factors were applied to both steps. Two VO scenarios labeled Plans A and B were evaluated to compare the benefits of alternative levels of energy efficiency.

The initial step of "total feeder prioritization" classified 3,757 feeders out of ComEd's total population of approximately 5,650 feeders using a simplified load flow analysis of feeder characteristics involving load type, load density, feeder lengths, existing voltage control settings, real and reactive loads, line voltage drops and losses, line regulators installed, and conductor loading. Feeders were categorized as viable or non-viable for VO implementation, and viable feeders were prioritized based on a potential voltage-reduction magnitude-sensitivity impact analysis, and subsequent energy savings potential.

For the "sample feeder detailed analysis", a sample of 70 feeders from 16 substations was selected using a stratified random sampling approach to fairly represent the total feeder population. Detailed analyses of planning and loadflow simulations were performed to determine expected annual energy savings (kWh) and peak power reductions (kW) for each of two VO scenarios. This sample feeder analysis included an assessment of system upgrades between the existing system and VO-modified plans, including benefits/costs for each VO scenario, which were then extrapolated back to the total ComEd system level using statistical ratio estimation techniques linking the sample group, study group, and system population. In addition, a recommended VO pilot project was outlined to demonstrate the proposed VO implementation strategies, verify estimated VO factors, and develop simplified VO M&V procedures for ComEd's distribution system.

It is important to note that the study is not an implementation plan for VO. In fact, the results are statistically valid, but represent an instant change from current operations to one where VO is implemented fully and effectively on each viable feeder.

C. Feasibility Study Results

The Commonwealth Edison Voltage Optimization (VO) Feasibility Study Final Report ("VO Feasibility Study Report"), dated January 6, 2015 and prepared by AEG, is attached hereto in Subsection F.

<u>Key AEG Feasibility Study Findings</u>

- ✓ VO is likely to be cost-effective for viable feeders
  - The high level estimated potential Total Resource Cost (TRC) benefit cost ratio for viable feeders ranges from 2.2 to 2.3
- ✓ Deployment costs are primarily to increase feeder efficiency, minimize voltage drop and monitor last customer and system voltages
- ✓ ComEd has a relatively efficient feeder design
- ✓ Existing voltage regulation practices provide an opportunity for voltage reduction
- ✓ Approximately 50% of all ComEd feeders are believed to be viable for VO (2,890 of 5,655 feeders)

- Viable feeder criteria - 12kV feeders that supply residential and small C&I customers
- Non-viable feeders continue using traditional voltage regulation

Summary of Feasibility Study Analysis

	Plan A (Reduced Cost)	**Plan B (Greater Savings)**
Potential VO Savings • **Energy (GWh/year)** • **Peak Load (MW)**	1350 260	1900 360
Total VO Estimated Costs	$425 M	$575 M
VO Program TRC	2.20	2.30
Levelized Cost of Energy Saved ($/kWh)	$0.0193	$0.0185
Number of Viable Feeders	2890	2890
Average Energy Savings per Viable Feeder (MWh/yr)	470	660
Average VO cost per feeder	$150 K	$200 K
Average Voltage Reduction	3.0%	3.8%

Key AEG Feasibility Study Recommendations

✓ Design/Implement VO verification project(s) to validate:
- Method used to estimate energy savings
- Residential and commercial VO factor assumptions
- Test voltage optimization strategies
- Validate Line Drop Compensation (LDC) voltage control schemes
- Test End of Line (EOL) voltage feedback for overriding LDC controls
- Switched capacitor VAR control schemes
- Measurement and Verification protocol
- Effectiveness of Integrated Volt VAR Control (IVVC) applications

✓ Develop and implement VO analysis training, operations, and maintenance materials

✓ Improve VAR management with small capacitor banks using controls with VAR sensing

✓ Install EOL voltmeters on every VO feeder and voltage control device at the lowest voltage location

- ✓ Examine AMI voltage/loading data to determine actual feeder voltage drop and load profiles to determine the need to upgrade distribution transformers.

D. Planned ComEd Validation Project

Based on the VO Feasibility Study Report and the AEG Recommendations, ComEd plans to conduct a VO Validation Project as follows:

- ✓ Conduct a validation project to confirm annual estimated energy savings, deployment costs and implementation technologies for at least 2 substations with 4-to-6 feeders each
  - Selected feeders will represent urban, suburban and rural areas and will contain those evaluated by AEG with both higher and lower benefit-cost ratios
- ✓ Evaluate and select appropriate VO technologies at the validation substations
  - Validate both LDC and IVVC control technologies
- ✓ Begin VO operations of the validation project in 2016. It is anticipated that data collected over a 12-month operating period will be sufficient to validate the assumptions and conclusions reached in the feasibility study. Additional data collection and evaluation for a period of up to 12 months may be necessary if unanticipated operational issues arise during the validation project.
- ✓ Assess and report learnings from the results of the validation project

E. Budget and Cost Recovery

A preliminary estimate of the cost of the validation project is $2,000,000. As indicated above, the estimated cost to fully implement VO is expected to be in the range of $425-575 million. This amount may exceed what is available in the AMI budget. Therefore, at some point prior to full implementation, an appropriate cost recovery mechanism will need to be considered and addressed. ComEd notes that proposed legislation was introduced on March 19, 2015 (currently, Amendment 1 to Senate Bill 1879; Amendment 1 to House Bill 3328) that revises the Public Utilities Act to expressly address voltage optimization as an energy efficiency measure. The proposed Bills would find that "Voltage optimization is an energy efficiency measure that can deliver cost-effective energy savings for all retail customers, including low-income customers." (220 ILCS 5/16-108.11(a) new) They would also authorize utilities to file plans with the Commission for the implementation of "cost-effective voltage optimization on identified elements of its electric delivery system," subject to Commission review, and make clear that the costs of implementing voltage optimization, as well as validation of VO, shall be recovered through Article IX rates or under Section 16-108.5 of the Public Utilities Act. (220 ILCS 5/16-108.11(b) new). Going forward, the continued implementation of voltage optimization would be addressed in ComEd's energy efficiency assessments. (220 ILCS 5/8-103 (b-5); 220 ILCS 5/16-108.11(d) new). ComEd supports these Bills, as proposed.

