation, type of automation and combination thereof, and level of feeder segmentation needs to be improved.*

In terms of recloser distribution, plan for 1000-1500 customer segmentation between reclosers as it will increase visibility on the feeder and provide a means for system operators to remotely isolate the fault to a 1000-1500 customer segment and restore all remaining customers on a feeder before Line crews are able to be deployed to site. *Between reclosers, strive for installing in-line switches to further divide into 500 customer count segments.*

[8] Buchanan TS, Highbury TS, Clarke TS, Talbot DESN1 and DESN2 TS's, Nelson TS, and Wonderland TS

In addition to automation in-line on the feeder, automation at the tie points is necessary to permit remote restoration of healthy feeder segments. Automated tie points should be established at feeder ends and mid-points on the feeder.

The 27.6kV feeders are designed for a maximum load of 600 amps. Under normal configuration, a 27.6kV feeder should be designed/operated to carry 400 amps. Under abnormal scenarios, such as planned or unplanned activities, the feeder can be loaded to a maximum of 600 amps. A 200 amp reserved capacity on the feeder allows for a three-feeder grouping that can sustain itself in all operating scenarios. This is highlighted through the following simplified example.

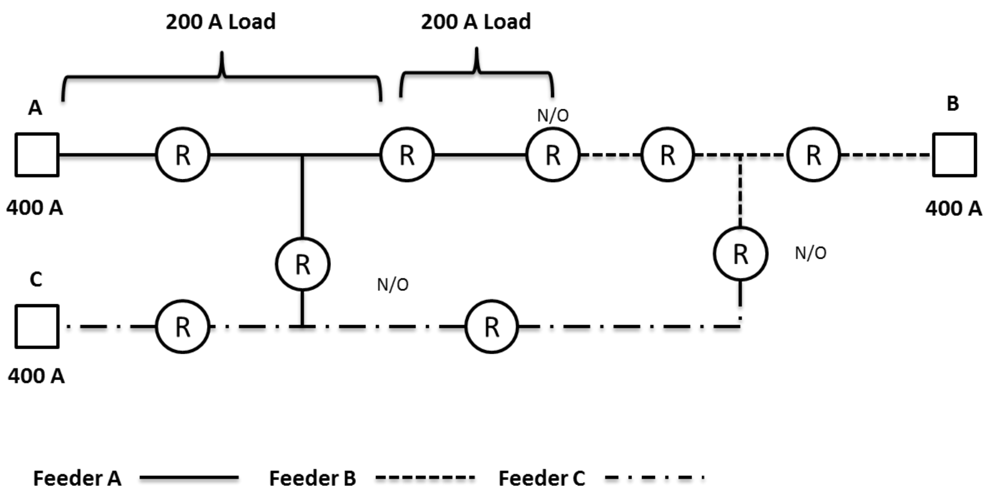

Figure 14: Three Feeder Grouping with Recloser Distribution

If feeder A is required to be removed from service, a maximum of 400 amps of load would need to be transferred. This load can be shared between feeders B and C. Special consideration needs to be given to the location of the tie points in relation to the load distribution along the feeder and the placement of in-line switches/reclosers to facilitating sharing of load.

In addition, special consideration should be given to establishing ties to feeders originating from a different bus, when feasible. This would help to mitigate against the impact of major events such as an entire bus outage at the station; a realistic occurrence which has happened a number of times.

Further discussion on the subject of reclosers will be discussed in Section 3.2.3.

The number of customers on a 27.6kV feeder varies greatly depending on location in the city, density of customers, and customer types. Excessively large number of customers on a feeder can adversely impact the reliability in the event of an outage. For example, during an outage event, where a feeder has 12,000 customers interrupted for 10 minutes the contribution of customer minutes of interruption (CMI) is 120,000 CMI. On the other hand, a feeder with 6,000 customers interrupted for 10 minute would contribute only 60,000 CMI. *As a rule of thumb, customers on a feeder should not exceed 6,000. Ideal distribution to target is between 4,000 to 5,000 customers per feeder.*

New rehabilitation programs similar to the 4.16kV system rebuilds will need to be carried out to address deteriorating assets. As shown previously, the reliability score of Buchanan TS, Talbot TS and Wonderland TS is more than three times worse than that of Clarke TS and Highbury TS. The root cause of this poor performance needs to be determined and corrected through capital programs structured to improve the performance. *The target for this planning horizon is to evaluate and rebuild degraded 27.6kV residential and industrial neighbourhood with poor performance in the service territories of Buchanan TS, Talbot TS and Wonderland TS.*

In terms of rebuilding aging underground subdivisions, it is expected that cable infrastructure replacement rather than cable rejuvenation will be the method adopted. Recent analysis[9], completed by London Hydro, showed that the incremental initial capital cost savings due to cable rejuvenation did not produce the desired reliability improvements. *Hence, a revised cable asset management program will be required that takes into account the condition of the cable assets by leveraging cable diagnostic tools (discussed in later sections) and cost/time implications of replacing cables rather than rejuvenating.*

Another study[10] performed by AESI on behalf of London Hydro evaluated the technical risk associated with overhead vs. underground supply strategy. In general, the report recommended to underground large intersections when feasible in coordination with city works and to consider rebuilding overhead supplied subdivisions that have reached end of life to an underground supply, when/where feasible.

Undergrounding lateral feeders can be cost intensive and needs to be evaluated closely based on the current capital constrained environment. Determining which laterals to underground can be based on a variety of criteria such as safety (eliminating primary in backyards) and reliability (heavily treed neighbourhood, ice storm preparation, etc.). Similar to the pilot project currently being conducted at the Oak Park Subdivision, where the 4.16kV overhead backyard primary supplied subdivision is being rebuilt to underground front-yard primary /secondary supply; *consideration should be given to rebuilding front and rear yard 27.6kV subdivisions to an underground front yard distribution.* It is recognized that this effort will require a long term commitment and long term vision to bring London Hydro's distribution system closer to an ideal scenario of overhead main trunk supplies and underground lateral distribution.

An excerpt from the AESI report states the following:

> *In general, undergrounding of main feeders is a very expensive proposition, with limited societal benefit. The geographical footprint of main feeders is small and some of the resulting societal benefits, such as planting trees, are very limited. There is little ground area in which to improve the social situation such as the limited space in an electrical right of way, or on a roadway. The money is better spent on a larger area such as a residential subdivision, where there is for example, more opportunity to plant trees.* ***Aesthetically this would lead in general to the main corridors, such as roadways where people travel being overhead, and the areas where people live being underground.*** *To overcome*

[9] London Hydro, *Evaluation of Cable Replacement vs. Silicone Injection*, August 2019
[10] *Technical Risk Assessment Overhead and Underground Strategy,* AESI, December 2014

the threat of an ice storm, the overhead main feeders should be hardened, with extra anchors, stronger insulators, larger poles, stronger conductors, which can be completed in a timely manner. But there are exceptions, high vehicle/pole incidents, road widening, designated underground areas should still be considered as candidates for undergrounding on a case by case basis.

The City's BRT project commencing in 2021 will result in the undergrounding of several sections of main trunk overhead circuits on main roads. *Therefore, it is recommended to review the reclosing strategy on the 27.6kV feeders that will see an increased level of mixed overhead and underground sections due to BRT infrastructure relocations.*

Regarding Hydro One's sustainment plans for Wonderland TS, evaluate the merit of upgrading the configuration from a Jones station to a Bermondsey station to take advantage of the increased transformation capacity (124 MVA LTR vs 190 MVA LTR). The timing of the actual need must be evaluated closely in light of the increased capital expenditures forecasted with BRT and other projects. As well, the opportunity for a London Hydro owned TS that increases operational flexibility and smart grid implementation needs to be considered.

Regarding Highbury TS, the LTR limitations must be identified as part of the Regional Planning activities starting in Q1 2020. Documenting this issue in the Needs Assessment phase will ensure that a plan will be developed to address the limiting components.

3.1.2 27.6kV Underground System (Downtown)

The Downtown Core is serviced through multiple underground distribution systems and requires careful consideration of new loads and where they will be connected. The 27.6kV distribution system downtown originates from two transformer stations (Talbot TS and Nelson TS). The 27.6kV serves the substations that convert down to 13.8kV for the primary supply of the secondary network system, customer owned substations, and London Hydro owned distribution transformers. The 27.6 kV distribution system downtown can be divided into two distinct systems: the 27.6 kV looped system and the 27.6 kV Ring Bus.

3.1.2.1 The 27.6kV Looped System

Purpose:

The 27.6kV Looped System consists of the two Talbot TS feeders 26M48 and 26M51, and one Nelson TS feeder 13M26. All of these feeders have the capability to support each other in an N-1 contingency scenario to supply the downtown core.

Vision:

This Distribution System is limited to the downtown core and it is expected that the load downtown will continue to grow to service new developments.

Strategy:

New developments downtown such as condominium towers, office and commercial towers should be connected to the 27.6kV looped system. Due to limited real estate and/or city right-of-way space downtown[11], *owners and their consultants must be notified in advance to provide above ground locations for London Hydro owned transformers, or, should they wish to proceed with customer owned transformers, room for London Hydro owned switchgear*.

Due to limited real estate, radial supplies to customers are not an effective mode of distribution in an underground urban development and must be avoided. The philosophies and plans for main feeders in the downtown core have been discussed in a previous report[12]. Conductor sizing of the main feeder is the standard 1000 kcmil TR-XLPE. The main feeder supplies several load centers downtown from which sub-feeders are taken-off to supply London Hydro owned service transformers and customer substations. The design of the sub-feeders was recommended to be #2/0 Cu EPR cable so that it can be pulled into a single duct (as opposed to three ducts) and provide at least 200 amps of capacity.

A future feeder supply from Nelson TS has been provisioned for the downtown core (13M25). This feeder can be leveraged when the load growth downtown materializes to a degree that exceeds the normal supply capacity of the feeders and impedes operational flexibility.

Since the 26M51 and 26M48 originate from Talbot TS J and Q busses respectively, care should be taken in balancing their respective loads considering the overall loading of the J and Q busses. Abnormally high unbalances of the Talbot Q and J busses can result in voltage unbalances that compromise operational flexibility.

3.1.2.2 The 27.6 kV Ring Bus (Downtown)

Purpose:

The 27.6 kV Ring Bus is supplied by Nelson TS 13M27 and 13M28 feeders. The primary purpose of the 27.6kV Ring Bus is to supply substations 10, 11, and 12 that form the primary supply points for the 13.8kV – 120/208 V Secondary Network system.

Vision:

The Ring Bus will continue to supply Substations 10, 11, and 12 to serve as a reliable supply for the secondary network system. In addition, the 27.6 kV Ring Bus will supply customers that are not in proximity to the 27.6 kV Non-Network system.

Strategy:

The 13M27 and the 13M28 feeders operate in parallel and are supervised by differential protection. As well, the 27.6kV loop (Bus) formed by Subs 10, 11, and 12 is operated in a closed ring fashion and is also

[11] Downtown buildings for the most part are constructed from property line to property line.
[12] *Downtown Intensification*, December 2015

supervised by differential protection (i.e. protections on the interconnecting cable segments, on the load center, and on the step-down substation transformers)[13]. Though the primary purpose of these stations is to supply the Secondary Network system, non-network loads could be and have been tapped off outside of the differential zone elements. Presently, there are three load tap points: Sub 10, Sub 12, and York/Colborne LC (LC 8717). The 27.6kV loads that have been supplied off the Ring Bus were not in proximity to any other 27.6kV feeders. *As a strategy, new 27.6kV load should only be connected to the Ring Bus when a 27.6kV looped system is not in close proximity.* For example, Labatt's customer substation will be supplied from the Sub 10 – Sub 12 200 amp loop via a London Hydro owned step-down transformer since that is the only available 27.6kV supply in proximity.

LC 8717 at York St. and Colborne St. is another location where load can be tapped off the Ring Network. At present, due to limitation of usable duct infrastructure along York St., this LC cannot be leveraged cost effectively to convert 13.8kV Network load at the fringes of the core. *The City has plans to upgrade the infrastructure along York Street in 2021-2022. It is recommended to work with the City to renew London Hydro's degraded duct and manhole infrastructure at the same time so that LC 8717 can be leveraged to supply future growth along York St. and to convert Network load.*

The 1000 kcmil cable connection between Sub 11 and Sub 12, repurposed an existing cable segment between Talbot and Wellington St. on Dundas St. that is 1989 years vintage (30 years in-service as of dated of this report). *Since this cable is being used on a critical system, cable condition diagnostic assessment should be carried out to plan for its timely replacement.*

3.1.3 13.8 kV Non-Network System (Downtown)

Purpose:

The 13.8kV non-network supplied both overhead and underground distribution downtown and the peripheries of downtown.

Vision:

The 13.8kV supply from Nelson TS is being phased out due to Hydro One's sustainment plans and London Hydro's larger system plans of creating a unified 27.6 kV distribution system considering other transformer stations within the City. The 13.8kV non-network system conversion to 27.6 kV and elimination of Nelson non-network DESN will be completed by 2021.

Strategy:

The majority of 13.8 kV load downtown and the peripheries have been converted to 27.6kV. There are primarily three large customers remaining as of the end of 2019. These customers are Labatt at 197

[13] Protections on the 120/208V Network Protectors mounted on the network transformers (NTs) are designed to operate on reverse power. Since 10 primary feeders supply 55 NTs that are interlaced throughout downtown, if the primary feeders originate from a different source bus, it would likely result in a different load (phase) angle that could cause reverse power to flow between feeders. This reverse power flow would cause the NT protector to trip and compromise redundancy/reliability.

Richmond St, City Centre at 380 Wellington St, and the former Bell building at 100 Dundas St. The mode of conversion for these customers will be finalized in the detail design phase early 2020. Final conversions are expected to be completed by end of 2020 thereby permitting the final clean up and removal of 13.8kV infrastructure in 2021.

3.1.4 Secondary Network System (Downtown)

Purpose:

There are two secondary network systems located downtown. The 27.6kV supplied mini-grid Network along Dundas Street from Talbot St. to Wellington St., and the 13.8kV supplied grid/spot network in the downtown core spanning bounded by Dufferin St to the north, Colborne St. to the east, York St. to the south, and Ridout St. to the west. The mini-grid and grid network systems service small office and commercial loads downtown. The spot network systems service larger commercial facilities requiring a higher level of reliability.

Vision:

Improve visibility and control of network protectors and reduce the 13.8kV supplied grid network system to where it is absolutely required when it makes sense to do so.

Strategy:

The 13.8kV primary supply to the secondary network system originates from subs 10, 11, and 12. The 4 MVA transformers at these substations step-down the 27.6kV supply from the Ring Bus to 13.8kV. Ten 13.8kV radial feeders are interlaced through the downtown core to feed network transformers that supply the grid network and spot network.

As part of the City of London's Dundas Place project, London Hydro developed plans to update the Network infrastructure along Dundas Street from Talbot St. to Wellington St.[14] The plans called for segmenting the secondary network into three operating networks: North Network, South Network, and Dundas minigrid network zones. The North and South networks are still supplied from Subs 10, 11, and 12 and have an N-2 design criteria. The Dundas minigrid network zones have an N-1 design criteria.

The construction and reliability of padmounted transformers and cables have improved since the 1950s. The looped supply distribution system downtown is a cost-effective alternative method to resupply secondary network customers that have the real-estate available for a padmounted transformer. *Based on customer criticality and operational flexibility, reduce the 13.8kV supplied grid network system to areas where it is absolutely required when it makes sense to do so as part of either City development or London Hydro deteriorated infrastructure upgrades.*

The network system is ideal for many small dense loads such as that along Dundas St. where buildings are built from property line to property line. The lack of above ground real estate for a padmounted

[14] *High Voltage Design Report for Dundas Flex Street,* December 2017

transformer drives the installation of a transformer to beneath ground.[15] The reliability sought for downtown in the event of a transformer failure is that power must be restored within four hours. This four hour restoration criteria necessitates the supply system to be a secondary network when transformers are underground. Where real estate is available for a padmount transformer solution, typical restoration can be completed within 4 hours. The cost and operational difficulties of an underground network system is higher than that of an above ground non-networked transformer installation. *Hence, when determining service methods, priority must be given in the following order: above ground padmount, above ground vault, below ground non-network. Presently, there are no plans to grow the network system.*

Historically, loads on the network have reduced due an increase in building vacancies. The City has undertaken efforts to improve the infrastructure downtown and increase intensification of downtown. Based on these efforts, the City is forecasting an increase in population downtown. It is likely that we could see many of the vacant buildings supplied off the network become reoccupied and increase their demand. *London Hydro will need to apply good engineering and operations practice to monitor existing load on buildings, secondary mains, and transformers to address any upgrades as required. The GIS model and infrastructure records of the secondary network system will need to be reviewed and validated to improve accuracy of the cyme model.*

Aside from the spot networks, there is no visibility as to the status of the network protectors and the loading of the network transformers. *Continue with plans to deploy technology to monitor network protectors, transformers, and vaults.*

3.1.5 4.16 kV Distribution

Purpose:

The 4.16kV distribution system is a legacy distribution system that primarily supplies subdivisions.

Vision:

The 4.16kV distribution system will proactively be phased out when/where feasible by converting to 27.6kV.

Strategy:

The 4.16kV distribution system has been progressively upgraded to 27.6kV due to its limited capacity, higher system loads, lower remaining life expectancy and lower reliability.

London Hydro has completed a study that developed a 10 year plan to prioritize areas to upgrade the 4.16kV circuits[16]. The 2019 4.16kV Conversion Progress Report considered historical reliability of the

[15] The underground vault servicing option is with reference to existing buildings that are not under renovation or planned to be combined and/or expanded to one large facility. Where a developer is developing a tower in place of these small commercial buildings, an above ground vault would be a requirement.
[16] London Hydro, *4.16kV Conversion Progress Report,* 2019

4.16kV circuits, age of the 4.16kV assets and a Transformer Health Index (THI) for the substation transformers. The approach of the study was based on ranking areas for conversion depending on the weighted/combined score that considered reliability of the circuits, age of poles, condition of station transformers, etc.

In addition, the plan defines strategies to repurpose substation transformers that have a good THI. That is, healthy transformers that are part of areas being converted will potentially serve as replacement or backups for areas that are required to remain at 4.16kV during the next 10 years but have a substation transformer that needs remediation according to the THI.

In order to support the 4.16kV 10-year outlook plan, it is recommended to:

- *Support O&M investment to maintain and extend the useful life of substation transformers (e.g. flush oils, increase rate of oil sampling and testing.*
- *Incorporate into the prioritizing matrix: the health index of poles, conductors and equipment in the 4.16kV system based on the 2019 Asset Condition Assessment by Kinectrics to further improve the conversion/rebuilds programs.*
- *Maintain a capital investment of $4M for the next 10 years for circuit conversion from 4.16kV to 27.6kV.*

The 4.16kV substation facilities (buildings / yards) are other assets of importance. London Hydro's substations are strategically located across the city. When conversions occur, these locations can be leveraged to support future distribution technologies (e.g. Battery Energy Storage Systems). *Therefore, it is recommended that substations at strategic locations be kept and maintained for future smart grid applications after conversions are completed.*

3.1.6 8.32 kV Distribution

Purpose:

The 8.32kV distribution system is a legacy distribution system that primarily supplies rural areas of the City.

Vision:

The 8.32kV distribution system will be sustained. Conversion to 27.6kV would occur as warranted by the need of increased capacity due to intensification.

Strategy:

The 8.32kV distribution area is in the peripheries of the City and covers an extensive area (Figure 15). The amount of load and customer distribution is relatively small. A vast area of the 8.32kV system is supplied via Sub 97 which has reached the end of its useful service life. Pole-mounted 8.32kV step-down transformers serve as a back up to Sub 97 and supply other rural areas.

