conEdison
a conEdison, inc. company

Martin F. Heslin
Assistant General Counsel
Consolidated Edison Company of New York, Inc.
4 Irving Place, Room 1815-S, New York NY 10003
212-460-4705   Fax: 212-677-5850
Email: Heslinm@coned.com

December 22, 2014
By Electronic Filing

Hon. Kathleen H. Burgess
Secretary
New York Public Service Commission
Three Empire State Plaza
Albany, New York 12223

Re: Cases 13-E-0030, *et al*., Con Edison's Electric, Gas, and Steam Rates
Con Edison's Voltage Reduction Study Report

Dear Secretary Burgess:

Attached herewith for filing is Consolidated Edison Company of New York, Inc.'s *Voltage Reduction Study Report*. The Joint Proposal adopted by the Public Service Commission in Cases 13-E-0030, et al, provides that Con Edison will conduct a "study of its use of distribution system voltage reduction, whether additional investment or revisions to current investment plans may reduce or avoid voltage reductions, and whether it is in customers' interest to make such investments." The Joint Proposal further provides for the Company to file a report on the results of the study within six months of the Commission's order adopting the Joint Proposal. By letter dated August 27, 2014, you granted Con Edison's request to file its report by December 22, 2014.

Very truly yours,

Martin F Heslin

Attachment

Cc.   Active Parties: Cases 13-E-0030, 13-G-0031, 13-S-0032

CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.

Voltage Reduction Study

12/22/2014

Study on the use of distribution system voltage reduction and whether additional investment or revisions to current investment plans may reduce or avoid voltage reductions, and whether it is in customers' interest to make such investments.

Contents

Executive Summary

Consolidated Edison Company of New York, Inc. ("Con Edison" or "the Company") conducted an in-house study on the use of distribution system voltage reduction (VR), whether additional investment or revisions to current investment plans may reduce or avoid voltage reductions and whether it is in customers' interest to make such investments.

Voltage reduction is incorporated into the reliability standards of the North American Electric Reliability Corporation (NERC) to reduce load during capacity and energy emergencies and in the New York Independent System Operator (NYISO) Emergency Operations Manual, which specifies the use of voltage reduction when a shortage of operating reserve is predicted. For summer 2014, the *NYISO Emergency Operations Manual* specified as much as 410MW of load reduction for a Con Edison system voltage reduction of 8%. For a New York State wide voltage reduction, the load reduction available was as much as 604MW.

When distribution feeder failures have occurred during periods of high loading, Con Edison implements VR to prevent the occurrence of additional failures, which would exceed the system's design criteria. The Company procedure for implementing VR considers the number of feeders out of service relative to the network design limit, the expected return time of the out of service feeders and the relative reliability of the network. These considerations act to reduce the use of VR since a number of coincident conditions must be met before VR is implemented. The Company systems are capable of implementing voltage reductions of 5% or 8% from nominal service voltage.

The industry standard for service voltage is the ANSI C84.1 standard, which specifies the voltage at the point of service (service voltage) where the utility and customer wiring connect, as well as the utilization voltage (voltage at the point of use). The ANSI C84.1 standard specifies voltages for normal and contingency conditions. Con Edison's service voltage standards specify service voltage for normal and contingency conditions as well. Con Edison's design minimum service voltage standard meets the ANSI C84.1 standard for normal and contingency conditions. However, Con Edison's system design specifications incorporate an additional level of resiliency allowing its networks to continue operating within design parameters with the loss of two feeders. The ANSI C84.1 standard does not have an equivalent condition and hence does not specify corresponding voltage level.

From 2010 to 2013, voltage reduction was implemented 64 times at 32 different substations supplying 45 distinct networks when system conditions have met the voltage reduction criteria. Of the 64 voltage reductions from 2010 to 2013, (55) or 86% were at 5% of nominal voltage and (9) or 14% were at 8% of nominal voltage. Voltage reductions were implemented on 37 unique days out of 1,460 possible days during which it could have been implemented over the four year period.

The data analysis regarding the outcome of voltage reductions shows that they are effective at reducing feeder failures. Over the four-year period 2010 to 2013, 116 feeder failures occurred before implementations of voltage reduction while only 12 occurred after. Analysis of the component failures that prompted voltage reductions indicated that known, higher failure rate components are the primary cause of failures prompting voltage reduction. The Company has well developed programs to address the performance of these components and the analysis demonstrated substantial reductions in the failure rates of those components along with improvement in overall feeder performance. In addition, the failures prompting voltage reduction occurred at loads well below feeder ratings, and accordingly, there was no indication of Company failure to properly reinforce its system and use voltage reduction in lieu of that reinforcement.

The study analyzed the relative reliabilities of the networks that experience voltage reduction and found that networks with lower reliability are more likely to experience a voltage reduction. The Company targets network reliability spend towards networks more likely to experience voltage reductions. The capital reliability expenditure in these networks was more than 10 times than that in the lower risk networks. The Company's existing capital programs are aimed at achieving a targeted level of reliability in all networks. Hence the Company's reliability programs act to reduce the potential for voltage reduction as they address network reliability.

In order to understand the impact of voltage reduction on customer service voltage, the study conducted modeling to characterize the service voltage received by customers during voltage reduction. An analysis of the Triboro network serving approximately 38,500 customers in upper Manhattan was performed for the N-2 condition (two feeders out of service) as well as N-2 with simultaneous 5% and then 8% voltage reductions. Five of the possible 276 N-2 contingencies with simultaneous 8% voltage reduction were analyzed in detail. The number of customers that would experience low voltage for each of these five specific combinations ranged from 61 to 187 customers. The study calculated the likelihood of occurrence of the two feeder combination causing low voltage for the specific 187 customers and estimated it at once in 1,280 years. So although voltage reduction may result in service voltage below the ANSI standard, the number of customers affected is relatively small as compared to those served, and due to the dependence of low voltage on specific feeder combinations, it is extremely unlikely that any specific group of customers would repeatedly be affected by low voltage from voltage reductions.

The study reviewed other prior studies conducted by NYU/Polytechnic institute on behalf of the Company to examine the sensitivity of customer equipment to low voltage. Laboratory tests were conducted on 54 separate devices covering 17 different categories of consumer and commercial equipment (such as heat pumps, motors, compressors, computers, laser printers, microwave ovens, etc.). All but one of the 54 devices tested continued to operate at the voltage equivalent of an N-2 contingency and 8% voltage reduction. Most devices continued to operate at voltages well below this voltage. The laboratory testing shows that many categories of consumer and commercial equipment have the ability to continue to operate despite supply voltage below the ANSI C84.1 standard.

As part of the VR study, five facilities were instrumented to examine the service voltage supplied by Con Edison as well as the utilization voltage available to equipment. The facilities included two hospitals and three commercial buildings. Supply and utilization voltages were found to meet the ANSI C84.1 standard although the internal voltage drop at one of the hospitals was greater than that allowed by the National Electric Code.

During the period of the monitoring, no voltage reductions were implemented in the networks supplying the five facilities so network simulations were performed to evaluate the potential impact of voltage reduction on those facilities. Those network simulations showed that for the worst case of each contingency (lowest voltage) across the five facilities (15 total instances) there were seven instances where the Con Edison supply voltage would be less than the ANSI standard. However, in only two of those instances were the actual utilization voltages at the equipment below the ANSI standard. This analysis showed that utilization voltage at the equipment is dependent on a number of factors and implementation of voltage reduction during an N-2 contingency does not assure that equipment will be affected with low voltage.

