Reliability Improvement of the Hydro One Distribution System using Pad-mount Transformers

by

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Abstract

Reliability in electrical engineering refers to the ability of power systems (transmission systems or distribution systems), to perform their intended function of providing an adequate supply of electrical energy to customers efficiently with a reasonable assurance of continuity and quality. Reliability studies are further classified into two categories: adequacy and security. Adequacy analysis is the examination of capabilities within the system to satisfy the customer load demand and system operational constraints. It does not include system dynamic and transient disturbances. System security follows system adequacy. Currently, the Hydro One distribution system is over-capacity in most populated regions, specifically the Mount Albert region. Further, with ageing assets and increasing anticipated future load growth, there is a need for temporary solutions to accommodate future commercial and residential load growth. The option of replacing ageing assets is not feasible due to high costs and implementation time, so alternatives must be looked at.

In this report, various alternatives including the use of pad-mount transformers to relieve distribution stations in the Mount Albert region are studied using CYME. Load flow analysis with CYMDIST is used to determine the feasibility of the alternatives. This provides solutions to accommodate future load growth in the region. This will improve the reliability of the region to reduce power quality and low voltage concerns. This will help Hydro One accommodate immediate load growth and address reliability concerns in the short term.

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Acknowledgements

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Finally, I would like to thank my family for their motivation and support throughout my MEng studies.

Glossary

CAIDI: The Consumer Average Interruption Duration Index (CAIDI) is the average interruption time per consumer affected by the interruptions per year (duration of interruptions (minutes)/number of customers affected by the interruptions/year).

CYME: The CYME power engineering software developed by EATON is a suite of applications composed of a network editor, analysis modules and user-customizable model libraries to perform systems analysis.

CYMDIST: This is the distribution system analysis package of CYME which bundles the modelling and analysis tools required to perform simulations for electric distribution system planning.

CYMTCC: This software package is used to determine time over-current protection for industrial, commercial and distribution power systems.

DG: Distributed Generation (DG) refers to the variety of electricity generating systems such as solar panels and combined heat and power which may serve a household or be a part of a microgrid.

GIS: A Geographic Information System (GIS) is a conceptualized framework that is able to capture and analyze spatial and geographic data.

LTR: The capacity of a station is determined by the Limited Time Rating (LTR) of one of the two transformers as it is assumed that one transformer is out of service leaving the remaining transformer to carry all the load.

OEB: The Ontario Energy Board (OEB) regulates provincial electricity and natural gas industries in the public interest.

PLL: The Planned Loading Limit (PLL) refers to the capacity up to which a station can be loaded without overloading the distribution system.

SAIDI: The System Average Interruption Duration Index (SAIDI) is the average time of interruptions per consumer per year (duration of interruptions/number of all customers/year).

SAIFI: The System Average Interruption Frequency Index (SAIFI) is the number of interruptions per customer per year (amount of interruptions/number of all customers/year).

Chapter 1: Introduction

1.1 Problem definition and motivation

The Hydro One distribution system is mostly radial in design with very little transfer capability of supply to customers. As a result, most component failures require immediate repair to restore service. The system consists primarily of sub-transmission feeders, distribution feeders, primary distribution feeders, pole-mount and pad-mount transformers and secondary distribution feeders [1]. Figure 1.1 provides a simplified illustration of the Hydro One distribution system.

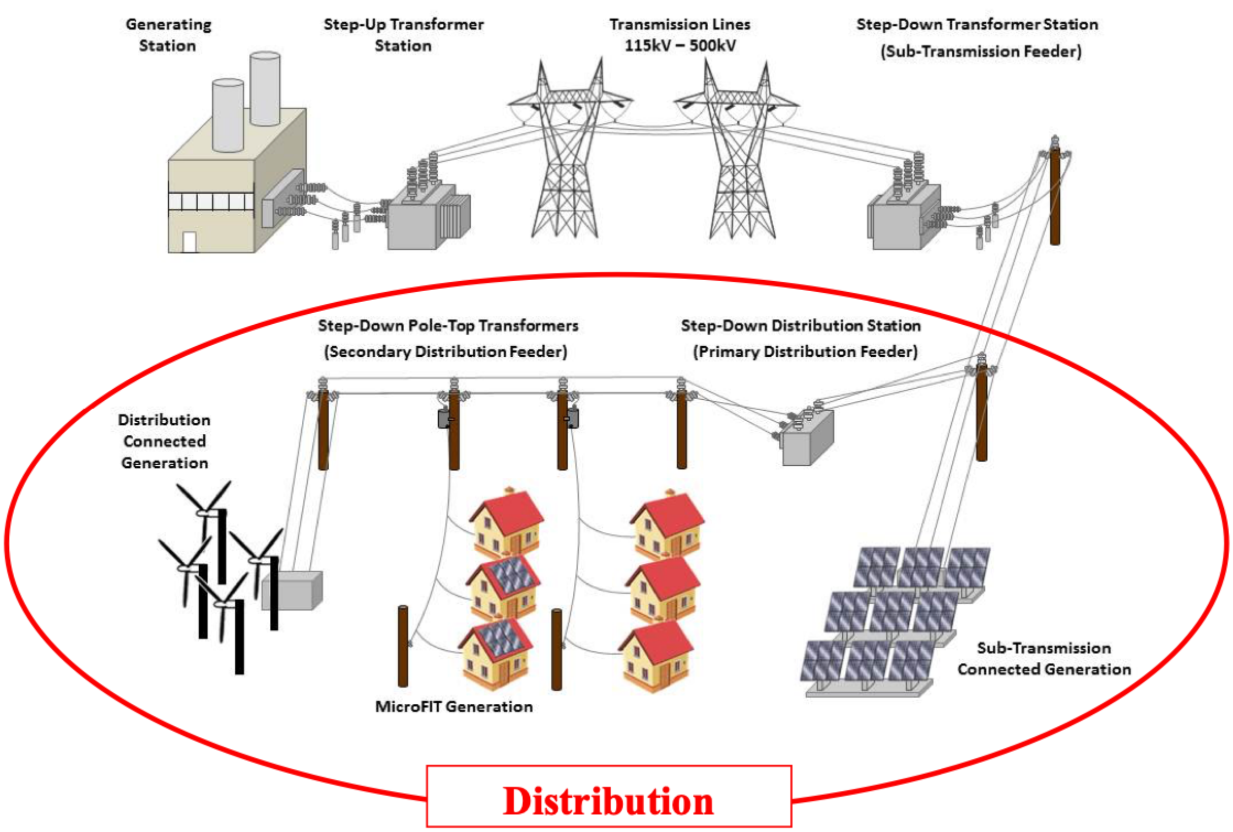


Figure 1.1: The Hydro One distribution system which is primarily comprised of feeders and transformers [1]

The sub-transmission feeders originate at transmission transformer stations and in some cases distribution stations. Typically, sub-transmission feeders supply service at 44 kV, 27.6 kV, 25 kV, 22 kV and 13.8 kV directly to end-users [1]. In some cases, regulating stations are needed to maintain voltages on sub-transmission feeders within the prescribed limits. This is because the line voltage increases or decreases depending on load variations at the distribution station supplied by the sub-transmission feeders. Distribution stations step down voltage from transmission or sub-transmission levels to primary distribution voltage for commercial, industrial and residential customers [1].

Primary distribution feeders operate from 4 kV to 13.8 kV. They are radial circuits that deliver power from distribution stations to individual customers via pole-top and pad-mount transformers. These transformers are used to step down the primary distribution voltages to the secondary voltage level used by residential and small commercial customers. Each single-phase pole-top or pad-mount transformer supplies customers at 240/120 V whereas a three-phase pole-top or pad-mounted transformer supplies a single customer at 600/347 V or 208/120 V [1]. The secondary distribution feeders connect pole-top or pad-mounted transformers to individual customers with the secondary voltage levels given previously. To date, pad-mounted transformers have not been designed to operate on 44 kV sub-transmission feeders [9].

For simplicity, distribution stations are denoted by DS, transmission stations by TS, sub-transmission level feeders as M-class feeders and distribution level feeders as F-class feeders.

With the Hydro One ageing assets and radial networks and a load forecast of around 1400 MW in the next ten years, it is impossible to accommodate commercial loads without replacing or refurbishing the existing distribution assets. Further, refurbishing or replacing these assets involves significant cost and time. With time constraints and competition from local distribution companies, it is essential to explore options which can temporarily resolve loading issues.

1.2 Mount Albert Area Study

To check the feasibility of pad-mount transformers to operate on distribution feeders and to accommodate anticipated future load growth, a study was conducted in the Mount Albert area. Mount Albert suffers from station overloading combined with voltage and power quality issues. Further, there is an anticipated load growth of 3 MVA in the next 2 years mostly due to commercial and residential customers.

Mount Albert DS has one 10 MVA station transformer and is used to supply the communities of Mount Albert and East Gwillimbury. Transformer T1 (44 kV to 8.32 kV) currently has three operational feeders, F1, F2 and F3, with the provision of an additional feeder, F4. The loading of this station is 10.44 MVA and is nearing the Peak Loading Limit (PLL) of 12.5 MVA based on 2016 Electronic Reading Ammeters (ERAs) data connected to the feeder head. ERAs give the peak loading in amperes at any instant The loading of T1 is 12.66 MVA based on recent new connections. There is a requirement for load relief or installing a transformer of higher capacity to satisfy for the additional demand as the load continues to grow.

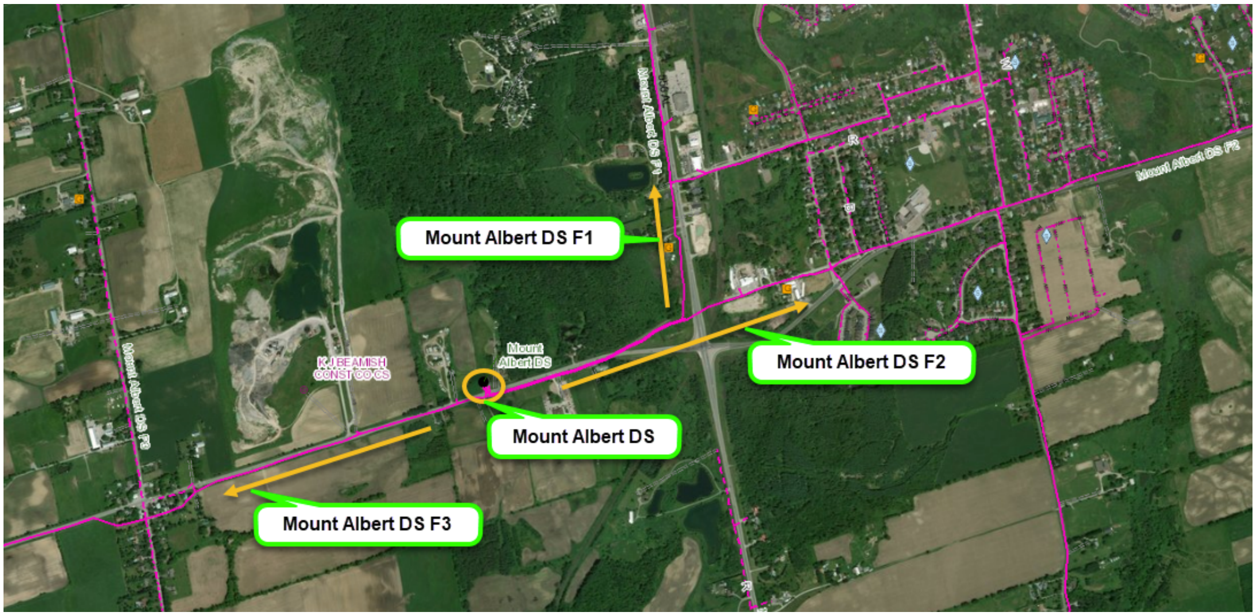


Figure 1.2: Current location of the Mount Albert DS and the three feeders.

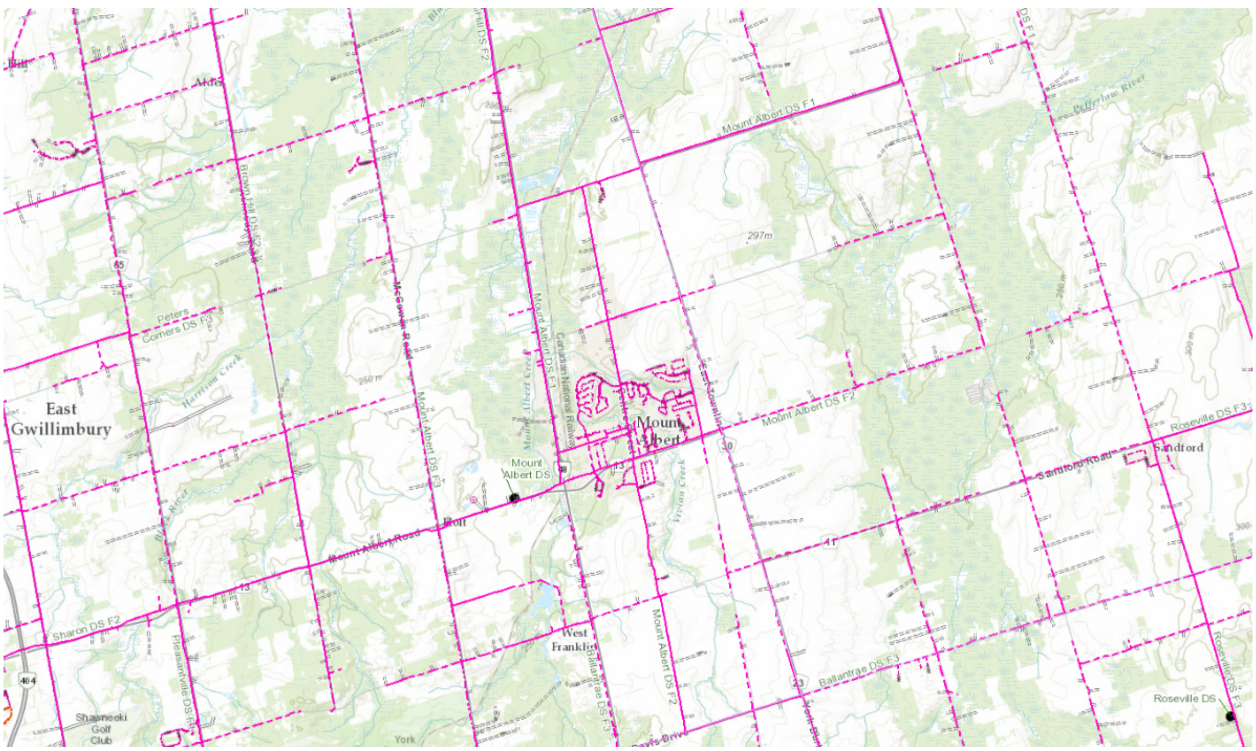


Figure 1.3: 8.32 kV supply to the Mount Albert region.