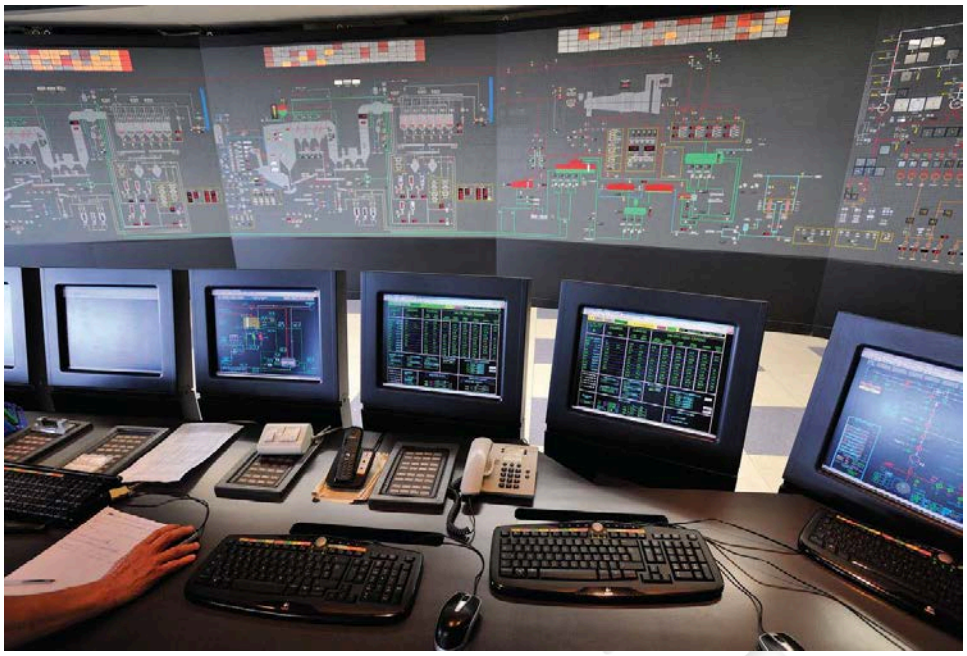
F. VO Feasibility Study Final Report

The VO Feasibility Study Final Report is attached below.

Report specifically developed for:

Commonwealth Edison Company

March 9, 2015



Voltage Optimization (VO) Feasibility Study

Final Report

Contract No. 01146430

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Distribution Feeder VO Screening
Potential VO Energy Savings and Cost Impacts

TASK 10: **Final Report**

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Contract No. 01146430

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All observations, conclusions, and recommendations contained herein attributed to AEG and UPS, and are the opinions thereof with no assurances. To the extent this information was provided by clients or others and used in the preparation of this study, AEG and UPS relied on same to be accurate, but gives no assurances or guarantees.

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1. Executive Summary

The Applied Energy Group (AEG) was contracted by Commonwealth Edison Company (ComEd) under Contract No. 01146430 to conduct an investigation of the feasibility and potential of energy savings and peak power reductions on ComEd's power system through systematic deployment of voltage optimization techniques and technologies. Voltage Optimization (VO) is defined to be a combination of Conservation Voltage Reduction (CVR) and Volt-VAR Optimization (VVO). VVO coordinates capacitor bank operation to reduce distribution losses and improve power factors. CVR initiates a systematic reduction of end-user voltages using load tap changers, line drop compensation, voltage regulators, and capacitors to reduce energy consumption.

The Illinois Commerce Commission (ICC) directed ComEd to conduct a feasibility study of adopting VO in the final order of Docket No. 13-0495 (2013 Energy Efficiency Plan). These programs are intended to reduce end-use customer energy consumption and peak demand while reducing utility distribution system energy losses. AEG conducted a feasibility study on ComEd's electric distribution system to quantify potential VO savings.

A primary objective of the study was to assess the magnitude of customer end-user and utility benefits available from two VO scenarios: A minimum cost VO scenario (Plan A) based on feeder upgrades required to bring the system up to ComEd defined performance standards; and a maximum savings scenario (Plan B) designed to optimize VO savings within the constraints of ComEd's Total Resource Cost (TRC) benefit-cost thresholds. In all cases, existing ComEd distribution system planning/design and operation guidelines were strictly followed. Not addressed was the impact of end-use energy savings on ComEd's distribution revenues and associated cost recovery.

1.1 Key Findings

- The potential to achieve cost-effective energy savings and demand reductions from VO on the ComEd distribution network is substantial. The study found cost-effective energy savings of as much as 1900 GWh-yr, equal to approximately 2% of ComEd's retail sales, at a cost of approximately $0.0185/kWh. This is roughly equivalent to ComEd's entire energy efficiency (EE) program goals for the next three years at a cost below most other EE program options.

- It is estimated 515 substations (64%) and 2,890 feeders (51%) are viable candidates for VO implementation with an average savings per viable feeder of 3.5%. This high savings estimate relative to other utility VO programs can be attributed to a number of factors, including low voltage drops across feeders due to short runs, relatively good system efficiencies (good phase and load balancing), favorable end-use load composition (low saturation of electric resistance heat), and current voltage settings (conservatively high).

- The primary determinants of feeder VO non-viability were voltage level (>25kV and <11kV

urban networks were excluded), and customer class (large commercial and industrial loads are not good VO candidates).

- A majority of the distribution system requires efficiency upgrades (best industry practices) for VO to be effective. For example, Plan A (minimum cost plan) requires a $425 million investment to allow average voltages at the customer meter to be reduced by 2.96%, accounting for the majority of energy savings.

- ComEd design guidelines specify maximum secondary voltage drops of 6.0 volts. However, for the VO study, a utility best practice of 3.6 volts was used (or 3% on a 120-volt base) to allow potential energy savings to be maximized.

- The maximum energy savings (Plan B) can be achieved by investing an additional $150 million – a total of $575 million – over Plan A, resulting in an average voltage reduction of 3.81%. The incremental Plan B investments increase the total program TRC B-C ratio from 2.20 to 2.30.

- Isolating non-viable feeders from viable feeders at the same substation (and voltage control zone) is one of the key challenges to VO implementation. The use of IVVC rather than physical space-prohibited substation voltage regulator banks is the recommended feeder isolation solution.

- Capital cost recovery, lost revenue adjustments, and energy efficiency program inclusion are key regulatory hurdles for ComEd's VO strategy.

1.2 Approach

AEG's approach was designed to provide ComEd with the following benefits:

- Reliance on proven, industry standard modeling and engineering methods that have been used at other utilities similar to ComEd.

- Efficient use of ComEd's existing CYME distribution data sets to ensure timely and cost-effective results.

- Robust statistical techniques yielding representative and defensible system-level VO benefits and costs, appropriate for regulatory submittal.

- National perspectives on VO activities based on the collective experience of the AEG team.

AEG's methodology followed two major steps: 1) "Total feeder prioritization" of potential candidates; and 2) "Sample feeder detailed analysis" using load-flow simulations. Estimated VO factors were applied to both steps.