The study examined the potential role of load curtailment programs to impact the use of voltage reduction. Data from 320 summer weekday feeder contingencies were compiled along with peak system load data to develop a regression model that defined a relationship between second contingencies (used as a proxy for voltage reductions) and system peak load. The analysis found that at the current system peak load, demand response actions help avoid approximately two voltage reductions per peak load day. The analysis also found that reducing the system peak through additional demand response actions has the potential to reduce second contingencies which would also reduce voltage reductions. However, moving from an average of four voltage reductions per peak load day to two per peak load day would require enrollment of an additional 485 MW of demand response, more than double the current enrollment.

The study also projected the capital costs to reduce the use of voltage reduction. Reliability analysis was performed on eight selected networks to quantify the existing probability of N-2 contingencies (used as a proxy for VR) and the probability of N-2 contingencies after replacing poorly performing components. The average improvement in the likelihood of N-2 contingencies was 30%, and the cost to avoid a given N-2 contingency in a single network was $24 million. The analysis was extended to all 64 second contingency networks and the total cost was in excess of $500 million.

Background of the Voltage Reduction Study

In Case 13-E-0030 – *Proceeding on Motion of the Commission as to the Rates, Charges, Rules and Regulations of Consolidated Edison Company of New York, Inc. for Electric Service*, the Company agreed to conduct an in-house study of its use of distribution system voltage reduction (“VR”), whether additional investment or revisions to current investment plans may reduce or avoid voltage reductions, and whether it is in customers' interest to make such investments.[1]

The study examined:[2]

a) Current Company policy for use of VR.
b) Industry standards for service voltage and use of VR.
c) Instances of use of VR over the last five years including reasons for VR implementation and outcome.
d) Analysis of root cause of component failures and efficacy of current programs to address them.
e) Analysis of correlation between VR implementation and network reliability, and relationship to current reliability capital programs.
f) Analysis of impacts of 5% and 8% VR on customer service voltage and compliance with power quality standards.
g) Review of existing studies known to the Company and/or provided by Staff or other Signatory Parties regarding impacts to customer equipment and operation, including (where available) but not limited to, existing studies regarding elevator control systems, elevator motors, industrial motors and motor control, large medical machines (*e.g.*, MRI machines) and the cooling equipment and power conditioners associated with such machines, refrigeration equipment used to store medication and other perishables and the cooling equipment used in data centers.
h) Role of load curtailment programs including demand response and customer appeals.
i) Projected capital costs to implement revision to current policy for use of VR.

---

[1] Cases 13-E-0030, et al. (Con Edison Electric, Gas and Steam Rates), *Order Approving Electric, Gas and Steam Rate Plans in Accord with Joint Proposal*, February 21, 2014, Appendix C, pp. 109-110.
[2] *Id.*

Overview of Con Edison Electric System

Con Edison delivers electricity to 3.3 million customers in New York City and Westchester County – a service territory of 660 square miles with a population of approximately 9 million people. Electricity is delivered through over 95,000 miles of underground cable and almost 34,000 miles of overhead cable. As shown in Figure 1, the Con Edison electric power delivery system is comprised of three distinct sub-systems: generation, transmission, and distribution.

Central power plants generate electricity that is transmitted over high-voltage transmission lines (69,000, 138,000, and 345,000 volts) that have the capability of delivering electricity over long distances.[3] These transmission lines supply the 62 distribution substations – known as area substations – where the voltage is reduced to primary distribution levels of 27 kV for Brooklyn and Queens, 33 kV and 13 kV for Staten Island, and 13 kV for Manhattan, the Bronx, and Westchester County.

From the area substations, 2,194 high-voltage primary feeders distribute the power and feed two types of distribution systems: network and non-network. Figure 1 shows the two types of systems. Approximately 86% of the distribution transformer capacity is served via the underground network system while the remaining 14% is served via the non-network system.

In the underground network system, the primary distribution feeders supply underground network transformers which in turn supply a grid of low-voltage underground cables ("secondary grid"), which supplies power to customers at customer utilization voltage. A network may have from six to 32 primary high-voltage feeders connecting the area substation to the network. There

---

[3] The New York Independent System Operator (NYISO) administers the delivery of power through the bulk power transmission system from generating plants to the distribution systems of the state's electric utility companies.

are approximately 26,000 underground network transformers. The secondary grid consists of multiple sets of low-voltage cables installed in ducts under the streets and connected in underground structures (manholes and service boxes). There are approximately 280,000 underground structures. Most network-system customers are served via the low-voltage secondary grid. Large industrial and commercial customers of more than one megawatt (MW) are often supplied directly by several primary feeders and dedicated transformers.

In the non-network system, primary distribution feeders leave the substation underground and may run underground or overhead to supply several types of transformer configurations, which in turn supply secondary cables or wires. In the 4 kV grid systems, the primary distribution feeders supply 4 kV unit substations, which in turn distribute electricity via 4 kV overhead feeders. In the autoloop system, the primary distribution feeders run overhead to supply pole mounted transformers. In the underground residential distribution system, the primary feeders serve pad-mounted transformers. In all of the non-network systems, transformers reduce the voltage to customer utilization levels that are supplied to customers via secondary wires or cables.

Load areas within network and non-network systems are designed to continue to serve customers when some primary feeders supplying the load area are out of service. Con Edison uses two types of network design criteria. “First contingency” designs can maintain operation at peak loads with the loss of a single feeder. “Second contingency” designs can maintain operation at peak loads with the loss of two feeders.

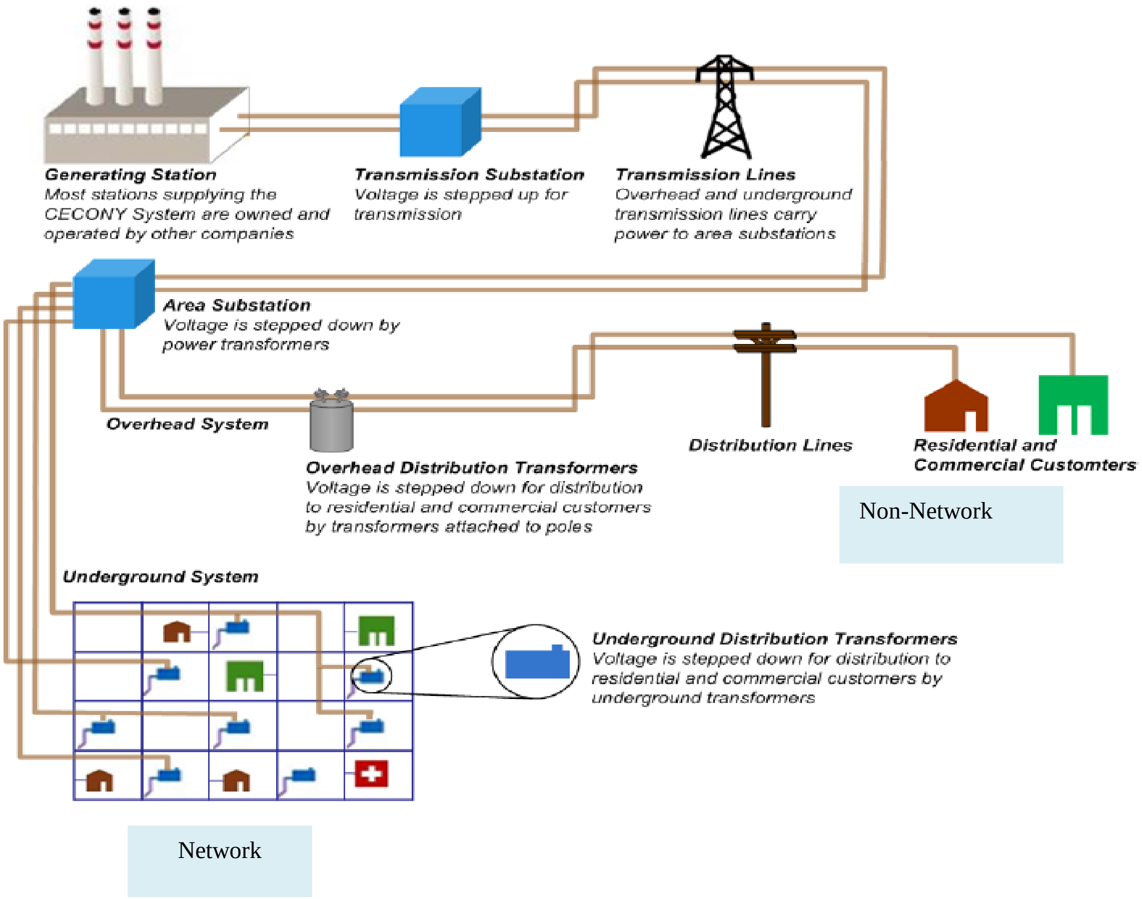


Figure 1

Figure 2 shows a one line diagram of a typical area substation with five substation transformers that take incoming electricity at transmission voltages and convert it to distribution voltages.