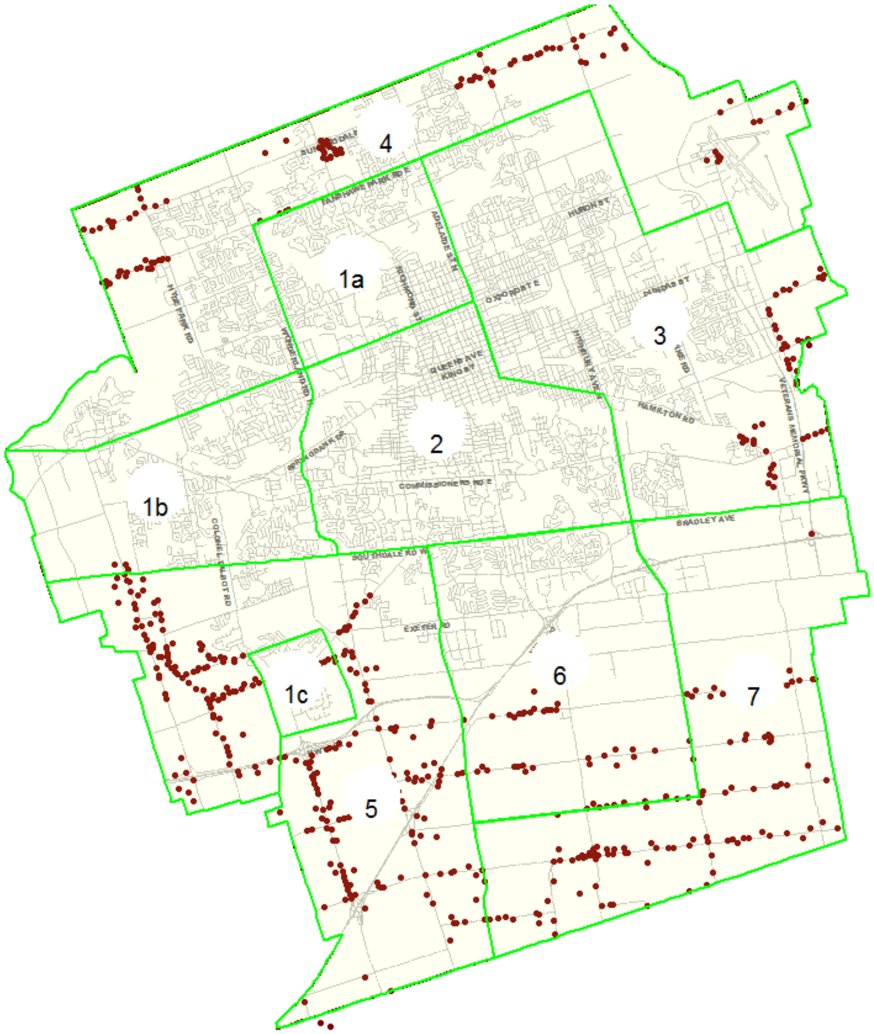

Figure 15: Map of 8.32kV Service Transformers

The following strategy is recommended of the 8.32kV distribution system:

- *Develop plans to phase out Sub 97 and determine if the pole-mounted step-downs provide sufficient capacity and redundancy to supply the rural services.*
- *Evaluate the feasibility of building to 27.6kV standards and running at 8.32kV to prime the area for future developments.*
- *Rural areas supplied by step-down transformers are frequently impacted during a storm event. Review (framing) separation of phases, implementation of spacers, cross-arms and tension on lines to prevent against galloping action.*
- *Consider implementing single phase recloser technology (e.g. fuse saver) on rural feeders to improve reliability during storm events.*

3.2 Leveraging Data and Technology

The general arrangement of the infrastructure and operations in the electricity distribution industry has not changed dramatically in the last century. However, advances in technology of power electronics and communications provide much more insight on how distribution systems behave under normal and abnormal conditions[17]. Utilities now have a large amount of data at their fingertips coming from multiple different sources. The distribution protection system provides instant status of their breakers and automated devices through SCADA systems. Electric meters send not only consumption data but also multiple status alarms from every service connected. GPS technology allows mapping near real-time location of the fleet vehicles. Communicating fault indicators narrow down the location of faults and more telemetry is available through advanced monitoring systems.

London Hydro is characterized for its vision, creativity and use of the most current technology and processes to enhance the distribution system. This section provides an overview of the distribution related technologies available in London Hydro, their relationship and how the information is used and maintained. In addition, recommendations are provided to support further enhancement of system reliability and proactive maintenance.

3.2.1 Outage Management System (OMS)

Figure 16 shows the systems that feed the Outage Management System (OMS). This system allows operators to receive near real-time alarms of status change of the field devices. It also allows operators to remotely change the state of the devices and perform isolation/restoration of power. The system reflects all changes in the field as the Geographical Information System (GIS) is updated. Smart meter messages are filtered and piped to OMS to allow identification of outages downstream of protection devices. The combination of these multiple sources into OMS provides the perfect scenario for near real-time field operations, maintenance and control of the distribution system.

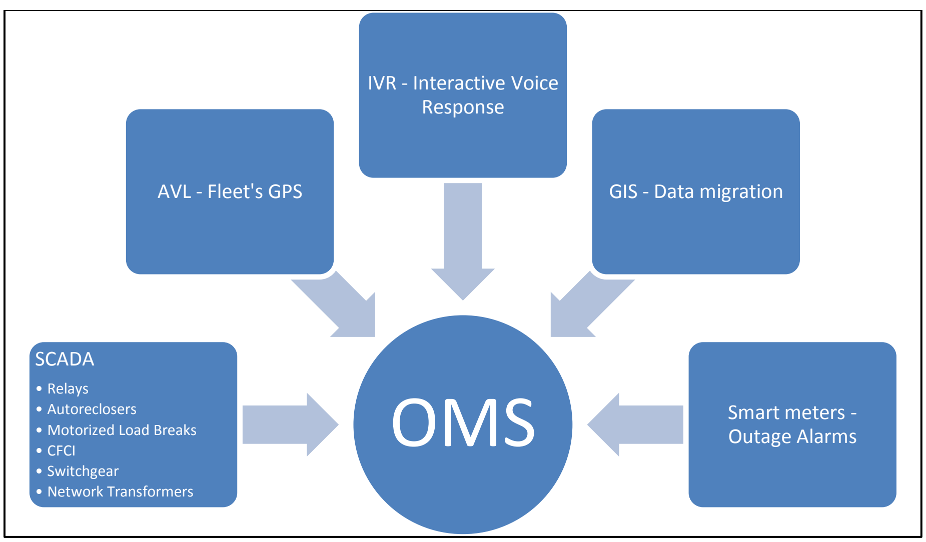

Figure 16: Systems supplying information to OMS

[17] Electric Power Distribution Handbook, *T.A. Short*, CRC Press, 2004

The OMS system is correctly perceived as the best tool for near real-time operation and control of the system. However, the OMS will benefit from the implementation of other features and enhancements of current features as follows:

- *Customer centric reliability reporting: currently, OMS allows querying customers and displays the number of interruptions. It has been identified that the interaction from the control operator is critical to maintain an accurate representation of the events. An internal analysis is needed to identify what processes can be put in place to allow consistency of the data (i.e. outage causes, partial restoration steps).*
- *Implement algorithms to handle step restoration sequences and properly record multiple interruptions and restorations related to the same outage event.*
- *Improve processes to ensure all customers affected by an outage are easily identified and restored. Implement logic to use power restore alarms from smart meters to support this process.*
- *Explore Fault detection, isolation and assisted restoration through Logic Assisted Restoration (LAR) in OMS. LAR will allow OMS to make recommendations to isolate outage areas and restore as many customers as possible. LAR could take advantage of the status information and alarms reported from the automated devices in the field and the multiple sources of information available to OMS, including enhancements discussed further in this section (e.g. CFCIs).*
- *Implement feeder loading tracking and historical recording in OMS. It is expected that such feature allows recording loading data per feeder while capturing configuration changes due to planned and unplanned switching to allow investigation of anomalies and exploration of alternatives to past scenarios.*

3.2.2 Metering data

With the advent of smart meters for residential customers, London Hydro decided to assume complete management and control of the head-end smart metering system. This has allowed making early and customized use of all the data available from the smart meters. The smart meter data is used to predict outages (feeding OMS), detect and improve power quality by analysis of voltage measurements, detect service abnormalities (i.e. unapproved generation, hot socket alarms and power theft among others).

There are other much more advanced meters typically installed for wholesale and large customers. These meters are power quality meters that can record and report harmonics, voltage and current variations, power factor, among other quantities. The power quality information collected from some of these meters has been proven to be highly valuable in the investigation of outage events, protection coordination and analysis of system abnormalities. Currently, London Hydro has been using the PQView software to collect and present the information from 10 of the power quality meters for engineering analysis. The information collected from power quality meters has permitted the understanding of outage events, their sequence and fault behavior. With this information, London Hydro has been able to review procedures to enhance the reliability of the system. *Therefore, it is recommended to expand the presentment of data available at power quality meters by increasing the number of meters connected to PQView.*

The metering data is recorded mainly by two systems, the smart meter system (RNI – Regional Network Interface) and the interval head-end system (MV90). Then, each of the systems exports its data to the Operational Data Store system (ODS).

Efforts have been made to make the metering data available for engineering analysis. Some of the initiatives include:

- Use Redshift as a data warehouse to collect metering information and pair it with the geographical information system and service information.
- Use java application to present and allow interaction/querying of the data in Redshift.
- Use of visualization tools like Tableau to analyze predefined presentments.
- Load data visualization in NetViewer (GIS tool) per service transformer.

Although the tools, described above, have very useful features, some of the challenges in developing a tool for engineering analysis of the data are: the diversity of formats, large amount of data, multiple not inherently compatible systems and the many multiple ways the data could be presented for analysis (preventing a predefined presentment). In addition, the majority of the tools have not been supported as a production system. This has prevented consistent maintenance, defect correction and upgrading of the tools.

In order to maintain the system in a proactive manner, fulfill customer expectations and achieve regulatory requirements, a dedicated engineering tool with production support is needed. The engineering tool for analysis of service supply is envisioned as a tool that interconnects metering, GIS, SAP, SCADA, and OMS systems with predefined presentments and with the flexibility to query custom information for engineering analysis; all available through one interface.

3.2.3 Remote Fault Indication (OH/UG)/Vault monitoring/Automated device coordination

During an outage event, accurate and timely localization of the faulted component or feeder segment has a critical impact on coordination of the isolation and restoration efforts. London Hydro has deployed non-communicating fault circuit indicators (FCI) on padmount transformers and on overhead lines. Instead of searching for the faulted segment by randomly patrolling the line and/or testing underground cables and transformers, field staff patrol the overhead lines and/or padmount transformers looking for the blinking light that indicates that the fault current passed the point. This activity allows faster isolation and restoration of the customers.

In addition, secondary spot network vaults with network distribution equipment currently send to SCADA information on the status of the protector, voltage and current readings. However, there is no visibility into the grid network transformers and this would enhance the operation and preventative maintenance of the system.

The non-communicating FCIs and status of the network protectors improves the location of faults and monitoring of the health of the system, respectively. However, the reliability of the distribution system would increase if the FCIs status is communicated directly to the control room and if there is a proactive health monitoring of vault equipment based on additional telemetry. The suggested steps to achieve the next level of enhancements are as follows:

- *Evaluate accomplishment of the current pilot with Communicating FCIs (CFCIs) for overhead circuits and proceed to prepare a plan to identify optimal locations for CFCIs.*
- *Propose technical documentation on the data flow from CFCIs and define how the information will be integrated in the production OMS system.*
- *Evaluate the accomplishments of the deployment of VaultGard and Transformer Ruggedized Telemetry Link (TRTL) on the mini-grid networks. Define how the telemetry will be stored, presented to engineering personnel and analyzed to predict failures.*
- *Consider the deployment of DigitalGrid technology for providing visibility into the grid network transformers.*
- *Perform an industry/technology research exploring fault locating technologies for underground circuits.*
- *Establish scope and viability to deploy settings and/or communication technology for reclosers*[18] *to coordinate their response to fault events, i.e. if two reclosers reached the fault target only the closest to the fault should operate. This initiative supports future LAR implementation for assisted restoration in OMS.*
- *Implement a system that can record, track, and maintain all the protective device settings (i.e. breakers, reclosers, interrupters). This tool should at minimum: allow to be written by only one user-role (admin), facilitate a revision/approval process of the settings in which settings can be proposed by users and only approved and posted by the admin, record changes/user/date-stamps, permit visualization of the data to a defined user-role (users) in a parametric manner, be linked to GIS, OMS, and CYME through a unique number attached to the most recent approved settings.*

3.2.4 Cable diagnostics

The different types of cables, their age and installation configuration, has a correlation with system performance and reliability. With the acquisition of the VLF Tan-Delta/PD testing equipment, a much more proactive and accurate assessment can be performed to determine the condition of cable assets in the system. The successful deployment of this testing equipment requires a structured plan for:

- Selection: prioritization process to select cables to be tested
- Testing plan: what test will be performed, its parameters and procedures to perform
- Reporting: develop standard formats to record data, comments, procedure's check list
- Tracking: develop a tracking system to record, cable's parameters, test parameters and conditions to allow tracking and repeatability

[18] For clarity, reclosers on the 27.6kV system do not perform reclose operations but rather act as a pole-mounted breaker. Reclosing operations for a fuse-savings scheme has been deferred to Hydro One's feeder breakers.

With the structured results of the testing, and the analysis of the results, it is imperative to develop a cable asset management program that would effectively prioritize cable assets for either maintenance, replacement or rebuild. The cable asset management program will focus on public safety and customer reliability.

3.2.5 Reliability tools and visualization

Currently, reliability statistics are based on an Access database that is manually updated daily. The information entered in the database comes from hand written log forms completed by the control room operators. There is valuable information in the logs when the outage events are investigated and analyzed. Some of the information found in the logs include outage time, restoration time, number of customers interrupted, cause of the interruption, supervisor/staff on site, switching sequences for restoration/isolation. However, most of this information is also available in OMS. The system records outage events, status changes of devices, number of customers interrupted. Specific issues have been encountered that prevent the use of these records for reliability statistics. Typically, there is a lack of consistency when an outage is created or predicted by smart metes or SCADA devices as there are details that have to be entered by the operator (e.g. outage cause). As described in section 3.2.1, there is a recommendation to establish procedures where operators will consistently enter all necessary information about an outage. *Therefore, the implementation of algorithms to handle step restorations and consistent information recording will establish the foundation for an accurate outage event recording system in OMS.*

With the premise of an accurate database in OMS that has all information related to outage events, we are able to implement tools that facilitate the analysis of this data for reliability and maintenance purposes. *It is recommended to implement a separate database for reliability. This database will include: age of asset at failure, geolocation of the cause of the event, comments from field staff, input from various departments that might get involved during the investigation of events (e.g. Standards, System Planning, Engineering Design, Metering, Health and Safety) as shown in Figure 17.*

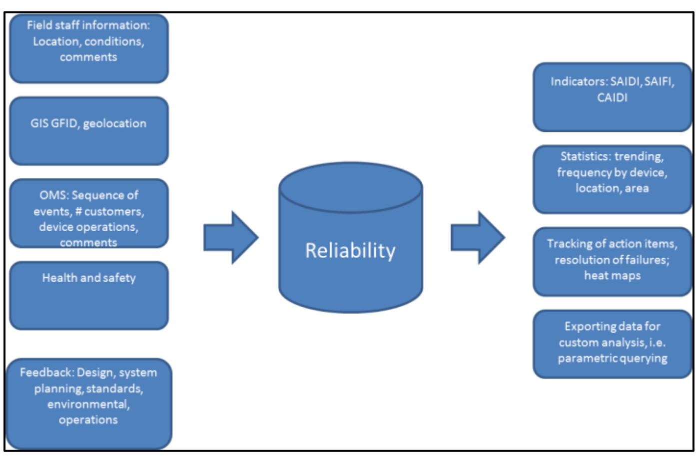

Figure 17: Reliability database, inputs and outputs

The proposed database should be leveraged to fulfill the following requirements:

- *A process that matches outage information and GIS mapping data for identification of poor reliability areas in the form of heat maps.*
- *An interface that allows parametric querying of: outage causes and defective equipment types.*
- *A statistical interface that calculate reliability indicators as outage events occur and creates a time-series heat map.*

3.2.6 Asset Management

London Hydro has been working on the implementation of a health index for its distribution assets. The final 2019 Asset Condition Assessment report will include a gap analysis identifying data information that would be beneficial for subsequent studies and planning. Some of these items include serial numbers for major equipment in GIS, SKU numbers for equipment, and asset year. It is necessary to update the assets' records in order to have a more accurate health index of the assets and avoid unnecessary replacements or miss necessary actions. More information will be available as the final study is published. *Therefore, it is recommended to analyze the data gap analysis and develop the requirements necessary to implement the respective changes.*

While the condition assessment results are available, it is necessary to prepare a data survey, file location mapping, and documentation of current processes. This information will be valuable at the moment of preparing the requirements and scheduling to implement changes according to the gap analysis results.

London Hydro has started a program to digitize field inspections using mobile devices in the field. While this program has been beneficial to start the transition from paper to electronic, a top-down planning approach is recommended to oversee all field data inspections as they play a vital role in the preventative maintenance of the system and the asset condition assessment. ….Improvements to MobilLink required.

3.3 Distributed Energy Resources

London Hydro has noticed an increase in the number of customers desiring connecting DERs to the system to aid in reducing their electrical costs attributed to Global Adjustment (GA). In some cases, two issues have been observed as follows:

- Customer cannot connect DER due to lack of generation capacity on the feeder/bus
- Customer feels the costs of Transfer Trip protection are exorbitantly high

Hydro One has developed new guidelines that look to address these issues to permit the connection of more DERs. Now, the need for available generation capacity, CIA study and/or Transfer Trip will depend on the duration of paralleling desired by the DER customer. These are summarized in the table below.

Table 3: HONI's new time based criteria for DER requirements

Scenario	Paralleling Duration	3-phase Fault Capacity	1-phase Fault Capacity	CIA Study	Transfer Trip
1	t < 100 ms	No	No	No	No
2	100 ms < t < 10 s	Yes	Yes	Yes	No
3	t > 10 s	Yes	Yes	Yes	Yes

Note that in the determination of the fault margin available, Hydro One has divided this assessment into two parts considering the type of fault. DERs that operate grid connected will have their fault contribution capabilities allocated towards the 3-phase and 1-phase capacities (i.e. Scenario 3). DERs that intend to parallel briefly and then disconnect from the grid (i.e. island in Scenario 1 and 2) will not have their capacities allocated.[19] Hence, there is an opportunity here to cap the DERs that can be continuously connected to a feeder/bus so that there will always be a reserved margin for momentarily connected DERs. This, in theory, could permit an unlimited number of generators to be connected momentarily. This strategy would future proof the system and not limit the potential for improvements in technology and cost reductions that may increase the deployment of microgrids and DERs. *This opportunity needs to be explored further to determine the operational processes and/or technology required to manage the connection of momentary DERs. As well, the merits and risks associated with potentially not approving the connection of DERs that wish to be permanently connected in lieu of maintaining a reserve capacity for future use will need to be considered.*

[19] In scenario 2, the maximum allowable 3-phase fault contribution by a DER is limited to 32 MVA based on their subtransient characteristic.

3.4 Environmental and Sustainability Considerations

3.4.1 Environmental Considerations

London Hydro has been a leader in the deployment of technology to ensure reliability of the distribution system. For example, for switchgear, London Hydro has kept up with technology and has installed air insulated, gas insulated SF6, and solid dielectric switchgear.

Air insulated switchgear is being proactively removed from service as this type of switchgear has moisture problems that lead to electrical arc development and failure of the equipment. In addition, the exposed electrical components are a high safety risk to operators.

Solid dielectric switchgear has been purchased by London Hydro since the year 2006, being an earlier adopter of such technology. Upon field deployment, there were failures of the new technology. However, newer advances in the technology and improved design have allowed the installation and application of solid dielectric switchgear in subdivisions and applications of less criticality. The performance of solid dielectric switchgear is currently under observation.

The other type of switchgear technology used by London Hydro is gas insulated SF6. This technology has multiple benefits: allows for compact light equipment, higher arc-quenching ability than air and higher reliability. The major disadvantage of the SF6 technology is that is it a potent greenhouse gas. To put it in perspective, if 1lb of SF6 gas is leaked to the environment the greenhouse gas emissions is equivalent to 2.2 passenger vehicles driven for one year[20]. As of September 2019, London Hydro had 148 lbs. of SF6 gas including equipment in stock. In average, each unit has 34lb of SF6. A complete leak in one unit is equivalent to the greenhouse emissions of 75 vehicles driven for one year or on average vehicle driven over 1.4 million kilometers.

The SF6 inventory of London Hydro equipment is controlled and monitored frequently and there are procedures structured for the safe handling, retrieval and response to low gas alarms of the SF6 gas[21].