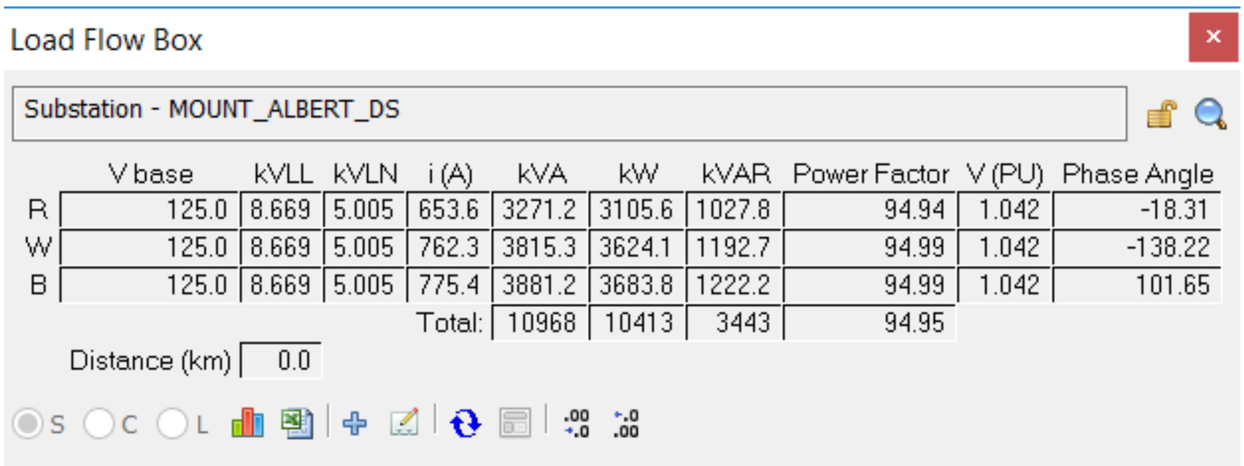
Figure 1.2 show the current location of the Mount Albert DS. The Mount Albert DS has three feeders with a 8.32 kV supply voltage, Feeder F1 to the north, Feeder F2 to the east and Feeder

F3 to the west. Figure 1.3 shows the voltage supply in the Mount Albert region. The pink lines indicate that the region is supplied by 8.32 kV distribution lines.

1.3 CYME and CYMDIST

CYME is a power engineering software package that provides analysis tools for transmission, distribution and industrial power systems. The evolution of distribution systems requires engineers to perform planning analyses and expert simulations to support operations, including protection and load assessments. CYME is used to model the whole distribution system for capacity, contingency, power quality and optimization analyses. CYMDIST is the distribution system analysis package of CYME. It bundles all the modelling and analysis tools required to perform the simulations required for electric distribution system planning. CYMDIST can be used to analyse unbalanced load flows, load allocation and estimation, faults and motor starting. The modeling capabilities of CYME include detailed representations of all portions of a distribution network. CYME for the Hydro One system includes predefined distribution networks including the sub-transmission system [5].

The analysis tool used in this project is the load flow toolbox. The steady-state performance of a power system under various operating conditions is simulated using CYMDIST for load flow analysis. It is the basic analysis tool for the planning, design and operation of an electrical power system [5]. Load allocation is done using values obtained from the load forecasting team at Hydro One. These values are used in CYMDIST. Figure 1.4 shows the results from the load flow analysis toolbox after simulating the Mount Albert DS. The toolbox shows the three phases. Red, blue and white phases are denoted by R, W and B, respectively. The base voltage in the Hydro One system is taken as 125 V. kVLL and kVLN refer to the line to line and line to neutral voltages in kV, respectively. Further, i(A) shows the current values for the three phases, and kVA, kW and kVAR indicates power. For this study, kVA will be used and is expressed in MVA where 1000 kVA equals to 1 MVA. The power factor in the Hydro One system is always maintained at 95%. The per unit (pu) voltage is considered to be 1.042 in this report to allow a margin for safety.


Load Flow Box

Substation - MOUNT_ALBERT_DS

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	653.6	3271.2	3105.6	1027.8	94.94	1.042	-18.31
W	125.0	8.669	5.005	762.3	3815.3	3624.1	1192.7	94.99	1.042	-138.22
B	125.0	8.669	5.005	775.4	3881.2	3683.8	1222.2	94.99	1.042	101.65
				Total:	10968	10413	3443	94.95		

Distance (km) 0.0

Figure 1.4: Load flow analysis toolbox results after simulating a distribution network in CYMDIST.

1.4 Report Structure

In this report, the results obtained based on the initial loading for the Mount Albert distribution station are compared with the CYME results obtained after implementing system modifications for the distribution stations involved. In Chapter 2, a statistical analysis of the CYME results is presented. The voltage and load profiles for various stations are presented to determine the current capacity limits in the Mount Albert region. Chapter 3 provides a summary of the results along with suggestions for future work.

Chapter 2: Analysis and Results

2.1 Transmission-side system check

The study area is supplied by a 230 kV transmission circuit.

Transmission line capacity

The study area is supplied by a 230 kV transmission circuit. Hydro One transmission circuits B88H, M81B, M80B and B89H supply the Brown Hill transmission station.

Transmission station capacity

Transmission Stations (TS) can be loaded to the Limited Time Rating (LTR). The capacity of a station is determined by the LTR of one of the two transformers as it is assumed that one transformer is out of service leaving the remaining transformer to carry all the load. The LTR is based on a summer 10 day continuous load rating. Operating the transformer above its LTR could cause decreased life expectancy of the asset. Over time, degradation of an asset leads to failure of the equipment and outage for Hydro One customers. To prevent this, relief is required for stations loaded above their LTR. The Mount Albert region is fed by Brown Hill TS at 230 kV/44 kV. Table 2.1 gives the peak loading for 2019 with a forecast of 0.6% for the next 10 years. It shows that the LTR varies for summer and winter seasons. Table 2.1 shows that there is adequate loading capacity for summer and winter peak loading limit seasons. The values in the Table 2.1 were obtained from the load forecasting team at Hydro One. This group is responsible for gathering data from the system.

Station	LTR (MVA)	PLL Season	Expected Load 2019 (MVA)	Expected Load 2024 (MVA)	Expected Load 2029 (MVA)	Remaining Capacity (%)
Brown Hill TS	230.1	Winter	80.1	82.8	84.6	65
Brown Hill TS	204.7	Summer	80.1	82.8	84.6	61

Table 2.1: Peak loading and remaining capacity for the Brown Hill TS.

Sub-transmission line capacities

The study area is supplied by a 44 kV sub-transmission line. The Hydro One planning guideline limit for 44 kV feeders is 25 MVA or 325 A. Loading above these limits will require relief on the feeder. Table 2.2 gives the peak loading for 2019 with a forecast of 0.6% for the next 10 years. This shows that there is adequate loading capacity for Brown Hill TS: Feeder M5. The values in the Table 2.2 are obtained from the load forecasting team of Hydro One.

Station	Feeder	Expected Load 2019 (A)	Expected Load 2024 (A)	Expected Load 2029 (A)
Brown Hill TS	M5	206.0	211.6	222.4

Table 2.2: Peak loading for the Brown Hill TS: Feeder M5 over the next 10 years.

Distributed generators

Distributed Generators (DGs) have become an important part of distribution systems in recent years. Distributed generation refers to electrical generation and storage performed by a variety of small, grid connected or distribution system connected devices referred to as Distributed Energy Resources (DERs). DER systems use renewable energy sources and play an increasingly important role in distribution systems. Distributed generation and storage enables the collection of energy from several sources and improves power supply security. As per the Hydro One planning guide, the presence of 1000 KW DGs on a distribution station may affect reliability. Table 2.3 shows the 10,000 kW DG is on the 44 kV Brown Hill TS. The 10,000 KW DG will not impact this study as it is not connected to the 8.32 kV Mount Albert DS. The values in the Table 2.3 were obtained from the load forecasting team at Hydro One.

Transmission Station	Transmission Station Feeder	Distribution Station	Distribution Station Feeder	Name Plate Capacity (kW)
Brown Hill	M5	Brown Hill	F2	320
Brown Hill	M5	Brown Hill	F2	320
Brown Hill	M5			10000
Brown Hill	M5	Mount Albert	F3	27

Table 2.3: Distributed Generators (DGs) on the Brown Hill TS and the connected distribution stations.

2.2. Distribution-side system check

Distribution station capacity

Distribution station transformers may be loaded in excess of their published nameplate loading ratings under conditions prescribed in Hydro One standards. Hydro One uses an approved methodology to establish Planned Loading Limit (PLL) ratings for transformers. PLL refers to the capacity up to which a station can be loaded without overloading the distribution system. Loading above the PLL requires relief at the earliest practical opportunity to avoid jeopardizing these valuable assets. The Mount Albert region is supplied by three distribution stations with varying capacities at 8.32 kV. Table 2.4 shows the current peak loading for the Mount Albert DS between 2016 and 2018 with a forecast of 1% over ten years. The values in this table were obtained from the load forecasting team at Hydro One.

Station	PLL (MVA)	Season	Expected Load 2016 (MVA)	Expected Load 2021 (MVA)	Expected Load 2026 (MVA)	Remaining Capacity (%)
Mount Albert DS	16	Winter	7	7.36	7.75	65
Mount Albert DS	12.5	Summer	10.1	11.04	12.14	2.8

Table 2.4: Peak loading of the Mount Albert DS over 10 years.

Distribution line capacity

Distribution feeder capacity is limited by line conductor ampacity and the voltage profile. From the Hydro One planning guide, the limits are 200 A and a feeder voltage of 94% to 106%.

Parameters that exceed these limits requires consideration of several aspects of line construction and operation as this will result in protection and power quality concerns. The Mount Albert region is supplied by three feeders from the Mount Albert DS with varying ampacities at 8.32 kV. Table 2.5 gives the highest three-phase peak current for the Mount Albert DS feeders found between 2016-2018 with a forecast of 1% for ten years along with the per unit (pu) feeder end voltage. The pu value is defined as the ratio of actual voltage to base or reference voltage. This data is not in-line with recent developments as there are a large number of commercial loads to be connected in future as per recent Hydro One agreements.

The values in Table 2.5 do not include the recent and anticipated future developments, so new data was obtained from ERAs connected to the feeder head. These values were used for model simulation in CYMDIST. Table 2.6 gives the ERA values for the Mount Albert DS in 2020. This shows a significant variation in the ERA values from the estimated load values in Table 2.5 which were obtained from the load forecasting team.

Station	Feeder	Estimated Load 2016 (A)	Feeder End Voltage (pu)	Estimated Load 2021 (A)	Feeder End Voltage (pu)	Estimated Load 2026 (A)	Feeder End Voltage (pu)
Mount Albert DS	F1	171	0.93	175	0.93	180	0.93
Mount Albert DS	F2	6	1.04	6	1.04	7	1.04
Mount Albert DS	F3	70	0.94	72	0.94	74	0.94

Table 2.5: Peak loading of Mount Albert DS Feeders F1, F2 and F3 over 10 years.

Mount Albert DS Loading (ERA)				
Year	**Feeder**	**Red (A)**	**White (A)**	**Blue (A)**
2020	F1	249	313	283
2020	F2	350	357	303
2020	F3	53	92	186

Table 2.6: Current loading values for the Mount Albert DS feeders.

2.3. Sustainment profile

Distribution stations

As distribution stations reach end-of-life, they need to be refurbished, upgraded or replaced. There are cost savings benefit in forecasting future needs of stations and requesting additional capacity during station upgrades. There were no stations due for refurbishment during the period of this study.

Transformer condition

Transformers are an important asset and must be kept in good working condition. A transformer needs to go through multiple tests to determine whether there are heating, moisture or insulation issues. The tests performed on a transformer are: Dissolved Gas Analysis Test (DGA), Standard Oil Test (SOT) and Furan test. DGA is an inspection of electrical transformer oil contaminants. Insulating materials within electrical equipment generate gases as they slowly break down over time. The composition and distribution of these dissolved gases are indicators of the effects of deterioration. SOT consists of measuring the breakdown voltage and physical and chemical properties of the transformer oil, which tends to deteriorate over time. The furan test shows the condition of the transformer paper insulation. Over time, the cellulose insulating material experiences degradation producing an aromatic compound called Furan. Furan determines the expected degree of polymerization for the paper in the equipment. This is an estimate of the percentage of solid insulation life remaining inside the transformer. Test results range from one to four with four being the worst. Transformers have a life expectancy of approximately fifty years, after which problems may arise [10]. Table 2.7 gives the age and condition of the transformers at the three distribution stations. All three distribution stations have transformers which are less than 30 years old. Further, the test report shows that the DGA, SOT and Furan values are less than four and hence within acceptable limits. The values in Table 2.7 were obtained from the load forecasting team at Hydro One.

Station	Phase	DGA	SOT	Furan	Built	Tested
Mount Albert DS	3-phase	3	3	1	1990	2019
Sharon DS	3-phase	3	3	1	1991	2019
Brown Hill DS	3-phase	3	3	1	1990	2019

Table 2.7: Transformer condition report for the three distribution stations.

Wood poles

Wood poles need to be replaced as they become sub-standard near end-of-life. Figure 2.1 shows the report on the wooden poles in the area. The poles are indicated in 4 colours. Red indicates immediate replacement is required whereas green indicates that the poles are in good condition. Grey and blue indicate that there are issues with the wooden poles but they do not require immediate replacement. Figure 2.1 shows the condition of the wooden poles in the Mount Albert region. All notifications are green indicating good condition so no poles need to be replaced. Note that the red dots in Figure 2.1 correspond to reclosers and fuses which are in poor condition.

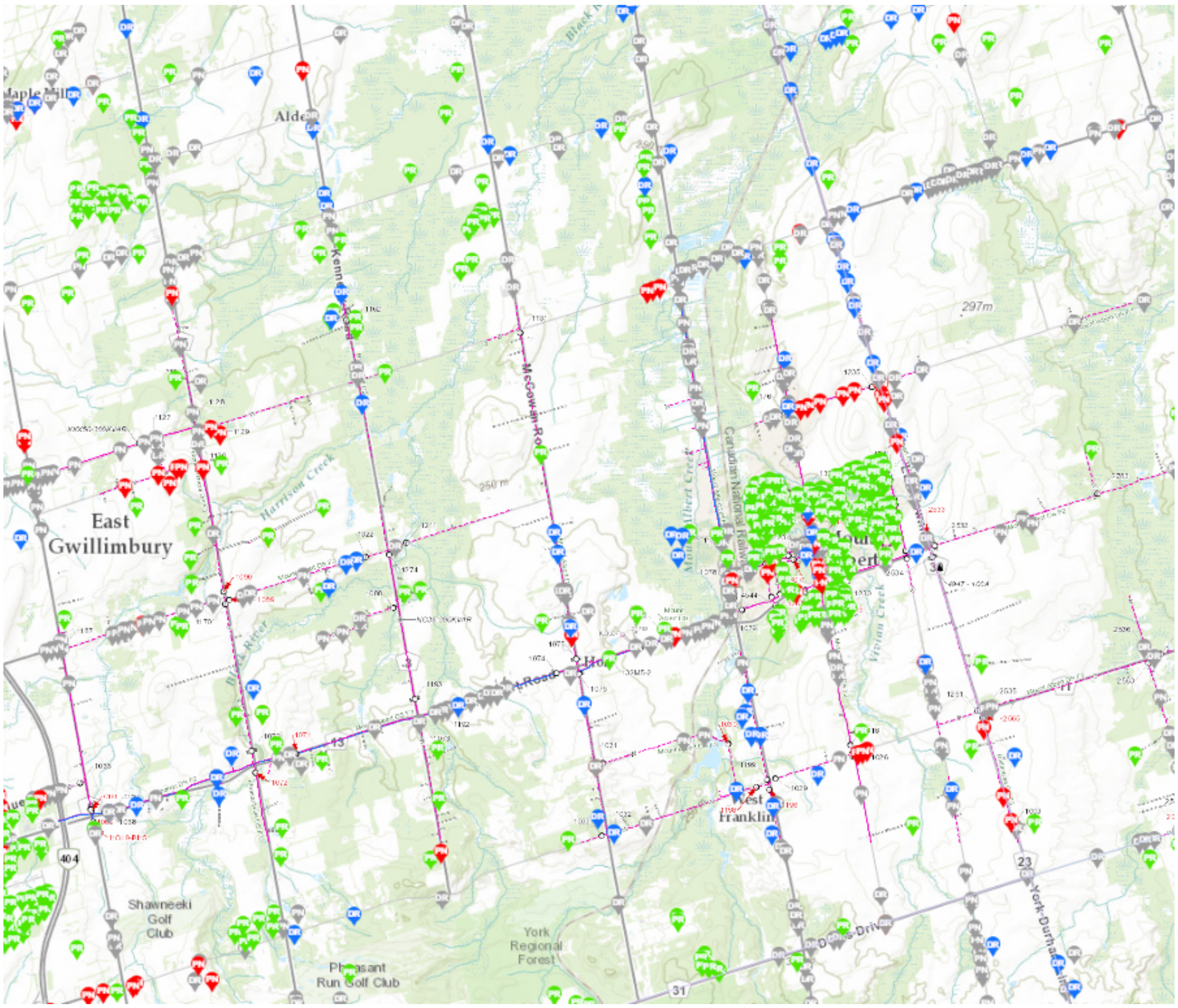


Figure 2.1: The condition of the wood poles in the Mount Albert region.