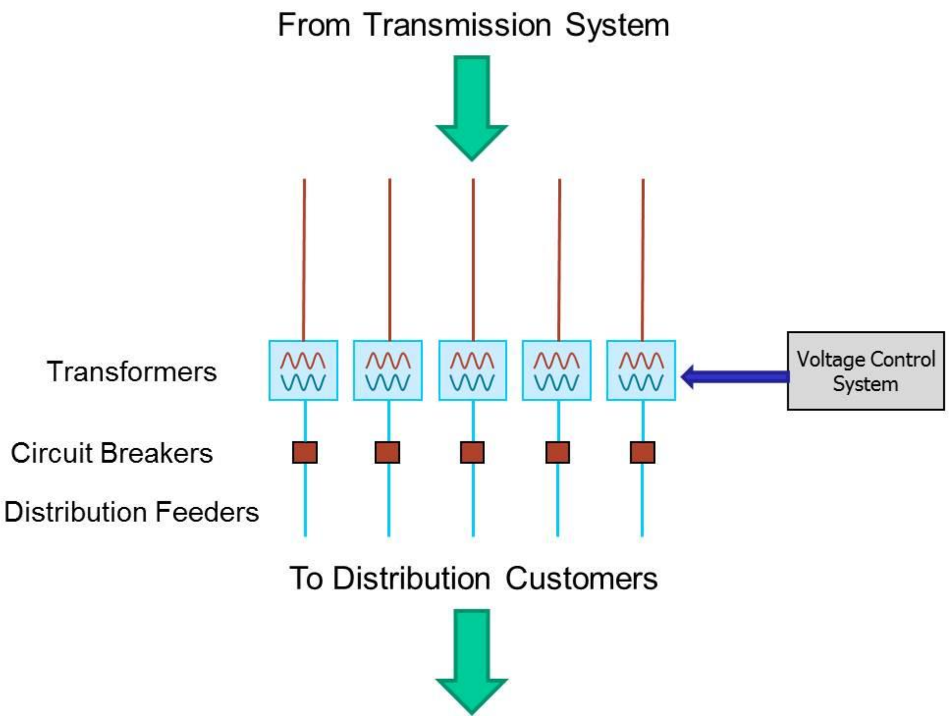


Figure 2

The area substation transformers are equipped with "load tap changers" which allow the transformer output voltage to be varied plus or minus 12 percent during operation. The substation transformer voltage is automatically controlled by a voltage control system, which is set to maintain substation voltage in accordance with a specified bus "voltage schedule" which in turn serves to maintain customer voltages within specified operating limits. As station loading increases, the control system raises the bus voltage to account for the increased voltage drop along the distribution feeders.

During periods when primary feeders fail or there is a deficiency of supply, the substation voltage may be reduced by setting the control system to provide a 5% or 8% reduction in voltage. Since all primary distribution feeders originate from the area substation bus, and since voltage reduction affects the station bus voltage, all networks or load areas served by a substation experience voltage reduction simultaneously.

Task1: Current Company Policy for Use of Voltage Reduction

Prior to each summer, the Company develops a load forecast for the upcoming summer peak period and plans capital investments to meet the forecasted load. The Company makes substantial capital investments in preparation for the summer peak load. In preparation for the summer of 2014, the Company invested $ 1.3 billion.

Con Edison's electrical distribution system is designed to operate under all of the following conditions: Summer peak load at a temperature variable (TV) of 86 degrees[4] and one primary feeder out of service in first contingency design areas or two primary feeders out of service in second contingency design areas.

During high load periods such as heat waves, Con Edison takes a number of operational steps to prepare its system and employees to meet the increased demand. Those steps include:

- Completing all outstanding repairs such that out of service equipment may be returned to service to supply the anticipated load.
- Cancellation of previously scheduled work so that equipment remains in service available to supply the anticipated load
- Coordination with NYC to prevent contractor damage to Company facilities[5]
- Augmented staffing to more quickly analyze and respond to problems

---

[4] Temperature variable is a weighted average of dry and wet-bulb temperatures calculated as an average of the highest three-hour temperature and humidity readings for a three-day period. The current day's weather forecast is weighted 70%, the prior day 20%, and the day prior 10%.

[5] Contractor damage is a leading cause of failures of cable sections between manholes

During heat wave operations, Company specification EO-4095, *Distribution Operations under Contingency Conditions*, provides operating guidance for periods of high loads or during system contingencies. The specification includes operator actions such as:

- Steps to reduce the risk of outages due to heavy equipment loading
- Steps to relieve overloads such as load shifting
- Emergency cooling of overloaded equipment
- Use of mobile electric generators to provide temporary power
- Steps to rapidly restore failed equipment to service
- Use of voltage reduction

During peak load periods or when feeder failures occur, the Company may implement its demand response programs to reduce load in areas experiencing problems. The programs are the Distribution Load Relief (Rider L) and the Direct Load Control (Rider U). The use of these programs is outlined in specification EOP-5022, *Automated VR Program and Demand Response Programs*.

In the event that feeder or other failures result in a network reaching or exceeding its design criteria, there is a risk of subsequent cascading feeder failures that could jeopardize network reliability. While the network system design provides the benefit of extremely high reliability due to the high level of redundancy, is the design is susceptible to cascading failures because loss of a primary feeder causes load to be shifted to the remaining in-service feeders. In the event of feeder failures, the Company may implement voltage reduction (VR) to reduce the risk of cascading feeder failures. Voltage reduction helps in this regard by reducing both voltage stress and loading on primary distribution components which reduces their likelihood of failure.

The procedure for implementing voltage reduction is defined in EOP-5022, *Automated VR Program and Demand Response Programs.* This specification describes the operation of the automated VR program, outlines the use of the Demand Response Programs and specifies the communications required during voltage reductions.

The Company's automated VR program utilizes a computer algorithm which provides decision support to operators for implementation of VR. The algorithm analyzes current operating conditions and issues either a VR warning or VR recommendation based on the following measures:

- Temperature Variable
- Network Reliability Index (NRI)[6] of the network experiencing the problem
- Number of feeders out of service relative to design limit
- Expected time of feeder return
- Network Load

A VR recommendation is issued for acute combinations of load, temperature variable, NRI and feeder outages while a VR warning is issued for less severe combinations of those measures. When the algorithm recommends VR, a recommendation for 8% VR is issued for networks with higher NRI (lower reliability) while a recommendation for 5% VR is issued for networks with lower NRI (higher reliability).

---

[6] NRI is a calculated measure of network reliability.