In terms of switchgear, it is recommended to:

- *Produce a report showing performance of the solid dielectric switchgear and conclude on the performance of the most recent units purchased to date.*
- *Perform industry/vendor research and/or collaborate with other LDCs to determine proven alternatives to SF6 gas insulated units that can be installed for critical loads and applications.*
- *Document and implement a database containing SF6 equipment records and maintenance.*
- *Research industry solutions for remote, near real-time options for monitoring of all of the SF6 gas equipment and its integration to OMS.*

An additional substance in London Hydro's equipment that is environmentally significant is the Polychlorinated biphenyl (PCB) found in the oil filled transformers. By 2018, the PCB content of all

[20] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator
[21] London Hydro, *Safe Work Practices – 1017 Working with Sulfur Hexafluoride (SF_6)*

London Hydro's transformers was recorded. It was found that, in case of leaking, over 95% of London Hydro's tested transformers do not exceed the prohibitions according to the PCB Regulations[22] [23]. Nonetheless, London Hydro strives to achieve PCB-free transformer fluid. The majority of transformers with PCB content between 50 ppm and 2 ppm are part of the 13.8kV, 8.32kV and 4.16kV systems. These transformers will be removed from service as conversion/upgrade projects are completed.

However, there are over 300 London Hydro transformers installed on customer owned poles. Typically, these services are part of annexed areas and/or services supplying farms. There are also services that supply houses/business in rural areas where a secondary service is not practical and a primary line is run past the property line supported on customer owned assets (poles). There is a risk of releasing PCB content into the environment if a customer owned pole, with a London Hydro transformer, fails due to poor condition or lack of guying to support the structure to withstand extreme weather conditions. *Therefore, it is recommended to:*

- *Create a process in which customers that own poles with London Hydro's equipment are made aware and responsible (documented) of the maintenance of the structures.*
- *To study solutions to address customer owned poles with poor supporting guying.*

Another material of interest in terms of environmental considerations is the Paper Insulated Lead Cable (PILC). London Hydro has been phasing out PILC cable through voltage conversion project such as 13.8KV (majority of PILC) and 4.16kV (substations egress) to 27.6kV and also through feeder replacement projects. By end of 2021, London Hydro will have removed over 23 km of PILC cable due to the elimination of the aged 13.8kV distribution system from Nelson TS. *It is recommended to leverage the asset condition study results in regards to PILC to prioritize its replacement based on its health index and continue replacement of PILC cable with Ethylene Propylene Rubber Cable (EPR).*

With respect to transformer fluid with PCB content and PILC cables, it is noted that the completion of conversion project is the most effective and economical way to remove the majority of these environmental risks. Nonetheless, substation transformers are such large assets, that any oil leakage would represent a significant negative impact to the environment. There are multiple options to mitigate the consequences of oil leakage in substation transformers. The most preferred option would be secondary containments. However, this is impractical for London Hydro's substations due to the very large investment required. It would be rather more practical to convert the circuit and remove the transformer from service. But, all stations cannot be removed at the same time. A responsible and planned investment strategy is rather preferred (as suggested in the 4.16kV Section). London Hydro's environmental department has equipped field service trucks with absorbent material and physical barriers to contain oil leaks when necessary. As a complement to this effort, and in order to act proactively against the risk, it is recommended that:

[22] PCB Regulations, *SOR/2008-273,* Canadian Environmental Protection Act, 1999
[23] London Hydro, *Environmental Report,* 2018

- *A team consisting of representatives from environmental department, engineering, and electrical maintenance and substation, develop custom emergency plans for each of the in-service substations. This emergency plan should at minimum contain drawings with specific instructions to be followed in case of oil leak, reference maps locating critical sewer points, contact/reporting protocols, and forms.*
- *Study technology available to remotely detect oil leaks and analyze feasibility of deployment to the substations.*

3.4.2 Climate Change Adaptation

The impact of weather conditions have always been considered as a major design parameter of public infrastructure. The rapid climate change challenges the design parameters used in the past and demand proactive planning. In the Canadian electrical distribution industry, extreme winds during the year 2018 contributed as much as twice the number of outages experienced in Canada during the year 2017[24]. Public service industries and academic studies recognize that municipalities must establish policies and procedures to adapt to climate change[25]. [26]. Specifically, southern Ontario has been identified as the region with the highest mean of annual precipitation in a year in Ontario. In addition, it also has been shown that the city of London is susceptible to higher number of severe rains[27], (Figure 18). These statistics are reinforced by the most recent Canada's Changing Climate Report: "*As mean precipitation is typically higher in southern Canada, the absolute amount of precipitation increase is higher in the south"*

[24] 2018 Distribution System Performance A Service Continuity Report Electric Power System Reliability Assessment, *Canadian Electricity Association,* 2018.
[25] The City of London: Vulnerability of Infrastructure to Climate Change, *Department of Civil and Environmental Engineering University of Western Ontario,* April 2011.
[26] The City of London: Vulnerability of Infrastructure to Climate Change, *Department of Civil and Environmental Engineering University of Western Ontario,* April 2011.
[27] London Hydro, Review of Vegetation Management, 2017

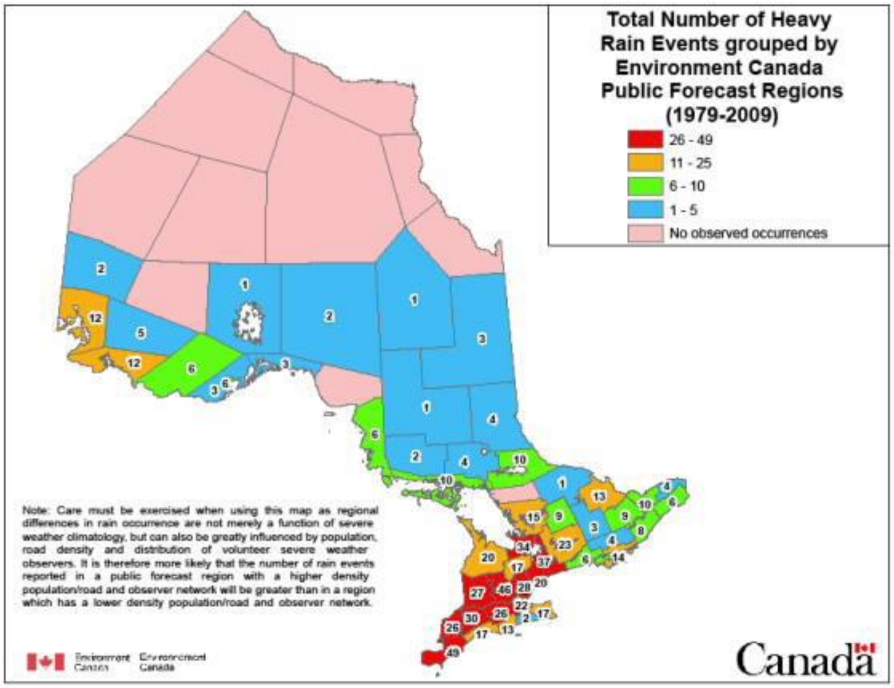

Figure 18: Total Number of Heavy Rain Events in Ontario (Environment Canada)

When the city of London experiences adverse weather conditions, London Hydro's infrastructure is subject to trees falling on the power lines due to high wind and/or precipitation (rain, ice, and snow), lightning strikes damaging equipment or power lines contacting each other due to high winds, flooding reaching distribution equipment, among other repercussions of severe weather. Based on over 10 years of historical outage data, and taking in consideration the variability of the data, it is expected that London Hydro's distribution system will experience as many as 165 sustained outages related to weather conditions every year, (Figure 19).

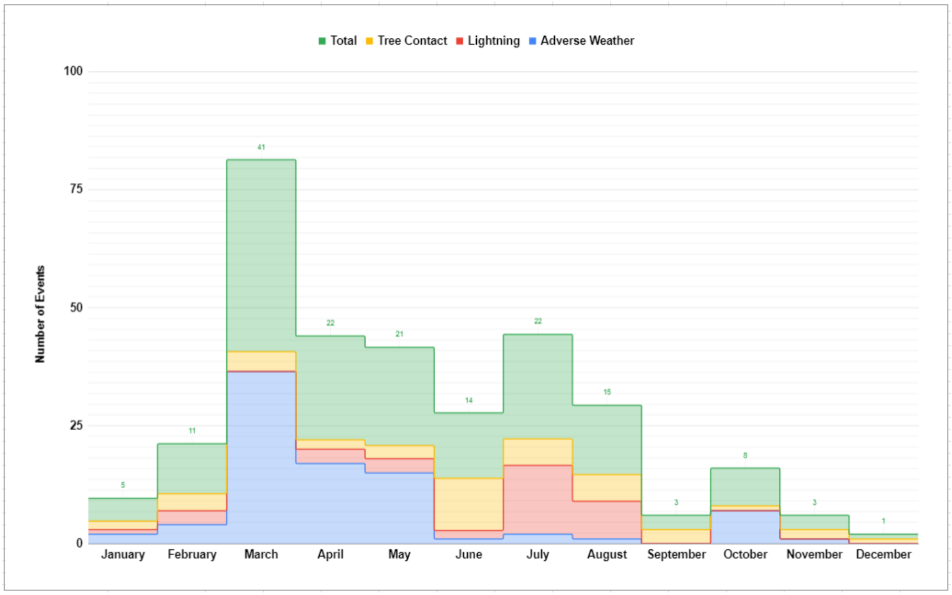

Figure 19: Outages related to weather conditions

London Hydro’s climate change adaptation strategy focuses on mitigating risks that might impact: public safety, environmental impact in case of equipment damage and reliability of power delivery.

The following are the structures/components of the distribution system that have been identified as in risk from weather conditions. In addition, action items to enhance resiliency and mitigate risk are listed:

1. Overhead structures
   a. Poles: continue the pole testing program for wooden poles and:
      - Include non-wood poles as part of the pole maintenance program.
      - Treat any pole with a remaining strength less than 40% at the time of testing and prioritize its replacement.
      - Establish a program to remind customers that own pole structures, with London Hydro’s circuits on them, of their responsibility on the maintenance of poles. In addition, document pole ownership and update London Hydro’s geographical information system.
      - Engage parties that own pole structures where London Hydro has circuits as part of joint use agreements (i.e. Bell, Hydro One), and discuss strategies to assess and maintain the structures.
      - Analyze pole damage due to grass trimmers at grade level and research, study, create solutions.
      - Assess and strengthen London Hydro’s river crossing structures.
   b. Conductors:
      - Quantify undersized conductors at feeder tie locations to enhance resiliency, isolation and restoral in weather related events.
      - Through feeder audits, identify locations that need: spacers, sag and tensioning.

2. Municipal Substations: based on the environmental risk registry assessment, coordinate and elaborate response plans for oil leakages.
3. Municipal tree planting programs: engage the City of London to implement the Electrical Safety Authority (ESA) Planting Under or Around Powerlines & Electrical Equipment Guideline.

4 Summary

This Distribution System Planning Strategy (DSPS) report documented the strategic framework to guide Engineering and Operations' capital programs for the next five years (2020 to 2024). This report is intended to be a high level strategy and did not delve into the specifics of project development. The expectation is that a five-year plan of projects for the Asset Sustainment Plan (ASP) will be developed based on the findings of Kinectric's Asset Condition Assessment (ACA) while following the principles of this strategic framework.

The recommended strategies with reference to the sections where they originated are summarized in the table below.

Summary of Recommended Strategies	Section
1. *To mitigate against the adverse impacts of increased number of customers and service area, the level of automation, type of automation and combination thereof, and level of feeder segmentation needs to be improved.* 2. *In terms of recloser distribution, plan for 1000-1500 customer segmentation between reclosers* 3. *Between reclosers, strive for installing inline switches to further divide into 500 customer count segments.* 4. *Special consideration should be given to establishing ties to feeders originating from a different bus, when feasible.* 5. *As a rule of thumb, customers on a feeder should not exceed 6,000. Ideal distribution to target is between 4,000 to 5,000 customers per feeder.* 6. *The target for this planning horizon is to evaluate and rebuild degraded 27.6kV residential and industrial neighbourhood with poor performance in the service territories of Buchanan TS, Talbot TS and Wonderland TS.* 7. *A revised cable asset management program will be required that takes into account the condition of the cable assets by leveraging cable diagnostic tools and cost/time implications of replacing cables rather than rejuvenating.* 8. Similar to the pilot project currently being conducted at the Oak Park Subdivision,	3.1.1 27.6 kV Overhead System

Summary of Recommended Strategies	Section
where the 4.16kV overhead backyard primary supplied subdivision is being rebuilt to underground front-yard primary /secondary supply; *consideration should be given to rebuilding front and rear yard 27.6kV subdivisions to an underground front yard distribution* 9. *Review the reclosing strategy on the 27.6kV feeders that will see an increased level of mixed overhead and underground sections due to BRT infrastructure relocations.* 10. *Regarding Hydro One's sustainment plans for Wonderland TS, evaluate the merit of upgrading the configuration from a Jones station to a Bermondsey station to take advantage of the increased transformation capacity (124 MVA LTR vs 190 MVA LTR).* 11. *Regarding Highbury TS, the LTR limitations must be identified as part of the Regional Planning activities starting in Q1 2020.*	
1. *New developments downtown such as condominium towers, office and commercial towers should be connected to the 27.6kV looped system.* 2. *Due to limited real estate, radial supplies to customers are not an effective mode of distribution in an underground urban development and must be avoided.* 3. *Owners and their consultants must be notified in advance to provide above ground locations for London Hydro owned transformers, or, should they wish to proceed with customer owned transformers, room for London Hydro owned switchgear*	3.1.2.1 The 27.6kV Looped System (Downtown)
1. *As a strategy, new 27.6kV load should only be connected to the Ring Bus when a 27.6kV looped system is not in close proximity.* 2. *The City has plans to upgrade the infrastructure along York Street in 2021-2022. It is recommended to work with the City to renew London Hydro's degraded duct and manhole infrastructure at the same time so that LC 8717 can be leveraged to supply future growth along York St. and to convert*	3.1.2.2 The 27.6 kV Ring Bus (Downtown)

Summary of Recommended Strategies	Section
Network load. 3. *Since the 13M27 cable along Dundas St between Talbot and Wellington is being used on a critical system, cable condition diagnostic assessment should be carried out to plan for its timely replacement.*	
1. Continue with conversions of 13.8kV non-network customers and target completion December 2020.	3.1.3 13.8 kV Non-Network System (Downtown)
1. Based on customer criticality and operational flexibility, reduce the 13.8kV supplied grid network system to areas where it is absolutely required when it makes sense to do so as part of either City development or London Hydro deteriorated infrastructure upgrades. 2. *When determining service methods for new developments, priority must be given in the following order: above ground padmount, above ground vault, below ground non-network.* 3. *London Hydro will need to apply good engineering and operations practice to monitor existing load on buildings, secondary mains, and transformers to address any upgrades as required.* 4. *The GIS model and infrastructure records of the secondary network system will need to be reviewed and validated to improve accuracy of the cyme model.* 5. *Continue with plans to deploy technology to monitor network protectors, transformers, and vaults.*	3.1.4 Secondary Network System (Downtown)
1. Support O&M investment to maintain and extend the useful life of substation transformers (e.g. flush oils, increase rate of oil sampling and testing). *2. Incorporate into the prioritizing matrix: the health index of poles, conductors and equipment in the 4.16kV system based on the 2019 Asset Condition Assessment by Kinectrics to further improve the conversion/rebuilds programs.*	3.1.5 4.16 kV Distribution

Summary of Recommended Strategies	Section
3. *Maintain a capital investment of $4M for the next 10 years for circuit conversion from 4.16kV to 27.6kV.* 4. *Therefore, it is recommended that substations at strategic locations be kept and maintained for future smart grid applications after conversions are completed.*	
1. *Develop plans to phase out Sub 97 and determine if the pole-mounted step-downs provide sufficient capacity and redundancy to supply the rural services.* 2. *Evaluate the feasibility of building to 27.6kV standards and running at 8.32kV to prime the area for future developments.* 3. *Rural areas supplied by step-down transformers are frequently impacted during a storm event. Review (framing) separation of phases, implementation of spacers, cross-arms and tension on lines to prevent against galloping action.* 4. *Consider implementing single phase recloser technology (e.g. fuse saver) on rural feeders to improve reliability during storm events.*	3.1.6 8.32 kV Distribution
The OMS will benefit from the implementation of other features and enhancements of current features as follows: 1. *Customer centric reliability reporting: currently, OMS allows querying customers and displays the number of interruptions. It has been identified that the interaction from the control operator is critical to maintain an accurate representation of the events. An internal analysis is needed to identify what processes can be put in place to allow consistency of the data (i.e. outage causes, partial restoration steps).* 2. *Implement algorithms to handle step restoration sequences and properly record multiple interruptions and restorations related to the same outage event.* 3. *Improve processes to ensure all customers affected by an outage are easily identified and restored. Implement logic to use power restore alarms from smart meters to support*	3.2.1 Outage Management System (OMS)

Summary of Recommended Strategies	Section
this process. 4. *Explore Fault detection, isolation and assisted restoration through Logic Assisted Restoration (LAR) in OMS. LAR will allow OMS to make recommendations to isolate outage areas and restore as many customers as possible. LAR could take advantage of the status information and alarms reported from the automated devices in the field and the multiple sources of information available to OMS, including enhancements discussed further in this section (e.g. CFCIs).* 5. *Implement feeder loading tracking and historical recording in OMS. It is expected that such feature allows recording loading data per feeder while capturing configuration changes due to planned and unplanned switching to allow investigation of anomalies and exploration of alternatives to past scenarios.*	
1. *It is recommended to expand the presentment of data available at power quality meters by increasing the number of meters connected to PQView.* 2. *In order to maintain the system in a proactive manner, fulfill customer expectations and achieve regulatory requirements, a dedicated engineering tool with production support is needed. The engineering tool for analysis of service supply is envisioned as a tool that interconnects metering, GIS, SAP, SCADA, and OMS systems with predefined presentments and with the flexibility to query custom information for engineering analysis; all available through one interface.*	3.2.2 Metering data
The suggested steps to achieve the next level of enhancements are as follows: 1. *Evaluate accomplishment of the current pilot with Communicating FCIs (CFCIs) for overhead circuits and proceed to prepare a plan to identify optimal locations for CFCIs.* 2. *Propose technical documentation on the data flow from CFCIs and define how the*	3.2.3 Remote Fault Indication (OH/UG)/Vault monitoring/Automated device coordination

Summary of Recommended Strategies	Section
information will be integrated in the production OMS system. 3. *Evaluate the accomplishments of the deployment of VaultGard and Transformer Ruggedized Telemetry Link (TRTL) on the mini-grid networks. Define how the telemetry will be stored, presented to engineering personnel and analyzed to predict failures.* 4. *Consider the deployment of DigitalGrid technology for providing visibility into the grid network transformers.* 5. *Perform an industry/technology research exploring fault locating technologies for underground circuits.* 6. *Establish scope and viability to deploy settings and/or communication technology for reclosers to coordinate their response to fault events, i.e. if two reclosers reached the fault target only the closest to the fault should operate. This initiative supports future LAR implementation for assisted restoration in OMS.* 7. *Implement a system that can record, track, and maintain all the protective device settings (i.e. breakers, reclosers, interrupters). This tool should at minimum: allow to be written by only one user-role (admin), facilitate a revision/approval process of the settings in which settings can be proposed by users and only approved and posted by the admin, record changes/user/date-stamps, permit visualization of the data to a defined user-role (users) in a parametric manner, be linked to GIS, OMS, and CYME through a unique number attached to the most recent approved settings.*	

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With the structured results of the testing, and the analysis of the results, it is imperative to develop a cable asset management program that would effectively prioritize cable assets for either maintenance, replacement or rebuild. The cable asset management program will focus on public safety and customer reliability.</td><td>3.2.4 Cable diagnostics</td></tr>
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Summary of Recommended Strategies	Section
3. *A statistical interface that calculate reliability indicators as outage events occur and creates a time-series heat map.*	
1. *It is recommended to analyze the data gap analysis from the recent Asset Condition Assessment exercise* 2. *London Hydro has started a program to digitize field inspections using mobile devices in the field. While this program has been beneficial to start the transition from paper to electronic, a top-down planning approach is recommended to oversee all field data inspections as they play a vital role in the preventative maintenance of the system and the asset condition assessment and develop the requirements necessary to implement the respective changes.*	3.2.6 Asset Management
1. *The opportunity to create a reserve generation capacity for momentarily connected DERs needs to be explored further to determine the operational processes and/or technology required to manage such DERs. As well, the merits and risks associated with potentially not approving the connection of DERs that wish to be permanently connected in lieu of maintaining a reserve capacity for future use will need to be considered.*	3.3 Distributed Energy Resources
In terms of switchgear, it is recommended to: • *Produce a report showing performance of the solid dielectric switchgear and conclude on the performance of the most recent units purchased to date.* • *Perform industry/vendor research and/or collaborate with other LDCs to determine proven alternatives to SF6 gas insulated units that can be installed for critical loads and applications.* • *Document and implement a database containing SF6 equipment records and maintenance.* • *Research industry solutions for remote, near*	3.4 Environmental and Sustainability Considerations

Summary of Recommended Strategies	**Section**
real-time options for monitoring of all of the SF6 gas equipment and its integration to OMS. *In terms of customer owned poles, it is recommended to:* • *Create a process in which customers that own poles with London Hydro's equipment are made aware and responsible (documented) of the maintenance of the structures.* • *To study solutions to address customer owned poles with poor supporting guying.* *In terms of PILC cables, It is recommended to leverage the asset condition study results in regards to PILC to prioritize its replacement based on its health index and continue replacement of PILC cable with Ethylene Propylene Rubber Cable (EPR).* In terms of risk associated with Substation transformer oil leaks, it is recommended that: • *A team consisting of representatives from environmental department, engineering, and electrical maintenance and substation, develop custom emergency plans for each of the in-service substations. This emergency plan should at minimum contain drawings with specific instructions to be followed in case of oil leak, reference maps locating critical sewer points, contact/reporting protocols, and forms.* • *Study technology available to remotely detect oil leaks and analyze feasibility of deployment to the substations.*	

4.16kV Conversion Progress Report

2019 Update

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Acknowledgements:

Many thanks go to Gelber Vargas, P.Eng. Assistant Distribution Engineer, for estimating required investment to convert remaining 4.16kV assets, for managing the development of a new Transformer Health Index (THI), providing support in the identification of future zones for rebuilding. Also thanks goes to Chow Peng, Summer Co-op Student, in the research and analysis of the annual transformer dissolved gas analysis and oil quality analysis to develop the THI. Thanks goes to Steve Legan, Stations Supervisor, for providing the necessary support and feedback that enabled the addition of the THI as a value added component for this 2019 revision of the report. Last, but not least, thanks to Jac Vanderbaan P.Eng., Director of Engineering, for review of the final report.

