VEC System Power Loss Study

by: Dean Denis; November 16, 2021

Executive Summary

The VEC transmission and distribution power loss study results are summarized in the table below. VELCO performed the transmission portion of the study and VEC the distribution portion. Packetized Energy, an independent Vermont energy software consultant, validated the distribution system loss percentages.

There were differences between VEC's and Packetized loss calculation methodologies including the system base case model and loading used which will be further explained in the report. It was anticipated that Packetized loss results might be higher than what VEC calculated utilizing Milsoft software due to the differences in loss calculation methodologies used.

System power loss values as a percentage of total system loads were found to be within the national average for all electric utilities per the 2012 EPRI document titled, "Assessment of Transmission and Distribution Losses in New York State"[1].

		Annual Load (MWH)	Annual Losses Estimated (MWH)	% losses of MWH load
Distribution (VEC)		418960	**14873**	**3.6**
Distribution (Packetized)		316812	**13083**	**4.1**
Transmission (VELCO)		393213	**7122**	**1.8**

VEC's financial system power losses are derived from ISO-NE's load settlement of VEC's monthly power purchases versus iVUE's tabulation of what VEC sold that month. For 2018, the focus of this loss study, financial power losses were approximately 7%. The bulk power transmission losses from the various ISO-NE's 'inlet' revenue meters to VEC's sole owned power system can be estimated by subtracting the total VEC system loss study results of 5.4% from 7% equaling 1.6%. The 2012 EPRI study[1] found that transmission system losses ranged from 1.5 to 5.8%, further validating the reasonableness of the VEC loss study results.

1 Introduction

This loss study is based upon information and methodologies found in a 2012 EPRI document titled, "Assessment of Transmission and Distribution Losses in New York State"[1].

It is stated in that document, "losses in electric transmission and distribution systems in the service territories of the participating New York utilities ranged from 1.5 to 5.8 percent for transmission losses and from 1.9 to 4.6 percent for distribution losses based on utility loss studies presented to the PSC in 2008 and 2009. These are comparable to other reported electric utility losses in the United States as reported by EPRI's Transmission Efficiency Initiative Study3 and EPRI's Green Circuits Study4."[1]

[1] Razanouski, M. (2012). Assessment of Transmission and Distribution Losses in New York State. EPRI and SAIC.

Analysis confirmed that New York utilities are using normal industry practices in calculating system losses and that there is not a single best practice that can be followed by every utility.[1]

From loss ranges identified above, VEC's sub- transmission and distribution power system losses appear to be in line with those found in the EPRI report.

1.1 Objectives

The study objectives are to adequately quantify VEC's sub-transmission and distribution system losses and determine if those losses are in line with those of other U.S. utilities. The resulting information will be used to further improve VEC's power system and capital improvement planning functions.

2 Study Area

The study area includes VEC's wholly owned sub-transmission and distribution systems.

2.1 System Modeling

VELCO used PSS/e software to model VEC's sub-transmission system.

VEC used Milsoft software to model the distribution system.

Packetized used their independently developed software products.

2.2 Load Analysis

Load duration curves from 2018 hourly substation Pi-data developed for use in the 2019 System Load and Voltage Study were further refined by VELCO System Planning and the basis for both VELCO and VEC study methodologies. Packetized loss calculation methodology doesn't necessitate the need for a load duration curve and instead uses hourly CIS customer load data directly. Packetized losses were based on 2020 customer load data.

3 Loss Analysis Methodology

3.1 Transmission (Bernadette Fernandes, VELCO System Planning. (2020). VEC Loss Study.)

The methodology used for the loss analysis is from Section B in document "Assessment of Transmission and Distribution Losses in New York State"[1]. See Appendix B.

The LSF (Loss Factor) is calculated for each VEC substation based on the adjusted hourly data provided. Due to significant data NOT available for Cambridge substation (4151 missing hours due to substation rebuild), the load duration curve at this substation was adjusted based on the nearby substation of Johnson #14. Derby had 52 missing hours but the load duration curve was NOT adjusted since it was assumed to be of minimal impact.

Radial sub-transmission lines serving only load were assigned a LSF based on the average LSF of the

load being served. Using VELCO SCADA information, 2018 load duration curves were created for generation impacting the loss analysis for Newport Hydro, Sheldon Hydro and KCW. In addition, a 2018 load duration curve was created for West Rock on the L250 line.

The VEC Coincident System Load duration curve was split into the top 1%, bottom 1% with the remaining hours split evenly. Substation Load duration curves were also divided into the same 5 load sections. Using the Coincident Load shoulder case, 5 similar cases were created by varying the KCW dispatch. The losses are calculated by PSS/e for the "Peak" load of each of the 5 areas load sections and multiplied by the loss factor to determine estimated annual losses. A total of 15 PSS/e cases were created: 5 for the VEC System Coincident Peak load points, 5 for the Substation non-Coincident Peak load points (includes Sheldon generation, Newport generation, and West Rock load), and 5 for the KCW dispatch. Load duration curves for West Rock load, Sheldon generation, Newport generation, and KCW generation are located in "VEC Generation and West Rock Load Duration Curves.zip".