Table 1 below summarizes voltage reduction implementation criteria:

Condition 1	• Average TV > 85°F for two days **AND** • Two or more feeders are out of service in a 2nd contingency network **OR** one or more feeders are out of service in a 1st contingency network
Condition 2	• Average TV > 82°F for two days **AND** • Network load > 85% peak design **AND** • More than two feeders out of service in a 2nd contingency network **OR** more than one feeder out of service in a 1st contingency network
Condition 3	• Average TV > 82°F for two days **AND** • Network load > 85% of peak design **AND** • Two or more conflicting feeders are out of service in a 2nd contingency network **OR** feeder returning to service after load peak in a 1st contingency network
Condition 4	• Network load > 95% of forecasted summer peak **AND** • Two or more conflicting feeders are out of service in a 2nd contingency network **OR** feeder returning to service after load peak in a 1st contingency network
Condition 5	• Average TV > 82°F for two days **AND** • Network load ≤ 85% of forecasted summer peak **AND** • More than two feeders out of service in a 2nd contingency network **OR** more than one feeder out of service in a 1st contingency network **AND** • Two or more conflicting feeders out of service in a 2nd contingency network OR feeder returning to service after load peak in a 1st contingency network

Table 1

Task2: Industry Standards for Service Voltage and the Use of VR

Industry Standards for Service Voltage

ANSI Voltage Standard

The American National Standards Institute (ANSI) coordinates the U.S. voluntary consensus standards system, providing a neutral forum for the development of policies on standards issue, and serves as a nationally recognized authority for standards development and conformity assessment programs and processes. The current service voltage standard ANSI C84.1-2011, *American National Standard for Electric Power Systems and Equipment – Voltage Ratings (60 Hertz),* establishes recommended steady state service and utilization voltage ranges for typically used system voltages and configurations under normal and emergency operations.

ANSI C84.1-2011 specifies both service voltage and utilization voltage. Service voltage is the voltage at the point where the utility system meets the customer system. Utilization voltage is the voltage at the point of utilization, *i.e.*, where the customer wiring connects to the equipment utilizing the electric service. Utility specifications apply only to service voltage.

ANSI C84.1-2011 specifies two categories for both service and utilization voltage. These are defined as Range A and Range B. ANSI specifies that the electric system shall be so designed and operated that most service voltages will be within Range A. The Range A service voltage allows for a plus or minus 5% variance from the nominal voltage of 120V. The occurrence of service voltages outside of these limits should be infrequent.

The Range B service voltage allows for a plus 5.8% or minus 8.3% variance from the nominal voltage of 120V. Range B includes voltages above and below Range A that result from practical design and operating conditions. Such conditions shall be limited in extent, frequency and duration. When the conditions occur, corrective measures shall be undertaken with a reasonable time to improve voltages from Range B to meet Range A requirements.

There are conditions that are beyond the control of the energy supplier or user, or both, which can cause infrequent and limited periods when sustained voltages outside of Range B will occur. When voltages occur outside the limits of Range B, corrective action shall be taken promptly. Figure 3 shows the ANSI voltage ranges while Table 2 shows the minimum voltages as a percentage of the nominal values.

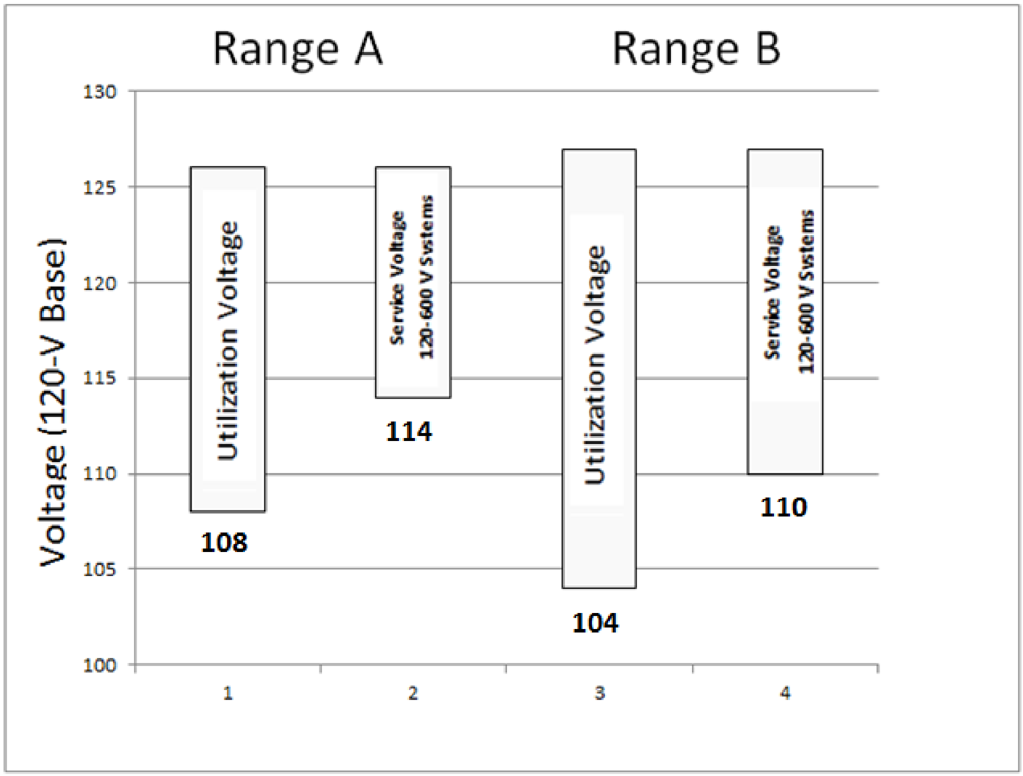


Figure 3

	Service		**Utilization**	
	Min	**Max**	**Min**	**Max**
Range A **(Normal)**	-5%	+5%	-10%	+4.2%
Range B **(Emergency)**	-8.3%	+5.8%	-13.3%	+5.8%

Table 2

NEMA Voltage Standard

The National Electrical Manufactures Association (NEMA) recommends that all electrical appliances and motors should operate at satisfactory condition at a voltage plus or minus 10% of the nameplate voltage. Nameplate nominal values are normally lower than the service voltage to accommodate the voltage drop in utility and customer wiring

Con Edison Service Voltage Standard

Con Edison specification EO-2065, *Low Tension A.C. Service Voltage Limits*, defines the limits of service voltage. EO-2065 specifies different service voltage limits for Con Edison's first contingency and second contingency design systems. For first contingency design systems, EO-2065 specifies different voltage ranges for normal operation with all feeders in service and for "N-1 operation" with one feeder out of service. These ranges match the ANSI C84.1 ranges "A" and "B". For second contingency design systems, EO-2065 specifies different voltage ranges for normal operation with all feeders in service, "N-1" operation with one feeder out of service and "N-2" operation with two feeders out of serve. The normal operating range and the "N-1" operating range match the ANSI C84.1 ranges "A" and "B". Con Edison's design incorporates an additional level of resiliency, not normally found in utility systems, such that second contingency networks are capable of operating with two feeders out of service, *i.e.*, "N-2" design.

The ANSI C84.1 standard does not recognize systems designed with such additional level of resiliency such as Con Edison's N-2 design. **Table 3** summarizes the Con Edison design minimum voltages and compares them to the ANSI C84.1 standard.

	First Contingency Areas		Second Contingency Areas		ANSI C84.1	
CONDITION	MAX	MIN	MAX	MIN	MAX	MIN
Normal*****	126	114	126	114	126	114
N-1******	126	110	126	110	127	110
N-2	N/A	N/A	126	105	N/A	N/A

Table 3

CON EDISON EO-2065 Minimum Design Service Voltage Limits and ANSI C84.1 Voltages

*** Corresponds to ANSI range A; ** Corresponds to ANSI range B**

Minimum service voltage limits reflect the voltage that *some* customers would receive during the specific operating condition (normal, N-1 or N-2). Since at any given time, service voltages vary across the network, the minimum service voltage standard reflects the service voltage for only a fraction of the customers served at any given time. More detail on actual numbers of customers receiving a given value of service voltage is discussed in the section on Task 6: "Impact on 5% and 8% Voltage Reduction on Customer Service Voltage."