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Executive Summary

Over the past 20 years, London Hydro has upgraded significant portions of the 4.16kV system to 27.6kV. The 4.16kV infrastructure is gradually being phased out due to its limited capacity, inability to serve load growth, and the higher system losses. London Hydro has thirty-three (33) 4.16 kV substations remaining in-service throughout the City. This is a substantial reduction from the forty-seven (47) 4.16kV substations in-service in 1995.

The 10-year 4.16kV system plan developed in 2011 identified three priority zones based on a coordinated approach using multiple evaluation factors such as age and condition of assets, reliability and system performance, and operational flexibility.

This 2019 report is intended to provide an update on the status of the priority Zones A, B, C, and D and to highlight the efforts required to convert/rebuild the remaining 4.16kV system.

Summary of Capital Investments and Remaining 4.16kV

Since the 2011 report, approximately $26M was invested towards rebuilding the 4.16kV system which translates to an average investment of $3.3M per year. To convert the remaining 4.16kV assets, it is estimated that $61.5M[1] will be required (excluding any environmental cleanup that may be required at substations and assuming full front lot conversion of the five rear lot overhead neighbourhoods). For the next 10 years, to convert the areas identified in Zones B to G, it is estimated that $31.6M will be required at a rate of investment of $4M per year. The 4.16kV system is expected to be in operation for the next 20 years at this investment rate.

Conversion Progress Update

Zone A: The scope of Zone A includes the conversion of the areas served by substations 1, 2, and 28 and portions of their associated backup feeders. Conversion of Zone A is complete.

Zone B: The scope of Zone B includes the conversion of the areas served by substations 18, 48, 54 and 92. Overall more than 50% of Zone B has been converted, primarily within subdivisions which are more difficult and resource intensive compared to conversions on arterial roads. Conversions on the arterial roads and decommissioning of the substations remains to be completed. A plan has been developed to address the remaining areas in the next 2-3 years subject to rate of Capital investments in this area.

Zone C: The scope for Zone C includes the conversion of the areas served by substations 15 and 40 and portions of their associated backup feeders from Subs 16 and 21. Overall nearly 60% of Zone C has been converted. There is a plan in place to convert the remaining subdivisions and decommission substations 15, 21 and 40 within 3-4 years subject to rate of Capital investments in this area.

[1] Estimated cost is based on today's dollars and does not account for time-value of money as the capital investment rate is expected to vary.

Zone D: The scope for Zone D includes the pilot project to convert a rear lot primary and secondary overhead system at Oak Park subdivision to a front lot primary and secondary underground system. Construction of phase 1 of this pilot is expected to start in Q3 2019.

Reliability & Asset Management

The reliability performance and distribution of degraded poles on the 4.16kV circuits is discussed in Section 3. In this 2019 revision, a new transformer health index (THI) was developed leveraging historical data for transformer dissolved gas analysis and oil quality analysis in combination with expected remaining life of the transformer based on London Hydro’s asset sustainment plan. The THI will be used as an additional factor to aid in prioritizing conversion zones.

1 Introduction

London Hydro has converted significant portions of the 4.16kV system over the past 20 years. The 4.16kV infrastructure is gradually being phased out due to its limited capacity, inability to serve load growth, and the higher system losses. A majority of the assets on the 4.16kV system are old and approaching the end of their useful service life. The goal is to continue the 4.16kV to 27.6kV conversions where feasible.

The 10-year 4.16kV system plan[2] developed in 2011 identified three priority zones based on a coordinated approach using multiple evaluation factors such as age and condition of assets, reliability and system performance, and operational flexibility.

London Hydro has thirty-three (33) 4.16 kV substations remaining in-service throughout the City as of May 2019. This is a substantial reduction from the forty-seven (47) 4.16kV substations in-service in 1995. The asset replacement resulting from the 4.16kV conversion/rebuild program is expected to have a number of positive impacts on future O&M costs such as:

- reduction in frequency of pole failure and the costs associated with outage response and reactive replacement when newer poles are installed as part of the voltage conversion;
- lower labour-intensive program of inspection and corrective maintenance[3];
- lower line losses; and
- improved overall system reliability, resulting in lower costs associated with outage response.

This 2019 report is intended to provide an update on the progress of the 4.16kV Conversion program and identify the remaining 4.16kV system with high level budgetary estimates for conversion/rebuild. A Substation Service Area Health Index (SSAHI) was developed utilizing Transformer Health Index (THI), age of pole assets, and reliability performance as a means to prioritize conversion of the various 4.16kV areas.

[2] A report entitled '4.16kV Aging Infrastructure System Planning Report – 2011' was released in October – 2011
[3] As compared to the periodic preventive maintenance required for legacy assets such as transformers and switches, which can no longer be economically maintained.

2 Overhead and Underground 4.16kV Rebuilds

Capital Projects for the years 2012-2019 targeted the priority zones recommended in the '4.16kV Aging Infrastructure System Planning Report – 2011'. The report recommended Zone A to be addressed in the years 2012-2013, Zone B to be addressed in the years 2014-2016, and Zone C to be addressed in the years 2017-2019. The Planning Report recognized that urgent situations could arise that impact investments into the 4.16kV system upgrades and thus the rate of converting the 4.16kV system. The Planning Report also recognized that the prioritization within the plan could change due to ongoing assessments and reliability evaluations.

Section 2.1 provides a brief summary of work completed to date. Overall, the plan outlined in the 2011 report has proceeded as indicated. At times, in lieu of work within the priority zones, upgrading and silicone injection of subdivisions with degraded (i.e. beyond expected useful service life) underground infrastructure was necessary for reliability improvements.

Section 2.2 provides a brief summary of the progress made in rebuilding the 4.16kV underground distribution system in subdivisions.

Section 2.3 combines all 4.16kV conversion / rebuild programs to summarize overall progress in the system.

2.1 Overhead 4.16kV Rebuilds

2.1.1 Zone A Status Update

Conversion of Zone A is 100% complete. Details as follows:

- 4.16kV Substations 1, 2, and 28 within Zone boundary were decommissioned and associated circuits converted to 27.6kV.
- Other 4.16kV backup feeders originating from Substations 16, 21, 22, and 52 were addressed as follows:
    - Substation16
        - Portions of the 16F1 and 16F2 have been removed
    - Substation 21
        - Feeder 21F3 and portions of the 21F2 have been removed
    - Substation 22
        - Minimal removal of 4.16kV infrastructure served by this station
    - Substation 52
        - Portions of the 52F1 and 52F4 have been removed

Table 1: Zone A Status Update

Station	2011 Rank	Overall Completion (%)	Circuit Conversions (%)	Transformers Converted (%)	4.16kV Station Decommissioned?
Sub 1	4	100 %	100 %	100 %	Yes
Sub 2	1	100 %	100 %	100 %	Yes
Sub 28	2	100 %	100 %	100 %	Yes

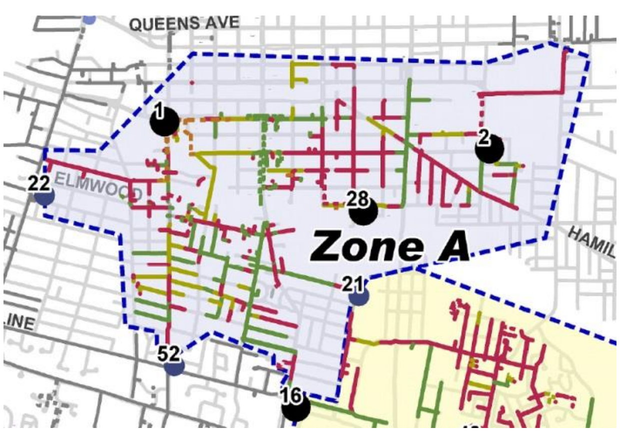


Figure 1: 4.16kV Map of Zone A in the 2011 Report

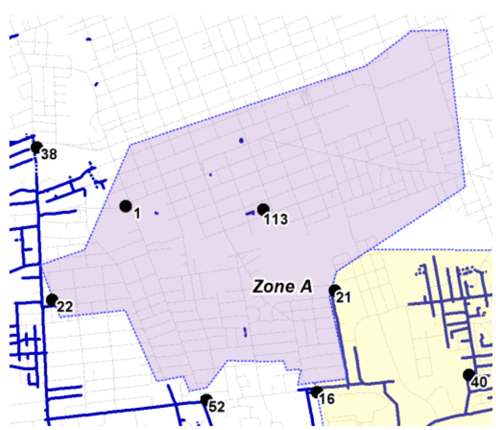


Figure 2: 4.16kV Map of Zone A as of August 2018

2.1.2 Zone B Status Update

Conversion of Zone B is partially complete (65%). Full conversion expected by 2021. Details as follows:

- 4.16kV Substations 18 and 54 within Zone boundary are still in service and stations 48 and 92 are scheduled for decommissioning in 2019
- Extensive conversion of 4.16kV circuits in subdivisions within Zone boundary has been completed
- 4.16kV circuit conversions along arterial roads was started in 2019

Table 2: Zone B Status Update

Station	2011 Rank	Overall Completion (%)	Circuit Conversions (%)	Transformers Converted (%)	4.16kV Station Decommissioned?
Sub 18	10	46 %	48 %	44 %	No
Sub 48	36	15 %	2 %	27 %	**2019**
Sub 54	25	70 %	65 %	76 %	No
Sub 92	3	96 %	91 %	100 %	**2019**
ZONE B Overall		65%	62%	69%	

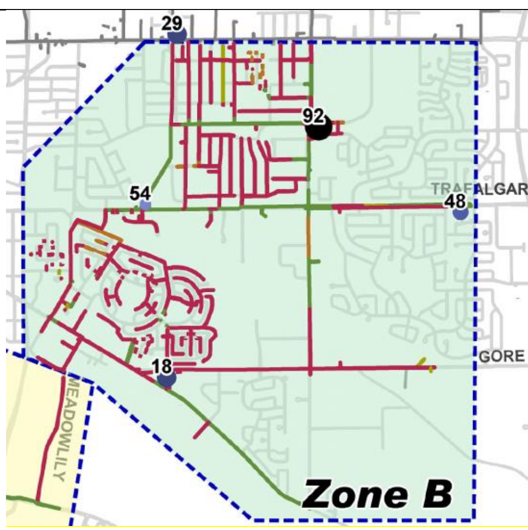


Figure 3: 4.16kV Map of Zone B in the 2011 Report

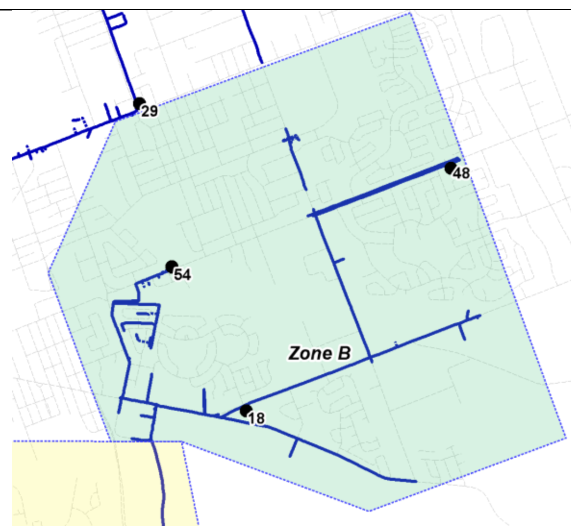


Figure 4: 4.16kV Map of Zone B as of May 2019

Continued conversion of Zone B is recommended to address the remaining 4.16kV infrastructure. This will offload remaining substations 18 and 54 to a point where they can be decommissioned. Substation

92 transformers are 1958 vintage and the associated switchgear is the oldest in the system (oil filled breakers). This substation is scheduled to be decommissioned in 2019 due to the progress of conversions along Clarke Road. Similarly substation 48 is scheduled to be decommissioned in 2019, however, its transformer is relatively young (38 years as of 2019) and will be reused in the system elsewhere to replace an aging transformer. The following plan is proposed for the continued conversion of Zone B:

Table 3: Proposed conversion to complete Zone B (Refer to Figure 5)

Steps	Description	Outcome
1 and 2	Convert Saskatoon St from Dundas St to Trafalgar, and convert Wavell St from Clarke Rd to Saskatoon St	Partial conversion of 29F1 and full conversion of 54F2 and 92F2 feeders
3 and 4	Convert Clarke Rd. from Atlantic court to Dundas St, to Wavell Rd, and to Trafalgar St	Partial conversion of 49F2 and full conversion of 92F3 feeder. *Now can decommission Sub 92*
5 and 6	Convert Trafalgar St from Thorne Ave to Clarke Rd to Lem Gardens. *48F2 tie to 18F3 is required until 18F3 is fully converted.*	Full conversion of 54F1, 48F1 and 48F2.
7 and 8	Convert Clarke Rd from Trafalgar St to Gore Rd and convert Gore Rd from Marconi Gate to Montebello Dr.	Full conversion of 18F3. *Now can decommission Sub 48.*
9 and 10	Convert Hale St. from Trafalgar St to Hamilton Rd and Hamilton Rd from Hale to Meadowlily Rd. Convert Hamilton Rd from Gore Rd to Clarke Rd. *18F1 tie to 15F3 is required until 15F3 is fully converted.*	Full conversion of 54F3 and partial conversion of 18F1. *Now can decommission Sub 54.*

Note Sub 54 transformers are of a relatively newer vintage (2 x 2.5MVA units of 2000 vintage) and can be reclaimed to replace older transformers in the 4.16kV system that will not be converted within 5 years.

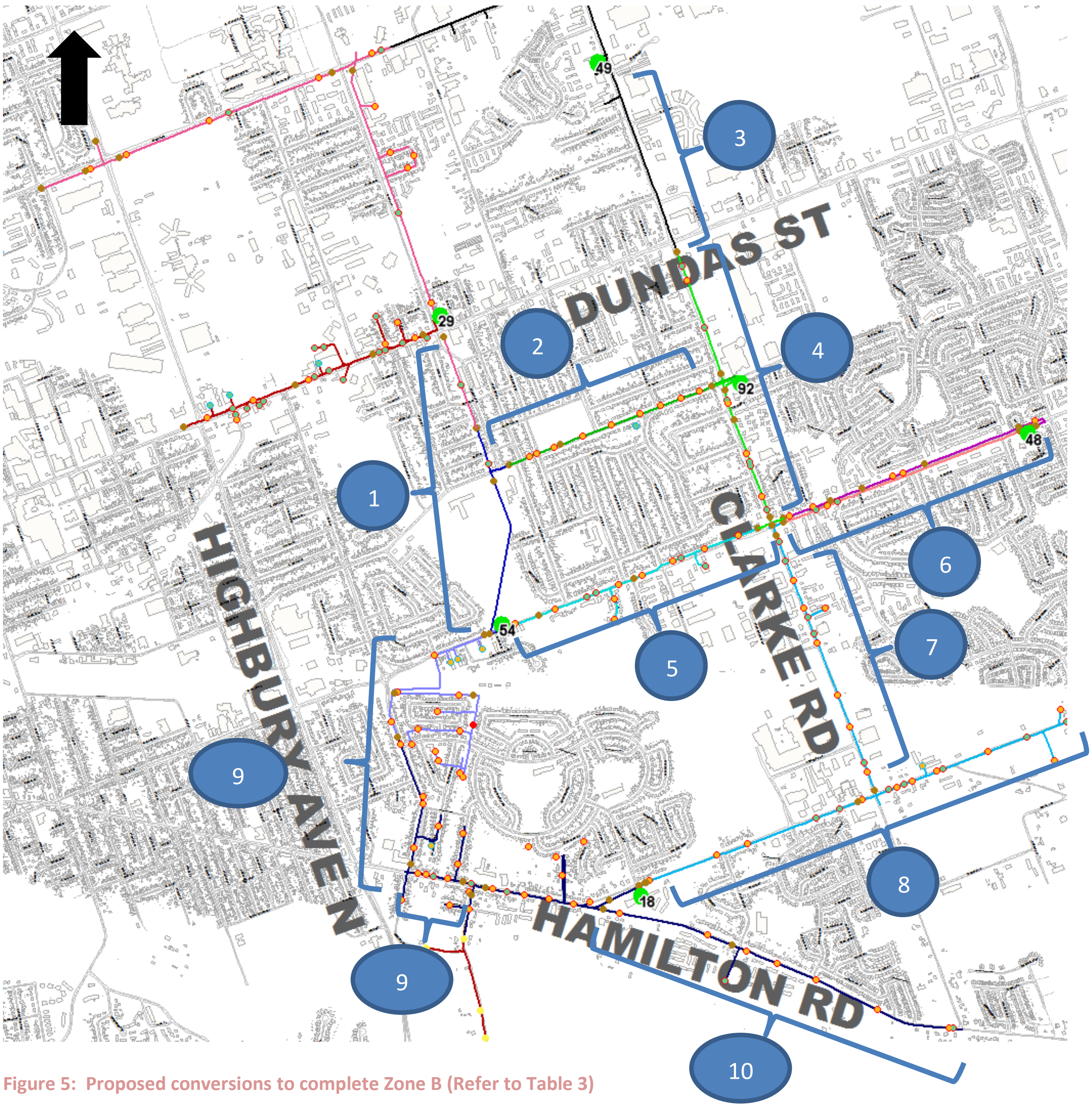


Figure 5: Proposed conversions to complete Zone B (Refer to Table 3)

2019 scope of conversion within Zone B is highlighted in the following figure. As can be seen, the area to be converted is extensive now that the challenging / resource intensive conversions within the substations have been completed.