3.2 Distribution

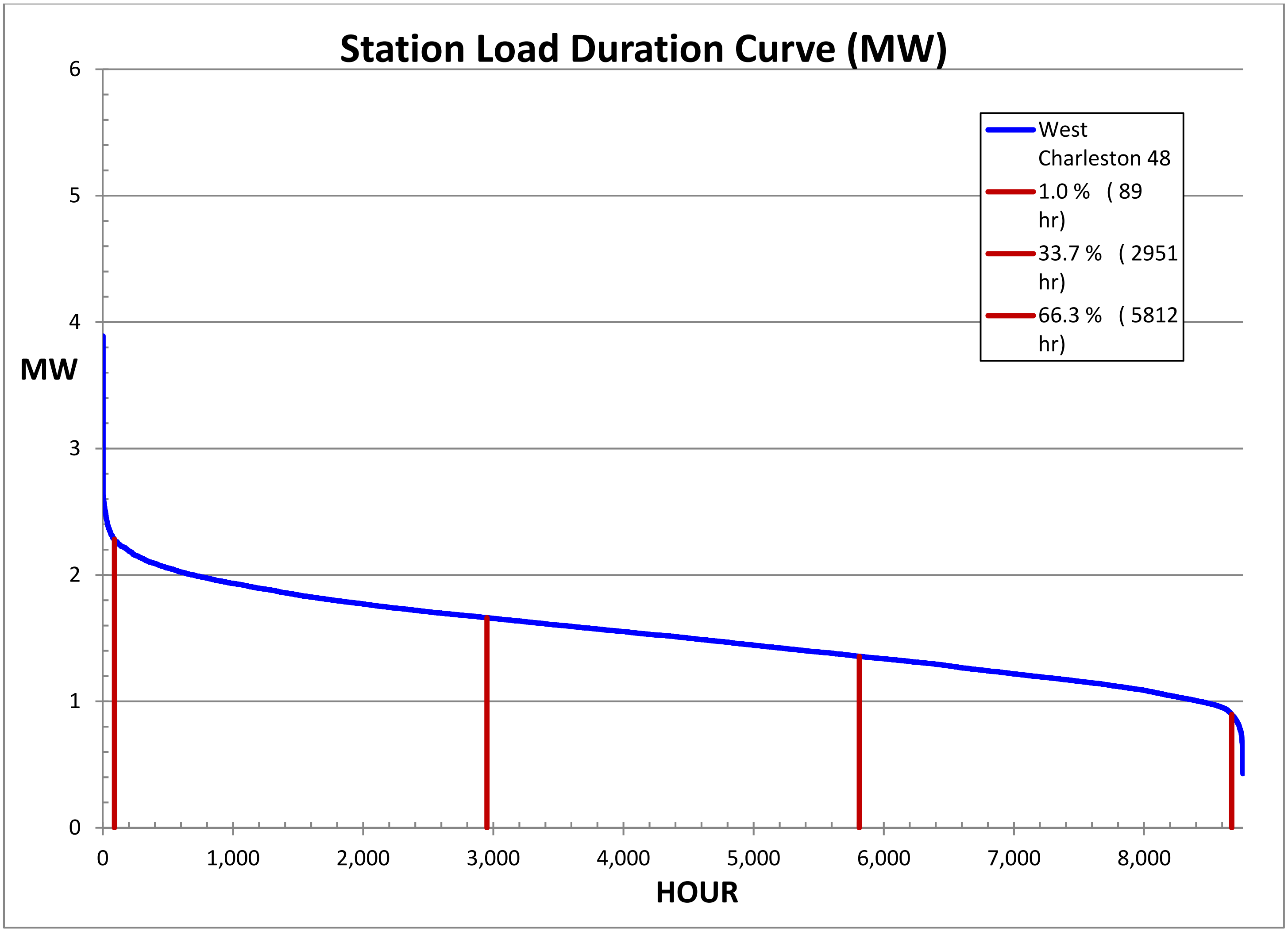
3.2.1 VEC Methodology

The methodology used for the distribution loss analysis is based on Section 3., Utility H, in document "Assessment of Transmission and Distribution Losses in New York State". This document can be found in Appendix B of VELCO's sub-transmission study.

Individual substation load duration curves were developed by VELCO as part of the sub-transmission loss study and used in this distribution loss analysis to determine peak, high, average and low loading levels and the total MWhr's of load for the individual substations.

Substation individual feeder phase loads were adjusted by percentage of total substation load in accordance with the levels identified in the load duration curve. The adjusted phase loadings were then allocated to the individual feeders and a loss report was generated using Milsoft's Windmil model.

The following graph is an example of a load duration curve with the *y axis* being peak load and the *x axis* hours of the year. This curve is developed from the hourly substation load data which can be summed for each hour of the year totaling the number of load MWhr's for the substation. Since losses are also a product of load level and duration of time the Milsoft model was run at the selected load levels and resulting calculated losses from the model multiplied by a time duration in order to approximate the total 'area' under the load-duration curve and hence MWhr's of losses. Because each substations' load duration curve is a little different depending on the served loads, the points selected along the curve to model in Milsoft were selected at different locations in order to better approximate the area under the curve.



3.2.2 Packetized Methodology

The methodology used by Packetized Energy's proprietary software allows for the calculation of losses at each hour of the year (8,760 data points) and does not rely on manually selected points along the load-duration curve in order to approximate the area under it to determine the total yearly MWhr losses. That is because the Packetized software can run the model for each load hour in a given data set automatically. Milsoft software isn't capable of doing the same since it is a manual process to change the load level at each substation and feeder before running the model again to calculate losses for that given load level.

The Packetized methodology, made possible by its' proprietary software is presumed to be more accurate, all else being equal, than selecting the individual load points represented along the load-duration curve and running the model manually each time in order to approximate the total area under the curve (Watt-hours), since it calculates the Watt losses for each hour of the year (8,760 hours).

4 Results

4.1 Transmission

VELCO System Planning performed the VEC sub-transmission loss study and delivered their results in (12/'20); This report is in addition to those results and will identify and recommend capital improvements found in that study and produce a project cost justification that includes the value of losses.

A yearly comparison of the northern portion (Zone 2) of the sub-transmission system 'inlet' or source meters and the corresponding VEC substation's 'outlet' or load meters resulted in a loss percentage of 1.84%, validating VELCO's power flow model result of 1.8%.

Summary of VELCO Results sorted by % losses based on loading:

					Load Point 1		
VEC Reference	**R (pu) System Base**	**X (pu) System Base**	**Xfmr base**	**Annual Losses Estimated (MWH)**	**loss Peak (MW)**	**Loading (MVA)**	**% losses based on Loading**
L31 (Highgate to Enosburg)	0.6712	0.5514		**1035**	0.30	6.96	**4.3**
LC43 (Lowell to Jay)	0.0638	0.3589		**3210**	2.15	59.14	**3.6**
L220 (Swanton Tap to So Alburgh)	0.4027	0.4549		**250**	0.07	4.33	**1.6**
L200 (Highgate to Sheldon - generators)	0.0668	0.1537		**553**	0.43	26.43	**1.6**
Eden 2 (Sub 2 transformer)	0.5529	3.8235	1.7	**64**	0.02	1.96	**1.1**
L220 (Highgate to Swanton Tap)	0.2188	0.1795		**133**	0.04	4.36	**0.9**
Madonna 15 (Sub 15 transformer)	0.1253	0.8667	7.5	**45**	0.05	6.30	**0.8**
LC43 (Lowell 5 to Jay 17)	0.0106	0.0601		**522**	0.35	57.88	**0.6**
LC33 (Enosburg to E Berkshire)	0.1989	0.1634		**48**	0.02	3.02	**0.6**