Industry Standards for the Use of Voltage Reduction

Industry standards for the use of voltage reduction include bulk power system operating authorities utilizing emergency voltage reduction to address system problems as well as conservation voltage reduction to reduce energy consumption.

NERC

The North American Electric Reliability Corporation (NERC) is responsible for developing and enforcing reliability standards to ensure the reliable operation of the bulk power system. NERC operating standard EOP-002-3, *Capacity and Energy Emergencies,* includes voltage reduction among the operating remedies to be used to reduce load during capacity and energy emergencies when a Balancing Authority (responsible for managing generation) cannot meet the Disturbance Control Standards. Voltage reduction is considered as a source of "non-synchronized reserve," *i.e.*, that portion of operating capacity which is available by synchronizing a generator to the network, and that capacity which can be made available by reducing load that is dependent on starting a generator to replace energy that is supplied from the grid.

NPCC

Northeast Power Coordinating Council (NPCC) is one of the nine regional reliability councils under NERC authority. The NPCC geographic region includes the State of New York and the six New England states as well as the Canadian provinces of Ontario, Québec. The NPCC document, *Regional Reliability Reference Directory #1: Design and Operation of the Bulk Power System*, specifies the use of voltage reduction among the operating measures to be taken immediately after the occurrence of a contingency if the readjustment of generation, load resources, phase angle regulators, and direct current facilities are not adequate to restore the system to a secure state.

ISO’s and RTO’s

All Independent System Operators (ISO’s) and Regional Transmission Operators (RTO’s) across the United States include system-wide voltage reduction in their emergency procedures to reduce system demand in response to a temporary shortage of capacity. Voltage reduction is implemented as part of the NERC EEA2 Alert Level. ISO’s and RTO’s typically include periodic voltage reduction tests as part of their system capability evaluations.

NYISO

The New York Independent System Operator (NYISO) is responsible for the reliable operation of New York State’s high-voltage transmission network, dispatch of electric power generators, administering and monitoring the wholesale electricity markets, and planning for the state’s energy future. The *NYISO Emergency Operations Manual* specifies the use of voltage reduction when a shortage of operating reserve is predicted. Voltage reduction implementation is classified as either manual or quick response. The load relief attainable by quick response voltage reduction is considered to be 10-minute reserve, as are other resources. For summer 2014, table C.1 of the *NYISO Emergency Operations Manual* specifies 256 MW of load reduction for a Con Edison system-wide voltage reduction of 5% and 410MW of load reduction for a Con Edison system-wide voltage reduction of 8%. For New York State-wide voltage reductions, the load reductions available are 441MW and 604MW, respectively.

Conservation Voltage Reduction

Conservation Voltage Reduction (CVR) reduces energy consumption by reducing supply voltage so that equipment runs at higher efficiency. CVR may provide energy savings and demand reductions of 3% or more on a continual basis. Pacific Northwest National Laboratory estimated the potential total U.S. energy savings from CVR to be as high as 6,500 MW-years or 56,940,000 MW-hours—the equivalent of the Grand Coulee Dam operating at nameplate capacity for a year.

Task 3: Instances of Use of VR over Last Five Years Including Reasons for VR Implementation and Outcome

Instances of the Use of VR

From 2010 to 2013, voltage reduction was implemented on Con Edison's distribution system 64 times at 32 different substations supplying 45 distinct networks when system conditions have met the voltage reduction criteria. Since many substations supply multiple networks or load areas, and voltage reduction is implemented at the station level, implementation of voltage reduction for one network/load area results all networks/load areas served from the station receiving voltage reduction. As a result, some networks have been in voltage reduction multiple times such that 95 total networks experienced a voltage reduction over the last four years including networks that experienced multiple voltage reductions.

Voltage reductions are more likely to impact customer service voltage and customer equipment when our networks/load areas are heavily loaded. Heavier loading and the associated higher current flow causes greater voltage drop in the supply lines resulting in lower supply voltages. Accordingly, voltage reductions outside of the summer period are much less likely to affect customer equipment. If the summer period alone is considered, then from 2010 to 2013, voltage reduction was implemented 56 times at 27 substations affecting 37 independent networks. Over this time period, 82 network areas experienced a voltage reduction including networks that experienced multiple voltage reductions.

Figure 4 shows the number of network/load areas that were placed in voltage reduction over the last five years. There were no voltage reductions in 2009 because there were no events that required it. Of the 64 voltage reductions from 2010 to 2013, 54 were at 5% and 9 were at 8%.

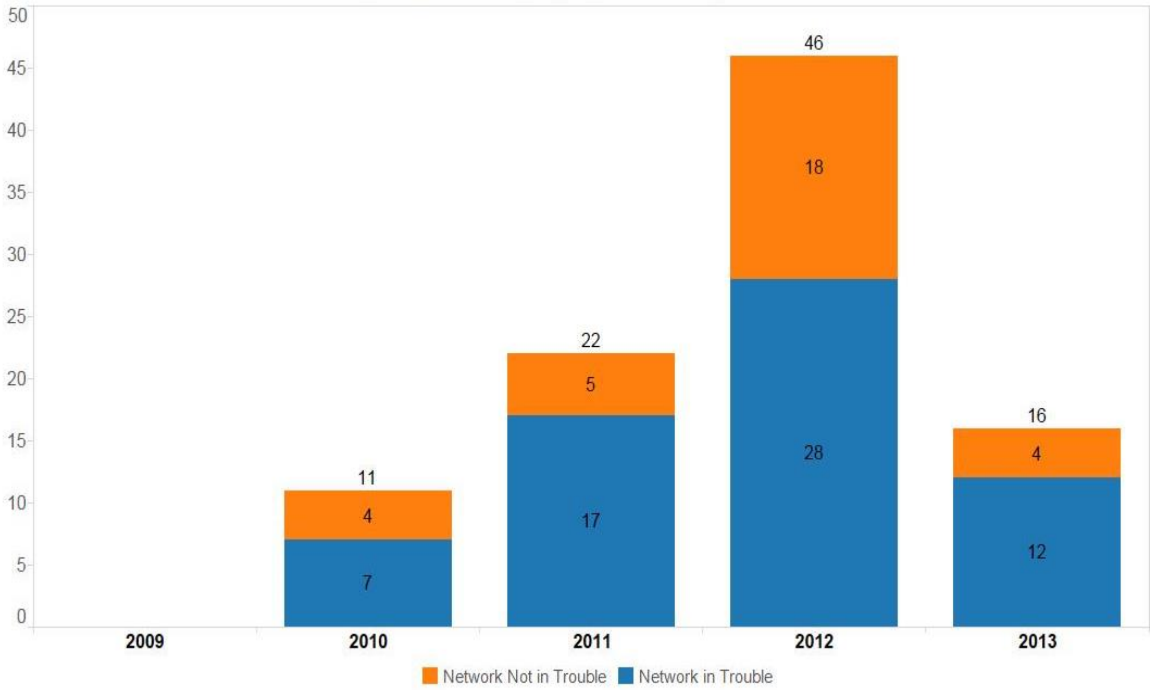
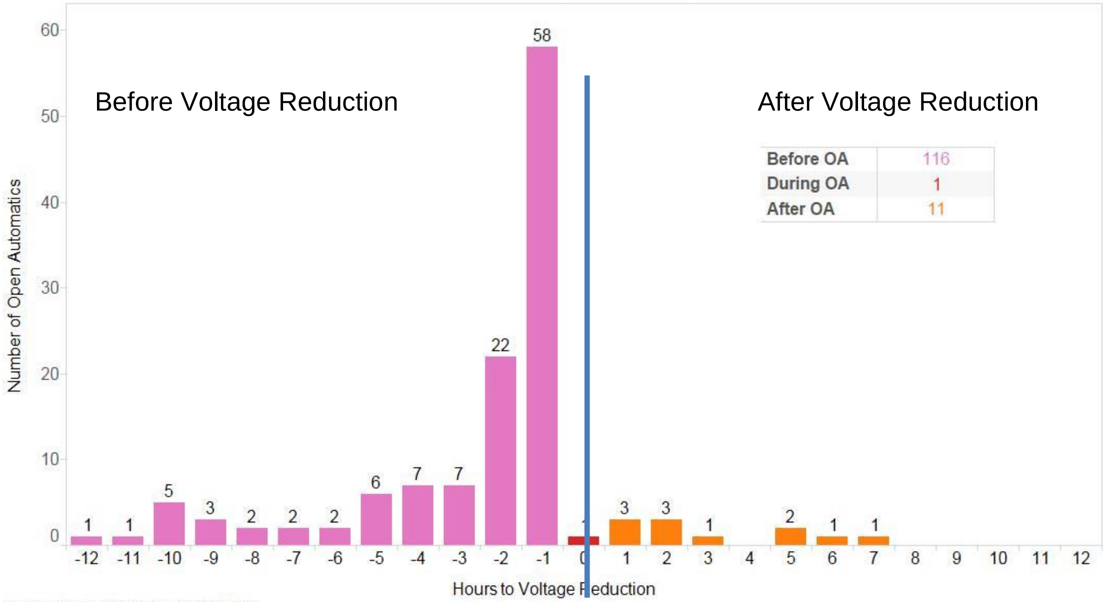