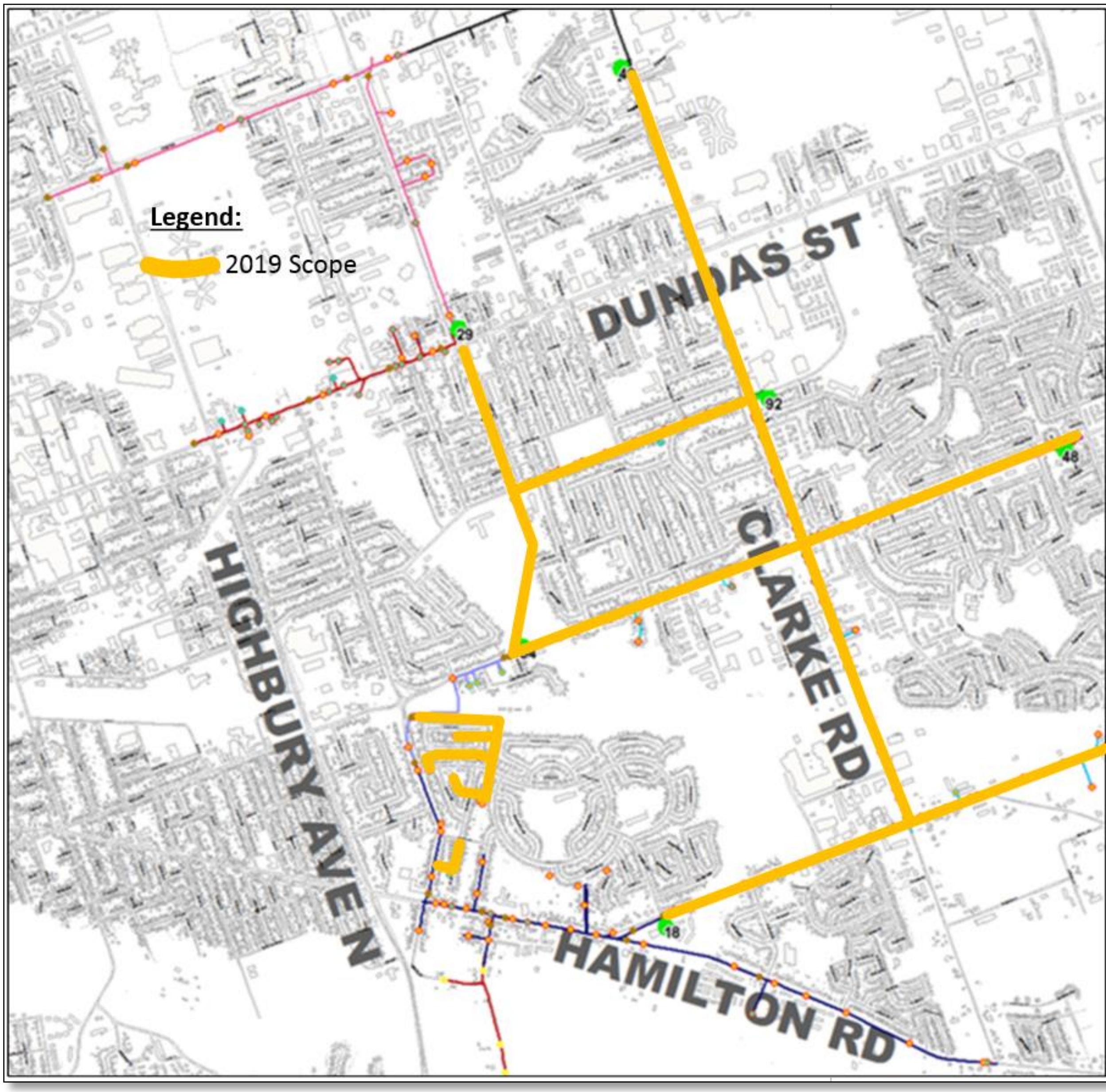


Figure 6: 2019 Scope of Conversion in Zone B

2.1.3 Zone C Status Update

Conversion of Zone C is partially complete (60%). Details as follows:

- 4.16kV Substations 15 and 40 within Zone boundary are still in service
- Conversions along Thompson Road have been completed.
- Pond Mills subdivision underground has been upgraded to 27.6kV as part of the SPOORE underground subdivision program
- Approximately 0.5km of 15F3 underground cable has been removed
- Other 4.16kV backup feeders originating from Substations 16 and 21:
  - Substation 16
    - 16F3 is loaded with approximately 300 customers and serves as a tie to 40F1 and 15F3
  - Substation 21
    - Only 21F2 feeder remains at Sub 21 with no load – serves as a feeder tie to 16F3

Table 4: Zone C Status Update

Station	2011 Rank	Overall Completion (%)	Circuit Conversions (%)	Transformers Converted (%)	4.16kV Station Decommissioned?
Sub 15	6	36%	35%	37%	No
Sub 16	5	69%	64%	75%	No
Sub 21	17	89%	78%	100%	No
Sub 40	32	48%	34%	63%	No
ZONE C Overall		59%	52%	66%	

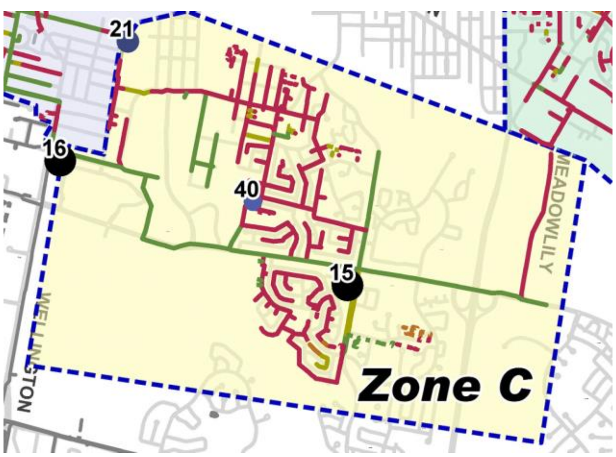


Figure 7: 4.16kV Map of Zone C in the 2011 Report

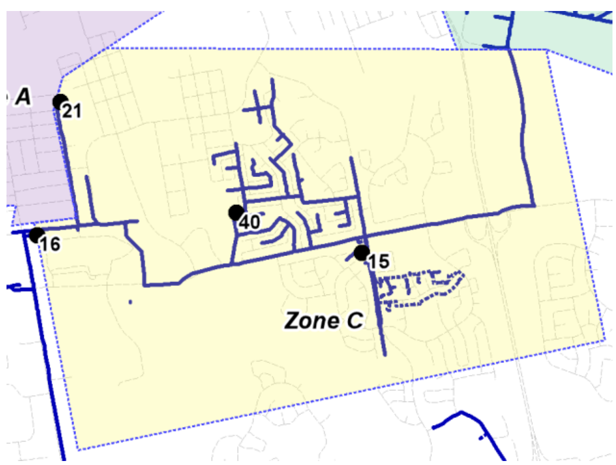


Figure 8: 4.16kV Map of Zone C as of May 2019

Continued conversion of Zone C is recommended to address old 4.16kV infrastructure. This will offload substations 40 and 15 to a point where they can be decommissioned. As well, Substation 18 can be decommissioned once 15F3 is fully converted. The following plan is proposed for the continued conversion of Zone C:

Table 5: Proposed conversions to complete Zone C (Refer to Figure 9)

Steps	Description	Outcome
1	Convert remaining Glen Cairn neighbourhood. *40F1 tie to 16F3 is required until 16F3 is fully converted.*	Full conversion of 40F1 and partial conversion of 15F3 and 16F3
2	Convert Hamilton Rd from Gore Rd to Meadowlily Rd and convert Meadowlily Rd from Gore Rd to Commissioners Rd. At Meadowlily and Norlan Ave, it is recommended to use a step-down transformer to soft convert the six single phase transformers south of the river to Commissioners Road. The area is a defined as a Tree Protection Area by the City of London and there development to warrant a 3-phase 27.6kV build is not expected in the foreseeable future. There are a number of poles on Meadowlily that are greater than 55 years old. Pole condition should be reviewed at the time of soft conversion to determine if these poles should be replaced.	Full conversion of 18F1 and partial conversion of 15F3. *Now can decommission Sub 18.*
3	Convert Commissioners Rd from Meadowlily Rd to Pond Mills Rd.	Partial conversion of 15F3
4	Convert Pond Mills Rd from Commissioners Rd to south of Deveron Crescent including the Pond Mills subdivision.	Full conversion of 15F3. *Now can decommission Sub 15.*
5	Convert Commissioners Rd from Pond Mills Rd to Adelaide St. *The 21F2 circuit along Fairview Ave is an express circuit to back up the 16F3. No conversion is required along Fairview Ave.*	Partial conversion of 16F3.
6 and 7	Convert Base Line Rd from Wellington St to Westminster Ave. *The 21F2 circuit along Fairview Ave is an express circuit to back up the 16F3. No conversion is required along Fairview Ave.*	Full conversion of 16F3. *Now can decommission Sub 21.*

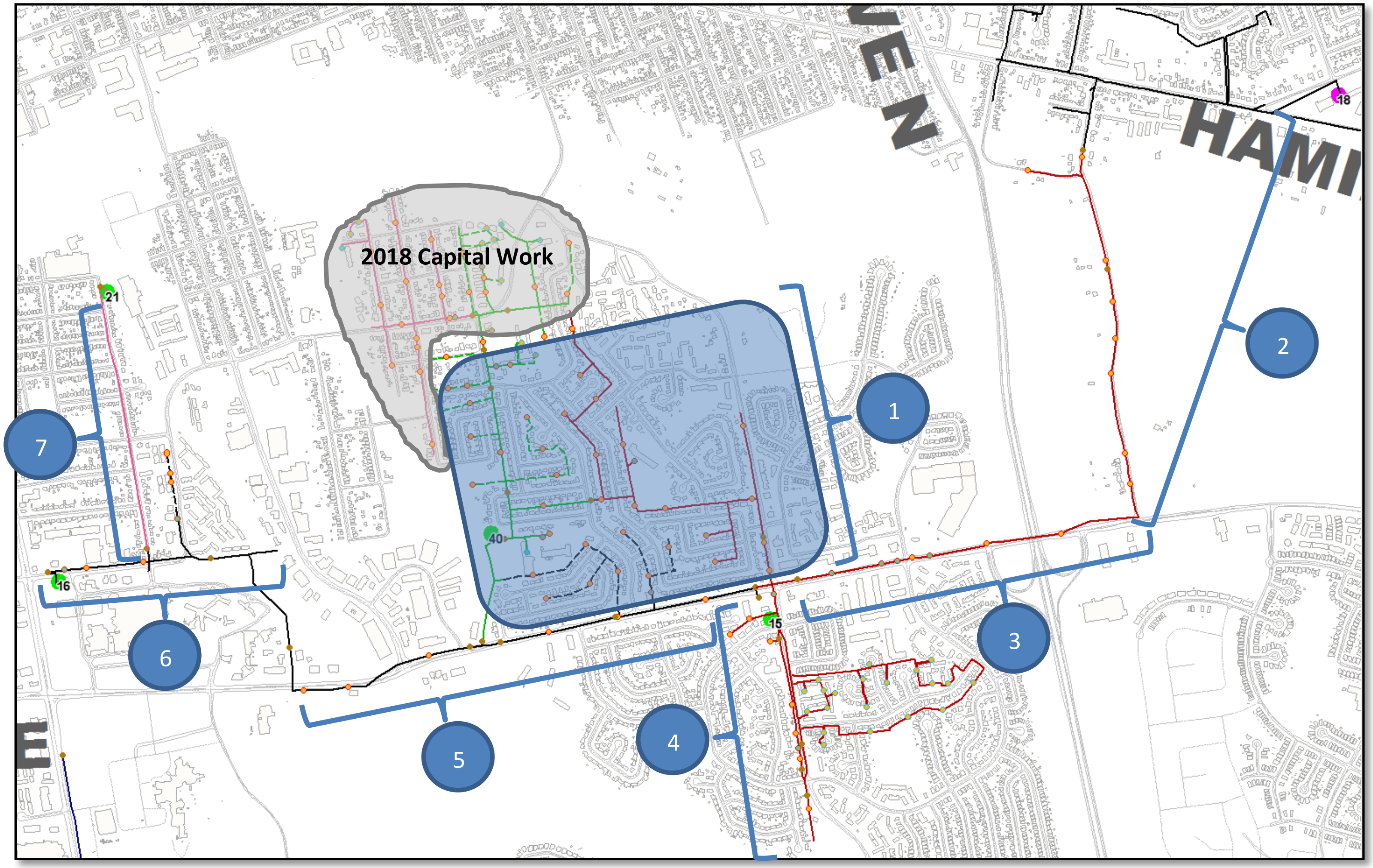


Figure 9: Proposed conversions to complete Zone C (Refer to Table 5)

2019 scope of conversion within Zone C is highlighted in the following figure. Area of conversion for 2019 was limited to the subdivision identified as Step 1 in Figure 9. This was due to shifting of conversion priorities to Zone D to address the degrading reliability at Oak Park Subdivision.

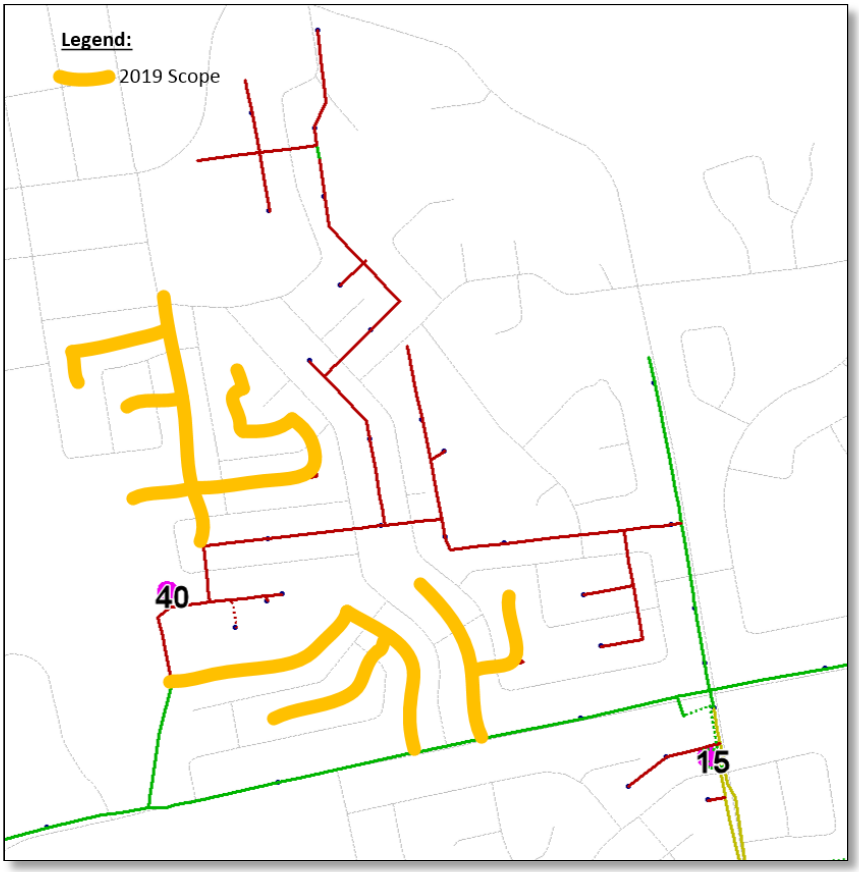


Figure 10: 2019 Scope of Work within Area 1 in Zone C

2.1.4 Zone D Status Update

Conversion of Zone D started in 2019 with a pilot project in priority Area 1. Details as follows:

- 4.16 kV substations within the boundary are Substations 25, 35, 39, 44, and 51
- This zone has been subdivided into four areas to be prioritized based on reliability performance. Within this zone there is a mixture of front lot and rear lot 4.16kV construction as shown in Figure 12 and Figure 13.

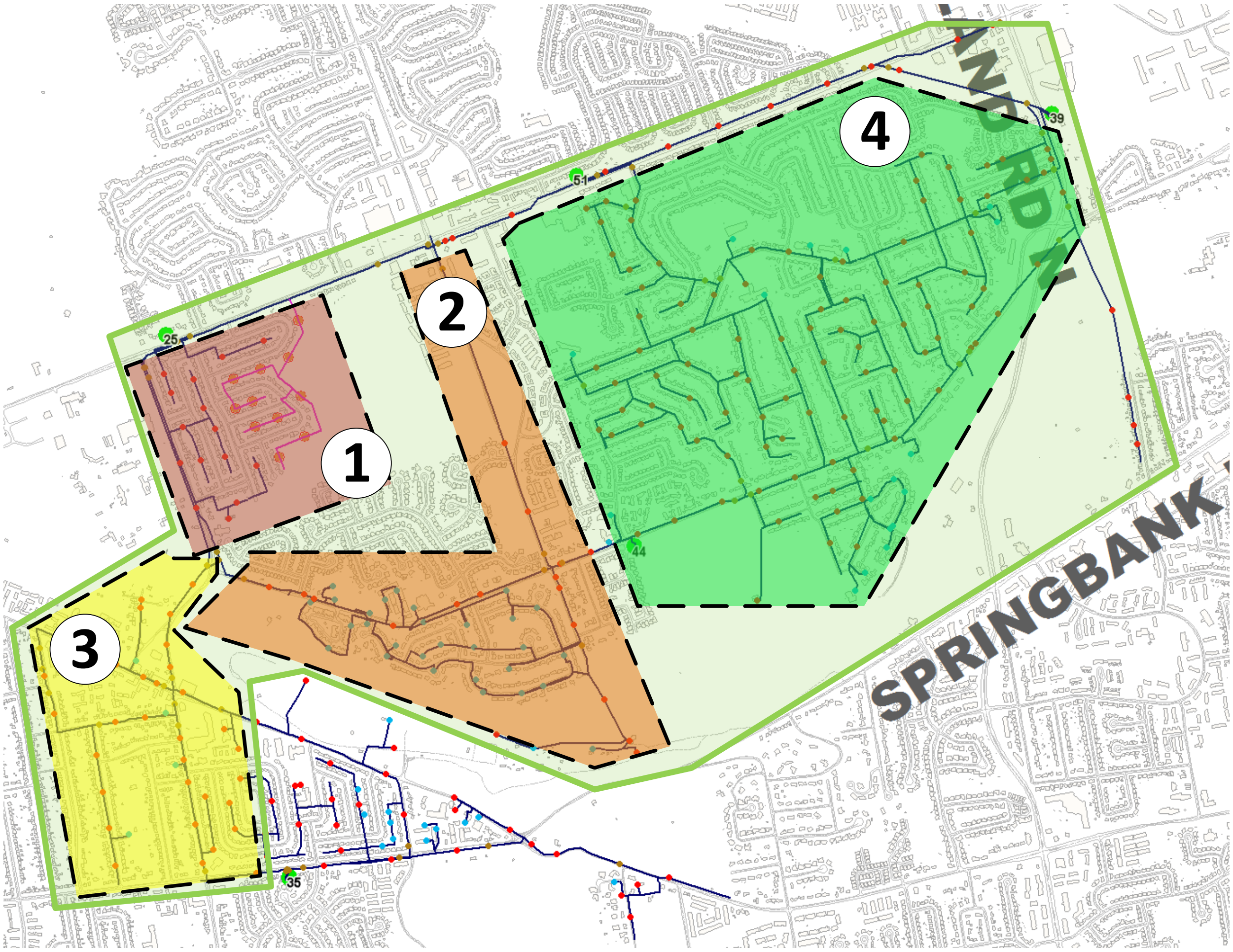


Figure 11: Zone D - Oak Ridge with prioritized areas

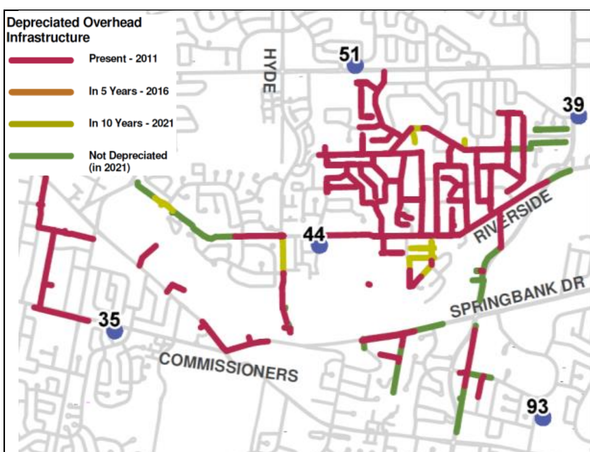


Figure 12: Zone D – Oakridge Front Lot circuits

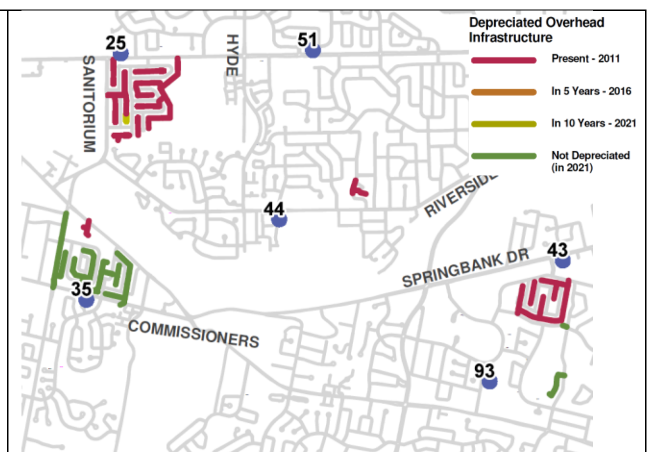


Figure 13: Zone D – Oakridge Rear Lot circuits

A pilot project was started in 2019 to convert a portion of the backyard overhead 4.16kV distribution in Area 1 to a front yard below grade distribution system. The portion targeted in 2019 with the overhead transformers that will be offloaded is shown in Figure 14. This area, over the past several years, has been experiencing a degradation in reliability in part due to a combination of poor soil conditions at the Sifton Bog, large trees some which are customer owned that are not maintained, and increasingly harsh weather conditions.