L250 (Highgate to Sheldon - Westrock)	0.0668	0.1537		**208**	0.05	9.27	**0.6**
LB7 (Cambridge B7 to Madonna)	0.1886	0.3023		**138**	0.01	2.79	**0.5**
Hinesburg 19 (Sub 19 transformer)	0.0795	0.9547	7.5	**68**	0.03	5.84	**0.5**
Johnson 14 (GMP tap to Sub 14 12.47kV bus)	0.3760	2.6000	2.5	**14**	0.01	1.30	**0.5**
Pleasant Valley 13 (Sub 13 transformer)	0.3760	2.6000	2.5	**16**	0.01	1.21	**0.5**
LH18 (Derby Sub tap to Sub 48)	0.0900	0.2071		**68**	0.03	5.36	**0.5**
Fairfax 1 (Sub 1 transformer)	0.1178	1.4160	5	**23**	0.01	3.30	**0.4**
LH18 (Newport to Derby Sub)	0.0369	0.0849		**132**	0.05	11.01	**0.4**
Montgomery 7 (Sub 7 transformer)	0.3760	2.6000	2.5	**9**	0.00	0.98	**0.4**
Island Pond 47 4A (Sub 47 12.47kV transformer)	0.0821	1.9474	3.8	**5**	0.01	4.07	**0.4**
Fairfax 12 (Sub 12 transformer)	0.2356	2.8320	2.5	**9**	0.00	1.23	**0.3**
Underhill 4 (Sub 4 transformer)	0.2324	2.7920	2.5	**9**	0.00	1.19	**0.3**
Cambridge 3 (Sub 3 transformer)	0.1880	1.3000	5	**5**	0.01	1.68	**0.3**
Jay Peak 40 (Jay Tap to Sub 40)	0.0400	0.0970		**21**	0.02	7.67	**0.3**
South Hero 29 (Sub 29 transformer)	0.0338	0.6875	100	**31**	0.02	7.85	**0.3**
LH16 (Sub 43 to Barton Tap - Rte 16)	0.0463	0.1090		**58**	0.02	5.87	**0.3**
South Albrugh 28 (Sub 28 transformer)	0.0299	0.7320	10	**27**	0.02	7.96	**0.2**

Newport 44 (T3 transformer)	0.0192	0.4563	22.4	**62**	0.03	11.90	**0.2**
Jay 17 (Sub 17 transformer)	0.1160	1.3940	5	**3**	0.01	2.15	**0.2**
Westford 11 (Sub 11 transformer)	0.2300	2.7640	2.5	**7**	0.00	0.99	**0.2**
West Charleston 48 (Sub 48 transformer)	0.0538	1.2760	5	**11**	0.01	3.91	**0.2**
Richford 31 (Sub 31 transformer)	0.0540	1.2800	5	**32**	0.01	4.34	**0.2**
Jay Peak 40 T2 (Sub 40 2nd transformer)	0.0539	0.6480	10	**14**	0.01	4.21	**0.2**
North Troy 41 (Sub 41 transformer)	0.0731	1.7333	3.75	**14**	0.01	3.00	**0.2**
LH18 (W Charleston to Sw 93)	0.0730	0.2510		**18**	0.01	2.83	**0.2**
L418 (Eden to Belvidere)	0.2632	0.4220		**4**	0.00	0.82	**0.2**
L418 (Belvidere to Montgomery)	0.2554	0.4094		**4**	0.00	0.83	**0.2**
Sheldon 32 (Sub 32 12.47kV transformer)	0.0711	1.6842	3.8	**14**	0.01	2.75	**0.2**
Derby 45 (Sub 45 transformer)	0.0270	0.6430	10	**36**	0.01	6.25	**0.2**
Irasburg 42 (Sub 42 transformer)	0.0377	0.8947	7.5	**16**	0.01	4.56	**0.2**
Lowell 5 (Sub 5 transformer)	0.1160	1.4000	5	**6**	0.00	1.33	**0.2**
Jay Peak 40 T1 (Sub 40 1st transformer)	0.0440	0.6810	10	**4**	0.01	3.46	**0.2**
Burton Hill 43 (Sub 43 transformer)	0.0413	0.9867	7.5	**7**	0.00	3.35	**0.1**

East Berkshire 30 (Sub 30 transformer)	0.0365	0.8667	7.5	**13**	0.00	3.34	**0.1**
L463 (GMP tap to Sub 13)	0.1257	0.2015		**4**	0.00	0.93	**0.1**
Richmond 8 (Sub 8 transformer)	0.0533	0.7400	7.5	**5**	0.00	2.05	**0.1**
LH18 (Section just b4 IP Sub)	0.0356	0.0655		**7**	0.00	2.84	**0.1**
L200 (Sheldon Sub across river - generators)	0.0044	0.0100		**36**	0.03	26.70	**0.1**
LH16 (Sub 43)	0.0174	0.0377		**22**	0.01	5.88	**0.1**
Island Pond 47 2A (Sub 47 34.5kV transformer)	0.0258	0.5925	12	**2**	0.00	3.11	**0.1**
LH18 (2 sections beyond Sw 93)	0.0289	0.0433		**6**	0.00	2.84	**0.1**
LH18 (section after Sw 93)	0.0248	0.0542		**5**	0.00	2.84	**0.1**
Newport T4	0.0192	0.4563	22.4	**10**	0.00	4.11	**0.1**
L200 (Short Section to Hydro from across river)	0.0029	0.0067		**24**	0.02	26.72	**0.1**
LH18 (Derby Sub tap to the Sub)	0.0087	0.0200		**10**	0.00	5.66	**0.1**
Williston 9	0.0146	0.5288	100	**3**	0.00	2.95	**0.0**
L250	0.0044	0.0100		**14**	0.00	6.68	**0.0**
LH16	0.0029	0.0063		**4**	0.00	5.89	**0.0**
LC41	0.0029	0.0067		**2**	0.00	3.80	**0.0**

4.2 Distribution

EPRI found that distribution system losses for the US utilities ranged from 1.9 to 4.6 percent.

The following information is based on the analysis results table that can be found below:

The VEC distribution system has a 3.6 percent total distribution system loss which is about the middle of the identified EPRI range.

Individual VEC substation MWhr losses ranged from a low of 0.5 percent to a high of 6 percent with 9 of the 35 substations being above 4.6 percent.

Individual substation's peak load losses ranged from a low of 1.7 percent to a high of 6.9 percent with 10 of the 35 substations being above 4.6 percent.