Fourteen (14) of ComEd's 19 operating regions were included in the study group. The initial step of "total feeder prioritization" classified 3757 feeders out of ComEd's total population of approximately 5650 feeders[1] using a simplified load flow analysis of feeder characteristics involving load type, load density, feeder lengths, existing voltage control settings, real and reactive loads, line voltage drops and losses, line regulators installed, and conductor loading. Feeders were categorized as viable or non-viable for VO implementation, and viable feeders were prioritized based on a potential voltage-reduction magnitude-sensitivity impact analysis, and subsequent energy savings potential.

Next, a sample of 70 feeders from 16 substations was selected using a stratified random sampling approach to fairly represent the total feeder population. Detailed analyses of planning and load-flow simulations were performed to determine expected annual energy savings (kWh) and peak power reductions (kW) for each of the two VO scenarios. This sample feeder analyses included an assessment of system upgrades between the existing system and VO-modified plans, including benefits/costs for each VO scenario, which were then extrapolated back to the total ComEd system level using statistical ratio estimation techniques linking the sample group, study group, and system population. In addition, a recommended VO staged deployment was outlined to demonstrate the proposed VO implementation strategies, verify estimated VO factors, and develop simplified VO M&V procedures for ComEd's distribution system.

The overall project design and process flow chart is shown in Figure 1. The numbers in the task boxes (T1, T2, etc.) refer to the 10 project tasks referenced throughout this report and listed below.

Task 1: Project Start Up (kick-off meeting)
Task 2: Develop Global Data Templates to facilitate data collection
Task 3: Sample Frame and Feeder Selection/Screening
Task 4: Develop Scenario Case List for "what-if" analysis
Task 5: Data Collection for representative feeders to be studied
Task 6: Conduct "What-if" Analysis on representative feeders
Task 7: Perform Benefit-Cost Analysis
Task 8: Extrapolate representative feeder results to system level
Task 9: Suggest Potential VO staged deployment to test study results
Task 10: Final Report/Presentation

[1] Except for secondary networks like the one serving downtown Chicago, which will need further discussion with the ComEd distribution planning group.

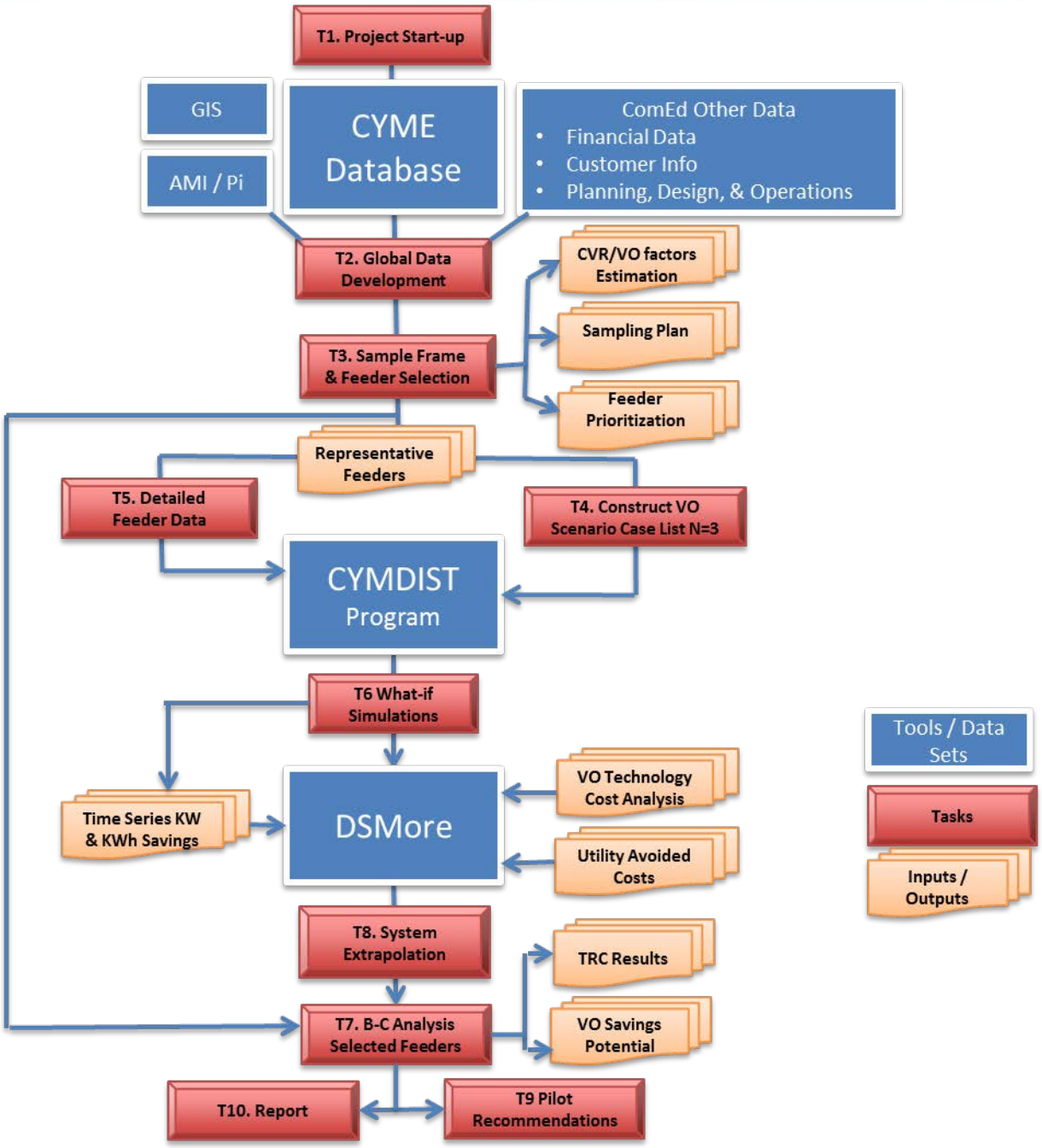


Figure 1 - Overall Project Design and Flow Chart

1.3 Project Results

The VO feasibility study results estimate the potential to reduce energy consumption by as much as 1900 GWh-y while reducing peak loads by approximately 360 MW. These results are based on the Plan B (maximum energy savings) analysis. The total upfront cost to implement Plan B is approximately $575 million, which represents an average savings per viable feeder of 3.5% at a

levelized cost of energy (LCOE) of $0.0185/kWh-saved. It is estimated VO is viable on 515 of ComEd's 806 substations, representing 2890 feeders. The minimum cost Plan A generates 1350 GWh-yr of savings at a cost of $425 million. A summary of Plan A and Plan B results are presented in Table 1.