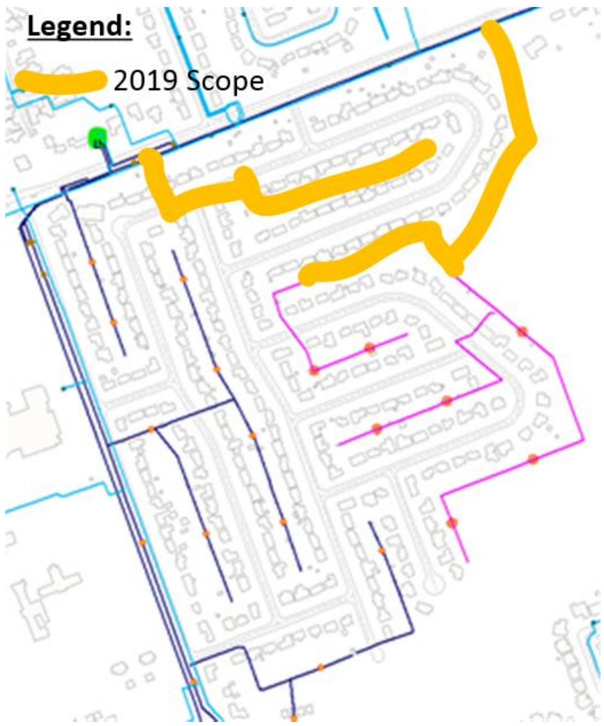


Figure 14: Area 1 – Oak Park Subdivision Circuit Distribution

London Hydro has experience in rebuilding backyard underground distribution to a front yard underground distribution with dedicated services to customer meters. A similar project was undertaken in 1999 to rebuild Oakridge Subdivision and Ridgeview Subdivision.

2.2 Underground 4.16kV Rebuilds

The SPOORE (Safety, Performance, Operability, Outage, Risk, & Environment) analysis has been utilized by London Hydro to assess degraded underground plant and cable replacement needs by evaluating the severity of service interruptions and cable faults per length of conductor. These performance indicators have a strong correlation with the service life of the equipment and are primarily used to identify priorities for subdivision rehabilitation.

In 2011, there were a total of 115km of underground primary cable operating at 4.16kV[4]. As of May 2019, there are 48km of primary underground cable servicing at 4.16kV.

Of the 48km of 4.16kV underground circuits remaining, about 20km are cables that are either a substation egress, an underground dip, or a riser connected to a step transformer. The remaining 28km of cable are located in 5 areas as shown in Figure 15.

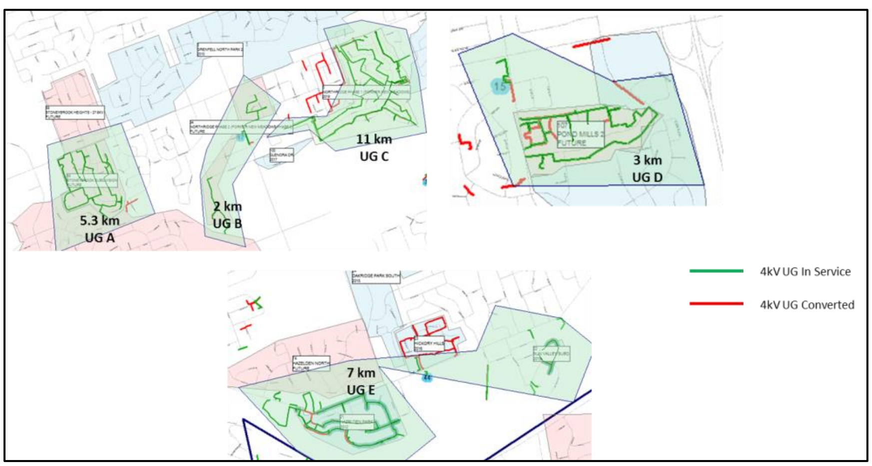


Figure 15: Most Significant 4.16kV Underground Areas Remaining

The table below illustrates some statistics from the 5 areas identified in the figure above.

Table 6: 4.16kV Underground Conductors Remaining within Most Significant Areas

		XFMR		
AREA	**km**	**OH**	**UG**	**Plan**
UG A	5.3	3	26	To be rebuild as per SPOORE analysis - TBD
UG B	2	1	44	To be rebuild as per SPOORE analysis - 2020
UG C	11	9	20	Currently being rebuilt - 2019
UG D	3	32	39	To be rebuild as per SPOORE analysis - TBD
UG E	7	13	8	Injected in 2012 - To be rebuild TBD

[4] Sub 98 and areas served by with 27.6/4.16kV (rabbit) transformers may not be included in the 2011 snapshot of the 4.16kV system.

2.3 Summary of 4.16kV Conversions

Large versions of the following figures are included in the Appendices. A contrast of the 4.16kV distribution system that is in service to the distribution system that has been removed is shown in Figure 16.

At the start of the 10-year 4.16kV program developed in 2011, the 4.16kV distribution system appeared as shown in Figure 17. Present day 4.16kV distribution system is shown in Figure 18. Comparing the two maps, one can observe that conversion of the 4.16kV system is relatively on track. In some areas there have been a slight set back to the plan due to higher priority capital investments required elsewhere, however, in other areas, 4.16kV conversion was expedited due to deteriorating performance.

Table 7 shows the summary of the infrastructure existent in 2011. Detailed information of the 4.16kV circuits in 2011 can be found in appendix 3: 4.16kV Final Matrix Summary_2011 Reference.

Table 7: Summary 4.16kV Infrastructure 2011

Substations	37
Length (km) OH	297
Length (km) UG	115
Customers	32,233

Table 8 summarizes the 4.16kV Infrastructure presently in-service within London Hydro's jurisdiction. The customer count includes those supplied by step transformers connected to the 27.6kV system (57 customers).

Table 8: Summary 4.16kV Infrastructure as of May 2019

Connected to Substations			
Primary Length (m)	OH	214,694	**261,157**
	UG	46,463	
Transformers	Pole	1,079	**1,309**
	Pad	230	

Connected to Step Transformers			
Primary Length (m)	OH	6,286	**7,645**
	UG	1,359	
Transformers	Pole	36	**49**
	Pad	13	

Step Transformers	
Talbot TS	12
Buchanan TS	1
Wonderland TS	3
Total	**16**

Substations	33	
Customers	13,601	(Includes Customers supplied by step transformers)

Total			
Primary Length (m)	OH	220,980	**268,802**
	UG	47,822	
Transformers	Pole	1,115	**1,358**
	Pad	243	

Figure 16: 4.16kV Map of Primary Circuits In Service and Converted (May 2019)

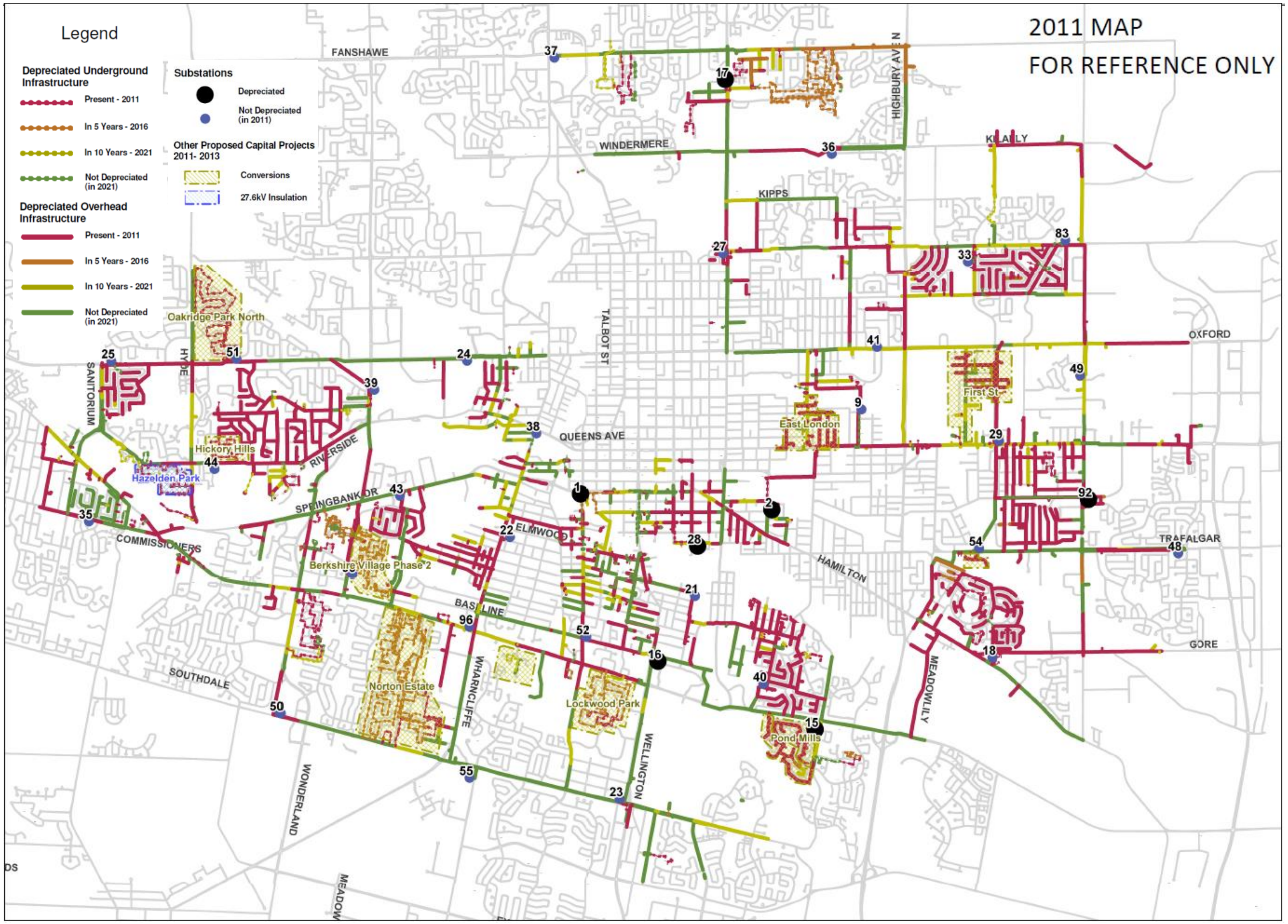


Figure 17: 4.16kV Map of Overhead and Underground Primary Conductors by Age (2011)

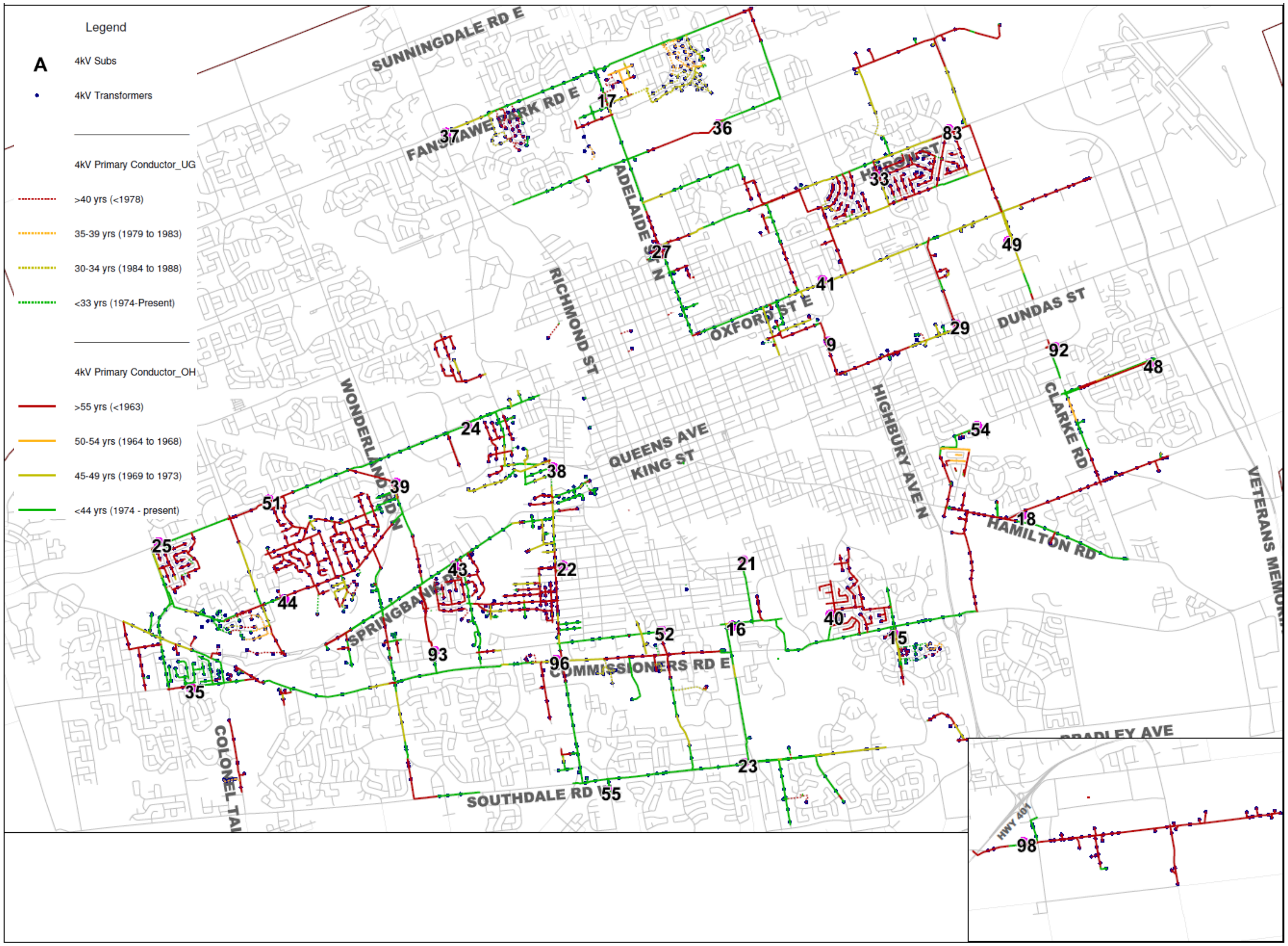


Figure 18: 4.16kV Map of Overhead and Underground Primary Conductors by Age (May 2019)

2.4 Summary of 4.16kV Capital Investments

The table below summarizes capital project investments made into converting the 4.16kV system to 27.6kV.

Table 9: Summary of 4.16kV Capital Project Investments

Year	Cost[5]	Cumulative Total
2011	$2,558,385	$2,558,385
2012	$5,896,787	$8,455,171
2013	$3,963,659	$12,418,831
2014	$3,590,500	$16,009,331
2015	$3,005,745	$19,015,077
2016	$2,528,883	$21,543,960
2017	$2,590,219	$24,134,179
2018	$1,881,419	$26,015,598

An average investment of $3.3M has been made every year since 2011 to 2018 to projects rebuilding the 4.16kV circuits to 27.6kV. Multiple estimating methods have been used to determine the remaining amount of investment required to complete the 4.16kV conversions.

The first method is based on the estimates prepared in the 2011 report, and an inflation of 2% per year was applied. This method of estimating indicates an investment of $63.6M is required to convert/rebuild the remaining 4.16kV system supplied by substations. Station decommissioning and 4.16kV areas supplied by step down transformers are not included in this estimate.

The second method uses experience gained during the last eight (8) years while planning and performing the conversions. A multi-project approach is better as we now have factual data that supports the investment pro-rated per pole, per kilometers of cable/conductor, per customer, considering asset location (e.g. backyard, front yard). Appendix 6 contains a detailed table describing the factors and estimated costs.

Using this second method of estimation, the remaining conversions require an investment of $42.5M. A contingency of 30% has been applied as we have learned that there are factors that can change the conversion approach. For example, extremely hard soil conditions (e.g. rock) that does not allow directional drilling. In addition, estimates need to be added for transformer removal and environmental study to assess the condition of the location of the substation and to know what needs to be done to reutilize the substation land in an environmentally responsible manner. The transformer removal and environmental study can cost between $55,000 and $68,000 dollars for stations with one and two transformers, respectively, including 30% contingency per location.

[5] Costs include overhead and underground work on depreciated areas and subdivision rebuilds of 4.16kV work performed.

In addition, there are 513 customers being supplied from step transformers. These transformers convert the 27.6kV to 4.16kV. The estimated cost per customer for these conversions is $3,500 dollars, for a total of $2.3M including contingency.

Therefore, the total investment required to convert/rebuild the 4.16kV system including substation decommissioning and 4.16kV step-down areas is $46.7M[6]. Note that, this value includes the environmental assessment at the stations but does not include the cost for remediation as this cannot be accurately estimated at this time.

As well, the $46.7M estimate is based on converting rear lot overhead neighbourhoods using the hybrid approach of $4,536 per service. Utilizing the conversion option rear lot to front lot conversion, which is being piloted at Oak Park subdivision in 2019, the initial capital cost per service is $9,889. For the 2,760 rear lot customers, it is estimated that an additional $14.8M capital investment will be required to convert these areas to front lot conversion – totaling $61.5M. Although the initial capital investment may appear high, it has been shown in the 2018 report[7] that the total cost of ownership per service when comparing the hybrid conversion approach to the front lot conversion approach is a negligible premium of 35%. This premium is further reduced when considering other benefits to a complete underground conversion solution such as safety to the public, reliability, and customer preference.

[6] This dollar value does not take into account the future time-value of investments.
[7] 4.16kV Conversion Plan – 2018 Update; Plan for Rear Lot to Front Lot Conversion, September 2018

3 Reliability & Asset Management

3.1 Reliability

The 2011 4.16kV planning report identified various areas where the infrastructure was degraded[8] and would be degraded in the years 2016 and 2021. Although the relative age of the 4.16kV system may be the same in various parts of the City, the performance of the 4.16kV feeders in terms of reliability and operational flexibility varies from one part of the City to another. Furthermore, the recent reliability performance of rear lot construction is generally poorer in comparison to front lot construction. This can be explained by considering the environmental conditions in backyards with greater tree related outages and longer repair times due to accessibility challenges which are further exacerbated by customer installations of pools, sheds, etc.

Recent reliability data, substation assessments, and Operation staff feedback was considered in identifying the next Zone of conversion. In selecting the new Zone for conversion, it is recognized that multiple zones may need to be rebuild in parallel due to developments in reliability, performance degradation, and balancing available construction resources efficiently. For example, Zone D encompasses areas that have both front lot and rear lot construction, were the rear lot area is recommended to be prioritized in 2019 due to poor reliability performance. This rear lot design and construction will require more underground design/construction staff resources as opposed to overhead design/construction staff resources. Conversely, the remaining areas of Zone B, C and D will require predominantly overhead design/construction staff resources. Therefore, Zone B and C can be addressed in parallel with the design/construction of the rear lot area in Zone D.

The performance of the 4.16kV feeders was evaluated based on outage data from 2013 to 2018. Scheduled outages were excluded from the dataset in order to focus on unplanned outages under London Hydro's control (loss of supply due to Hydro One was excluded).

The number of customers interrupted and the duration in minutes of interruption per feeder were merged to get reliability indicators for Feeder Average Interruption Duration Index (FAIDI) and Feeder Average Interruption Frequency Index (FAIFI). In order to classify the performance of the feeder based on FAIFI and FAIDI, the indicators were weighted as 70% and 30% respectively[9].

Similarly, the Substations supplying the 4.16kV feeders were ranked based on the reliability of its feeders, Table 10. That is, the aggregated FAIFIDI performance indicator ratings determined the performance of the respective substation.

[8] The term "degraded" used in this report denotes infrastructure that is aged and operating beyond expected useful service life.

[9] The frequency of interruptions was considered as having a higher impact to customer as opposed to the duration of the interruption. In addition, the FAIFI trend was steadier whereas the FAIDI trend fluctuated significantly.