Vegetation Management

The intent of the distribution forestry program is to complete the required line clearing and bush control as quickly and efficiently as possible in order to reduce future work. The vegetation clearing cycle is 6 to 8 years. Vegetation management is essential to system reliability. There are no current reliability issues due to vegetation, so clearing should continue on planned cycles. Table 2.8 shows the last line clearing year for the station feeders in the Mount Albert region. The last clearing was conducted in 2019 for all feeders, there are no forestry issues for the feeders in this study. The values in Table 2.8 were obtained from the sustainment team at Hydro One.

Station Feeder	Last Line Clearing Year
Brown Hill TS M5	2019
Mount Albert DS F1	2019
Mount Albert DS F2	2019
Mount Albert DS F3	2019
Sharon DS F1	2019
Sharon DS F2	2019
Sharon DS F3	2019
Brown Hill DS F1	2019
Brown Hill DS F2	2019
Brown Hill DS F3	2019

Table 2.8: Last line clearing year for the station feeders.

2.4. Reliability

Reports to the Ontario Energy Board (OEB) require the following reliability metrics: System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI) and Customer Average Interruption Duration Index (CAIDI). Tables 2.9 and 2.10 show the SAIDI, SAIFI and CAIDI numbers for the Brown Hill TS and Mount Albert region feeders for the years 2018-2020. The concern is raised when the feeder is in the top 100 worst feeders. An index of 0 means there have been no outages on the feeder. Table 2.9 shows that Brown Hill TS M12 ranks 90 in the SAIFI list of the 100 worst feeders. Thus, attention is required to improve the reliability of this feeder. Table 2.10 shows that Sharon DS F3 has a CAIDI ranking of 40, so it is one of the top 100 worst feeders. The values in Tables 2.9 and 2.10 were obtained from the load forecasting team at Hydro One.

Feeder	SAIDI		SAIFI		CAIDI	
	SAIDI	Rank	SAIFI	Rank	CAIDI	Rank
Brown Hill TS M12	0.0183	193	0.0058	90	1.6578	2439
Brown Hill TS M1	0.0000	2769	0.0000	2872	11.5400	166
Brown Hill TS M3	0.0000	2593	0.0005	1044	0.0278	2875
Brown Hill TS M5	0.0000	9999	0.0000	9999	0.0000	9999
Brown Hill TS M6	0.0000	9999	0.0000	9999	0.0000	9999
Brown Hill TS M2	0.0062	607	0.0012	595	1.7663	2389
Brown Hill TS M11	0.0035	907	0.0038	181	0.5847	2775
Brown Hill TS M4	0.0001	2439	0.0013	558	0.0317	2872

Table 2.9: Reliability for the Brown Hill TS feeders.

Feeder	SAIDI		SAIFI		CAIDI	
	SAIDI	Rank	SAIFI	Rank	CAIDI	Rank
Mount Albert DS F1	0.0016	1370	0.0005	1041	5.4517	954
Mount Albert DS F2	0.0096	410	0.0011	609	8.8457	387
Mount Albert DS F3	0.0029	1037	0.0006	944	5.0536	1053
Sharon DS F1	0.0001	2413	0.0001	2237	3.4202	1603
Sharon DS F2	0.0011	1564	0.0001	1934	6.2296	774
Sharon DS F3	0.0000	2736	0.0000	2843	16.6562	40
Brown Hill DS F1	0.0057	653	0.0004	1170	8.1318	467
Brown Hill DS F2	0.0088	442	0.0008	814	8.6759	403
Brown Hill DS F3	0.0122	319	0.0010	677	10.1238	265

Table 2.10: Reliability for the distribution stations in the Mount Albert region.

2.5 Initial station conditions

Installing two pad-mount transformers is a viable option as the transformers (each 3 MVA), would be able to support the future load growth in the Mount Albert region. Figure 2.2 shows the proposed location of the pad-mount transformers. The future commercial and residential developments are shown in yellow and green, respectively. The new pad-mount transformers will be placed to the north of the future commercial developments indicated in yellow. Figure 2.2 gives the location of the Mount of Albert DS and the 8.32 kV supply to the region indicated by pink lines. Feeder F1 is along the future commercial development area and stretches further north, Feeder F2 is along the future residential development area and extends to the east while Feeder F3 extends to the west from the Mount Albert DS.

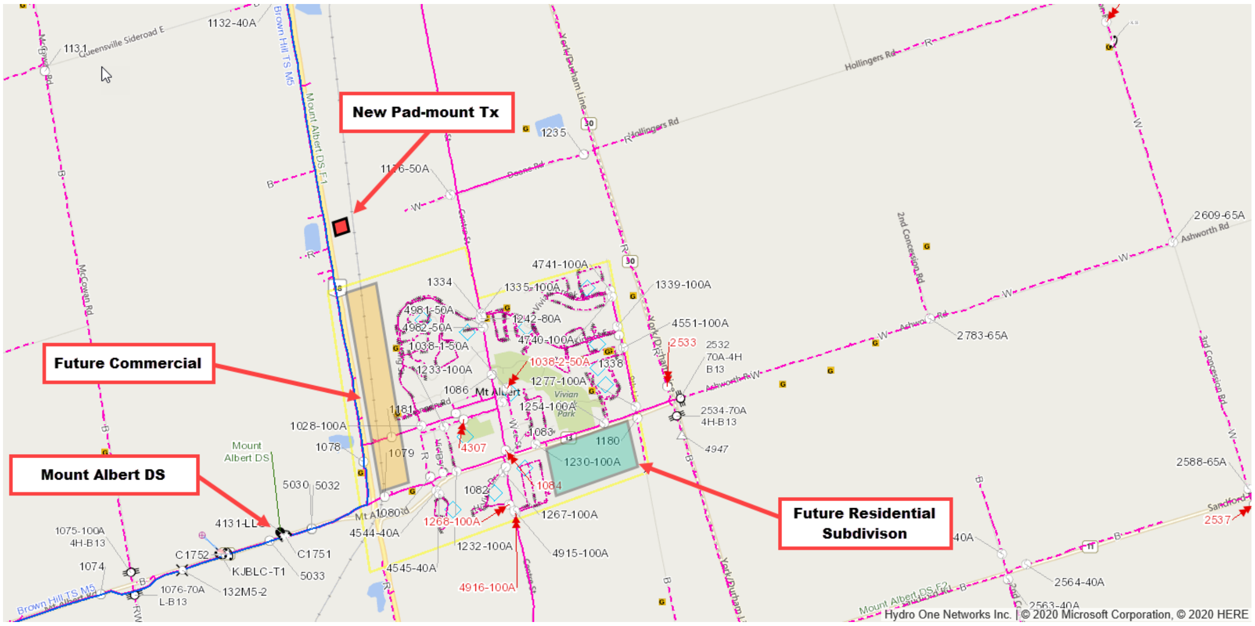
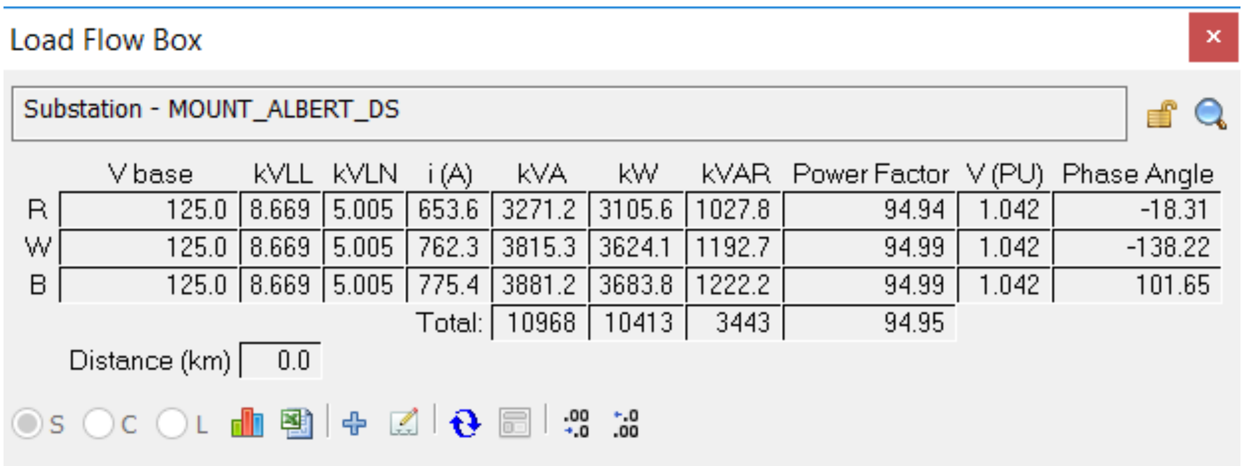


Figure 2.2: Proposed location of pad-mount transformers in the Mount Albert region.

Figure 2.3 gives the voltage and load profiles of the Mount Albert DS after simulation in CYME. The current loading of this station is 10.968 MVA. Table 2.4 shows that the PLL of Mount Albert DS is 12.5 MVA. Figure 2.3 shows that this station is near capacity and can only accommodate an additional 1.532 MVA. Hence, there is need of temporary relief to accommodate future load growth. Further, the three current phases for the Mount Albert DS are imbalanced as shown in Figure 2.3. The installation of pad-mount transformers and load transfer can balance the three phase currents. Figures 2.4, 2.5 and 2.6 show that the loading of Feeder F1 is 4.246 MVA, Feeder F2 is 5.058 MVA and Feeder F3 is 1.663 MVA, respectively. Further, Feeder F1 is approaching its ampacity limit, so it cannot accommodate any additional load. To understand the voltage profile of the region, it is essential to also know the end-of-line voltages. This will ensure there are no voltage regulation or power quality issues. As per the Hydro One planning guideline, a base voltage below 114 V indicates a low voltage. Figure 2.8 shows that the single phase end-of-line voltage for Feeder F1 is below 114 V, indicating that there may be more power quality issues in case of an additional load on Feeder F1. Figure 2.9 shows that the red phase (three phase), end-of-line voltage is 110.3 V and Figure 2.10 shows that the white phase (single phase), end-of-line voltage is 107.7 V. This is below the base voltage of 114 V, indicating low voltage issues. An additional load on these phases will give rise to power quality issues. Figures 2.11 and 2.12 show that the end of line voltages for Feeder F3 are above 114 V.


Load Flow Box

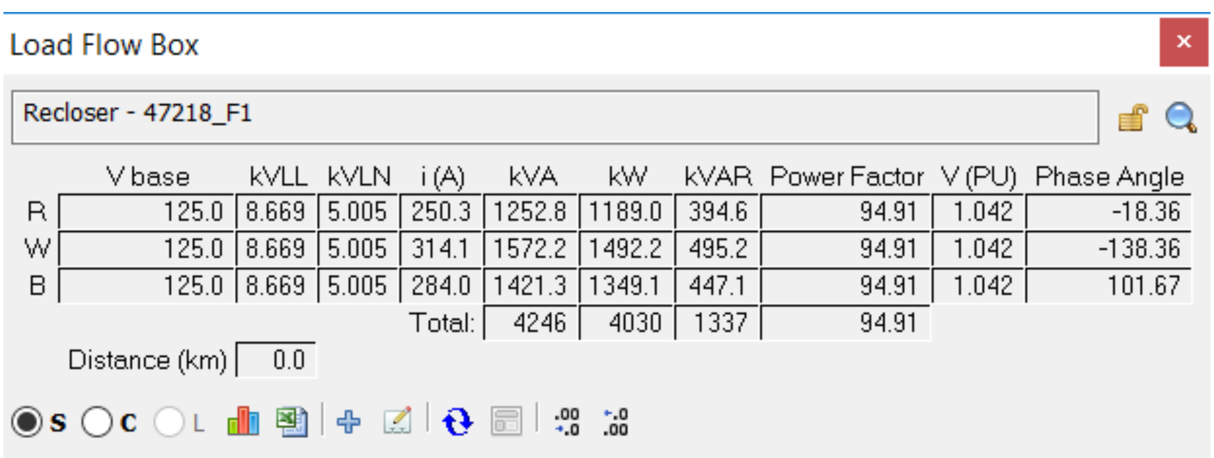
Substation - MOUNT_ALBERT_DS

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	653.6	3271.2	3105.6	1027.8	94.94	1.042	-18.31
W	125.0	8.669	5.005	762.3	3815.3	3624.1	1192.7	94.99	1.042	-138.22
B	125.0	8.669	5.005	775.4	3881.2	3683.8	1222.2	94.99	1.042	101.65
				Total:	10968	10413	3443	94.95		

Distance (km) 0.0

S C L

Figure 2.3: CYME results showing the voltage and load profile for Mount Albert DS.