Summary of Distribution System Loss Results:

					Load Point 1			
VEC Substation	**#**	**Annual Load (MWH)**	**Annual Losses Estimated (MWH)**	**% losses of MWH load**	**loss Peak (kW)**	**NLL (kW)**	**Loading (kVA)**	**% losses based on Loading**
FAIRFAX	1	11347	**468**	**4.1**	113.00	27.84	3054.12	**4.6**
EDEN	2	8858	**386**	**4.4**	42.00	23.04	1760.27	**3.7**
CAMBRIDGE	3	7617	**344**	**4.5**	54.00	22.27	1816.82	**4.2**
UNDERHILL	4	4772	**196**	**4.1**	23.00	14.17	1072.68	**3.5**
LOWELL	5	6244	**288**	**4.6**	25.00	19.99	1181.22	**3.8**
ST. ROCKS	6	6488	**391**	**6.0**	82.00	17.62	1850.13	**5.4**
MONTGOMERY	7	4107	**192**	**4.7**	25.00	13.72	899.69	**4.3**
RICHMOND	8	3623	**182**	**5.0**	**37.0**	12.18	1164.14	**4.2**
TAFTS CORNERS	9	12840	**425**	**3.3**	**76.0**	19.76	2710.29	**3.5**
JERICHO	10	5178	**104**	**2.0**	**13.0**	6.74	1137.17	**1.7**
WESTFORD	11	4211	**157**	**3.7**	**22.0**	10.39	891.61	**3.6**
FAIRFAX 12	12	5461	**249**	**4.6**	42.00	12.07	1097.24	**4.9**
PLEASANT VALLEY	13	4549	**170**	**3.7**	16.00	14.91	1109.82	**2.8**
JOHNSON	14	5529	**214**	**3.9**	27.00	15.77	1171.23	**3.7**
MADONNA	15	14513	**269**	**1.9**	90.00	14.67	6058.12	**1.7**
JAY	17	4616	**168**	**3.6**	9.00	14.76	924.18	**2.6**
HINESBURG	19	24617	**825**	**3.4**	156.00	45.09	5198.59	**3.9**
ST. ALBANS	20	819	**24**	**3.0**	3.00	2.41	277.54	**1.9**
HIGHGATE SPRINGS	27	2430	**44**	**1.8**	10.00	3.35	744.83	**1.8**
SO. ALBURGH	28	23734	**1120**	**4.7**	411.00	37.71	6531.02	**6.9**
SO. HERO	29	25053	**772**	**3.1**	161.00	42.75	6019.61	**3.4**
EAST BERKSHIRE	30	16864	**883**	**5.2**	161.00	33.62	3295.05	**5.9**
RICHFORD	31	21500	**517**	**2.4**	58.00	17.52	3439.82	**2.2**
SHELDON	32	13182	**598**	**4.5**	127.00	21.51	2635.62	**5.6**
JAY PEAK	40	12304	**62**	**0.5**	137.00	3.53	4268.59	**3.3**
NO. TROY	41	10790	**543**	**5.0**	84.00	23.68	2270.14	**4.7**
IRASBURG CZN	42	18584	**843**	**4.5**	121.00	37.52	3396.65	**4.7**
BURTON HILL	43	11762	**583**	**5.0**	128.00	26.44	2743.29	**5.6**
NEWPORT	44	51707	**1172**	**2.3**	229.00	35.52	8721.23	**3.0**

DERBY	45	33678	**1048**	**3.1**	233.00	33.90	6397.32	**4.2**
ISLAND POND EAST	46	6357	**321**	**5.0**	81.00	12.65	1822.32	**5.1**
ISLAND POND WEST	47	8940	**335**	**3.7**	45.00	17.59	1638.53	**3.8**
W. CHARLESTON	48	13319	**720**	**5.4**	111.00	25.97	2440.01	**5.6**
NORTON	50	2483	**100**	**4.0**	8.00	5.37	373.27	**3.6**
CANAAN	51	10884	**163**	**1.5**	40.00	7.51	2722.64	**1.7**
System Totals:		418960	**14873**	**3.6**	3000.00	693.54	92834.80	**4.0**

5 Recommendations

5.1 Transmission

VELCO's reported losses were sorted by greatest "% losses based on loading". Following were their overall observations:

1. High losses on transformers loaded near their nameplates such as Hinesburg #19.
2. High losses long sub-transmission lines with small conductor such as the L31 Highgate – Enosburg 46 kV.
3. High losses on sub-transmission lines connected to generation such as LC43, Crossroads – Lowell #5.
4. Much lower losses on a significant portion of the VEC system.

Taking these items in turn:

5.1.1 High losses on transformers loaded near their nameplates:

Hinesburg transformer: The Hinesburg substation has 3, 2,500kVA single phase transformers for a total three phase capacity of 7.5MVA. The percent losses based on peak loading are 0.5%. Losses at peak loading are 30kW. Total Annual Estimated Losses are 68MWHrs. VEC is aware of this transformer loading which is caused by a combination of native VEC loads of approximately 3-4MVA, GMP meter point load of approximately 2MVA, and the 2MW battery storage project's charging requirements. These loads are within the transformer's nameplate ratings and the transformer is monitored to ensure it doesn't exceed nameplate ratings. A transformer is its' most efficient in terms of losses at 100% of nameplate ratings.

Recommendations: No capital improvements have been identified or recommended at this time.

5.1.2 Long sub-transmission lines with small conductor:

L31 line between VELCO Highgate and VEC Enosburg:

From Highgate to Enosburg Substation are 13.5 miles of 1/0 ACSR Raven conductor and from Enosburg Substation to Richford Substation are 4 miles of 1/0 ACSR Raven conductor. The percent losses based on peak loading are 4.3%. Losses at peak loading are 300kW. Total Annual Estimated Losses are 1,035MWHrs.

The line is a combination of single wood pole with flat crossarms and horizontal line post insulator construction. The line is mostly single wood pole with flat crossarm construction. The pole vintages are late 1980's ('88-'89).

Recommendations: Reconductor 46kV sub-transmission line from VELCO Highgate to VEC Enosburg with 336 Linnet conductors. The line needs maintenance due to repeated insulator failures causing disturbances to Westrock operations. For this reason and the higher amount of system losses, it is VEC's highest priority from a sub-transmission line improvement perspective.

Estimated Cost and Results: Assuming the pole plant is mostly passable the cost per mile to replace cross-arms, insulators and conductor will be about $110k / mi (based on H16 1A reconductoring to 336 ACSR w/o OH's). 13.5 miles from Highgate to Enosburg x $110k / mi = $1,485,000.

Reconductoring to 336 Linnet would produce loss savings of approximately 832MWhr's / year, which amounts to approximately an 80% reduction in losses from the existing conductor. The peak losses would reduce by approximately 80% or from 300kW to 60kW.

From Craig Kieny: If 800 MWh/s year reduce, we would be talking likely in the $32,000 - $35,000/year savings in energy, plus call it 100 kW savings at VT peak each month on average, which would be another $12,000/year.

In summary loss savings could be, conservatively, approximately $44k / year.