Figure 19 below shows the 4.16kV feeders in service and their reliability performance ranked relative to each other from least performing to best performing.

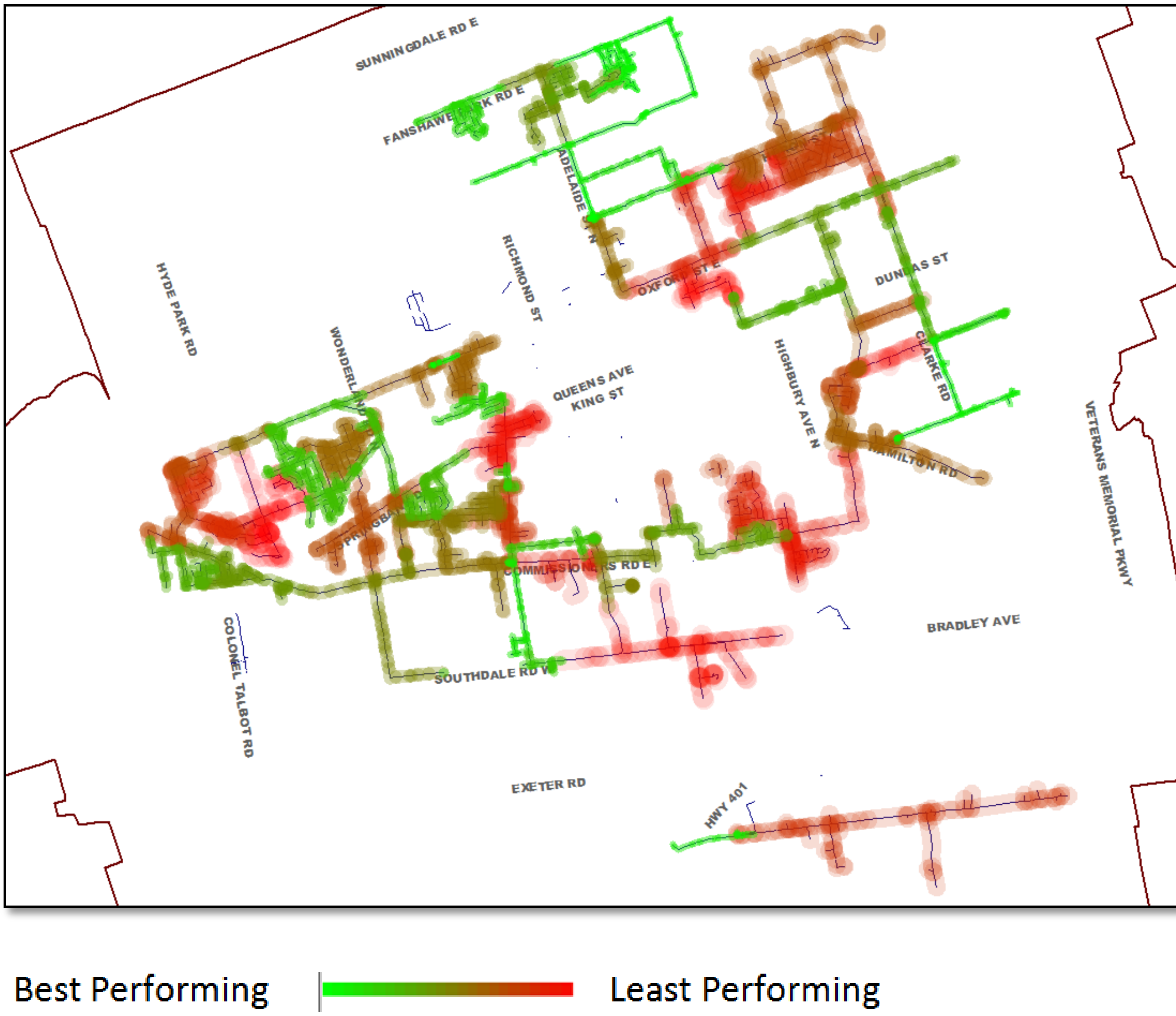


Figure 19: 4.16kV feeder reliability performance (2018)

Correspondingly, Figure 20 shows the aggregation of feeder performance allocated to the respective Substation.

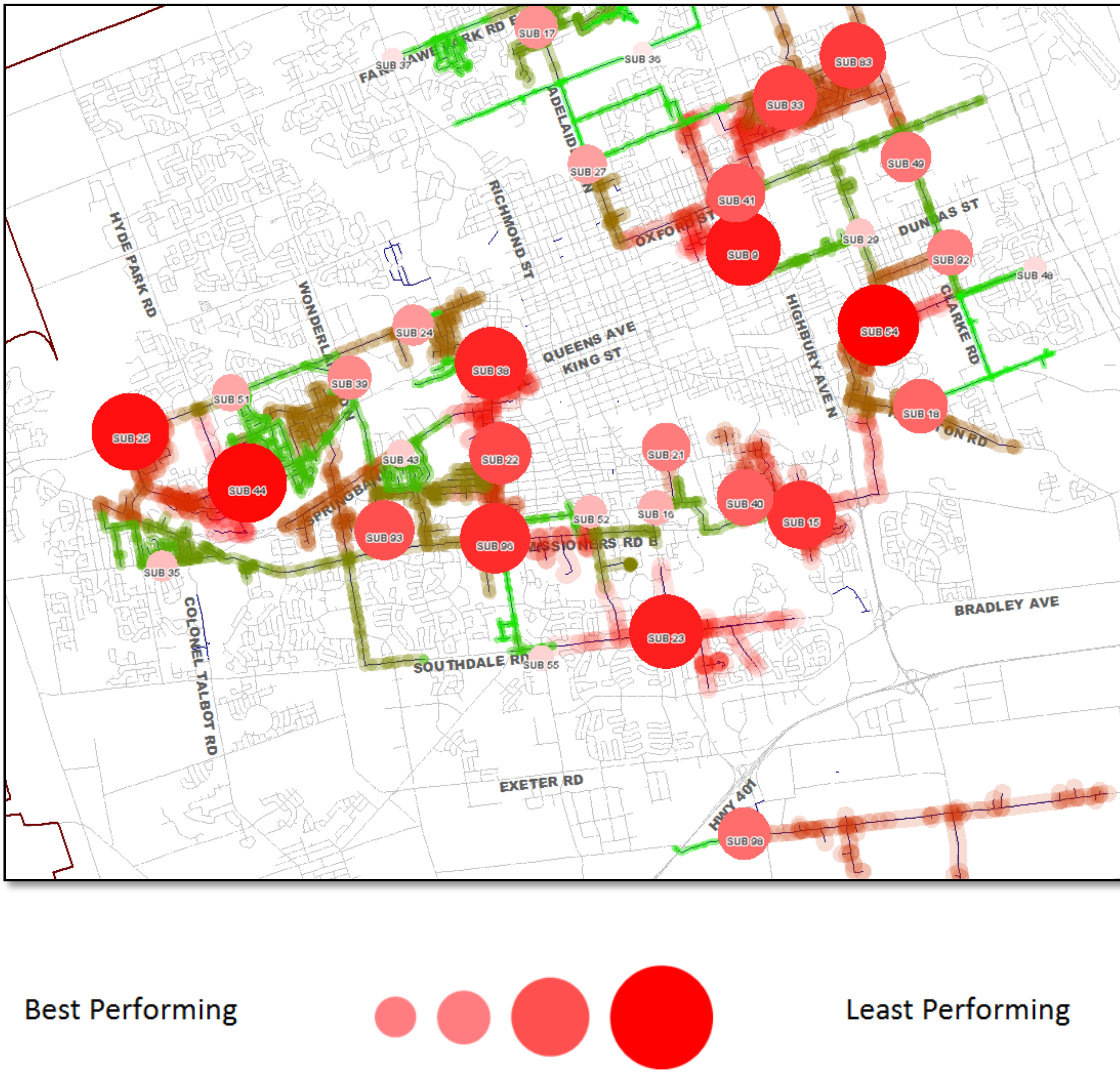


Figure 20: 4.16kV substation reliability performance (2018)

Table 10 shows the ranking of the 4.16kV Substations according to their reliability as part of London Hydro's distribution system.

Table 10: Reliability 4.16kV Substations (2018)

Substation Transformer	Reliability (RANK1: GOOD)
48-T1	1
36-T1	1
55-T1	1
51-T1	1
37-T2	1
43-T1	1
35-T1	1
29-T1	1
37-T1	1
16-T1	2
24-T1	2
52-T1	2
27-T1	2
98-T2	3
39-T1	3
49-T1	3
18-T1	3
17-T1	3
98-T1	3
21-T1	3

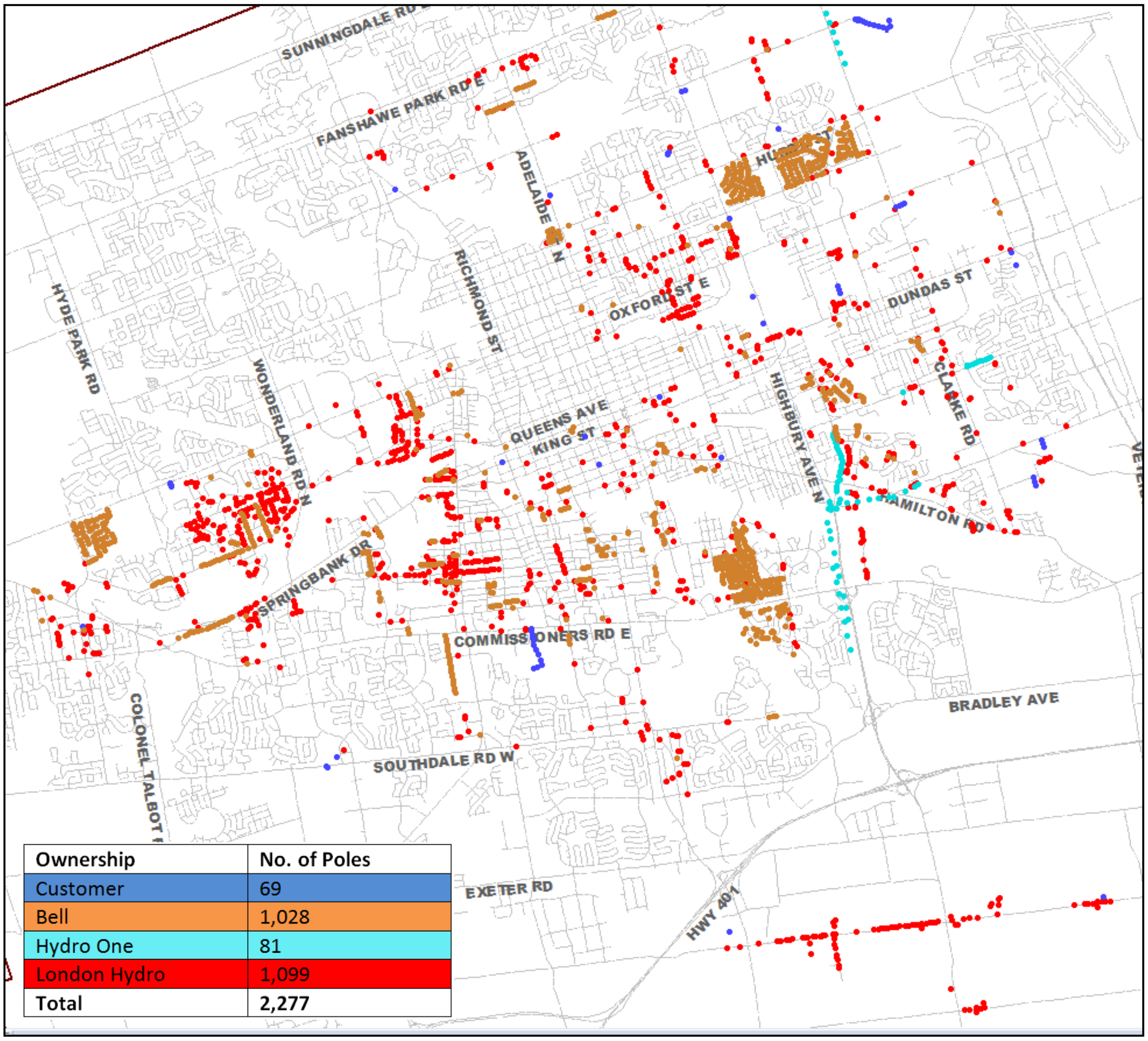
Substation Transformer	Reliability (RANK1: GOOD)
83-T2	4
33-T1	4
83-T1	4
40-T1	4
15-T2	4
93-T1	4
41-T1	4
22-T1	4
38-T1	5
44-T1	5
54-T1	5
54-T2	5
96-T1	5
25-T1	5
09-T1	5
23-T1	5

3.2 Asset Management

3.2.1 Poles

The 2015 Asset Sustainment Plan evaluated the rate of replacement of overhead circuits, including poles. Poles are tested on an annual basis to ensure public safety and worker safety, and the test results are a main driver for developing the capital replacement plan. Based on London Hydro's empirical data over a six year period, the average estimated life span of a pole is 55 years. The ASP determined that on average 686 poles per year would need to be replaced (including third party poles) in order to address all poles that were greater than 55 years of age in 2015 or will reach 55 years of age over the next 15 years.

The Figure below illustrates poles older than 55 years on the 4.16kV system (including third party poles) as of August 2018. There are 2,277 poles older than 55 years on the 4.16kV system.[10] In total, there are 3,571 poles older than 55 years in the entire system. As expected, the 4.16kV system is an older system and as such 64% of degraded poles (>= 55 years of age) support 4.16kV infrastructure. Targeting investments into 4.16kV conversions zones is a cost effective means to upgrade a legacy distribution system while satisfying the commitments in the ASP.



Ownership	No. of Poles
Customer	69
Bell	1,028
Hydro One	81
London Hydro	1,099
Total	2,277

Figure 21: Degraded poles (>55 years, beyond expected useful service life) of on the 4.16kV System (2018)

While some areas are being rebuilt from overhead to underground, and others are being converted using a hybrid approach, the pole infrastructure remains as the most prevalent item when replacing in a like for like manner. Not all the poles in the 4.16kV system are owned by London Hydro. In most cases, when a third party owns the pole, London Hydro has taken ownership of the pole in cases such as on

[10] These are poles that either have 4 kV circuits only, or a combination of 4.16kV and 27.6kV circuits.

backyard to hybrid conversions. Figure 22 shows that 83% of the poles in the 4.16kV system are London Hydro's while 14% belong to Bell.

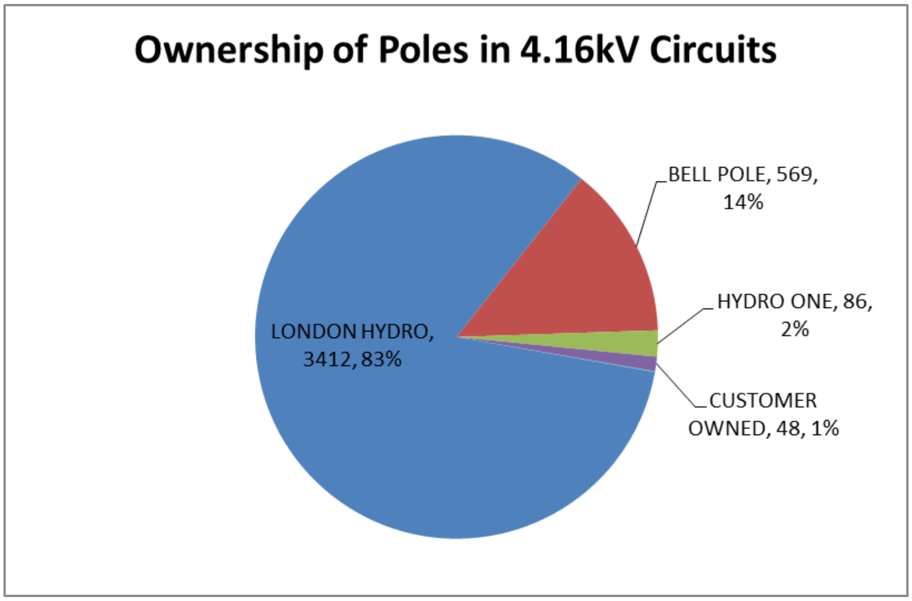


Figure 22: Ownership of Poles in the 4.16kV System (2018)

Figure 23 shows the age distribution of poles in 10 year groups with a significant population older than 30 years. Pole replacements are further filtered according to pole test data that is taken every year and re-testing done according to their remaining strength. Work is underway to develop a pole health index leveraging age, remaining strength, and criticality as an additional metric to further improve on our prioritization matrix.

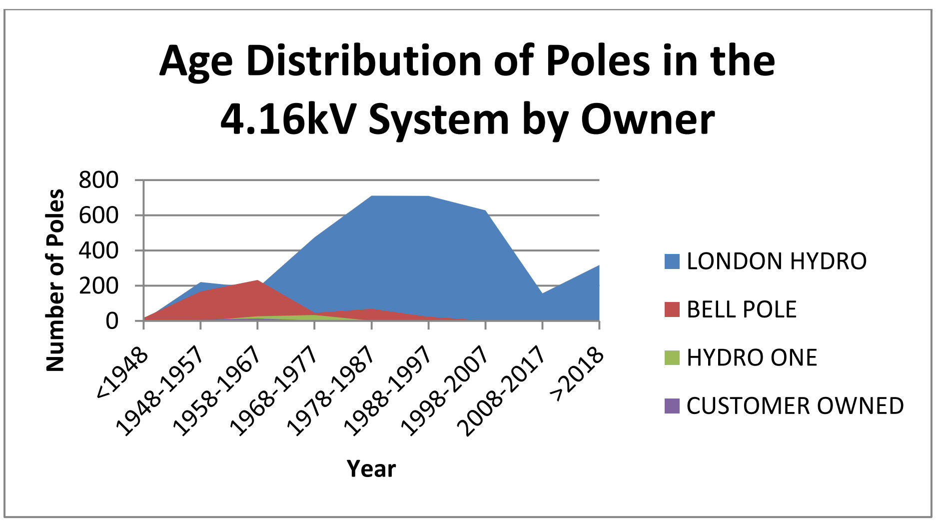


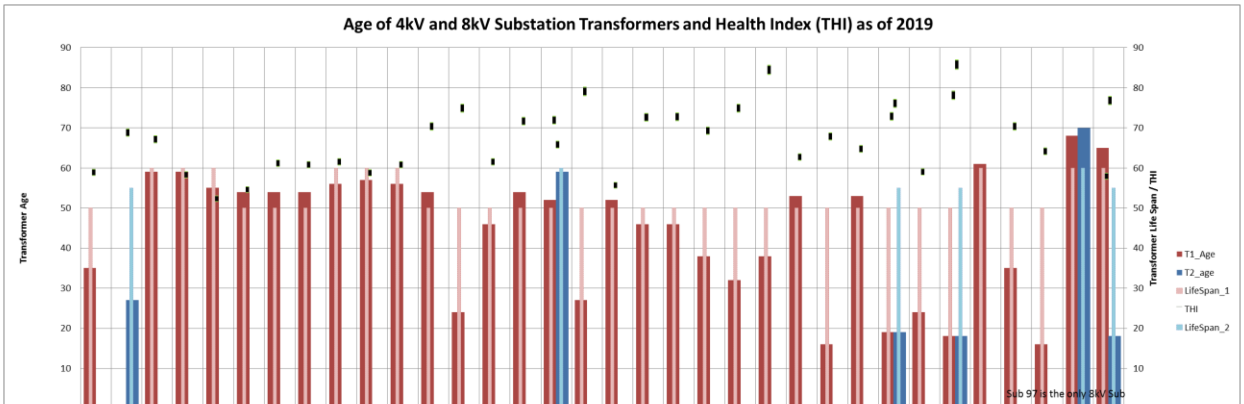
Figure 23: Age Distribution of Poles in the 4.16kV System by Owner (2018)

3.2.2 Substations

The condition of the 4.16kV Substations has been assessed according to the Transformer Health Index (THI) implemented by London Hydro based on industry knowledge[11], field staff feedback, and laboratory results of the oil samples taken every year.

The THI serves as a systematic approach to evaluate a transformer's performance. The THI ranking allows the engineering team to make factual decisions in prioritizing the conversion, replacement, and decommission of substations. The four essential analyses examined are the transformer's projected years of operations remaining, the Dissolved Gas Analysis (DGA), Oil Quality Analysis (OQA), and the quality and frequency of routine maintenance done every year. The THI has been built based on data from 2010 to 2018 (9 years).