Load Flow Box

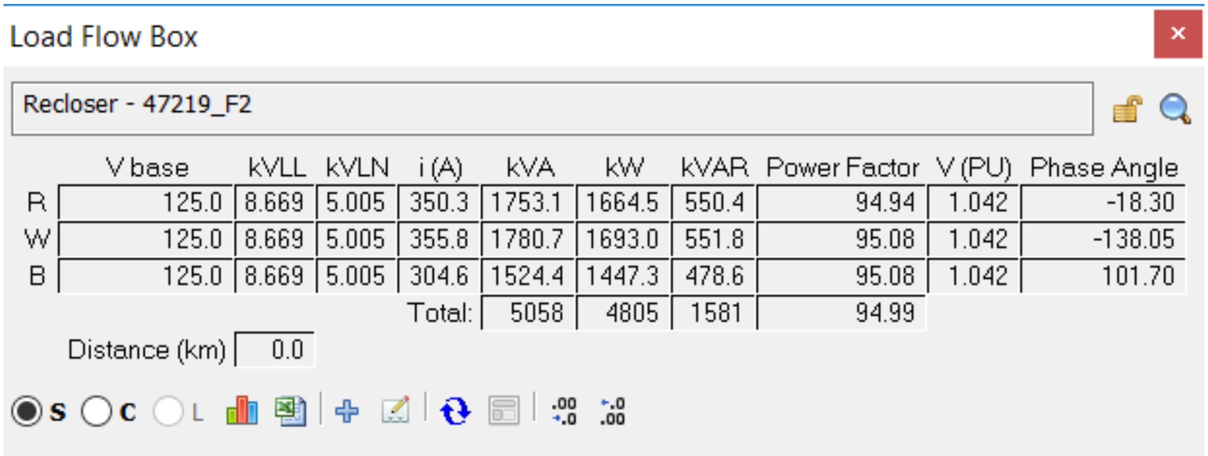
Recloser - 47218_F1

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	250.3	1252.8	1189.0	394.6	94.91	1.042	-18.36
W	125.0	8.669	5.005	314.1	1572.2	1492.2	495.2	94.91	1.042	-138.36
B	125.0	8.669	5.005	284.0	1421.3	1349.1	447.1	94.91	1.042	101.67
				Total:	4246	4030	1337	94.91		

Distance (km) 0.0

S C L

Figure 2.4: CYME results showing the voltage and load profiles for Mount Albert DS: Feeder F1.



Load Flow Box

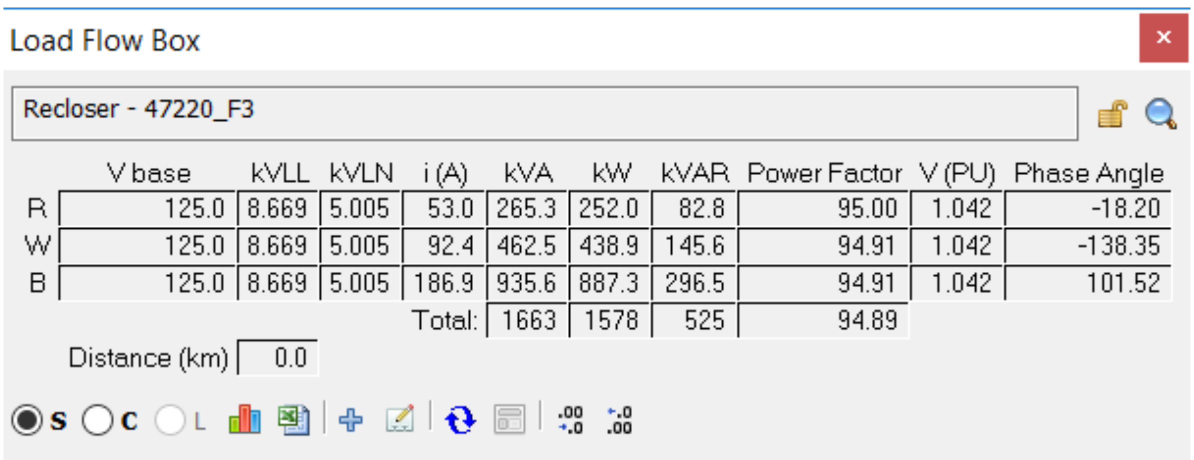
Recloser - 47219_F2

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	350.3	1753.1	1664.5	550.4	94.94	1.042	-18.30
W	125.0	8.669	5.005	355.8	1780.7	1693.0	551.8	95.08	1.042	-138.05
B	125.0	8.669	5.005	304.6	1524.4	1447.3	478.6	95.08	1.042	101.70
				Total:	5058	4805	1581	94.99		

Distance (km) 0.0

S C L

Figure 2.5: CYME results showing the voltage and load profiles for Mount Albert DS: Feeder F2.



Load Flow Box

Recloser - 47220_F3

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	53.0	265.3	252.0	82.8	95.00	1.042	-18.20
W	125.0	8.669	5.005	92.4	462.5	438.9	145.6	94.91	1.042	-138.35
B	125.0	8.669	5.005	186.9	935.6	887.3	296.5	94.91	1.042	101.52
				Total:	1663	1578	525	94.89		

Distance (km) 0.0

S C L

Figure 2.6: CYME results showing the voltage and load profiles for Mount Albert DS: Feeder F3.

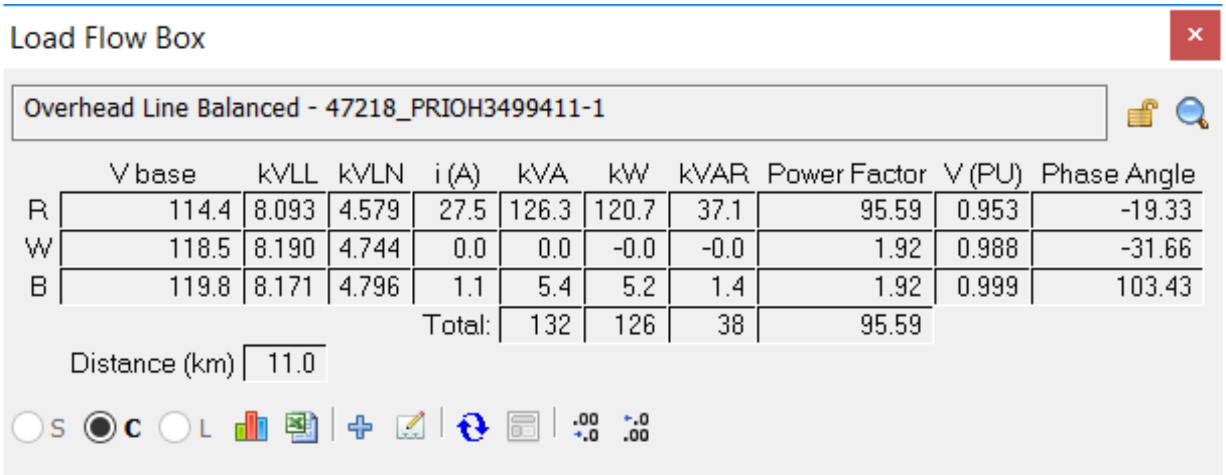


Figure 2.7: CYME results for the 3-phase end-of-line voltage for Mount Albert DS: Feeder F1.

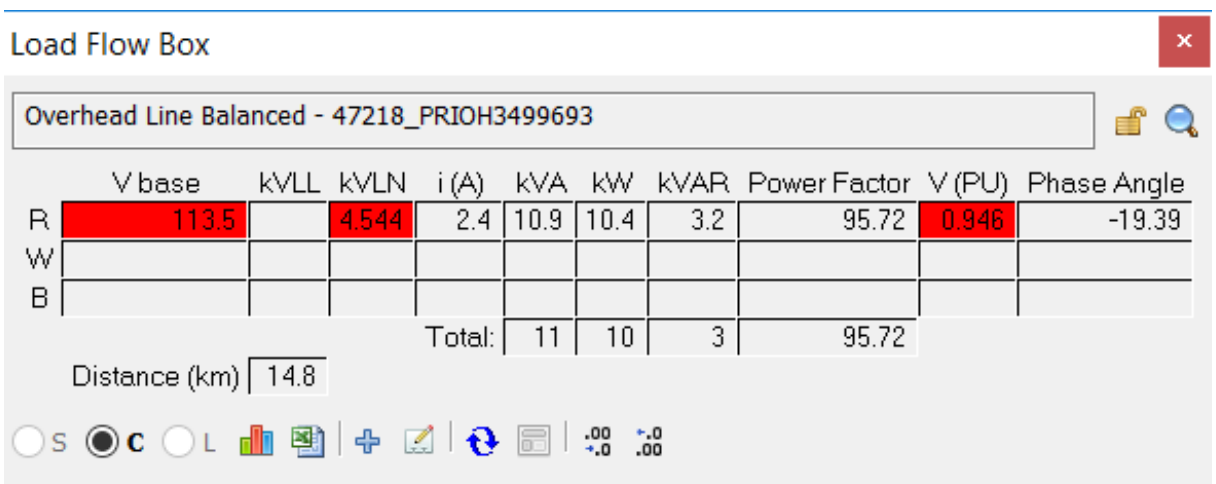


Figure 2.8: CYME results for the 1-phase end-of-line voltage for Mount Albert DS: Feeder F1.

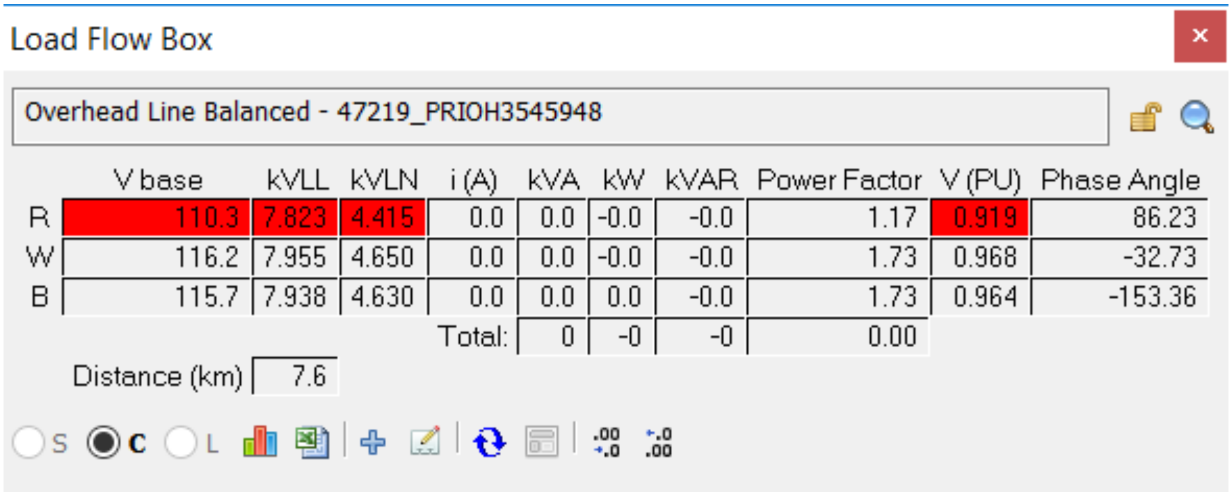


Figure 2.9: CYME results for the 3-phase end-of-line voltage for Mount Albert DS: Feeder F2.

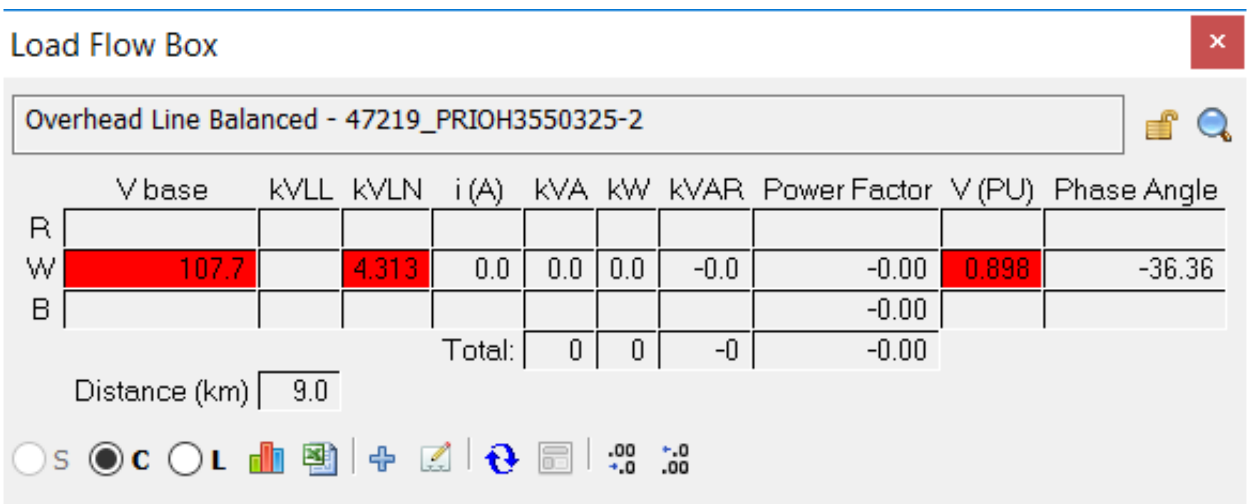
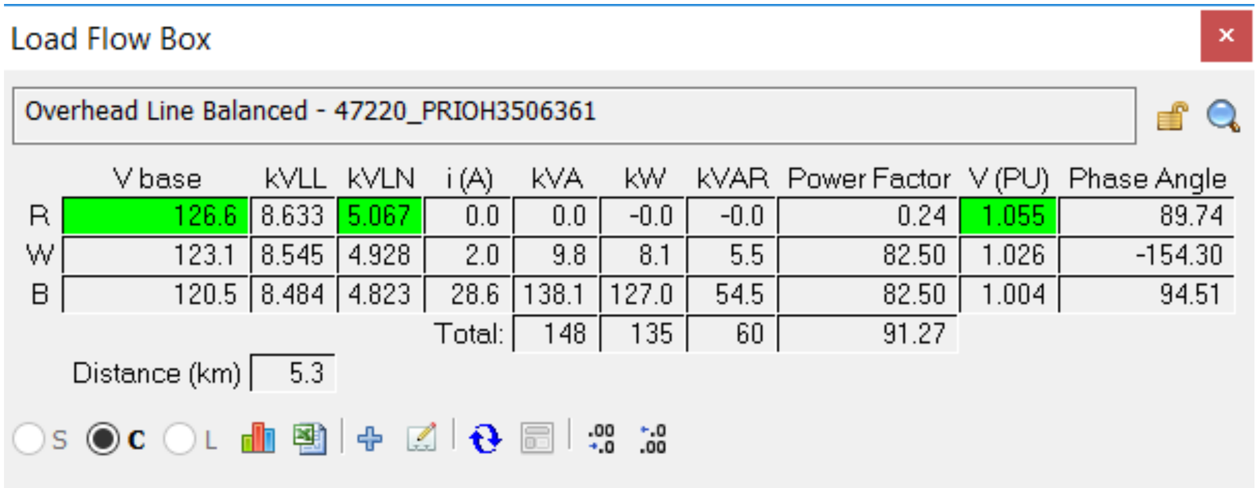


Figure 2.10: CYME results for the 1-phase end-of-line voltage for Mount Albert DS: Feeder F2.