Table 1 - Summary of Project Results

	Plan A	Plan B
Total VO Savings Potential		
- Energy (MWh-yr)	1,350,371	1,912,952
- Peak Load (MW)	257	364
Total VO Installed Costs	$425,466,877	$574,232,508
VO Program TRC	2.20	2.30
Levelized Cost of Energy ($/kWh)	$0.0193	$0.0185
Number of Viable Feeders	2,890	2,890
Number of Viable Substations	515	515
Average Energy Savings (MWh-yr)		
- per viable feeder	467	662
- per viable substation	2,624	3,718
Average VO Cost		
- per viable feeder	$147,222	$198,699
- per viable substation	$826,902	$1,116,030

Energy savings from VO occur in two forms: Distribution line loss reductions and end-use load reductions. As seen in Figure 2, a majority of the energy savings comes from end-use load reductions. For Plan A, only 6% of total savings comes from distribution loss reduction. For Plan B, which includes more system improvements, distribution savings increase to 11%.

VO benefits are achieved through a number of capital improvements and operation changes on the distribution system. Total capital expenditures to achieve these benefits are $425 million for Plan A (minimum cost) and $574 million for Plan B (maximum savings). Capital costs include equipment, labor, and overhead. This equates to average costs per substation of $826,902 and $1,116,030 for Plans A and B respectively (Figure 3).

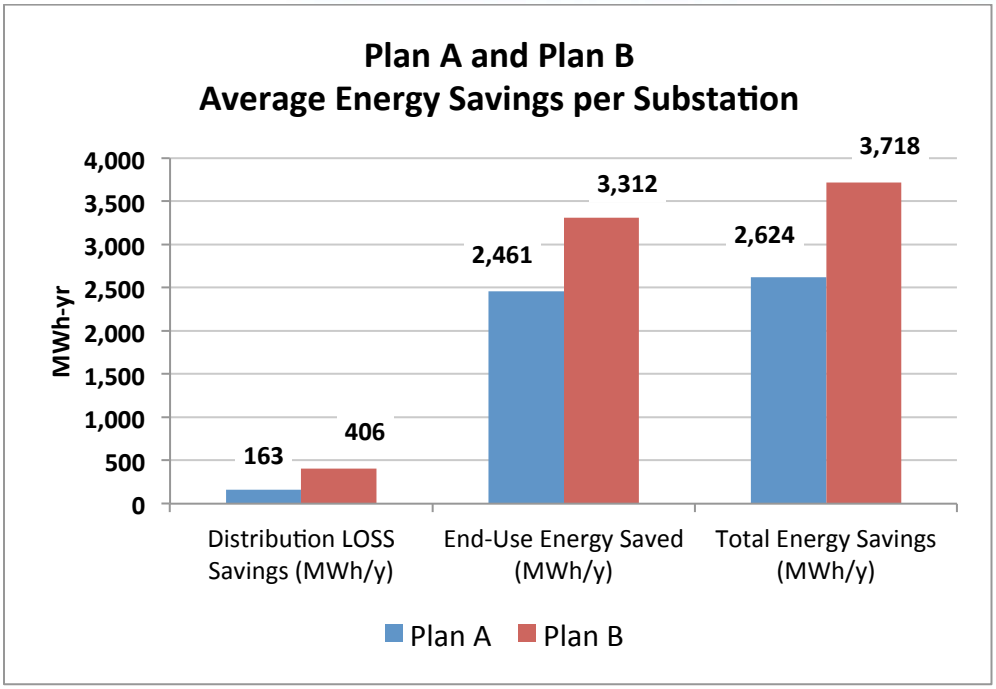


Figure 2 - Average Savings per Substation

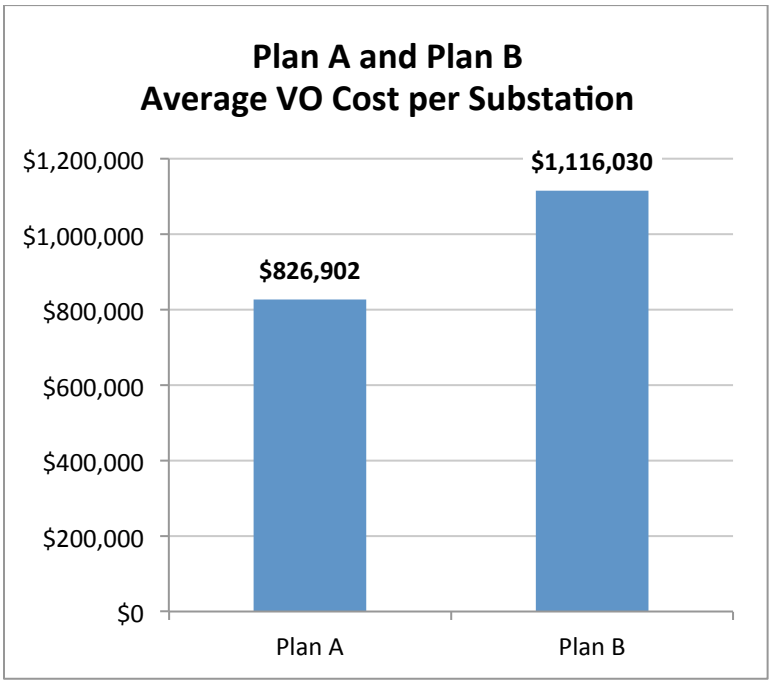
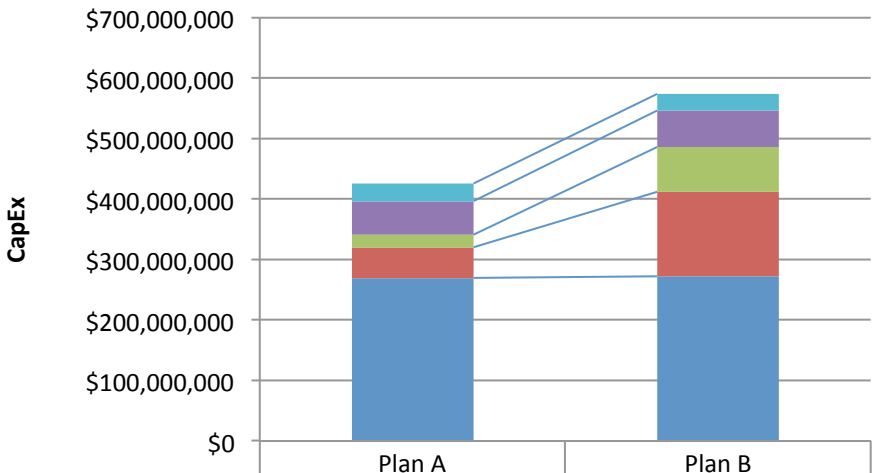


Figure 3 - Average VO Cost per Substation

Capacitor banks, both switched and fixed, represent the largest single capital expense (CapEx) item, accounting for over half of the total costs for both Plan A and Plan B. Voltage regulators and sensors are the next two largest expense categories. Additional voltage regulators and system upgrades (such as line reconductoring and phase upgrades) account for most of the additional Plan B costs. Integrated Volt/VAR Control (IVVC) is used primarily for isolating non-viable feeders with comparable costs in both plans. Figure 4 compares itemized VO costs for Plans A and B.