VELCO Highgate to VEC Sheldon L200 & L250:

These line conductors were identified in the SHEI solutions study along with the VEC Sheldon 46:34.5kV transformer used to back-up GMP line to St. Albans and the GMP Sheldon substation located nearby as an additional export interface. The resulting line losses due to the Westrock load and Enel generation to and from Highgate are 1.6% and 0.6% of peak loads respectively which is acceptable compared to L31 and all other sub-transmission lines.

Recommendations: No capital improvements have been identified or recommended at this time, however, VEC has approached both GMP and VELCO and will continue to discuss the possibility of upgrading the 46:34.5kV transformer in our Sheldon substation in order to support the SHEI flows to St. Albans per the VELCO study and/or to 'phase' the 34.5kV from Sheldon with GMP's St. Albans source. Presently a 'dump pick-up' is required to close and use the 34.5kV transformer source from Sheldon due to a 30° phase shift in the Sheldon transformer (winding configuration).

Swanton Village tap to VEC South Alburgh substation L200:

This 46kV sub-transmission line is approximately 14 miles long and contains #2 conductor. The losses as a percentage of peak load are 1.6%.

Recommendations: No capital improvements have been identified or recommended at this time. The VAOT has planned to widen Route 78 for years and subsequently relocate a portion of this line. VEC has land rights for the VAOT to expand the road into and still maintain the VEC relocated sub-transmission line within our existing easement corridor. VAOT would fund the cost of this relocation work and VEC would benefit by installing larger conductor. For this reason, scheduling has become an issue, if VEC were to rebuild this portion of line in place at its' sole costs, VAOT would need to reimburse VEC to relocate the new line further off the roadway to accommodate their road widening project.

5.1.3 High losses on sub-transmission lines connected to generation:

From C43 breaker at Jay Tap to Lowell substation #5: VEC is aware of higher losses on the sub-transmission system associated with large generators such as KCW. Since losses are a square function of line currents, large line currents result in higher losses however, losses as a percentage of loading is within tolerance due to the relatively large conductor size and hence lower conductor resistances to transmit the power.

Recommendations: No capital improvements have been identified or recommended at this time.

5.1.4 Lower losses on a significant portion of the VEC system:

All remaining sub-transmission lines and substation transformers identified in the loss study had losses of 1.1% or less of their respective peak loadings. This is an indication that these sub-transmission line conductors and substation power transformers are adequately sized to deliver peak loading power efficiently and with relatively low power losses.

Recommendations: No capital improvements have been identified or recommended at this time.

5.2 Distribution

While there are some approaches to loss reduction that can be applied system-wide, such as load balancing and power-factor correction, most efficiency improvements are evaluated on a case-by-case basis.[1]

Based on the work performed by the New York utilities, EPRI, and SAIC, as well as their reviews of other industry studies, electric losses can be reduced by system improvements on the distribution system. Generic or case-specific cost/benefit analysis is required to justify required expenditure for these system improvements.[1]

Their findings for the distribution system:

1. Phase balancing reduces line and neutral conductor losses.[1]
2. Distribution capacitor banks on the feeders to improve the feeder power factor reduces line losses.[1]
3. Capacitor banks at or near the substation improve the station power factor caused by the substation power transformer VAR requirement, measured at the high side of the power transformer and reduce load losses in the substation transformer.[1]
4. Use of life-cycle evaluation for equipment sizing (initial installation of distribution transformers and conductors) reduces transformer core and coil losses.[1]

VEC already incorporates the above items into their existing system planning functions, particularly (1.-3.) within the 'System Load and Voltage Study' and (4.) with the transformer loss evaluations for both large and small transformer purchases and a conductor sizing standard taking losses into account. Capacitors are a least cost solution to reduce line currents by improving power factor at the load level and hence line losses. They are widely used as a least cost solution to improving system line voltages and utilized widely in the VEC distribution system.

There are areas where changes in operations or investment in equipment can reduce electric system losses; however, before taking corrective action, it is important for the utility to perform cost/benefit analyses to determine whether the proposed action is economical. Many loss-reduction techniques are not cost effective on their own but may be economical when system upgrades or improvements are made. [1]

As utilities make improvements to their systems to reduce losses, it can help to first identify the cause of losses and separate losses into technical and non-technical categories. Technical losses are due to the loading and electrical characteristics of the electrical system; non-technical losses are caused by factors outside the electric system, such as metering inaccuracies, billing errors, and energy theft. Distinguishing the cause and type of losses can help in developing appropriate strategies to mitigate them. [1]

The two main areas that utilities focus on to reduce losses are (1) replacing existing infrastructure and (2) changing design and planning criteria for future infrastructure investments to improve efficiency. The cost to replace existing infrastructure can be high compared to the cost savings through loss reduction; however, the incremental cost to build higher efficiencies into future capital projects could be low compared to efficiency gains.[1]

VEC plans to fully utilize the specific methods and results from this study to further improve upon its overall system planning functions and making capital infrastructure investment decisions. It is anticipated that its capital projects ranking methodology will incorporate a new weighting factor for power loss efficiency improvement.

To better understand and determine whether there were any significant non-technical losses within the VEC distribution system a comparison was made between the total power metered into the substations including distributed energy resources (DER) and the total iVUE metered load. 418,960MWhr substation + 45,363MWhr's of DER source power compared to 444,169MWhr's of iVUE metered load. This indicates a 4.54% distribution system loss which is within 1% of the modeled losses of 3.6% and still below the 4.6% high end of range found in the EPRI study.

Discussion of Results:

It is interesting to note that nearly 42 percent of the overall distribution system's MWhr losses come from the 'no-load' losses of the service transformers. No-load losses are caused by the magnetizing current needed to energize the core of the transformers, and don't vary according to the loading on the transformer. They are constant and occur 24 hours a day, 365 days a year, regardless of the load on the transformer. The largest contributor to no-load losses are hysteresis losses from the molecules in the transformer's core laminations resisting being magnetized and demagnetized by the alternating current's magnetic field. This resistance by the molecules causes friction that results in heating. The choice of size and type of core materials reduces hysteresis losses. VEC bids and purchases all system transformers based on a present value economic analysis of the total unit life cost of ownership and the present cost of energy for both load and no-load losses. The table below includes only no-load losses from the distribution service transformers:

VEC Substation	#	Annual Load (MWH)	Annual NLL Estimated (MWH)	% NLL of MWH load	loss Peak (kW)	NLL (kW)	Loading (kVA)	% NLL based on Loading
FAIRFAX	1	11347	**251**	**2.2**	0.00	27.84	3054.12	**0.9**
EDEN	2	8858	**205**	**2.3**	0.00	23.04	1760.27	**1.3**
CAMBRIDGE	3	7617	**201**	**2.6**	0.00	22.27	1816.82	**1.2**
UNDERHILL	4	4772	**126**	**2.6**	0.00	14.17	1072.68	**1.3**
LOWELL	5	6244	**177**	**2.8**	0.00	19.99	1181.22	**1.7**
ST. ROCKS	6	6488	**160**	**2.5**	0.00	17.62	1850.13	**1.0**
MONTGOMERY	7	4107	**122**	**3.0**	0.00	13.72	899.69	**1.5**
RICHMOND	8	3623	**109**	**3.0**	0.00	12.18	1164.14	**1.0**

TAFTS CORNERS	9	12840	177	1.4	0.00	19.76	2710.29	0.7
JERICHO	10	5178	60	1.2	0.00	6.74	1137.17	0.6
WESTFORD	11	4211	93	2.2	0.00	10.39	891.61	1.2
FAIRFAX 12	12	5461	108	2.0	0.00	12.07	1097.24	1.1
PLEASANT VALLEY	13	4549	132	2.9	0.00	14.91	1109.82	1.3
JOHNSON	14	5529	141	2.5	0.00	15.77	1171.23	1.3
MADONNA	15	14513	132	0.9	0.00	14.67	6058.12	0.2
JAY	17	4616	130	2.8	0.00	14.76	924.18	1.6
HINESBURG	19	24617	404	1.6	0.00	45.09	5198.59	0.9
ST. ALBANS	20	819	21	2.6	0.00	2.41	277.54	0.9
HIGHGATE SPRINGS	27	2430	30	1.2	0.00	3.35	744.83	0.4
SO. ALBURGH	28	23734	343	1.4	0.00	37.71	6531.02	0.6
SO. HERO	29	25053	381	1.5	0.00	42.75	6019.61	0.7
EAST BERKSHIRE	30	16864	302	1.8	0.00	33.62	3295.05	1.0
RICHFORD	31	21500	155	0.7	0.00	17.52	3439.82	0.5
SHELDON	32	13182	192	1.5	0.00	21.51	2635.62	0.8
JAY PEAK	40	12304	30	0.2	0.00	3.53	4268.59	0.1
NO. TROY	41	10790	210	1.9	0.00	23.68	2270.14	1.0
IRASBURG CZN	42	18584	334	1.8	0.00	37.52	3396.65	1.1
BURTON HILL	43	11762	236	2.0	0.00	26.44	2743.29	1.0
NEWPORT	44	51707	316	0.6	0.00	35.52	8721.23	0.4
DERBY	45	33678	303	0.9	0.00	33.90	6397.32	0.5
ISLAND POND EAST	46	6357	114	1.8	0.00	12.65	1822.32	0.7
ISLAND POND WEST	47	8940	157	1.8	0.00	17.59	1638.53	1.1
W. CHARLESTON	48	13319	230	1.7	0.00	25.97	2440.01	1.1
NORTON	50	2483	47	1.9	0.00	5.37	373.27	1.4
CANAAN	51	10884	67	0.6	0.00	7.51	2722.64	0.3
System Totals:		418960	6193	1.5	0.00	693.54	92834.80	0.7

System Improvement discussion:

Island Pond East or the 2A feeder was investigated further due to its' unique characteristic of serving a sizeable 7.2kV load at Guildhall that represents approximately 22% of the total peak load on the 19.9kV distribution feeder. The model was run with the Guildhall load opened to see the effect on losses.

					Load Point 1			
VEC Substation	**#**	**Annual Load (MWH)**	**Annual Losses Estimated (MWH)**	**% losses of MWH load**	**loss Peak (kW)**	**NLL (kW)**	**Loading (kVA)**	**% losses based on Loading**
IP 2A without Guildhall	46	5582	123	2.2	46.00	6.55	1503.21	3.5
ISLAND POND EAST	46	6357	321	5.0	81.00	12.65	1822.32	5.1

Losses dropped by 1.6% in table above. The difference in annual MWhr savings was 198MWhr's. At an estimated $43/MWhr, the annual loss savings by serving Guildhall from Eversource is approximately $8,514.

A second 833kVA stepdown transformer in Bloomfield and an additional phase conductor was installed (early 2021) down to the Maidstone Lake tap (Hall Road) as an express to carry Guildhall load separate from Maidstone Lake load on the existing phase.

The Milsoft Windmil model for the 2A was adjusted to show the peak load on the Guildhall tap line out of Bloomfield and a new loss comparison was made between the single and two-phase scenarios to see the difference in total losses.

VEC Substation	#	Annual Load (MWH)	Annual Losses Estimated (MWH)	% losses of MWH load	loss Peak (kW)	NLL (kW)	Loading (kVA)	% losses based on Loading
2A with added ph to Guildhall		6357	**338**	**5.3**	131.00	12.53	2240.92	**6.4**
ISLAND POND EAST	46	6357	**385**	**6.0**	153.00	12.46	2243.68	**7.4**

Losses dropped by 1.0% from table above. The difference in annual MWhr savings was 47MWhr's. At an estimated $43/MWhr, the annual loss savings by adding a second phase to split the load is approximately $2,021.

It should be noted that the justification to add the second phase was due to VEC planning criteria for single phase maximum loading being exceeded by 2.5 times (100A load with 40A criteria) and the low voltage conditions being experienced at Maidstone and Guildhall during peak times. The planning criteria drove the phase addition and the second phase solved the low voltage condition. The planning criteria is still exceeded, but to a much lesser extent. A 1% drop in feeder losses by adding the second phase would also bring down the feeder's percent losses to 4.1 bringing the feeder in line with the US average range of 1.9 to 4.6 percent.

Reconductoring of the existing single phase was modeled to determine the effects on losses and compare to the previous modeled results. The table below includes both the addition of a second phase and reconductoring of the existing single phase to 336 ACSR primary and neutral conductor.

VEC Substation	#	Annual Load (MWH)	Annual Losses Estimated (MWH)	% losses of MWH load	loss Peak (kW)	NLL (kW)	Loading (kVA)	% losses based on Loading
2A with added ph to Guildhall		6357	**338**	**5.3**	131.00	12.53	2240.92	**6.4**
ISLAND POND EAST	46	6357	**385**	**6.0**	153.00	12.46	2243.68	**7.4**
Reconductor 1 ph to 336ACSR		6357	**315**	**5.0**	103.00	12.67	2260.83	**5.1**

Losses dropped by 2.3 percent from above table compared to existing single-phase losses and 1.3 percent compared to adding a second phase conductor. The incremental difference in MWhr savings from reconductoring the phase conductor was 23MWhr's. At an estimated $43/MWhr, the incremental annual loss savings from reconductoring as opposed to adding a second phase is approximately $989 or approximately 50 percent more savings than adding a second phase however, this incremental cost benefit is not significant enough to justify reconductoring over adding a new phase conductor.