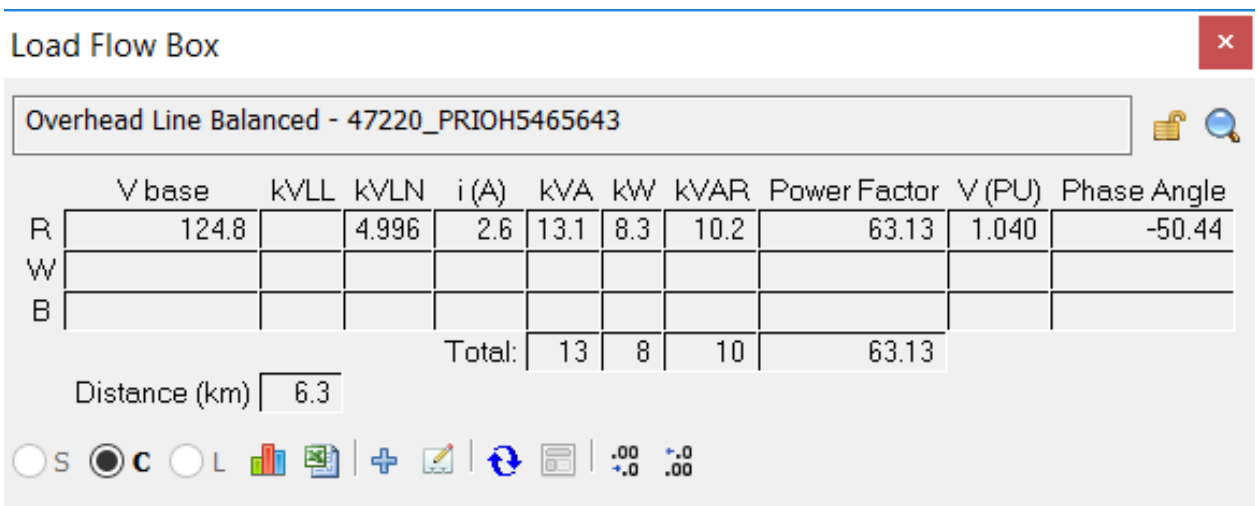
Load Flow Box

Overhead Line Balanced - 47220_PRIOH3506361

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	126.6	8.633	5.067	0.0	0.0	-0.0	-0.0	0.24	1.055	89.74
W	123.1	8.545	4.928	2.0	9.8	8.1	5.5	82.50	1.026	-154.30
B	120.5	8.484	4.823	28.6	138.1	127.0	54.5	82.50	1.004	94.51
				Total:	148	135	60	91.27		

Distance (km) 5.3

Figure 2.11: CYME results for the 3-phase end-of-line voltage for Mount Albert DS: Feeder F3.



Load Flow Box

Overhead Line Balanced - 47220_PRIOH5465643

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	124.8		4.996	2.6	13.1	8.3	10.2	63.13	1.040	-50.44
W										
B										
				Total:	13	8	10	63.13		

Distance (km) 6.3

Figure 2.12: CYME results for the 1-phase end-of-line voltage for Mount Albert DS: Feeder F3.

Figures 2.13, 2.14 and 2.15 show the voltage levels for the Feeders F1, F2 and F3 after simulation in CYMDIST. The protection devices such as fuses and reclosers are represented by blue and yellow circles, respectively. The voltage levels are defined by 4 colours. Red indicates a voltage below 114 V while green shows a voltage above 125 V. Further, orange indicates a voltage level between 114 V and 120 V while yellow indicates a voltage level between 120 V and 125 V. Figure 2.13 shows that the voltage for Feeder F1 is primarily between 114 V to 120 V. Hence, there are no power quality issues associated with this feeder. Figure 2.14 shows that the voltage for Feeder F2 varies. The voltage for a large section of Feeder F2 is between 114 V and 120 V while a small section has a voltage above 125 V. Figure 2.15 shows that the voltage for Feeder F3 is mostly between 114 V and 120 V, but a small section is below 114 V. This problem can be solved without using a pad-mount transformer. Feeder F1 has a few sections experiencing low voltage which is not reflected in Figure 2.13 as the CYME workspace shows the feeder at a macroscopic level.

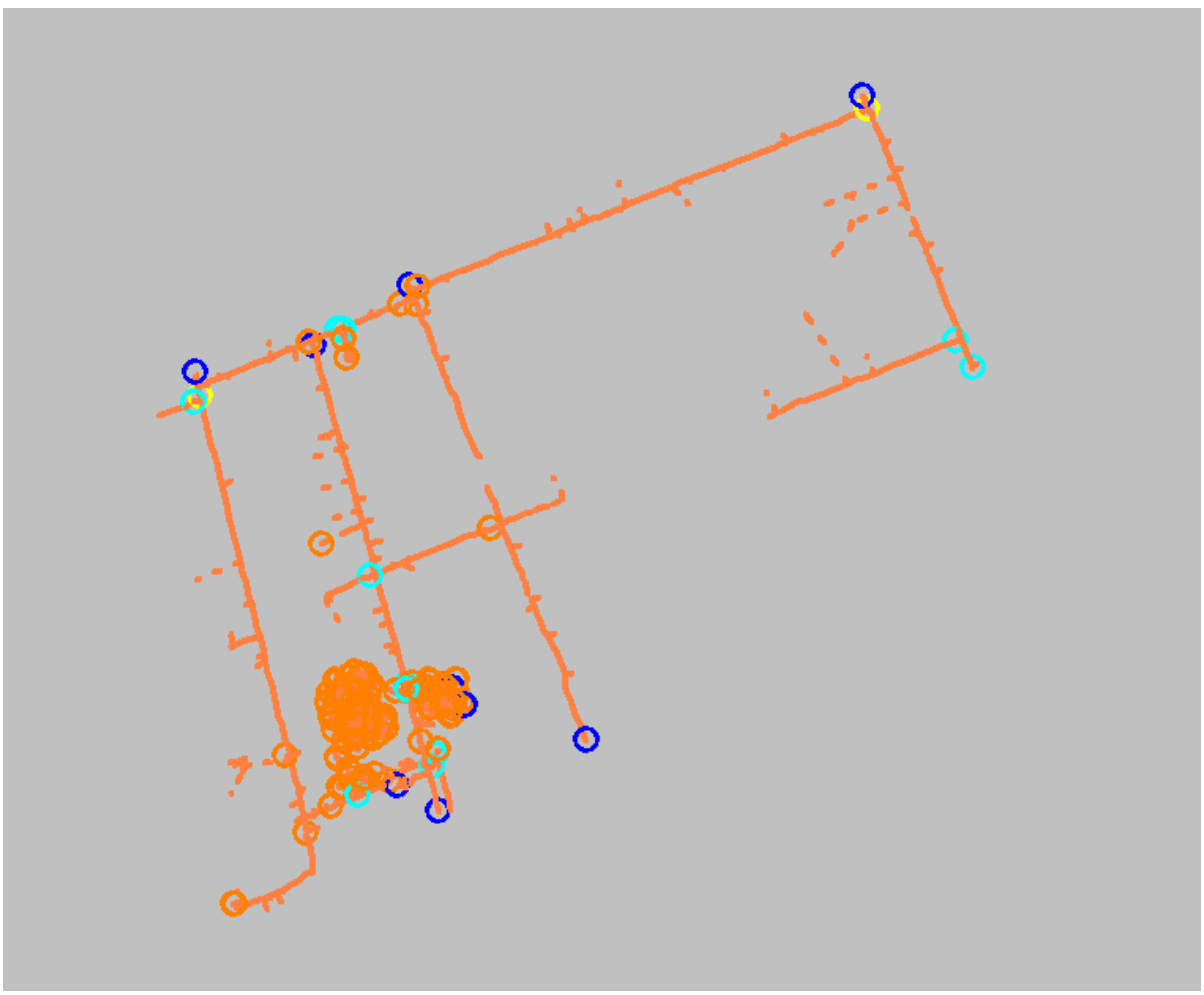


Figure 2.13: CYME results showing the voltage levels for Mount Albert DS: Feeder F1.

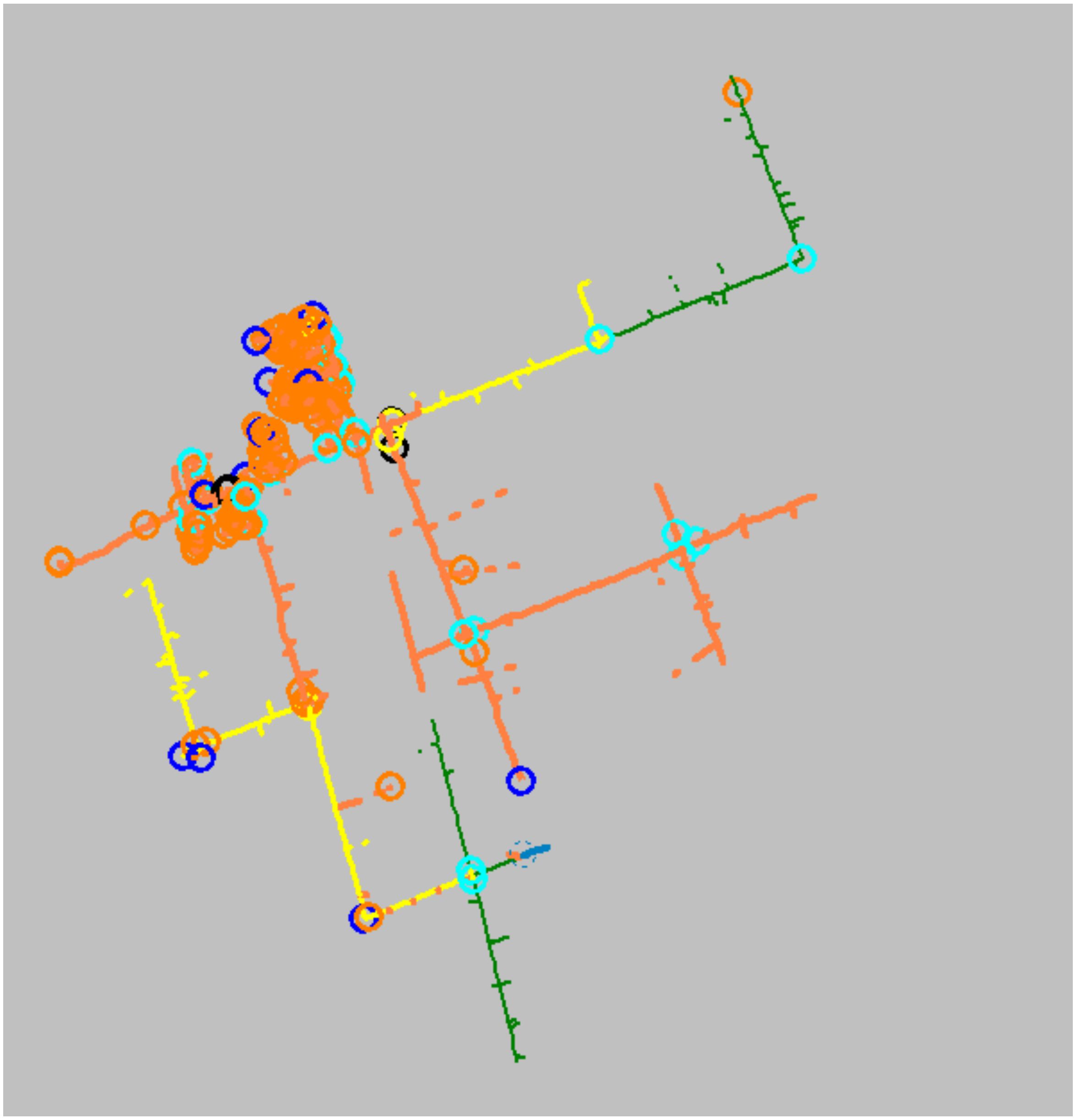


Figure 2.14: CYME results showing the voltage levels for Mount Albert DS: Feeder F2.

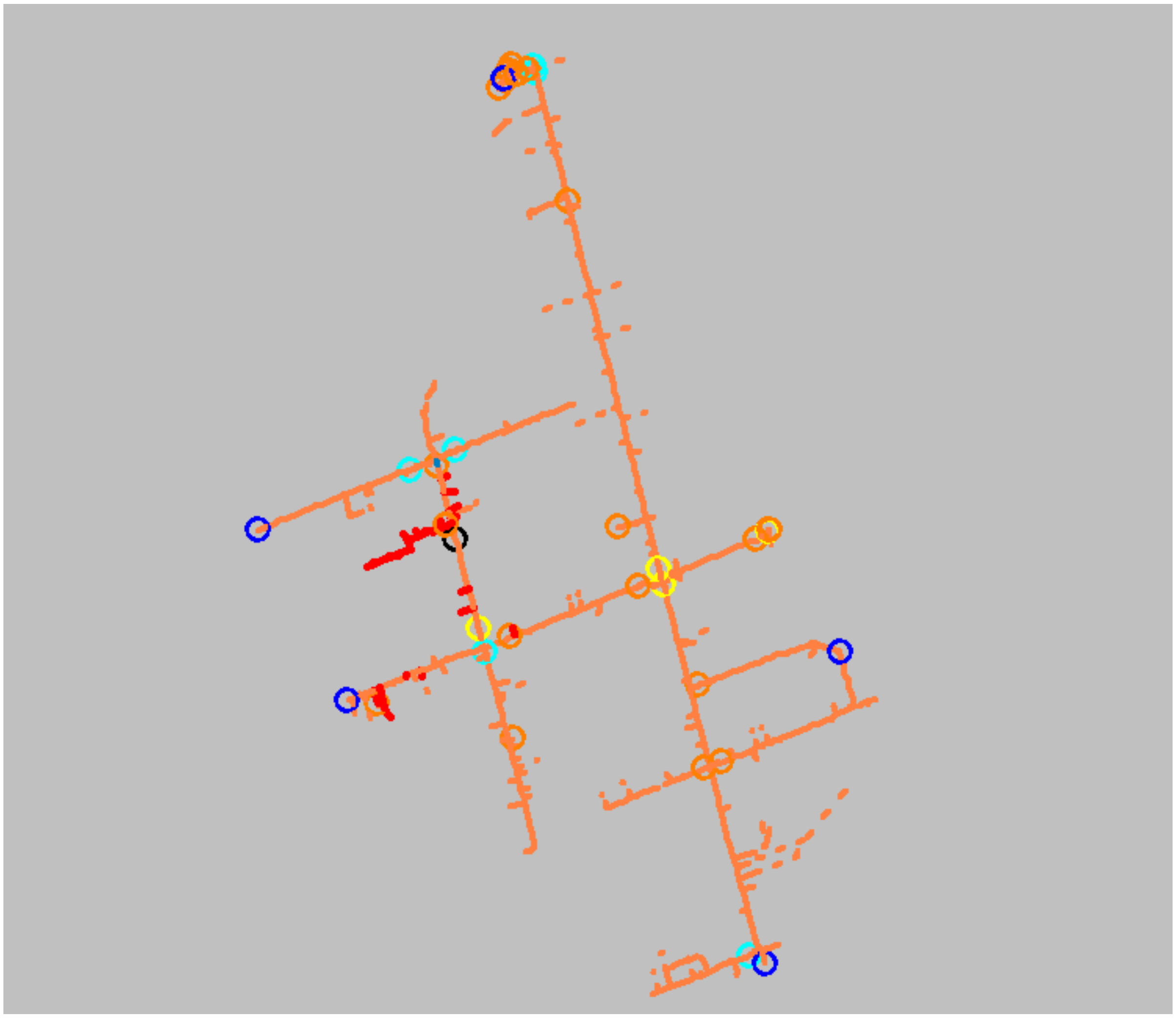


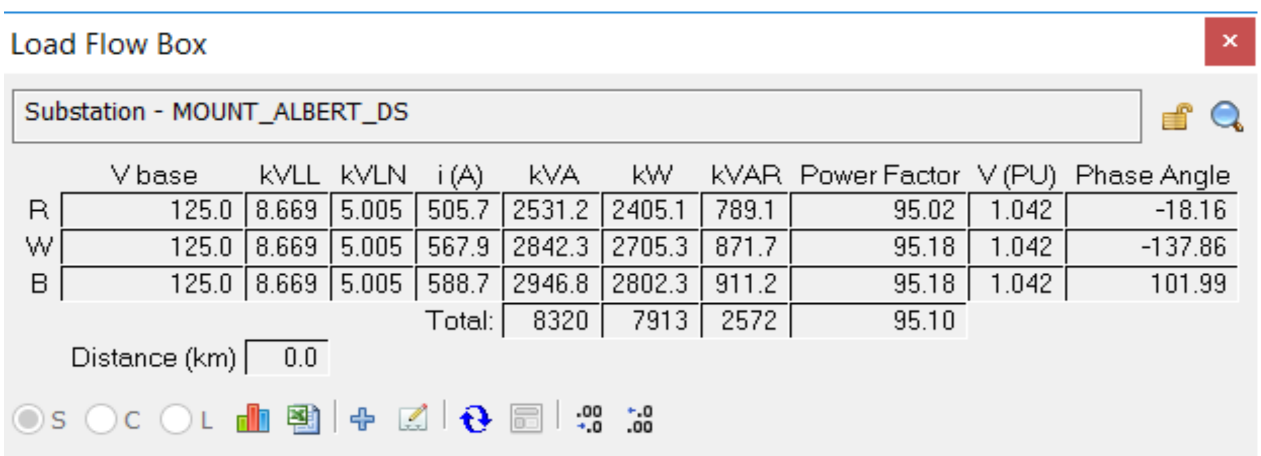
Figure 2.15: CYME results showing the voltage levels for Mount Albert DS: Feeder F3.