	Plan A	Plan B
IVVC	$28,708,191	$28,136,885
Sensors	$56,038,389	$60,404,979
System Upgrades	$20,336,883	$73,909,567
Voltage Regulators	$50,641,249	$138,897,955
Capacitor Banks	$269,742,165	$272,883,121

Figure 4 - VO Cost Itemization

A key study result is the screening and ranking of substations by VO cost and savings potential. This data can then be used to develop VO energy efficiency (EE) supply curves that present how much savings is available at a given cost. Figure 5 presents substation-based VO EE supply curves. While rankings were only developed for substations in the 14-region study group, the supply curves depicted in Figure 5 have been extrapolated to the system level.

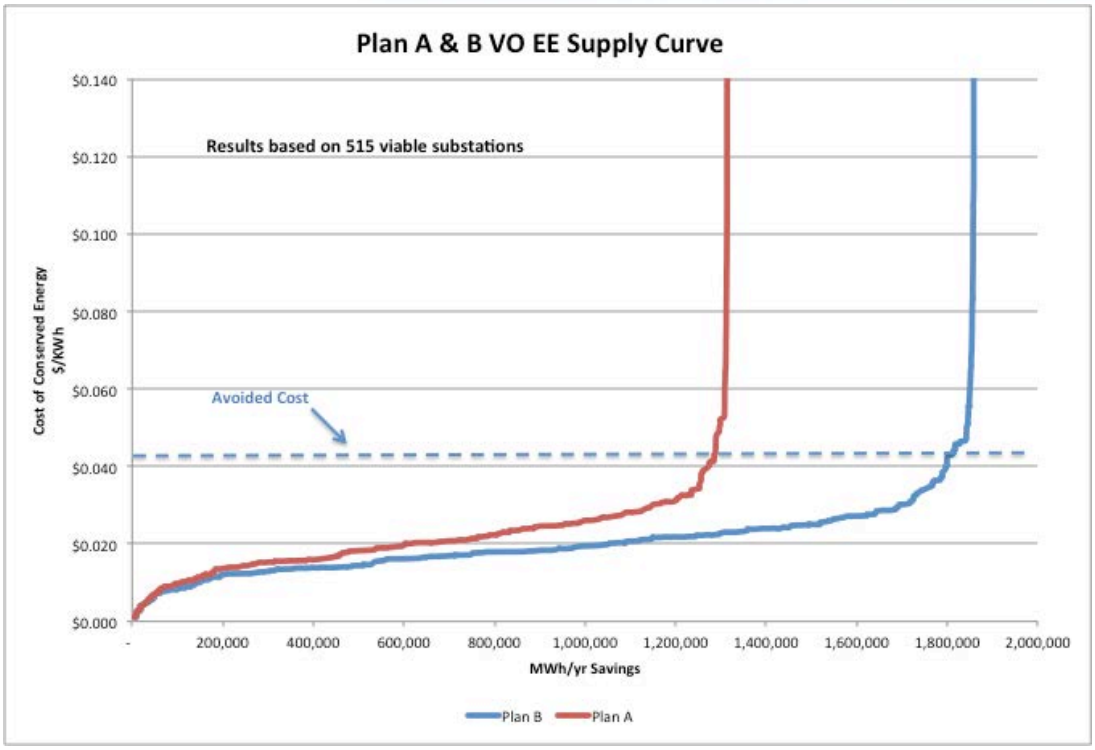


Figure 5 - VO EE Supply Curves

A key driver of the VO Feasibility Study was to assess the cost effectiveness of using VO to meet ICC EE program goals. Figure 6 provides an analysis of cost and savings potential in relationship to ComEd's 2014-2016 program goals. EE program data comes from ComEd's ICC filings for program years 2014, 2015, and 2016 and is based on total 3-year program costs and savings potential. VO cost and savings estimates are based on Plan B results and assume the entire VO program is implemented over the same 3-year period. This assumption may or may not be ComEd's actual implementation roadmap, but provides a basis of comparison between the two program types.

The key take-away from the chart is that VO has the potential to double ComEd's EE potential at a comparable cost to other EE program options.