When comparing the two possible options, adding a second or third phase as compared to reconductoring the primary and neutral conductors of an existing single phase, construction cost differences should be considered. Larger and heavier single-phase conductors just as often lead to pole changeouts and additional guying requirements as do add additional conductor phases. The primary and neutral currents drop in half with the addition of a second phase assuming relatively balanced loads between the two phases can be accomplished. For the reconductored phase and neutral option, the same primary and neutral return currents would exist, just with a lower conductor resistance due to the larger conductor being installed. Since conductor losses are the product of line currents 'squared' multiplied by conductor resistance, reducing primary and neutral line currents has a squared logarithmic reduction in losses as compared to lowering the conductor resistance. The loss reduction benefits of installing two or more phases would be increased by this same 'current squared' function as line loading increases. Two-phase power is able to serve approximately two-thirds more load than single phase without increasing losses.

The goal of the power system being to provide reliable, least cost power with a load balanced three-phase power system model having the greatest load carrying capability with the lowest amount of individual phase and neutral current losses, from a line loss perspective, VEC's system planning criteria to add a second or third phase where feasible and when existing single-phase peak loads exceed 40 Amps is a more reasonable investment as compared to reconductoring single phase with larger conductors.

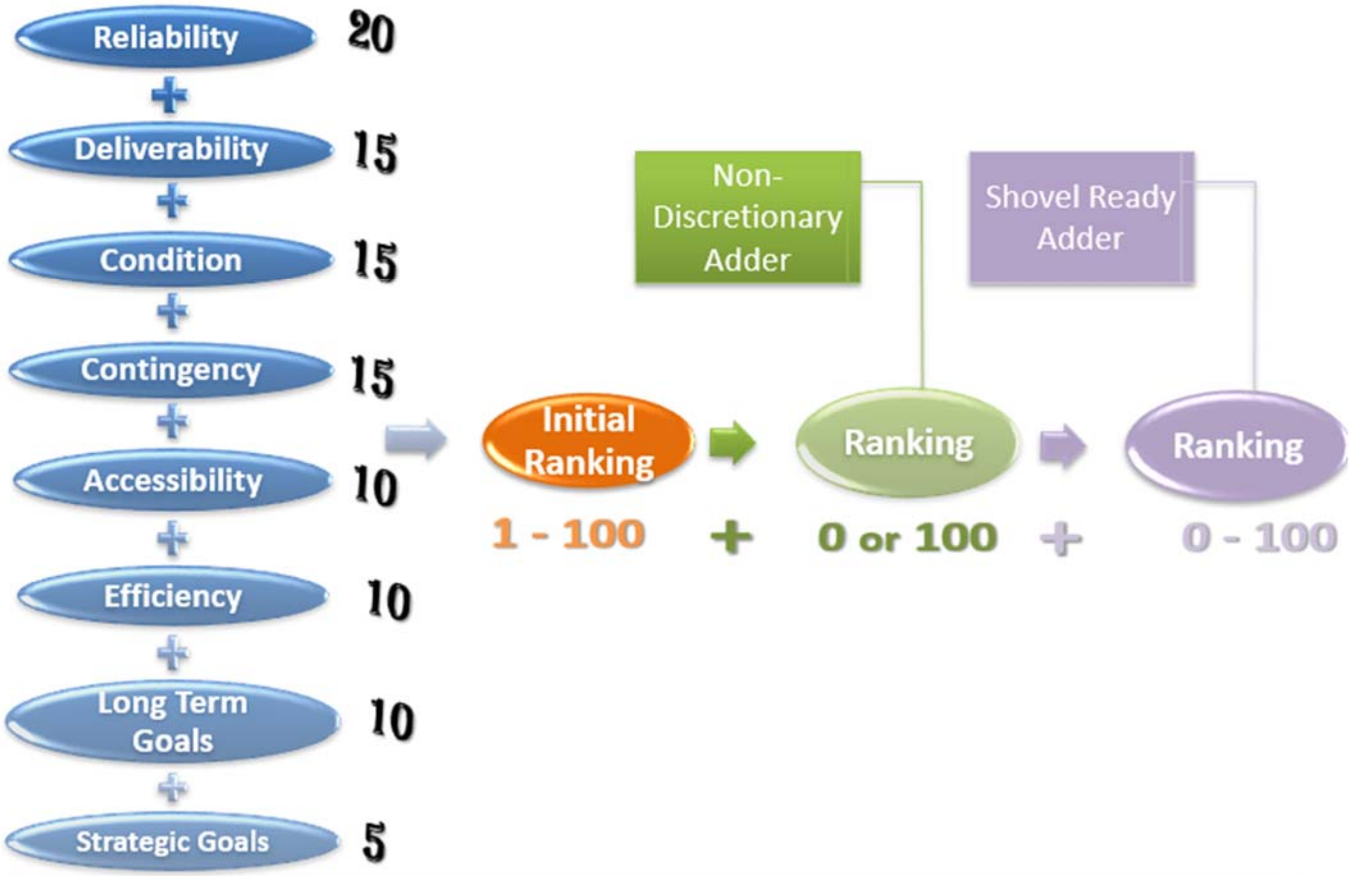
6 Next Steps

Since this loss study encompasses the entire VEC owned transmission and distribution system and the results fall within the national range for all utilities as determined by EPRI and validated by independent sources; the need to replicate the study is not anticipated in the foreseeable future. Furthermore, only a very significant portion of the system loading and/or equipment efficiency make-up would necessitate a completely new study be performed.

VEC has access to Packetized Energy's proprietary software which is much like the Milsoft Windmil software being utilized now but with the added capability to more easily breakdown power losses by 'primary conductors', service and stepdown 'transformers' and 'secondary conductors' over a wider range of load data points.

VEC plans to utilize the Packetized software as a tool to help better quantify how individual system improvements and alternatives impact efficiency and power losses and incorporate that information into project prioritization and ranking criteria depending on results.

The following chart shows VEC's new IRP project prioritization scheme to incorporate power efficiency.



- The maximum value for the Efficiency metric is 10 points.
- The table below is used to calculate the Efficiency value.