2.6 Station conditions after implementing Scenario 1

Figure 2.16 shows the installation locations for two 3 MVA pad-mount transformers. This requires building a new three phase line for 2.3 km and installing a new switch at the end-of-line of this three-phase line in normally closed position. Normally closed position allows a continuous flow of current in any situation unless the switch is opened. Further, opening the normally closed switch 1234 allows the transfer of load from Mount Albert DS: Feeder F1 to one of the new pad-mount transformers.

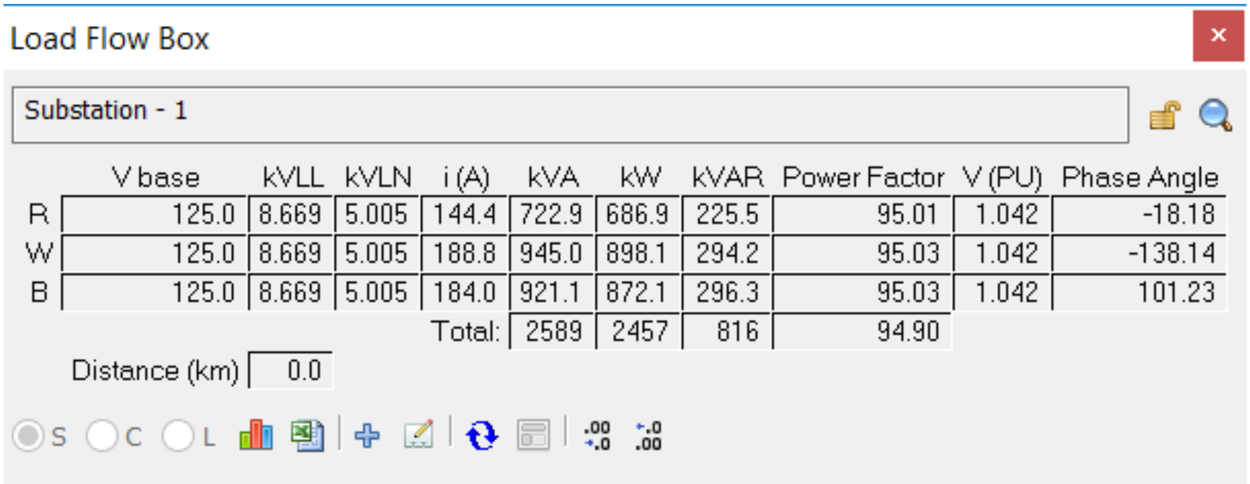
Figure 2.16: Installation location of two 3 MVA pad-mount transformers in Scenario 1.

Figure 2.17 shows that the loading of Mount Albert DS is reduced to 8.32 MVA from 10.968 MVA due to the new transfer. The red, white and blue current phases are better balanced with little variation in the values as shown in Figure 2.17. Figure 2.18 shows that the pad-mount transformer has been loaded at 2.589 MVA. Thus, the transformer loading is within the acceptable limit of 3 MVA. Figure 2.19 shows that the loading of Mount Albert: Feeder F1 has been reduced to 1.599 MVA from 4.246 MVA. This is critical as it will allow this feeder to accommodate additional load growth in the Mount Albert region. Feeders F2 and F3 remain unchanged as the load transfer has been done from Feeder F1 to the pad-mount transformer. Figure 2.20 shows that the transfer of loads does not have any impact on Feeder F2 as the load transfer is done primarily from Feeder F1 to the pad-mount transformer. Figure 2.21 shows that the transfer of loads does not have any impact on Feeder F3. Most of the load growth in the region is supplied by the 8.32 kV Feeder F1 as shown in Figure 2.2. Further, a suitable switch is not available in the Mount Albert DS network for enabling the load transfer from Feeder F1 to Feeder F2 or Feeder F3. Therefore, Feeders F2 and F3 cannot accommodate any additional loads arising due to commercial and residential development in the Mount Albert region.



	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	505.7	2531.2	2405.1	789.1	95.02	1.042	-18.16
W	125.0	8.669	5.005	567.9	2842.3	2705.3	871.7	95.18	1.042	-137.86
B	125.0	8.669	5.005	588.7	2946.8	2802.3	911.2	95.18	1.042	101.99
				Total:	8320	7913	2572	95.10		

Figure 2.17: Voltage and load profiles for the Mount Albert DS after installation of pad-mount transformers and load transfer from Feeder F1 to the pad-mount transformer.



Load Flow Box

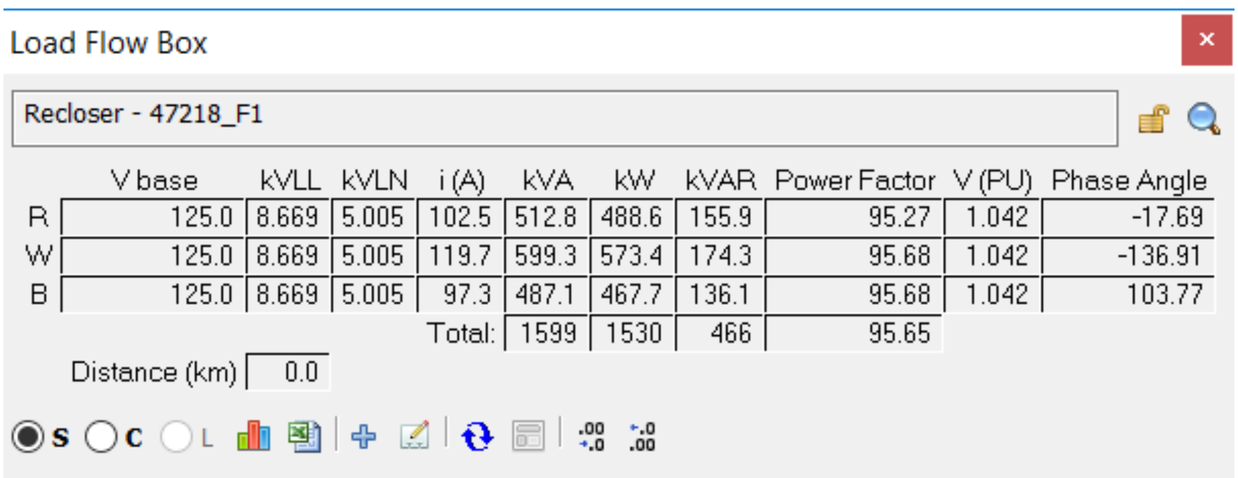
Substation - 1

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	144.4	722.9	686.9	225.5	95.01	1.042	-18.18
W	125.0	8.669	5.005	188.8	945.0	898.1	294.2	95.03	1.042	-138.14
B	125.0	8.669	5.005	184.0	921.1	872.1	296.3	95.03	1.042	101.23
				Total:	2589	2457	816	94.90		

Distance (km) 0.0

S C L

Figure 2.18: Voltage and load profiles for the newly installed pad-mount transformer.



Load Flow Box

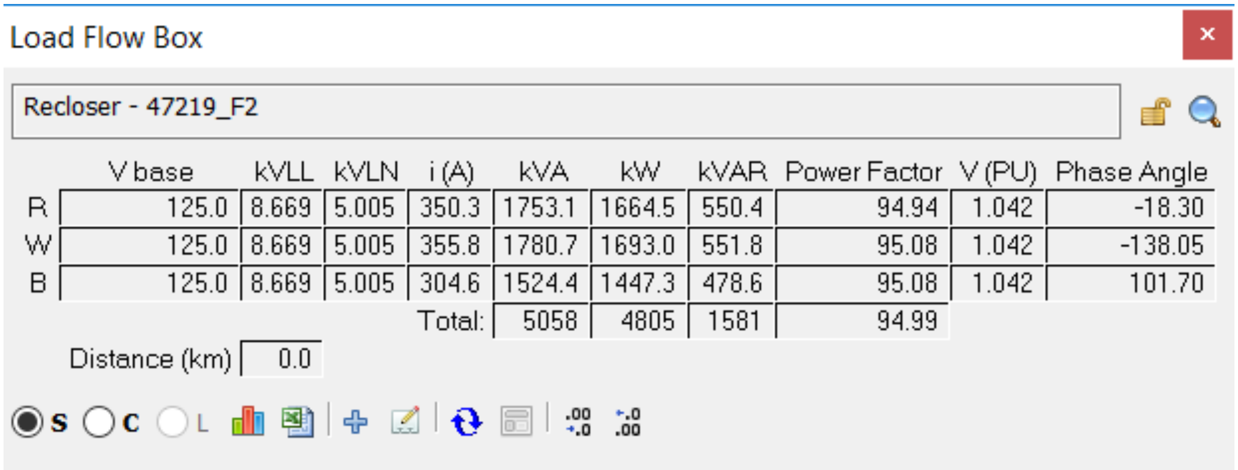
Recloser - 47218_F1

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	102.5	512.8	488.6	155.9	95.27	1.042	-17.69
W	125.0	8.669	5.005	119.7	599.3	573.4	174.3	95.68	1.042	-136.91
B	125.0	8.669	5.005	97.3	487.1	467.7	136.1	95.68	1.042	103.77
				Total:	1599	1530	466	95.65		

Distance (km) 0.0

S C L

Figure 2.19: Voltage and load profiles for Mount Albert DS: Feeder F1.



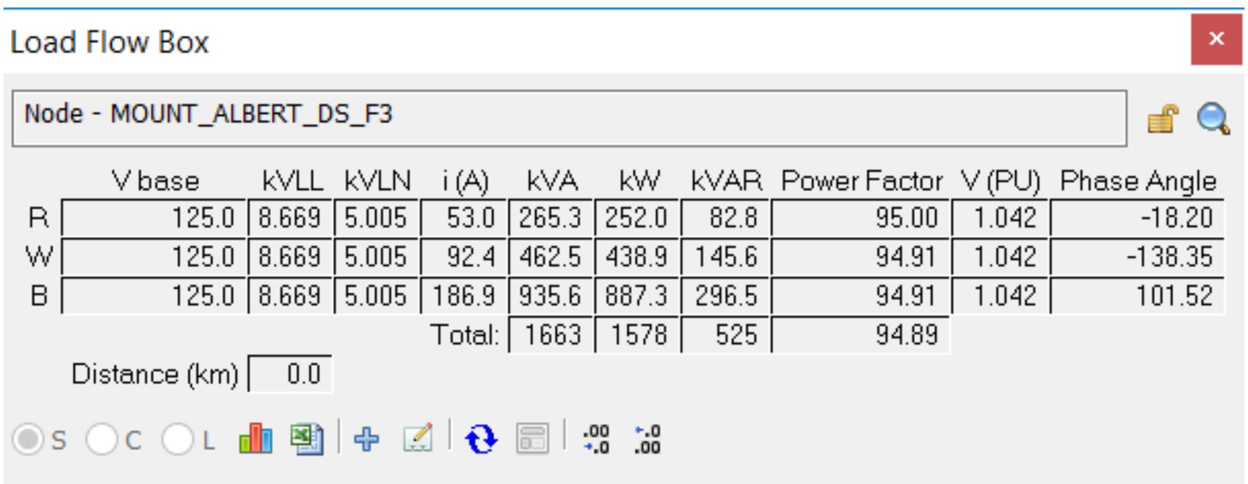
Load Flow Box

Recloser - 47219_F2

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	350.3	1753.1	1664.5	550.4	94.94	1.042	-18.30
W	125.0	8.669	5.005	355.8	1780.7	1693.0	551.8	95.08	1.042	-138.05
B	125.0	8.669	5.005	304.6	1524.4	1447.3	478.6	95.08	1.042	101.70
				Total:	5058	4805	1581	94.99		

Distance (km) 0.0

Figure 2.20: Voltage and load profiles for Mount Albert DS: Feeder F2.



Load Flow Box

Node - MOUNT_ALBERT_DS_F3

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	53.0	265.3	252.0	82.8	95.00	1.042	-18.20
W	125.0	8.669	5.005	92.4	462.5	438.9	145.6	94.91	1.042	-138.35
B	125.0	8.669	5.005	186.9	935.6	887.3	296.5	94.91	1.042	101.52
				Total:	1663	1578	525	94.89		

Distance (km) 0.0

Figure 2.21: Voltage and load profiles for Mount Albert DS: Feeder F3.