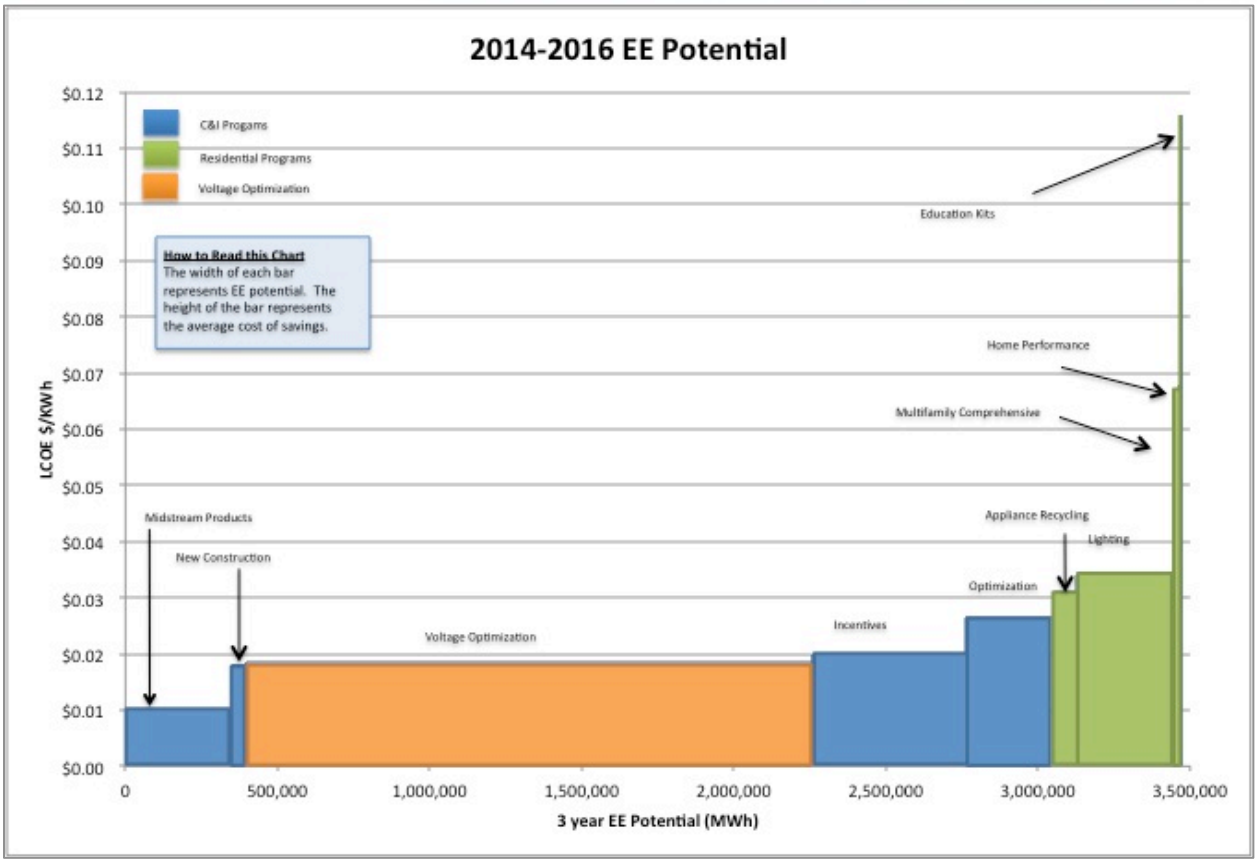


Figure 6 - EE and VO Benchmark Supply Curve

1.4 Key Recommendations

- Design/implement a VO staged deployment per the outline provided in Section 9.
- Develop and implement VO analysis training materials for distribution planning engineers, distribution operations personnel, and energy efficiency engineers. Recommended contents include engineering modeling assessments, economic analysis methods, capacitor placement methods, LTC/regulator/capacitor control settings, and annual volt/VAR maintenance and reporting procedures.
- Improve feeder VAR management with smaller capacitor banks (600 kVAR). Include VAR sensing and local control on all switched banks. Follow the Task 6 VAR application guidelines.
- Install EOL volt meters on every VO feeder and voltage control zone at the lowest voltage location to collect/transmit data and provide annual reporting of voltage performance.

- Examine AMI voltage/loading data to determine actual feeder voltage drop and load profiles. Results can be used to establish standards for addressing maximum allowable voltage drops (distribution transformer and secondary voltage drops) and minimum allowable primary voltages (i.e., 118.6 volts for an allowed 3.6 volt drop). Evaluate potential impacts (probability of customer transformers needing replacement) of primary voltages violating minimum standards. Revise transformer sizing guidelines based on this customer loading information.

- Maintain, correct, and/or upgrade GIS-CYMDist interface, software, and distribution system models at least annually or as needed.

2. Introduction

This report provides an overview of the approach used to perform a Voltage Optimization (VO) assessment of ComEd's distribution system to quantify energy savings potential (ESP) and associated cost impacts for each feeder. Prioritization methods, process steps, assumptions, and related formulations are described. A representative sample set of viable substation and feeder candidates (consisting of 16 substations and 47 viable feeders, down from 50, as explained in Section 7) are provided along with a method for extrapolating results to total system values. The process to develop "what-if" plans (Base Case, Plan A, and Plan B) for each viable feeder is described. VO thresholds used as the basis for feeder efficiency improvements are summarized along with application priorities and improvements rationale. VO staged deployment recommendations are described to verify M&V techniques, projected savings, and associated costs. Section 10 summarizes system-wide results, key findings, and recommendations for ESP, associated system improvements, ComEd standards, and operating practices.

The ComEd distribution system infrastructure and equipment database forms the basis for VO evaluation, which is obtained from ComEd's latest Geographical Information System (GIS), Transformer Load Management (TLM) System, Customer Information System (CIS), and Global Data sources. All initial screening evaluations are performed using Eaton's CYMDist load flow distribution analysis software assuming base case summer peak load conditions. Below is a summary of system and performance characteristics derived from the screening. All voltages are on a 120V base unless otherwise indicated.

2.1 General Distribution System Characteristics Investigated

- Distribution system includes a total of 5655 feeders (3757 feeders investigated)
- Total number of substations 806 (542 substations investigated)
- Number of viable VO feeders 1920
- Number of viable VO substations 346
- Investigated feeders serve 3.301 million customers
- Total number of residential customers is 2.897 million
- Total number of commercial customers is 406,658
- Total number of commercial customers <1MW is 406,658 and >=1MW is 271
- Average number of customers per feeder is 879
- Average feeder length to furthest point from source is 4.1 miles
- Average feeder has 4.9 miles of OH line and 4.3 miles of UG line
- There are 493 in-line voltage regulators connected or 0.13 regulators per feeder
- There are 4,650 shunt capacitors connected or 1.24 capacitors per feeders
- Average size of shunt capacitor banks connected is 1313 kVAR
- Total feeder summer peak load investigated is 16,699 MW and 4145 MVAR (lag)

- Total distribution transformer capacity is 52.683 million kVA
- Average distribution transformer loading is 35.0% of nameplate capacity
- Total distribution xfmr screened load is 18.428 million kVA.
- Total distribution xfmr screened load for residential is 9.023 million kVA.
- Total distribution xfmr screened load for commercial <1MW is 9.003 million kVA.
- Total distribution xfmr screened load for commercial >=1MW is 0.402 million kVA.

Note: *The number of commercial customers and amount of loads served for primary-fed services has not been identified for this initial screening evaluation.*

2.2 Feeder Performance Characteristics

- Length of overloaded conductor is 187.99 miles (approximately 0.3% of system total)
- Average feeder source load imbalance is 21.9%
- Average source feeder voltage setting average is 124.81V for substation bus.
- Average end-of-line lowest voltage is 120.5V three-phase and 120.1V single-phase
- All voltage regulation devices have no Line-Drop-Compensation (LDC) applied
- Substation voltage regulation bandwidths are 3.0V
- In-line voltage regulator average voltage setting is 125.0V
- In-line voltage regulators have volt bandwidths of 2.0V
- "Native" accumulated average volt-drop per feeder is 5.7V with no capacitors connected, all in-line volt-regulators on neutral tap, and 98% source power factor
- Average feeder average primary voltage is 123.68V

Note: *The amount of overloaded conductors of the 3757 feeders screened is based on power flows using conductor information from GIS and should be verified.*

Figure 7 summarizes the number of feeders served by each ComEd substation. Observations:

- 70% of ComEd substations serve 5 or less feeders.
- 15% serve between 5 and 15 feeders.
- 10% serve between 15 and 25 feeders.
- 5% serve more than 25 feeders.