Figure 4

The majority of the voltage reductions were due to feeder failures; however, seven were due to other causes. Five were due to Hurricane Sandy which resulted in equipment failures that took feeders out of service. One was due to a contractor performing underground excavation that damaged six feeders supplying the Yorkville network. And one was due to a manhole fire which destroyed four feeders in a single structure resulting in a fourth contingency in the Yorkville network. Appendix 1 lists all voltage reductions from 2010 to 2013.

Outcome of Voltage Reductions

Voltage reduction is used as a reliability tool to prevent feeder failures from cascading. **Figure 5** shows four years of feeder performance before and after voltage reduction in the network/load areas where voltage reduction was implemented from 2010 to 2013. The data shows that for the 12 hours prior to voltage reductions, there were 116 unique feeder failures (open automatics or OA's). The majority of those (58) occurred one hour prior to implementing voltage reduction. In the 12 hours after voltage reductions, there were only 12 OA's, one of which occurred at the same time as the voltage reduction. The significant reduction in feeder failures after implementation of voltage reductions during the period 2010 to 2013 indicates that voltage reduction is an effective tool in preventing cascading feeder failures and keeping the system within design parameters.



*Includes Cut In Open Automatics

Figure 5
Open Automatics* Before and After Voltage Reduction Implementation 2010-2013

Task 4: Analysis of Root Cause of Failure and Efficacy

Con Edison is unique among utilities in that it analyzes most components from failed primary feeders to determine the root cause of failure. The Company's failure database has over 85,000 records of failure. During the years 2010 to 2013, there were 124 feeder outages that preceded the implementation of voltage reductions during the summer period. Figure 6 shows the component failures that caused those outages. The majority (63%) were splices followed by cable (23%) and terminations (9%). Transformer failures and other causes such as contractor damage were responsible for the remainder.

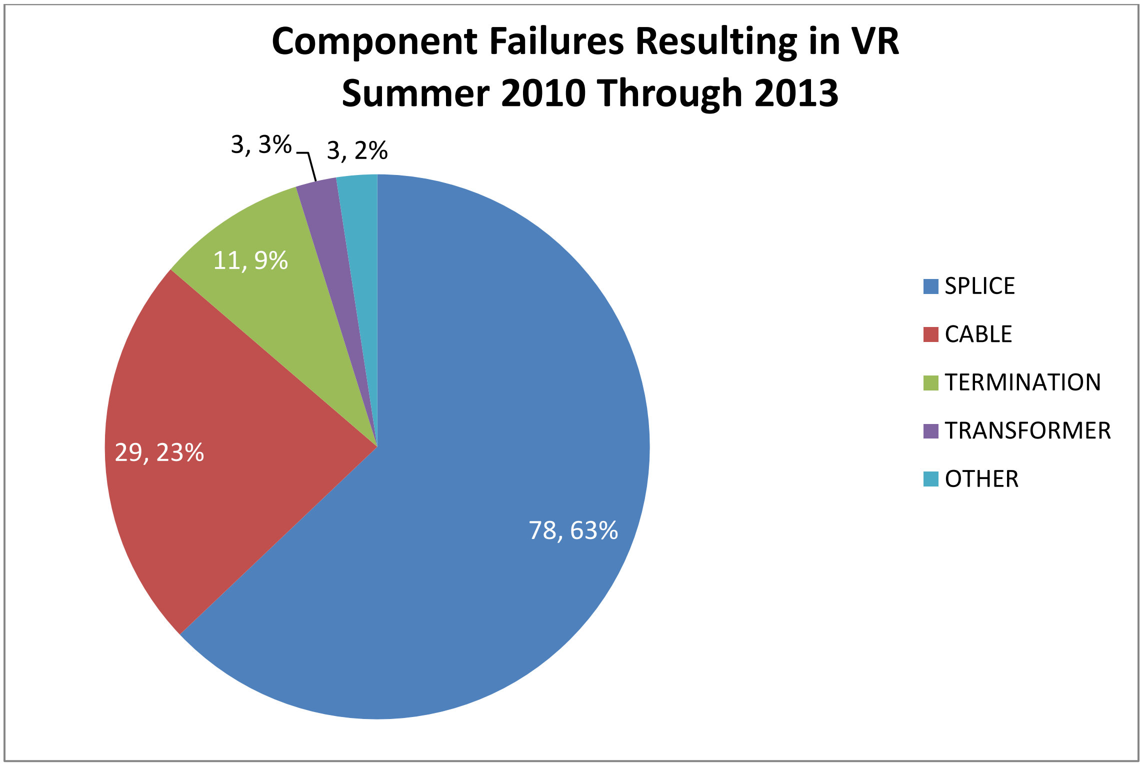


Figure 6

Figure 7 shows the splice failures that resulted in voltage reductions from 2010 to 2013. More than half of these splice failures were "stop joints," a type of joint that connects older paper insulated lead covered (PILC) cable to newer polymeric insulated cable. Stop joints are responsible for a disproportionate number of failures compared to their population. Stop joints have a failure rate 11.8 times that of newer extruded dielectric joints (0.617 percent vs. 0.052 percent). Ten percent of splice failures were "Lead-Wipe" joints which connect PILC cable to PILC cable.