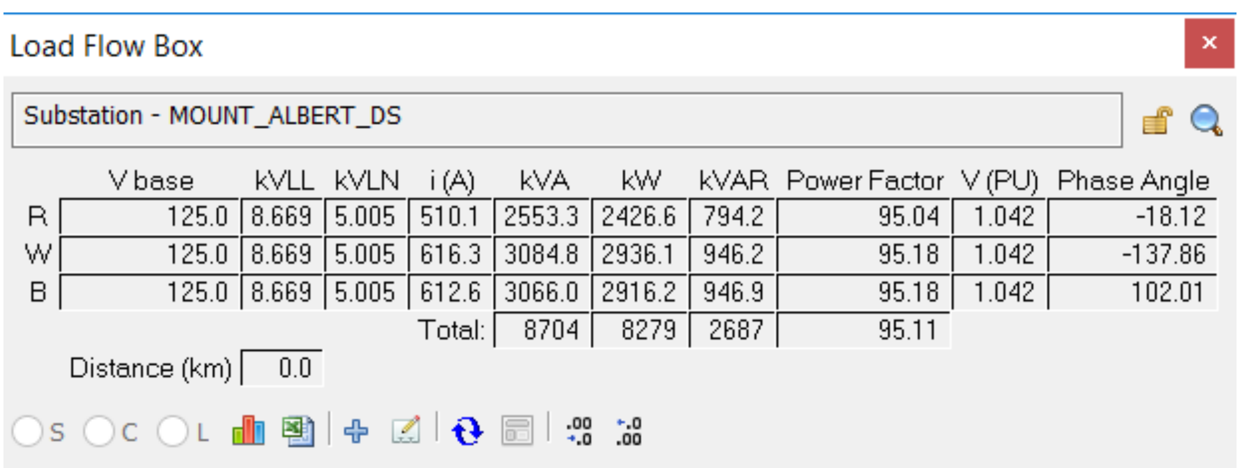
2.7 Station conditions after implementing Scenario 2

Figure 2.22 shows the installation location of two 3 MVA pad-mount transformers. This requires building a new three phase line for 2.9 km and installing a new switch at the end-of-line of this line in normally closed position. Normally closed position allows a continuous flow of current in any situation unless the switch is opened. Further, a new normally open switch as shown in Figure

2.22 should be added to allow the transfer of 2.5 MVA of load from Mount Albert DS: Feeder F1 to the pad-mount transformer.

Figure 2.22: Installation location of two 3MVA pad-mount transformers in Scenario 2.

Figure 2.23 shows that the loading of the Mount Albert DS has been reduced to 8.7 MVA from the 10.968 MVA. The red, white and blue phases are imbalanced, specifically the red phase. In this case, additional re-phasing of distribution lines should be done to further balance the station. Balancing of the phases is not part of this project as the simulated values will differ from the values after the load transfer. Figure 2.24 shows that the pad-mount transformer has been loaded to 2.186 MVA. Thus, the loading of the transformer is within the acceptable limit of 3 MVA. Figure 2.25 shows that the loading of the Mount Albert DS: Feeder F1 has been reduced to 1.983 MVA from 4.246 MVA. This is critical as it allows the feeder to accommodate additional load growth in the Mount Albert region. Feeders F2 and F3 remain unchanged as the load transfer has been done from Feeder F1 to the pad-mount transformer. Figure 2.26 shows that the transfer of loads does not have any impact on Feeder F2 as the load transfer is done primarily from Feeder F1 to the pad-mount transformer. Further, Figure 2.27 shows that the transfer of loads does not have any impact on Feeder F3. Most of the load growth is in the region supplied by the 8.32 kV Feeder F1 as shown in Figure 2.2. Further, a suitable switch is not available in the Mount Albert DS network to enable the load transfer from Feeder F1 to Feeder F2 or Feeder F3. Therefore, Feeders F2 and F3 cannot accommodate any additional loads due to commercial and residential developments in the Mount Albert region.

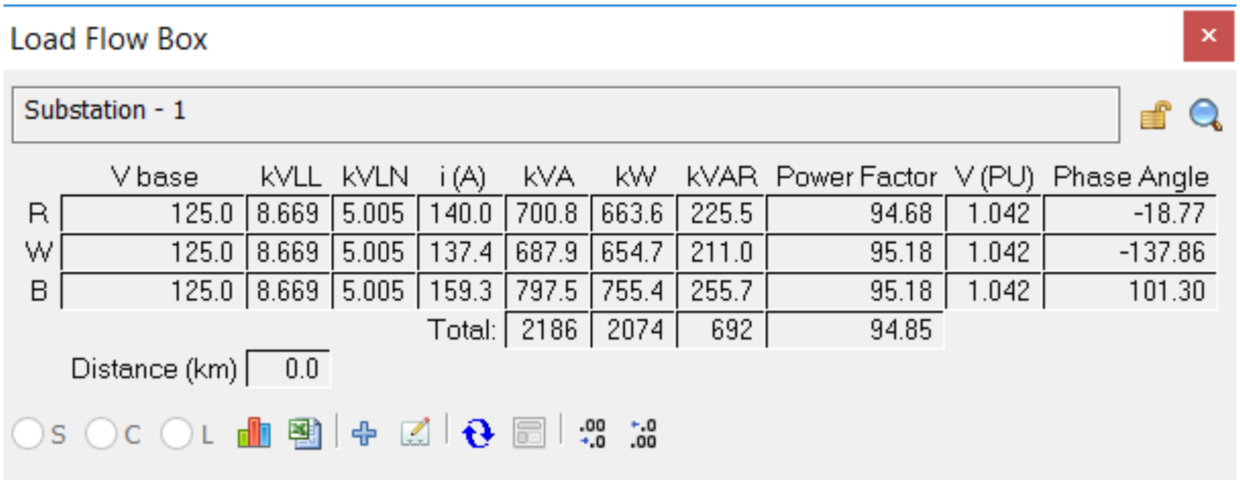

Load Flow Box

Substation - MOUNT_ALBERT_DS

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	510.1	2553.3	2426.6	794.2	95.04	1.042	-18.12
W	125.0	8.669	5.005	616.3	3084.8	2936.1	946.2	95.18	1.042	-137.86
B	125.0	8.669	5.005	612.6	3066.0	2916.2	946.9	95.18	1.042	102.01
				Total:	8704	8279	2687	95.11		

Distance (km) 0.0

Figure 2.23: Voltage and load profiles for the Mount Albert DS after installation of pad-mount transformers and load transfer from the feeder F1 to the pad-mount transformer.



Load Flow Box

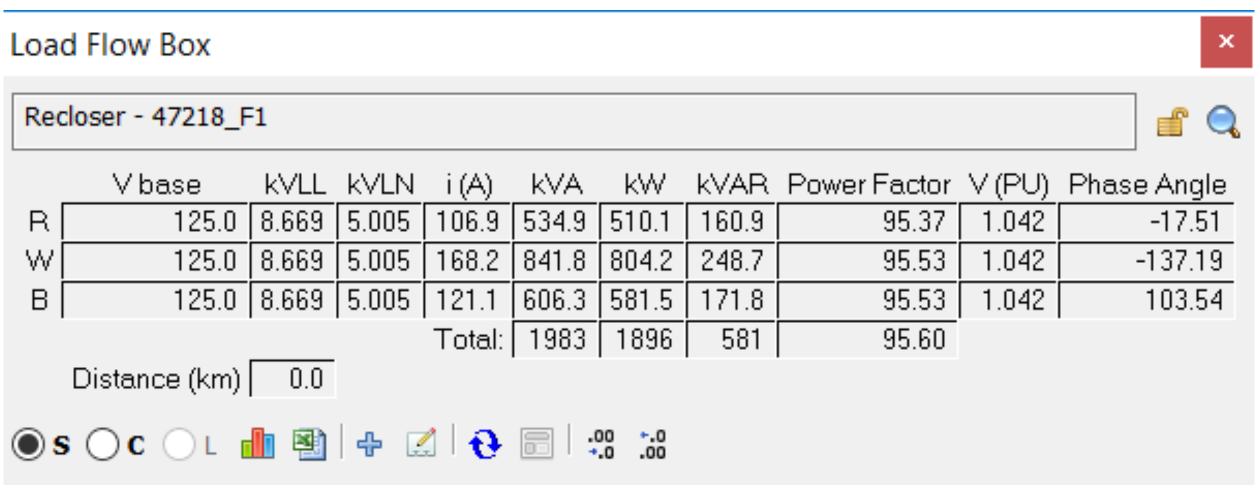
Substation - 1

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	140.0	700.8	663.6	225.5	94.68	1.042	-18.77
W	125.0	8.669	5.005	137.4	687.9	654.7	211.0	95.18	1.042	-137.86
B	125.0	8.669	5.005	159.3	797.5	755.4	255.7	95.18	1.042	101.30
				Total:	2186	2074	692	94.85		

Distance (km) 0.0

S C L

Figure 2.24: Voltage and load profiles for the newly installed pad-mount transformer.



Load Flow Box

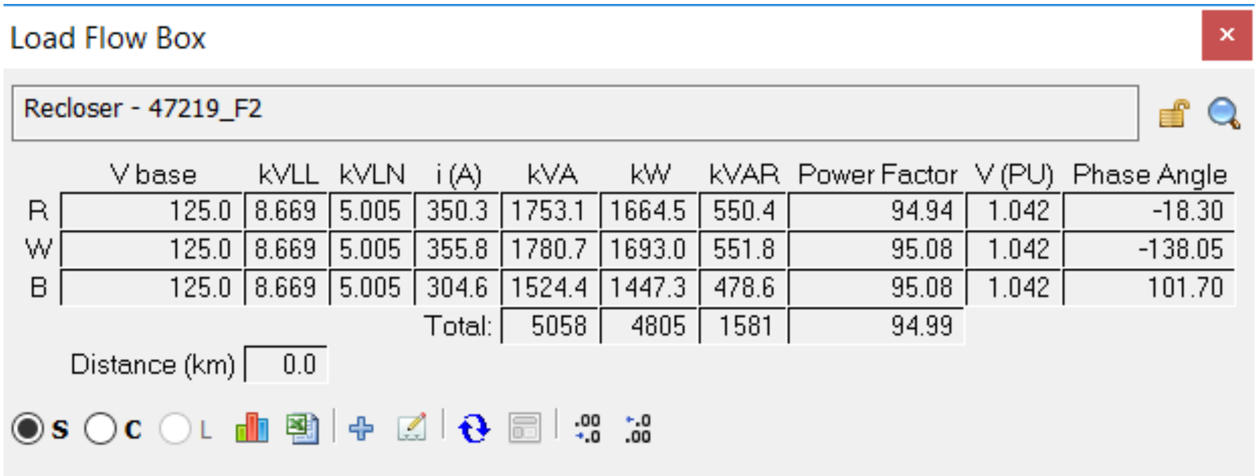
Recloser - 47218_F1

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	106.9	534.9	510.1	160.9	95.37	1.042	-17.51
W	125.0	8.669	5.005	168.2	841.8	804.2	248.7	95.53	1.042	-137.19
B	125.0	8.669	5.005	121.1	606.3	581.5	171.8	95.53	1.042	103.54
				Total:	1983	1896	581	95.60		

Distance (km) 0.0

S C L

Figure 2.25: Voltage and load profiles for Mount Albert DS: Feeder F1.


Load Flow Box

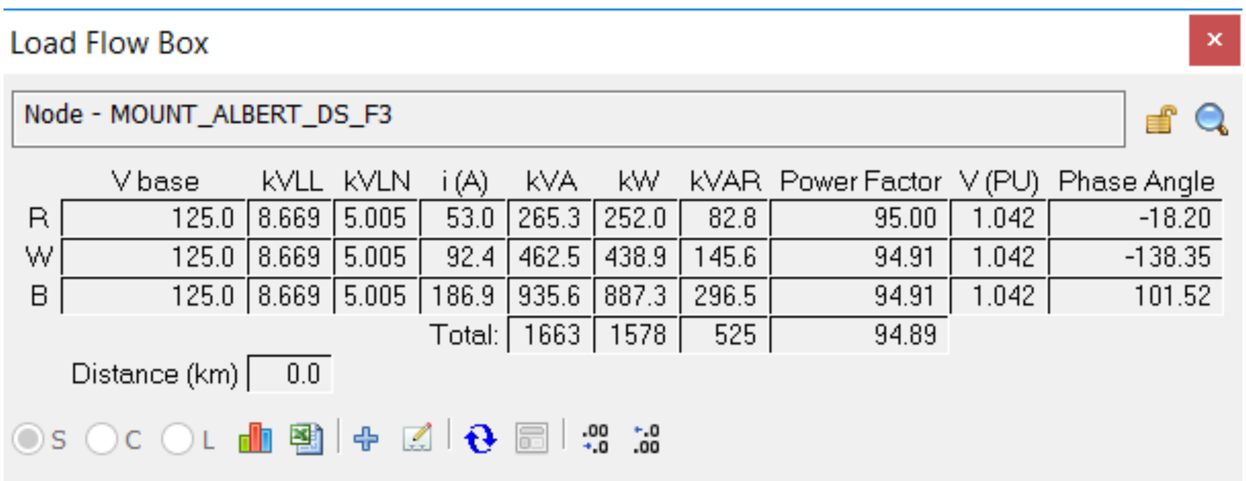
Recloser - 47219_F2

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	350.3	1753.1	1664.5	550.4	94.94	1.042	-18.30
W	125.0	8.669	5.005	355.8	1780.7	1693.0	551.8	95.08	1.042	-138.05
B	125.0	8.669	5.005	304.6	1524.4	1447.3	478.6	95.08	1.042	101.70
				Total:	5058	4805	1581	94.99		

Distance (km) 0.0

S C L

Figure 2.26: Voltage and load profiles for Mount Albert DS: Feeder F2.


Load Flow Box

Node - MOUNT_ALBERT_DS_F3

	V base	kVLL	kVLN	i (A)	kVA	kW	kVAR	Power Factor	V (PU)	Phase Angle
R	125.0	8.669	5.005	53.0	265.3	252.0	82.8	95.00	1.042	-18.20
W	125.0	8.669	5.005	92.4	462.5	438.9	145.6	94.91	1.042	-138.35
B	125.0	8.669	5.005	186.9	935.6	887.3	296.5	94.91	1.042	101.52
				Total:	1663	1578	525	94.89		

Distance (km) 0.0

S C L

Figure 2.27: Voltage and load profiles for Mount Albert DS: Feeder F3.

2.8. Comparative analysis of the scenarios

The capacity of the Mount Albert DS is 12 MVA and additional future load growth of 3 MVA is anticipated soon. Two scenarios were considered for installing the two 3 MVA pad-mount transformers to provide relief to the Mount Albert DS. Note that pad-mount transformers are always installed in pairs as one transformer acts as a backup for the other so they are not operated simultaneously. Figure 2.28 shows that the station loading is reduced from 10.968 MVA to 8.32 MVA in Scenario 1 and from 10.968 MVA to 8.704 MVA in Scenario 2 after installing the pad-mount transformers. Further, Scenario 1 can accommodate an additional 0.374 MVA compared to Scenario 2. Typically, commercial developments account for loads more than 1 MVA and residential developments range between 1 KVA and 1 MVA. Hence, the additional 0.374 MVA is useful in the case of future residential developments that do not require high loads. Further, Figure 2.29 shows that the pad-mount transformer is loaded up to 2.589 MVA in Scenario 1 compared to 2.186 MVA in Scenario 2. As a result, the pad-mount transformer will be used close to its limit of 3 MVA in Scenario 1 as shown in Figure 2.18. The unused capacity for the pad-mount transformer in Scenario 1 is 0.411 MVA. The unused capacity of 0.814 MVA in Scenario 2 is a disadvantage as the pad-mount transformer will not be used close to its limit. Further, there is no possibility to transfer other loads to the pad-mount transformer due to the configuration so the unused 0.814 MVA cannot be used to accommodate future load growth. The cost of building a new three phase line is $400,000 per km. So, for Scenario 1 this is $920,000 whereas for Scenario 2 it is $1,160,000. The difference in cost is not significant as the cost of the transformer is $1,500,000.