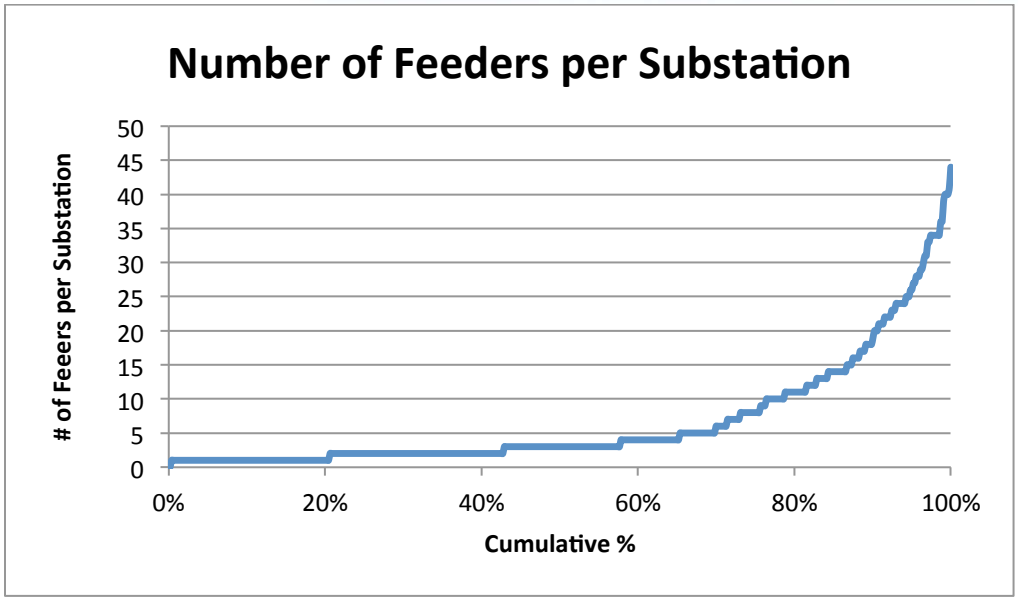


Figure 7 - Number of Feeders per Substation

The VO objective is to improve distribution system efficiency by cost-effectively managing voltages to maximize system loss reductions and end-use energy savings. Typical improvements include upgrades such as metering, load balancing (line reconfiguration, tap changes, minor phase upgrades and/or reconductoring), improved VAR (capacitor) management, and the addition of in-line voltage regulators. System efficiency also includes optimal loading and sizing of equipment for loss reduction, requiring long-range infrastructure improvements and replacements, expensive capital outlays, which are not included in this investigation. However, minimum upgrades to correct marginally overloaded lines or equipment are included.

An ideal (optimal) feeder can be described as one where an incremental change in power/energy NPV costs equals the incremental change in VO improvement NPV costs. Ideal feeder characteristics can vary between feeders and among utilities based on customer load type, cost of purchased power, and feeder electrical configuration. The following list describes ideal feeder characteristics based on Northwest Planning Conservation Council (NWPCC) Regional Technical Forum (RTF) VO M&V Protocol guidelines [5]:

- Source and in-line voltage regulator voltages near 119.0V for light load conditions
- Source and in-line voltage regulator voltages less than 124.0V for peak load conditions
- Primary minimum voltages near 119.0V for every hour of operation
- In-line voltage regulator bandwidths of 2.0V
- Source feeder load imbalance less than 20.0%
- Accumulated voltage drops for Voltage Control Zones (VCZ) less than 4.0V
- Primary line and distribution transformer no-load energy loss less than 2.0%

- Source reactive load near 100% compensated for every hour of operation
- Minimum allowed primary voltage 118.6V (assume 2.0V BW)
- Maximum allowed secondary voltage drop 3.6V (3%VD)

The analysis included development of ComEd-specific VO factors for summer and winter peak conditions. Factors were determined in Task 4 using empirical relations based on regional climate data and typical appliance mix by customer class.

All feeders served by a common substation or power transformer were evaluated as an integrated Voltage Control Zone (VCZ), since each feeder was impacted by the same source voltage regulator or LTC. Not all feeders can cost-effectively achieve performance thresholds. However, significant cost-effective savings are possible with some system upgrades.

Initial screening quantified performance indicators (Keywords) for each feeder (derived from load flow simulations) to identify viable feeder and substation candidates. Screening was based on summer peak load.

Before assessments could be performed, the following actions were required:

- Obtained feeder source MW and MVAR hourly data
- Determined residential and commercial VO factors
- Modeled and simulated (with CYMDist) distribution system feeder performance

The analysis tabulated the following major feeder characteristics to identify needed upgrades, approximate potential energy savings, and estimate implementation costs for each plan:

1) Identify and/or establish minimum allowed primary voltage.
2) Identify existing overloaded equipment and make appropriate corrections.
3) Improve source feeder load imbalance and reduce neutral currents.
4) Improve VAR compensation effectiveness to maintain near unity power factor 8760 hr/yr.
5) Reduce accumulated volt-drop for each Voltage Control Zone (VCZ) from source to lowest voltage point with additional VCZs (by adding voltage regulators).
6) Revise voltage control settings for source transformer LTCs and in-line voltage regulator to reflect the lowest maximum voltage necessary for peak loads and minimum voltage for light loads.

3. Data Collection Process

To facilitate the data collection process, a Global Data Request (GDR) template was populated with available system information needed for feeder VO prioritization and detailed sample feeder analyses. Included were the following data categories:

- General system information
- CYME and GIS database interface information
- Utility annual report and five-year capital information
- Distribution system equipment identifications and performance
- Planning and design voltage guidelines; planning and design loading guidelines
- Reactive load management VAR guidelines
- Distribution system metering
- Customer load data research information
- Distribution planning investment cost estimates
- Financial data assumptions

In addition to the GDR, the availability of specific distribution system data for the representative substations and feeders selected for more detailed VO analysis was captured using a set tables. Data included the following:

- General substation information
- Substation service area CYME and GIS database modeling data
- Substation equipment information
- Specific substation feeder information

The detailed data collection process followed a 3-step process as follows:

- Step 1: Check-boxes were marked by ComEd based on data availability using a set of interactive tables to simplify the collection process.