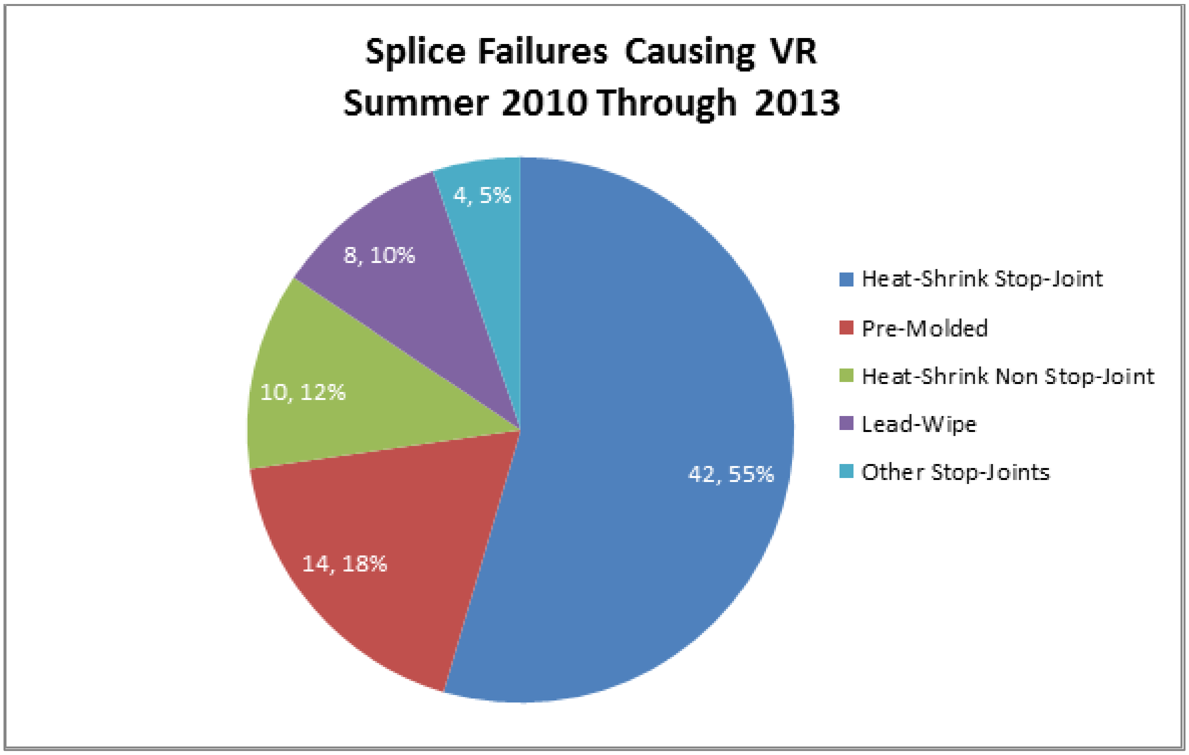


Figure 7

Figure 8 shows cable failures that caused voltage reductions during the summer, 2010 to 2013. PILC cable was responsible for 41% of the cable failures that resulted in voltage reduction. PILC cable has a failure rate two and one half times that of newer EPR cable (0.065 percent vs. 0.026 percent). PILC is 12% of the system but is responsible for approximately 24% of cable failures.

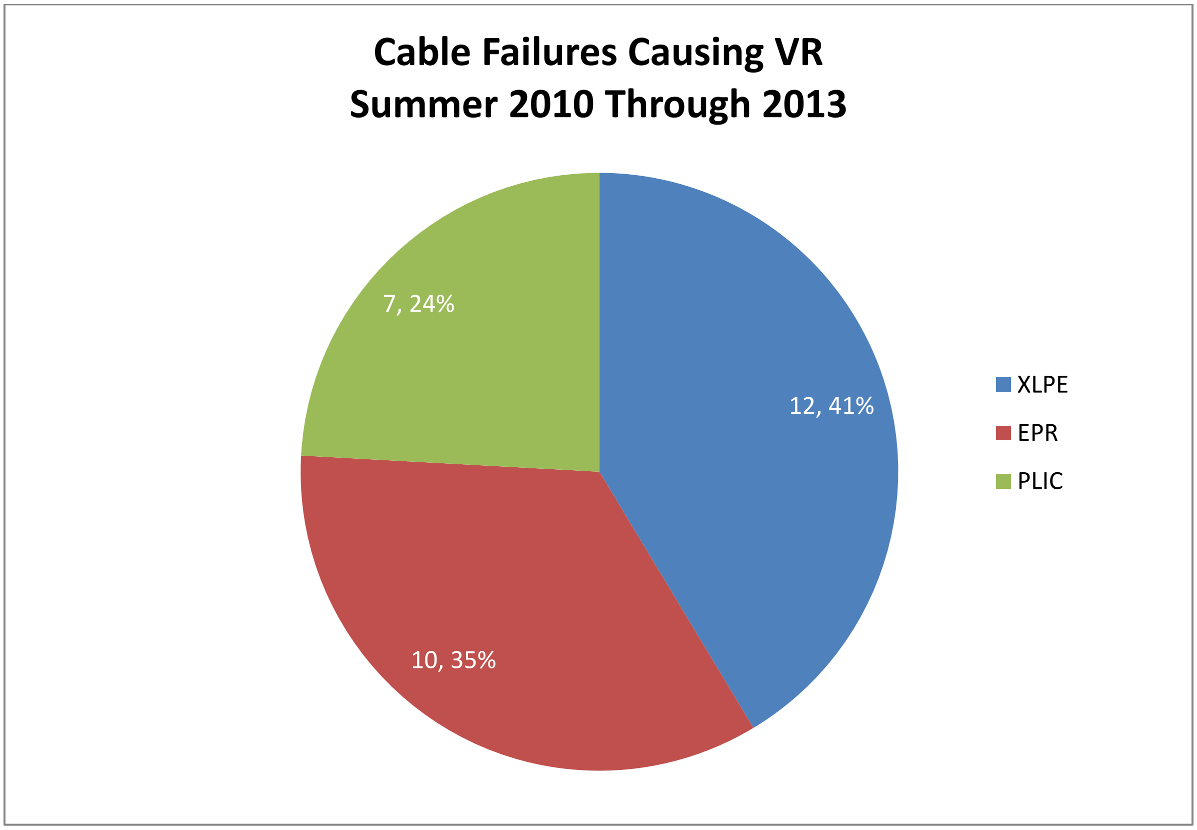


Figure 8

Among all the component failures that resulted in voltage reductions during the summer periods, 2010 to 2013, approximately 46% of failures, were due to thermally sensitive components. Thermally sensitive splices (stop joints or lead-wipe joints) accounted for 41% of failures, and thermally sensitive cable (PILC) accounted for approximately 5% of failures.

Among the Company's capital reliability programs is the PILC cable removal program, which removes PILC cable and associated stop joints from primary distribution network feeders. Working with other PILC cable removal methods, this program will reduce the amount of PILC cable on network feeders to less than 10% of the total population of primary distribution network cable by year-end 2020. The Company's focus on the improvement in primary feeder performance is evident from the reduction in both PILC cable failure rates and stop-joint failure rates shown in Figure 9.