Figure 2.30 shows the Feeder F1 loading for the two scenarios. This indicates that Scenario 1 has the capability to accommodate higher loads than Scenario 2. This would be beneficial as an additional 0.384 MVA of load could be accommodated in the form of residential developments. Figure 2.31 shows that the transfer of loads does not have an impact on Feeder F2 as the load transfer is done primarily from Feeder F1 to the pad-mount transformer. Further, Figure 2.32

shows that the transfer of loads does not have an impact on Feeder F3. Most of the load growth is in the region supplied by the 8.32 kV Feeder F1 as shown in Figure 2.2. Further, a suitable switch is not available in the Mount Albert DS network to enable the load transfer from Feeder F1 to Feeder F2 or Feeder F3. Therefore, Feeders F2 and F3 cannot accommodate additional loads arising due to commercial and residential developments in the Mount Albert region.

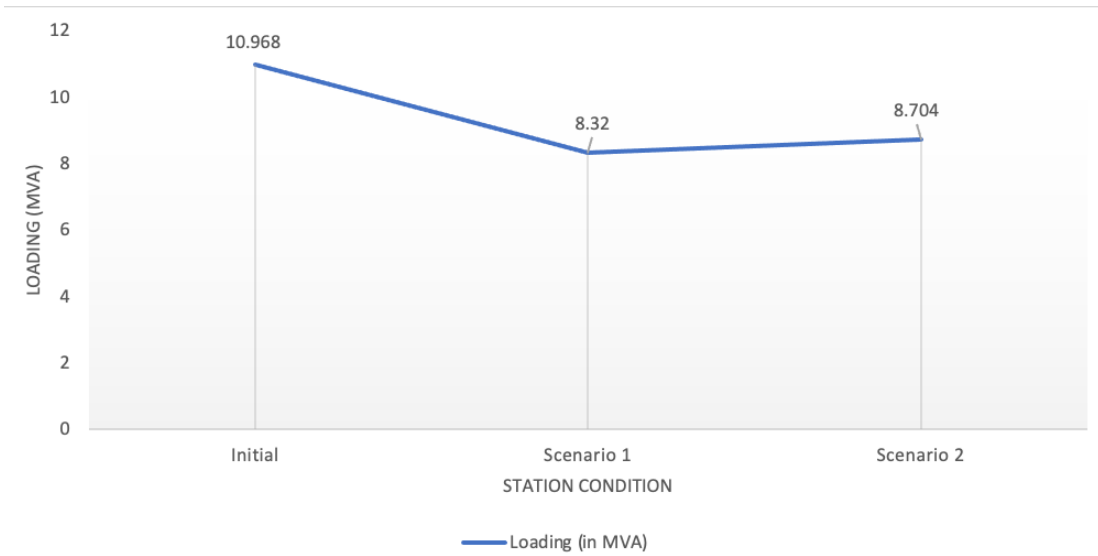


Figure 2.28: The change in station loading for the two scenarios.

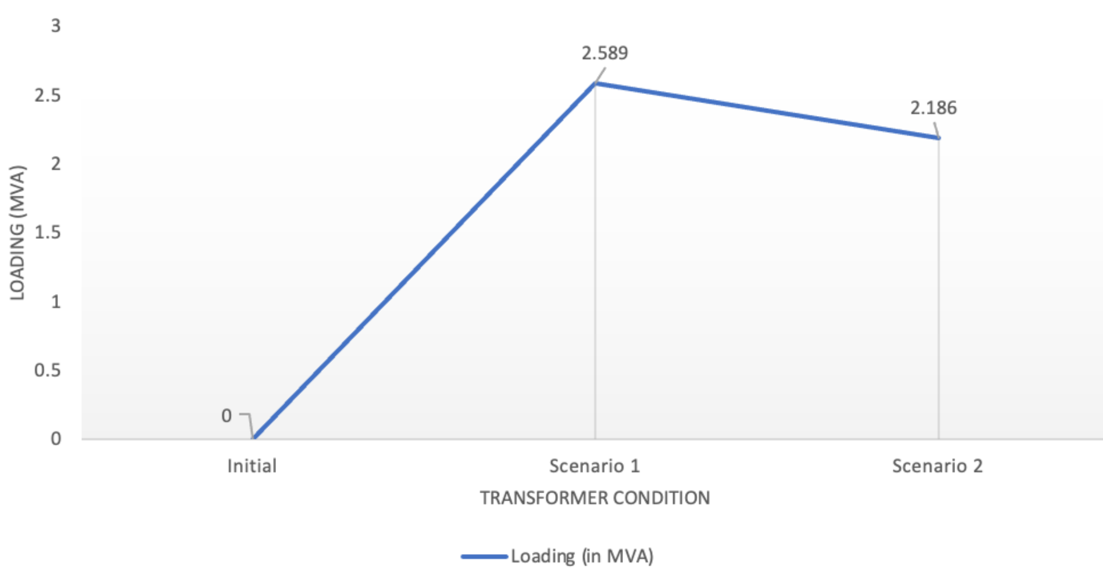


Figure 2.29: The change in the transformer loading for two scenarios.

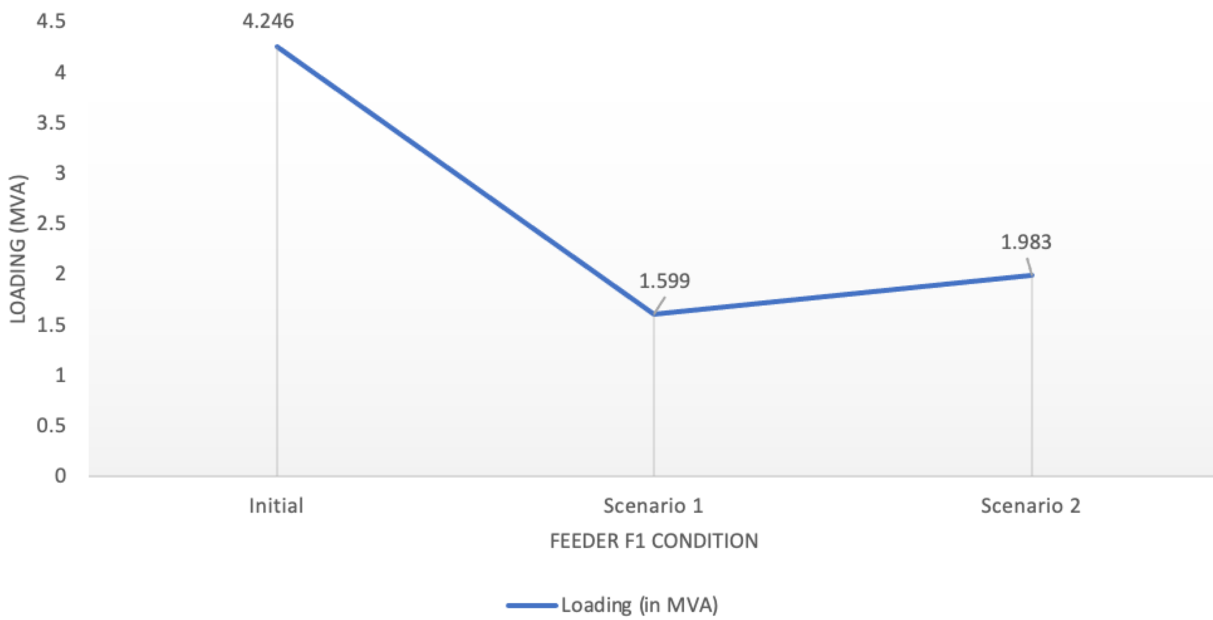


Figure 2.30: The change in Feeder F1 loading for two scenarios.

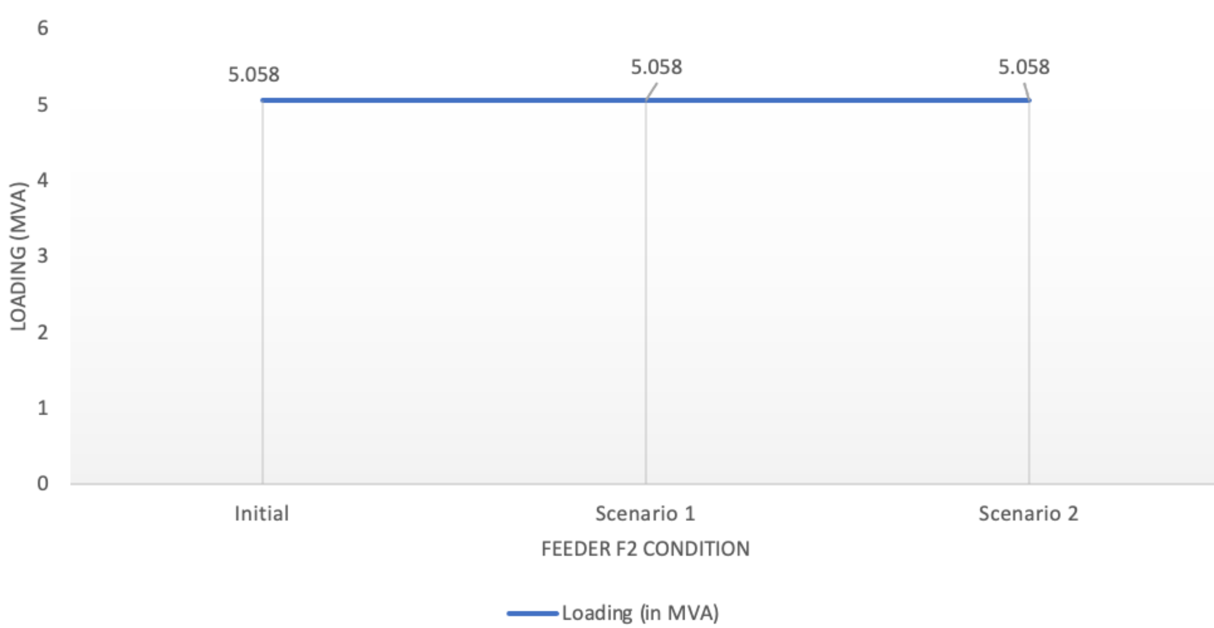


Figure 2.31: The change in Feeder F2 loading for the two scenarios.

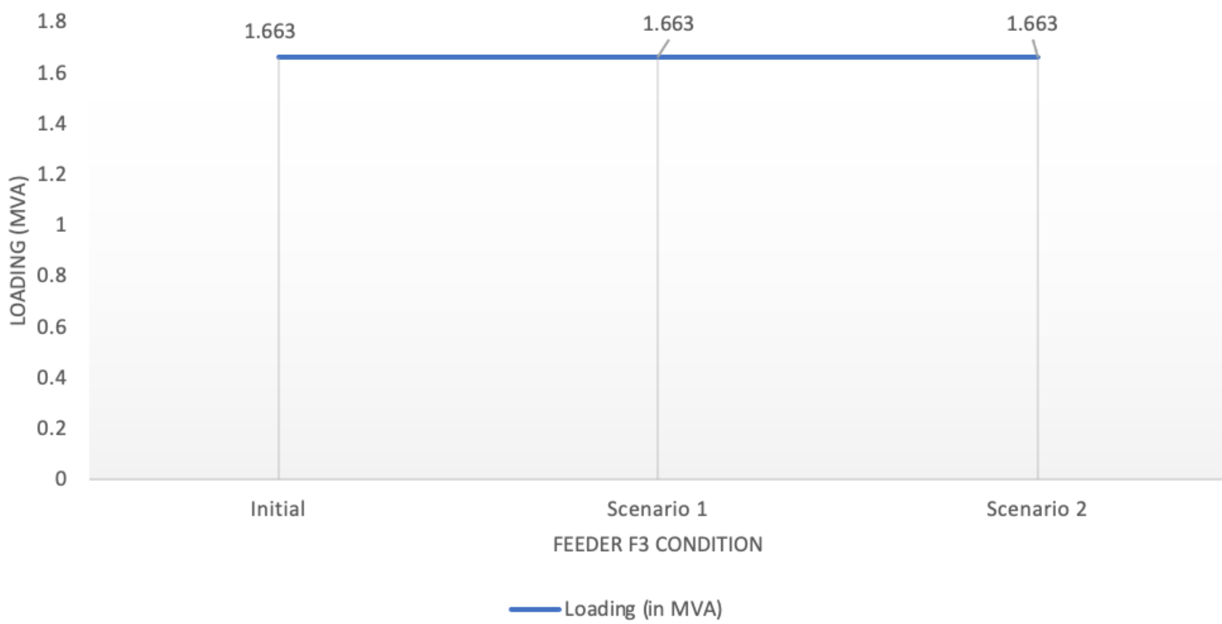


Figure 2.32: The change in Feeder F3 loading for the two scenarios.

Chapter 3: Conclusions and Future Work

The Mount Albert distribution station is near capacity and immediate relief is required to accommodate the anticipated future commercial and residential development of 3 MVA. The peak loading limit of the Mount Albert DS is 12.5 MVA, while the current peak loading is 10.968 MVA. Thus, the 3 MVA of future load growth in the Mount Albert region cannot be accommodated by the Mount Albert DS, so pad-mount transformers were proposed to accommodate this load growth. Two scenarios were considered. In Scenario 1, a new 2.3 km three phase line is built and a switch installed at the end of line of this line in normally closed position. Further, the normally closed switch 1234 is opened to enable the transfer of load from the Mount Albert DS: Feeder F1 to the pad-mount transformer. As a result, the Mount Albert DS can accommodate the additional load. In Scenario 2, a new 2.9 km three phase line is built and a switch installed at the end of line of this in normally closed position. Further, a new normally open switch is created to allow the transfer of 2.5 MVA of load from Mount Albert DS: Feeder F1 to the pad-mount transformer.

The results obtained from the CYME analysis were compared with the initial loading profile of the Mount Albert distribution station. Scenario 1 is preferred over Scenario 2 because it can accommodate higher loads than Scenario 2. This would be beneficial as an additional 0.384 MVA of load could be accommodated in the form of residential developments. Further, the results showed that the installation of pad-mount transformers will accommodate the anticipated future load growth in the Mount Albert region. Previously, installing pad-mount transformers to accommodate large scale loads was not considered, so the additional loads arising from commercial and residential developments could not be accommodated by the Hydro One distribution system. With recent developments in technology and growing interest among engineering firms to develop high capacity pad-mount transformers, these transformers can now be used to accommodate large loads in a short time frame.

Future work includes improving the performance of pad-mount transformers and identifying regions where pad-mount transformers can be located to accommodate anticipated load growth. This will help Hydro One slow the replacement of ageing assets, hence delaying investments and accommodate larger loads in a shorter time to gain a strategic advantage over competitors in the distribution sector.

The SAIDI and CAIDI of the stations which ranked below 100 in the station reliability tables should be improved. This can be done by installing behind-the-meter powerwalls. Behind-the-meter refers to energy production and storage systems that directly supply homes and buildings with electricity. The energy produced and stored by these systems is separate from the grid and so does not need to be metered before being used. A powerwall is a battery that stores energy, detects outages and automatically becomes an energy source when the grid is unavailable. This can ensure a continuous supply of power to customers despite power outages [8]. As a result, the duration for which customers are without power can be decreased, hence improving the SAIDI and CAIDI values for the station. This will help Hydro One improving its performance as per the OEB guidelines.

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