- Step 2: Data for a complete substation set (substation and feeders) was collected in the following formats: Draw File (.dwg), AutoCAD (.dxf), MS Word (.docx), MS Access (.mdb), PDF (.pdf), and/or Excel (.xlsx).

- Step 3: Additional data was requested as the needed during the analysis process.

All information was kept strictly confidential, with access limited to AEG project team members only.

4. VO Screening and Representative Feeder Selection

The steps below describe the screening process for VO energy savings, implementation costs (VO Costs), sorting of results, and selecting representative sample feeders/substations for detailed VO sample assessments.

Even though not part of the screening process, VO results extrapolation to total-system values is an important next step. As such, it is helpful to understand the context in which this occurs. Therefore, the extrapolation method is also provided below as Step 12.

Step 1 Perform an initial screening of all ComEd feeders to identify "viable" and "non-viable" feeder candidates. NOTE: Due to time and feasibility constraints, only 14 of the total 19 regions were included in the feeder screening process. The five regions that were not included will be statistically accounted for in the final results.

Step 2 Estimate potential VO energy savings (ESP) for each "viable" feeder.

Step 3 Convert energy savings per feeder to present value (PV) energy savings per feeder (ESP$).

Step 4 Estimate PV implementation costs per feeder (VO Costs). Allocate Class 1 non-viable feeder isolation costs to all other viable sister feeders on the same substation. Class 1 refers to feeders that have high amounts of commercial load or overloaded line miles. Class 2 refers to feeders where the voltage class is too high >25kV or too low <11kV or is network loop fed.

Step 5 Calculate the Benefit-Cost Ratio (BCR) and the Levelized Cost of Energy (LCOE) for each "viable" feeder candidate.

Step 6 Sort feeders by ESP. Rank each "viable" feeder consecutively from highest savings to lowest. The highest feeder rank (e.g., 4178) represents the highest energy savings potential. "Non-viable" feeders are listed but are ranked "zero" to signify they offer no cost-effective energy savings potential. Generate VO Energy Efficiency Supply Curves showing cumulative energy savings potential by LCOE.

Step 7 Group "viable" and "non-viable" feeders from **Step 6** by substation name. Each substation may include many feeders. Since feeders originating from a common substation bus have the same source voltage regulation, VO is best evaluated on a substation basis. Each substation is labeled with the total number of feeders, total potential energy savings, total costs, average energy savings per feeder, and average costs per feeder.

Step 8 Calculate total substation costs, average costs per feeder, and BCRs.

Step 9 Sort "viable" substation candidates by potential energy savings per feeder. Rank each "viable" substation consecutively from highest savings to lowest. The highest substation rank represents the highest energy savings potential per feeder. "Non-viable" substations are listed but ranked at "zero" to signify they offer no cost-effective energy savings potential.

Step 10 Group "viable" substations into four substation reference categories (or strata) by energy savings and cost per substation. Substations are divided by energy savings into categories of high-ESP$ and low-ESP$. They are further divided by substation costs of high-VO Costs and low-VO Costs. "Non-viable" substations are not included in the reference categories. The high-low VO Cost strata boundary is defined by the median VO Cost for all viable substations. The strata boundary for ESP$ is subsequently defined by the median ESP$ for low cost and high cost groups. This results in an equal distribution of substations in each of the four reference categories. The substation reference categories of high-low ESP$ and high-low VO Cost (HL, HH, LL, LH, listed in order of importance) are as follows:

HL Substations with high ESP$ >$1,474,535 and low VO Cost <=$362,267

HH Substations with high ESP$ > $1,474,535 and high VO Cost > $362,267

LL Substations with low ESP$ < $161,347 and low VO Cost <= $362,267

LH Substations with low ESP$ <$161,347 and high VO Cost > $362,267

Step 11 Select representative random substations from each reference category to include a total of 50 "viable" feeders (viable feeder final count was reduced from 50 to 47 as explained in Section 7, which did not significantly affect the sample design or precision). Due to the high variance of the number of feeders per substation in the reference categories (e.g., high ESP substations tend to be larger and have more feeders), the number randomly chosen substations for each category (strata) will vary. However, the number of feeders per strata will be somewhat consistent. This sampling method has two benefits: 1) It increases the VO estimation precision for the entire population, and 2) allows for statistical precision to be determined for each of the four strata.

Step 12 Extrapolate results from the sample substation VO detailed analysis to the entire system of reference categories. Extrapolation is not part of the screening process but is included here to better understand the overall process of how detailed sample assessment results are applied to the substation reference category sample frame. For each substation reference category, ratio adjustment factors for VO Cost and ESP are developed by comparing average feeder results from the sample to average feeder results from the population. Strata-specific ratio adjustment factors are then applied to the feeder results

of the population, adjusting each individual feeder's VO Cost and ESP estimate up or down proportionally by substation, region, and total system. VO energy savings and costs are then recalculated based on ratio-adjusted feeder results. This extrapolation step is repeated for each sample VO option evaluated.

Feeder screening requires each feeder be assigned a relative VO potential savings and cost. These potential values are based on a set of formulations derived to fairly represent typical savings and implementation costs; and are applied independently to feeders, providing a robust method for comparing relative feeder potentials.

The formulations determine potential energy savings, costs, and BCR for each feeder. "Non-viable" feeder candidates have zero energy savings potential. The approach assumes cost-effective minimal upgrades as a VO pre-requisite. Formulations are described in the Task 3 final report.

4.1 Screening Results

A total of 14 regions, 3757 feeders (67%), and 542 substations (70%) were screened, providing a comprehensive representation of overall system conditions and performance. Table 2 lists ComEd regions screened with feeder and substation counts for each region. The exclusion of Chicago North does not materially affect the study results. A significant portion of the feeders are non-viable due to the following: 1) Rated 4kV and supply the low voltage grid (129 feeders); 2) Feed primary networks (200 feeders); and 3) Supply 1000kW or larger commercial loads (due to no sub-transmission being in the area) (many feeders).

Feeder prioritization summary results are shown in Table 3. Of the 3757 feeders evaluated, 1920 were classified as viable (51%) candidates and 1837 as non-viable. For the non-viable, 770 were Class 1 non-viable, and 1067 Class 2 non-viable. Class 1 refers to feeders with high amounts of commercial load or overloaded line miles. Class 2 refers to feeders where the voltage class is too high >25kV or too low <11kV or is network loop fed.

Highlighted key metrics include the following:

Total Feeders Classified	3757 Feeders . . . 100%
Viable VO Feeder Candidates	1920 Feeders . . . 51%
Non-Viable Feeder Candidates	1837 Feeders . . . 49%
Average Feeder BCR	1.05