The transformer's projected years of operations remaining is measured based on its manufactured date. If the transformer is manufactured before the year 1965, its projected lifespan is 60 years. If the transformer is manufactured at or after the year 1965, its projected lifespan is 50 years[12]. The transformer's age has shown to be a low indicator of the transformer's health when it is within the extremes of its life span. That is, it can experience infant mortality (equipment failure near its manufacturing and operation date), or it can operate within satisfactory parameters when near its theoretical life span. Therefore, combination of other variables such as, oil analysis and routine maintenance in the THI help to better determine proper operation of the transformers at any age. Figure 24 shows the Substation transformers age versus transformer health index.



Substation No.	9	15	16	17	18	21	22	23	24	25	27	29	33	35	36	37	38
T1_Age	35		59	59	55	54	54	54	56	57	56	54	24	46	54	52	27
T2_age		27														59	
LifeSpan_1	50		60	60	60	50	50	50	60	60	60	50	50	50	50	50	50
THI	59.8		68.2	59.2	53.2	55.5	62.1	61.8	62.5	59.7	61.7	71.4	76.1	62.5	72.8	73.0	80.2
THI_T2		69.9														66.9	
LifeSpan_2		55														60	

Substation No.	39	40	41	43	44	48	49	51	52	54	55	83	92	93	96	97	98
T1_Age	52	46	46	38	32	38	53	16	53	19	24	18	61	35	16	68	65
T2_age										19		18				70	18
LifeSpan_1	50	50	50	50	50	50	50	50	50	50	50	50	60	50	50	60	60
THI	56.5	73.8	73.8	70.3	76.1	85.7	63.7	68.9	65.7	74.0	59.9	79.3		71.4	65.2		58.8
THI_T2										77.2		87.0					78.0
LifeSpan_2										55		55				60	55

Figure 24: Age and Transformer Health Index of Substation Transformers (2019)

The overall process for implementing the THI is multi-level, starting from the Maintenance Department. The field staff collect transformer oil samples and send them to Morgan-Schaffer to be analyzed. Once

[11] https://www.tdworld.com/test-and-measurement/building-transformer-health-index
[12] Transformer life span as per London Hydro's 2015 Asset Sustainment Plan

the lab reports are received, the engineers analyze the quantity of dissolved gas using interpretation techniques and tools recommended in standards IEEE C57.104-2008 and IEC 60599-1999. These interpretations will be used as parameters for the DGA. In addition to the DGA, the OQA also leverages on the lab reports from Morgan-Schaffer. The laboratory tests, which adhere to the standard ASTM D1816, returns the dielectric strength of the oil. The dielectric strength represents the maximum electrical field that the oil can withstand without failure of its insulating properties. An in-depth OQA involves the following parameters: moisture in oil, power factor, interfacial tension, presence of sediments and neutralization number. All of these variables substantially contribute to the dielectric strength of the oil.

Table 11 shows the ranking of the 4.16kV Substations according to the THI. Transformers ranked as in good condition, are transformers that have shown a steady trend of their oil quality and dissolved gasses within acceptable parameters. Transformers ranked with least health condition, are transformers that require action[13].

Table 11: Transformer Health Index - 4.16kV Substation Ranking (2019)

Health Index (Rank 1: Good)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Substation	83-T2	48-T1	112-T1	38-T1	83-T1	98-T2	54-T2	107-T1	33-T1	44-T1	54-T1	41-T1	40-T1	37-T1	36-T1	29-T1	93-T1	43-T1	15-T2	51-T1
Health Index (Rank 1: Good)	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	
Substation	16-T1	37-T2	52-T1	96-T1	49-T1	24-T1	35-T1	22-T1	23-T1	27-T1	106-T1	55-T1	9-T1	25-T1	17-T1	98-T1	39-T1	21-T1	18-T1	

THI ranking cross referenced with circuit reliability statistics (from Table 10) provides a means to prioritize conversion, replacements, decommissions, as well as the frequency and quality of maintenance done for these substations. Action to be taken as a result of THI and reliability can be summarized, in general, as shown in Table 12.

Table 12: Summary Action from THI and Reliability of 4.16kV Substations and their Circuits.

THI	Reliability	Action
Good	Good	Maintain
Good	Bad	Convert/Rebuild and reclaim transformer
Bad	Good	Maintain, decommission, replace transformer with reclaimed equipment
Bad	Bad	Convert/Rebuild Circuit

The result of the THI and Reliability condition of the 4.16kV Substations and their circuits are summarized in Table 13.

[13] A detailed THI assessment report has been developed that includes recommendations to improve the operation and maintenance of the substation transformers.

Table 13: THI and Reliability Cross Referenced (2019)

Good Satisfactory Poor

Score	THI - Rank	Substation	Circuit Reliabilty
87.032	1	83-T2	D
85.731	2	48-T1	A
83.326	3	112-T1	0
80.240	4	38-T1	E
79.337	5	83-T1	D
78.039	6	98-T2	C
77.200	7	54-T2	E
77.047	8	107-T1	0
76.097	9	33-T1	D
76.067	10	44-T1	E
73.962	11	54-T1	E
73.846	12	41-T1	D
73.791	13	40-T1	D
73.017	14	37-T1	A
72.754	15	36-T1	A
71.435	16	29-T1	A
71.432	17	93-T1	D
70.289	18	43-T1	A
69.892	19	15-T2	D
68.898	20	51-T1	A
68.192	21	16-T1	B
66.877	22	37-T2	A
65.741	23	52-T1	B
65.168	24	96-T1	E
63.665	25	49-T1	C
62.478	26	24-T1	B
62.466	27	35-T1	A
62.102	28	22-T1	D
61.767	29	23-T1	E
61.738	30	27-T1	B
60.495	31	106-T1	0
59.902	32	55-T1	A
59.784	33	9-T1	E
59.714	34	25-T1	E
59.180	35	17-T1	C
58.823	36	98-T1	C
56.465	37	39-T1	C
55.450	38	21-T1	C
53.170	39	18-T1	C

While the THI and Reliability help determine tentative course of action, other factors such as infrastructure age, load, number of customers, and criticality will determine priorities that align with budgetary availability.

3.2.3 Conductors

The age of the conductors is a significant contributor to prioritize the 4.16kV conversions areas. Approximately 82% of the conductors are overhead and the remaining 18% are underground. The age of the conductors goes from sections installed the present year to conductors older than 69 years. Figure 25 and Figure 26 show the age distribution of the overhead and underground conductors. Almost 25% of overhead conductors (54km) and 50% of the underground cables (22 km) are past expected useful service life, respectively.

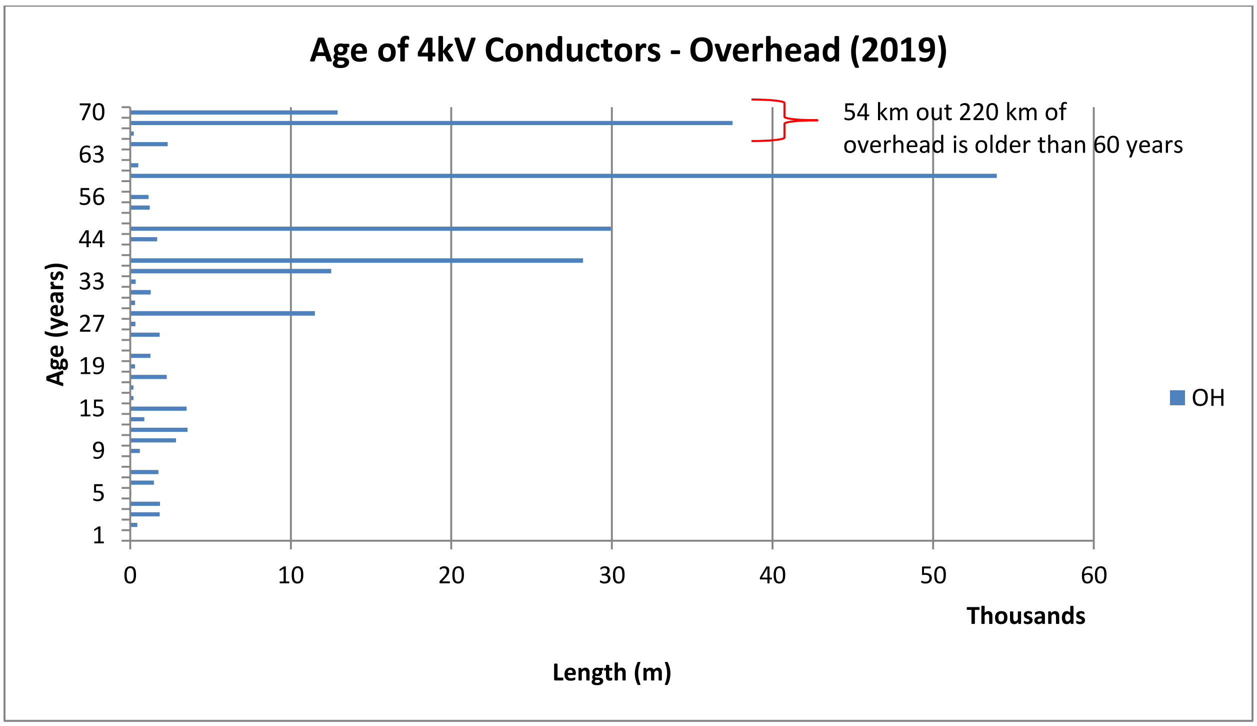


Figure 25: Age distribution of Overhead Conductors in the 4.16kV System (2019)

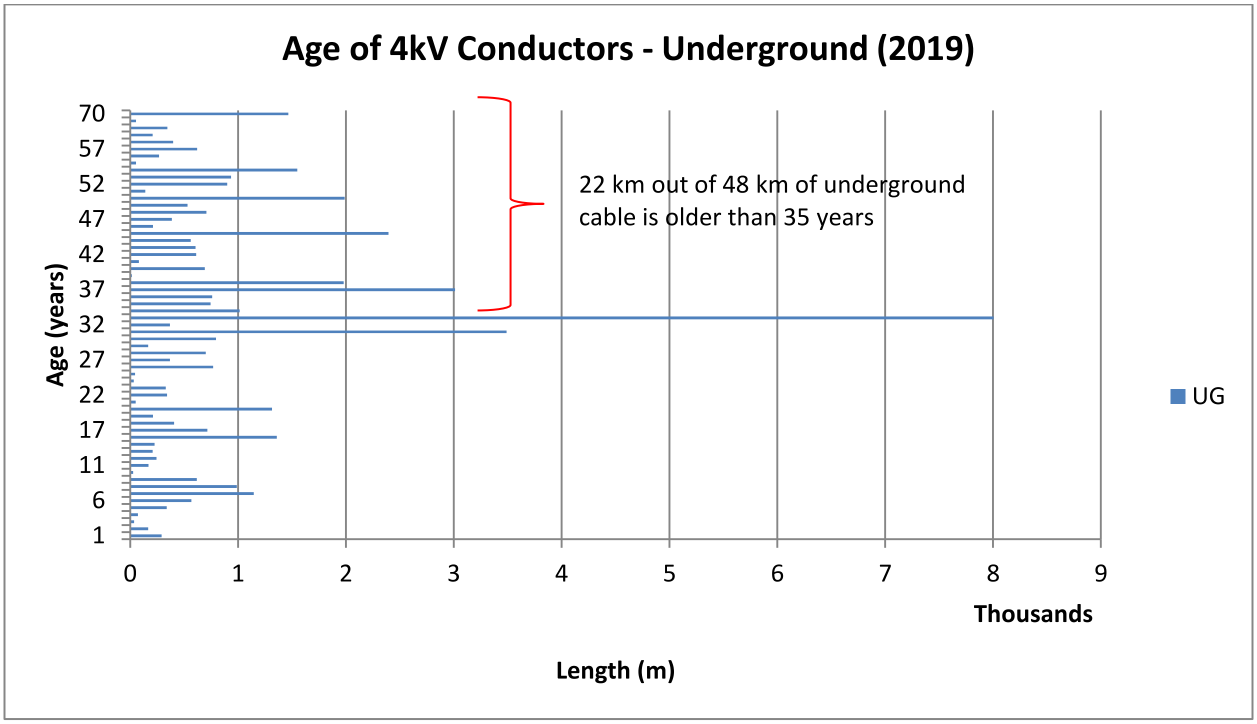


Figure 26: Age distribution of Underground Conductors in the 4.16kV System (2019)

4 10-Year Outlook for the 4.16kV Conversion / Rebuild Program

The Reliability and Asset Management data discussed in section 3 was leveraged to select priority areas to rebuild for the next 10 years. These areas include the completion of Zones B, C, and D previously identified. As well, new Zones E, F, and G have now been created as shown below in this section. The total capital investment requirement for the Zones B to G is estimated to be $31.6M.

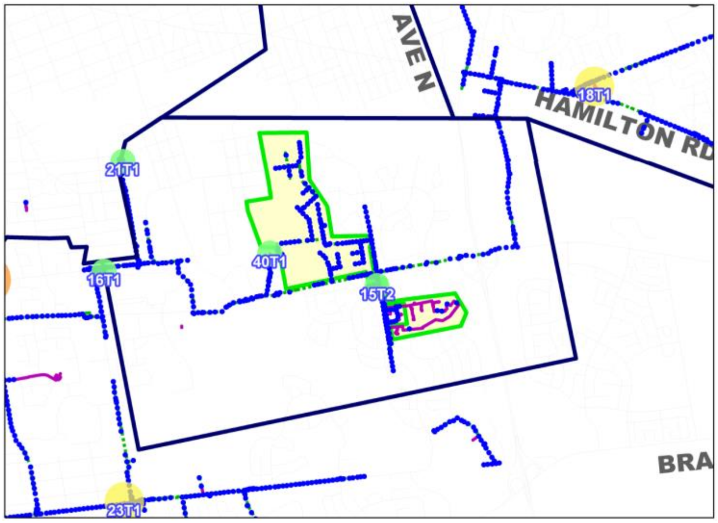
It is expected that the investment allocated towards the 4.16kV conversion/rebuild program will vary from year-to-year depending on capital availability and priorities at a given year. An investment rate of $4M per year for the next 10 years is recommended to address the conversion zones identified and catch up on the 4.16kV rebuild program. The 4.16kV system is expected to remain in-service at least for the next 20 years. Considering the age and health distribution of the substation transformers, discussed in section 3.2.2, some investment in either a station transformer or temporary overhead step-down transformers may be required in the interim.

Zone B is estimated to require $1.2M to complete the remaining rebuild. This is expected to be completed in 2020.

Zone B						Planning Estimate
XFMR		COND (km)		Poles	Customers	$1.2M
OH	UG	OH	UG			
66	5	11	1	283	780	

Figure 27: Zone B Area Map (2019)

Zone C is estimated to require $3.9M to complete the remaining rebuild in 2020.



Zone C						Planning Estimate
XFMR		COND (km)		Poles	Customers	$3.9M
OH	UG	OH	UG			
61	21	13	3	399	808	

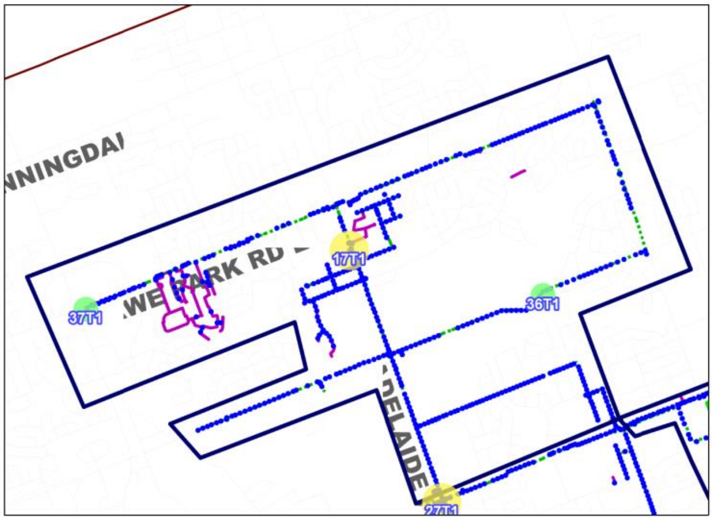
Figure 28: Zone C Area Map (2019)

Zone D is estimated to require $11.1M to rebuild. This will likely take 5 years to complete in parallel with other rebuild efforts in other zones.

Zone D						Planning Estimate
XFMR		COND (km)		Poles	Customers	$11.1M
OH	UG	OH	UG			
198	52	40	10	954	2,074	

Figure 29: Zone D Area Map (2019)

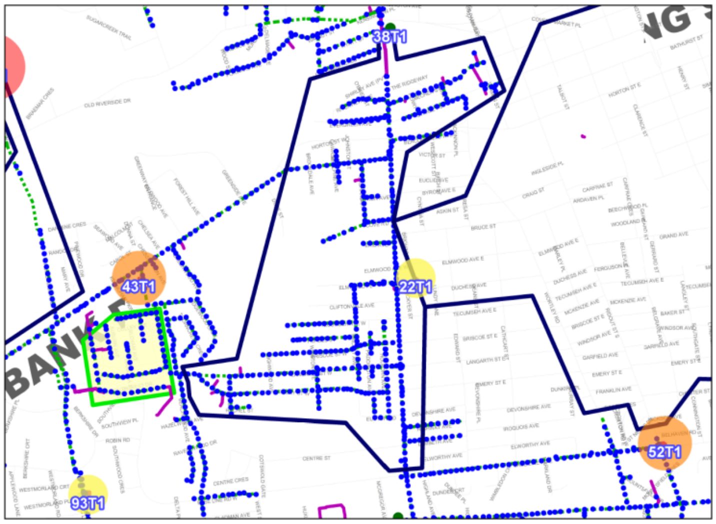
Zone E is the area supplied by Substations 17, 26, and 37. Due to the combination of upcoming City Road Works at Richmond and Fanshawe, failure of the switchgear at Substation 36, and relatively light load in the area, this zone has been selected to be prioritized. This zone is estimated to require $1.6M to rebuild and will likely take 3-4 years to complete.



Zone E						Planning Estimate
XFMR		COND (km)		Poles	Customers	$1.6M
OH	UG	OH	UG			
69	35	20	8	494	1,312	

Figure 30: Zone E Area Map (2019)

Zone F is the area supplied by Sub 22 and Sub 38 along Wharncliffe Rd between Baseline Rd and Cavendish Crescent. This area has some of the poorest reliability and old infrastructure. Zone E is estimated to require $1.2M to rebuild.



Zone F						Planning Estimate
XFMR		COND (km)		Poles	Customers	$1.2M
OH	UG	OH	UG			
107	9	13	1	416	1,829	

Figure 31: Zone F Area Map (2019)

Zone G is the area supplied by Sub 33 and Sub 83. It has large area of rear lot overhead infrastructure. This area has been estimated to require $12.6M to rebuild – the estimate assumed rear lot overhead areas will be converted to front lot underground. Due to the complexity of this area, it is expected that it could take 4-5 years to complete conversion of this zone.

Zone G						Planning Estimate
XFMR		COND (km)		Poles	Customers	$12.6M
OH	UG	OH	UG			
120	10	24	3	569	1,311	

Figure 32: Zone G Area Map (2019)

5 Conclusion

Overall, the plan outlined in the 2011 report has proceeded as indicated. At times, in lieu of work within the priority zones, upgrading and silicone injection of subdivisions with degraded underground infrastructure was necessary for reliability improvements.

Since the 2011 report, approximately $26M has been invested towards rebuilding the 4.16kV system which translates to an average investment of $3.3M per year. To convert the remaining 4.16kV assets, it is estimated that $61.5M[14] will be required. The 10-Year Outlook with new conversion zones will require an investment of $31.6M at a rate of $4M per year. This estimate considers rear lot overhead neighbourhoods being converted to front lot underground systems as in the case of this year's pilot project at Oak Park subdivision.

Within the next 20 years, it is expected that some new 4.16kV assets (e.g. step-down or substation transformers) may at times be necessary as part of maintaining the system to deal with degraded equipment that are past expected useful service life.

In this 2019 revision, a new transformer health index (THI) was developed leveraging historical data for transformer dissolved gas analysis and oil quality analysis in combination with expected remaining life of the transformer based on London Hydro's asset sustainment plan. The THI was used as an additional factor to aid in prioritizing conversion zones and the selection of new Zones E, F and G. Furthermore, there are plans underway to develop a pole health index leveraging age, remaining strength, and criticality as an additional metric to further improve on our prioritization matrix for the 4kV conversion/rebuild program.

[14] Note all estimates do not account for any environmental cleanup that may be required at substations.