Value	Description
0	Project does not impact losses or increases losses
1	Project decreases losses

7 Loss Study Addendum:

South Alburgh substation review:

South Alburgh substation is the second highest peak loaded substation in the VEC system at 6,531kW's with the fourth highest MWhr's delivered at 5.7%, ranked the highest in losses as a percentage of its' peak loading at 6.9% and eighth in kWhr losses as a percentage of its' total kWhr's served at 4.7%. It ranked first in losses of its' peak loading as a percentage of the system loading at 13.7% and second in kWhr losses as a percentage of system kWhr losses at 7.5%. In comparison, Newport, the highest peak loaded substation at 8,721kW's with the highest MWhr's delivered at 12.3%, ranked twenty-seventh in losses as a percentage of its' peak loading at 3% and thirtieth in kWhr losses as a percentage of its' total kWhr's served at 2.3%. It ranked third in losses of its' peak loading as a percentage of the system loading at 7.6% and first in kWhr losses as a percentage of system kWhr losses at 7.9%

South Alburgh's load losses accounted for 92% of its' total losses during load peaks and nearly 58% during load dips. East Berkshire in comparison, the next highest ranked in total losses as a percentage of peak loading, had 10% lower load losses during its' load peak and approximately the same percentage as South Alburgh during its' load dips.

South Alburgh's 1A feeder load losses represented approximately 70% of the total substation's load losses and 49% of its' no-load losses. Of the two remaining feeders, the 4A's load losses represented approximately 81% of the remaining load losses and 45% of the remaining no-load losses.

Below is a table of the loss results comparing three targeted reconductoring projects on the 1A and one reconductoring project on the 4A. Rte. 78 West reconductored approximately 1.6 miles of #2 ACSR primary and neutral to 336 ACSR primary and neutral and Rte. 78 East reconductored approximately 0.7 miles of #2 ACSR primary and neutral to 336 ACSR primary and neutral. Both sections had at least 4/0 primary back to the source. The third reconductoring was the 1/0 neutral from the substation to where it changed to 4/0, a distance of approximately two miles.

The 4A improvement was to model reconductor approximately one-mile of 1/0 primary and neutral to 336 ACSR primary and neutral from the substation to Summit Road where the feeder splits from the 3A headed to Isle La Motte.

There are sections of #4 cu further downline from Rte. 2 to Isle La Motte that were modeled with 336 ACSR primary and neutral and compared to reconductoring from the substation to Summit Road; no significant differences were found in the results although some improvement was made. The 1A was modeled as being reconductored from 4/0 to 556 ACSR primary and neutral from the substation to Rte. 78; no significant differences were found although results were similar to the combined 1A and 4A reconductoring models.

VEC Substation	#	Annual Load (MWH)	loss Peak (kW)	NLL (kW)	loss Period (kWH)	Loading (kVA)	% losses based on Loading
SO. ALBURGH Base-case	28	23734	493.00	37.76	530.76	6584.56	**8.1**
Reconductor Rte. 78 W		23734	485.00	37.84	522.84	6500.07	**8.0**
Add Reconductor Rte. 78 E		23734	468.00	38.05	506.05	6483.42	**7.8**

1A improvements							
So Alburgh 1A		23734	322.00	18.61	340.61	3586.62	**9.5**
Reconductor Rte. 78 W		23734	289.00	18.67	307.67	3688.44	**8.3**
Add Reconductor Rte. 78 E		23734	280.00	18.87	298.87	3653.59	**8.2**
Reconductor 1A neutral to Rte. 78		23734	277.00	18.88	295.88	3672.36	**8.1**
So Alburgh base-case with all 1A improvements made		23734	414.00	38.03	452.03	6561.16	**6.9**
4A improvements							
Base-case with 4A reconductor from sub to Summit Rd (old sub)		23734	480.00	37.77	517.77	6495.16	**8.0**
So Alburgh base-case with all 1A and 4A improvements made		23734	400.00	38.04	438.04	6567.28	**6.7**
Base-case with 4A improvements not captured anywhere above							
Regulators/capacitors at Isle La Motte		23734	486.00	38.54	524.54	6501.48	**8.1**
Reconductor #4 cu Upper Isle La Motte		23734	475.00	37.94	512.94	6490.22	**7.9**
Reconductor #4 cu Lower Isle La Motte		23734	456.00	38.17	494.17	6471.38	**7.6**
Reconductor both #4cu sections to Isle La Motte		23734	441.00	38.32	479.32	6456.43	**7.4**
Reconductor 1A from sub		23734	429.00	37.99	466.99	6444.73	**7.2**

The 1A feeder reconductoring model showed a 1.5% improvement in losses with all the aforementioned 1A feeder improvements modeled and a 1.2% improvement to the substation as a whole. An additional 0.2% improvement was achieved when including the 4A reconductoring to Summit Road. Considering the estimated total costs for these improvements being nearly $700k, the incremental improvement in losses appears negligible.

Furthermore, the impact on voltage from the improvements weren't overly significant; amounting to approximately a 1V improvement (on 120V base) with the 4A reconductoring from 1/0 to 336 and all three 1A improvements resulted in some locations showing less than 1V improvement to approximately a 2V improvement at other locations. A 100kVAr capacitor addition would improve the line voltage by at least as much.

This analysis appears to show that reconductoring projects to lower losses on the distribution system aren't an effective tool for specifically identifying needed system improvements, that the Voltage and Load planning tools are much more effective at identifying system improvements that lead to higher member satisfaction at the least cost.

St. Rocks substation review:

St. Rocks substation is the median loaded substation in the VEC system at 1,850kW's with the twenty fourth highest MWhr's delivered at 2.5%, ranked sixth in total losses as a percentage of its' peak loading period at 5.4% and first in kWhr losses as a percentage of its' total kWhr's served at 6%. It ranked fourteenth in losses of its' peak loading as a percentage of the system loading at 2.7% and fifteenth in kWhr losses as a percentage of system kWhr losses at 2.6%.

The 2A feeder represents approximately 82% of the substation's peak loading losses, with 84% of the load and 72% of its' no-load losses. The three-phase feeder is relatively well balanced at peak with phase loading of 69, 59 and 66 Amps and 6.5 Amps in the neutral.

The three-phase back-bone of the feeder is made up of 4/0 ACSR primary with a mix of 4/0 and 1/0 AAAC neutral for most its' length, then to 1/0 primary and neutral near the very end. It then turns to two-phase with 1/0 AAAC primary and neutral.

Two single phase lines both down-line from two phase lines, Egypt Road (opposite side of 2J10) and Kittell Road (opposite side of 2D2) have 45 and 43 Amps respectively and hence violate VEC's planning criteria of 40 Amps limit on single phase lines. A model of Phase B and C were extended down Egypt Road and Phase A and B down Kittell Road balancing the loads between phases. The loss report showed no change from base-case. The single-phase at the lower end of Kittell Road with 21 Amps of load on it has a conductor size of #4AWAC that was changed in the model to 1/0 AAAC and the loss report still showed no change from base-case.