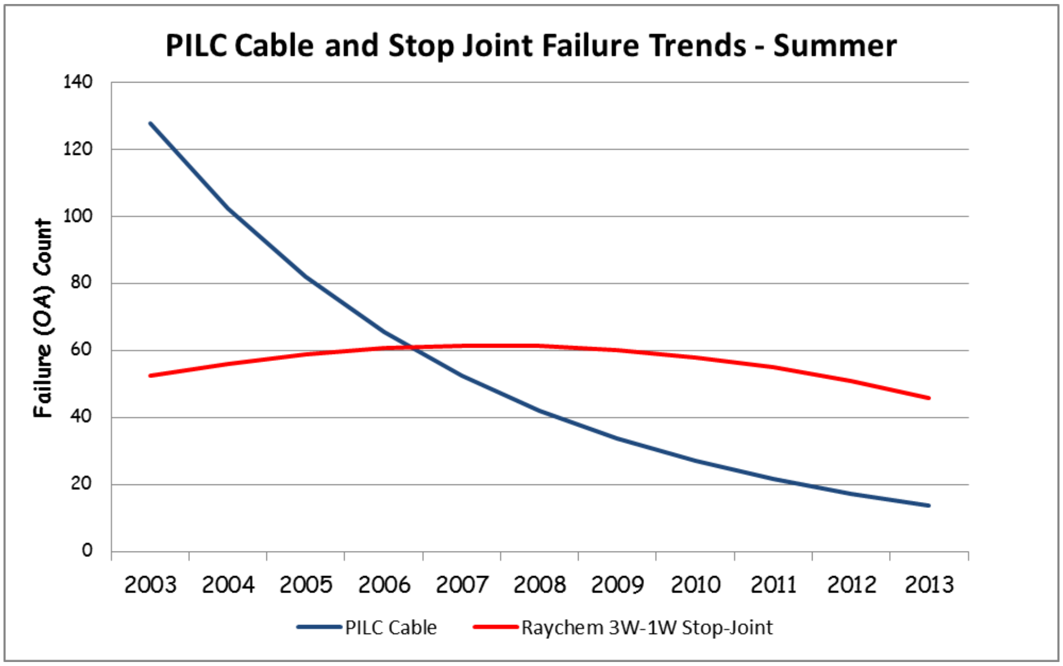


Figure 9

Since voltage reductions are implemented in response to network contingencies, typically the result of feeder failures, improving component performance and consequently reducing feeder failures works to reduce the likelihood of voltage reductions. Figure 10 shows a 36 month rolling average of daily distribution feeder failures (open automatics). The failure trend from 2007 to 2013 has been steadily downward as a result of the focus of the capital programs previously discussed.

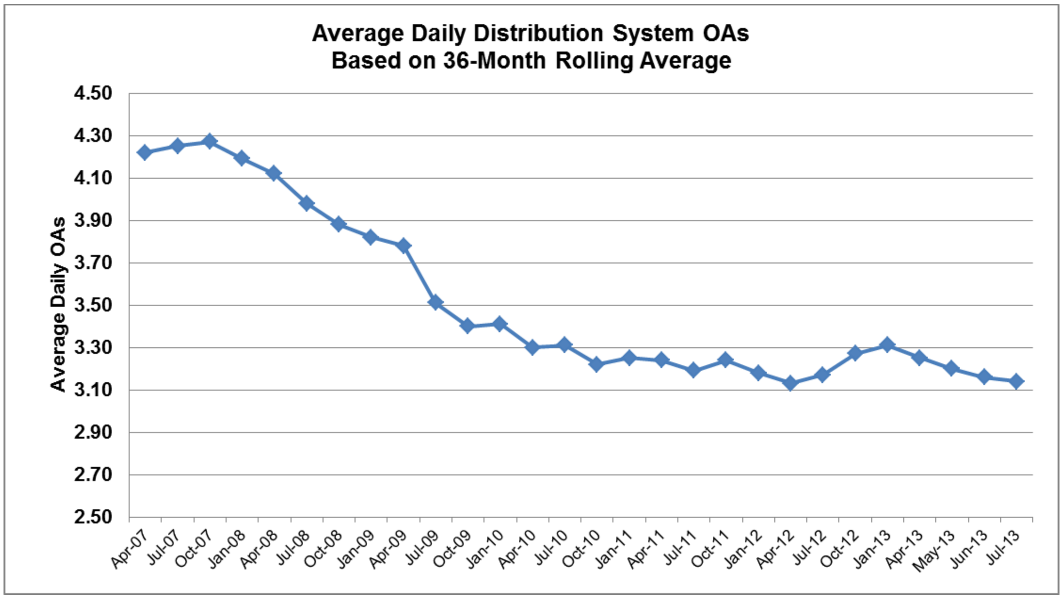


Figure 10

Figure 11 shows feeder loadings vs. feeder emergency ratings for feeder failures occurring prior to voltage reduction from 2010 to 2013. Feeder loadings were all less than feeder emergency ratings for all feeder failures preceding voltage reductions.

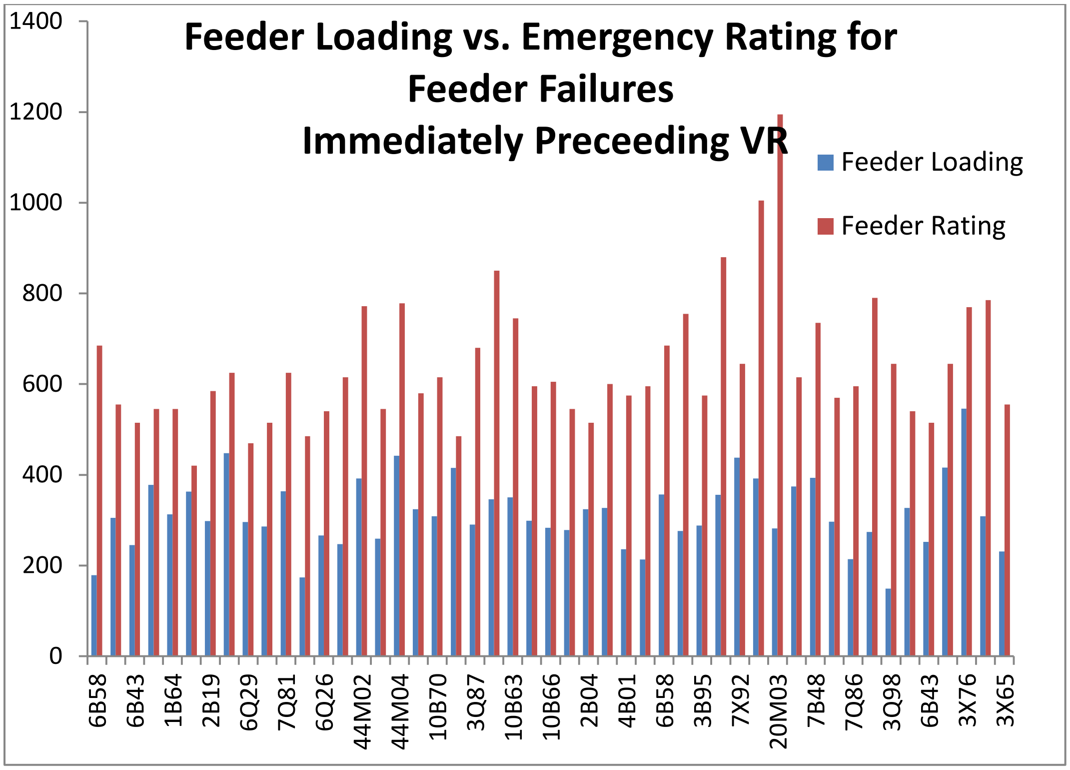


Figure 11

The Company's analysis determining the root cause of primary feeder failures shows that thermally sensitive components are key drivers of feeder failures that result in implementation of voltage reductions. The Company's has existing capital programs in place that target those components, and those programs have been effective at reducing failure rates of the thermally sensitive components and improving feeder performance.

Task 5: Correlation between VR Implementation and Network Reliability

Con Edison measures and models network reliability and failure risk using the Network Reliability Index ("NRI") tool. NRI simulates failures using monte-carlo analysis, a probabilistic method that allows the simulation of multiple iterations of component failures. NRI contains a model of each feeder along with the individual components and their failure rates. The component failure dependency on loading is also modeled. The program runs 20 years of simulations to determine the mean time to occurrence of the "NRI state," a condition in which there is a potential for cascading feeder failures that would lead to a network shutdown.

Figure 12 shows summer 2012 network performance with networks divided into three groups: "high risk," "medium risk" and "low risk." These are relative groupings according to the network relative NRI. The number of voltage reductions is shown on the vertical axis, and one-year capital expenditure for reliability programs is shown for each network group. The reliability programs included in the capital expenditure are the network reliability (new feeder installation) program, the PILC replacement program and the underground sectionalizing switch program.[7] Higher risk networks experienced significantly more voltage reductions than lower risk networks. Those networks had correspondingly higher capital reliability expenditures than the lower risk networks.

---

[7] These programs have since been integrated into a single program called "Primary Feeder Reliability"

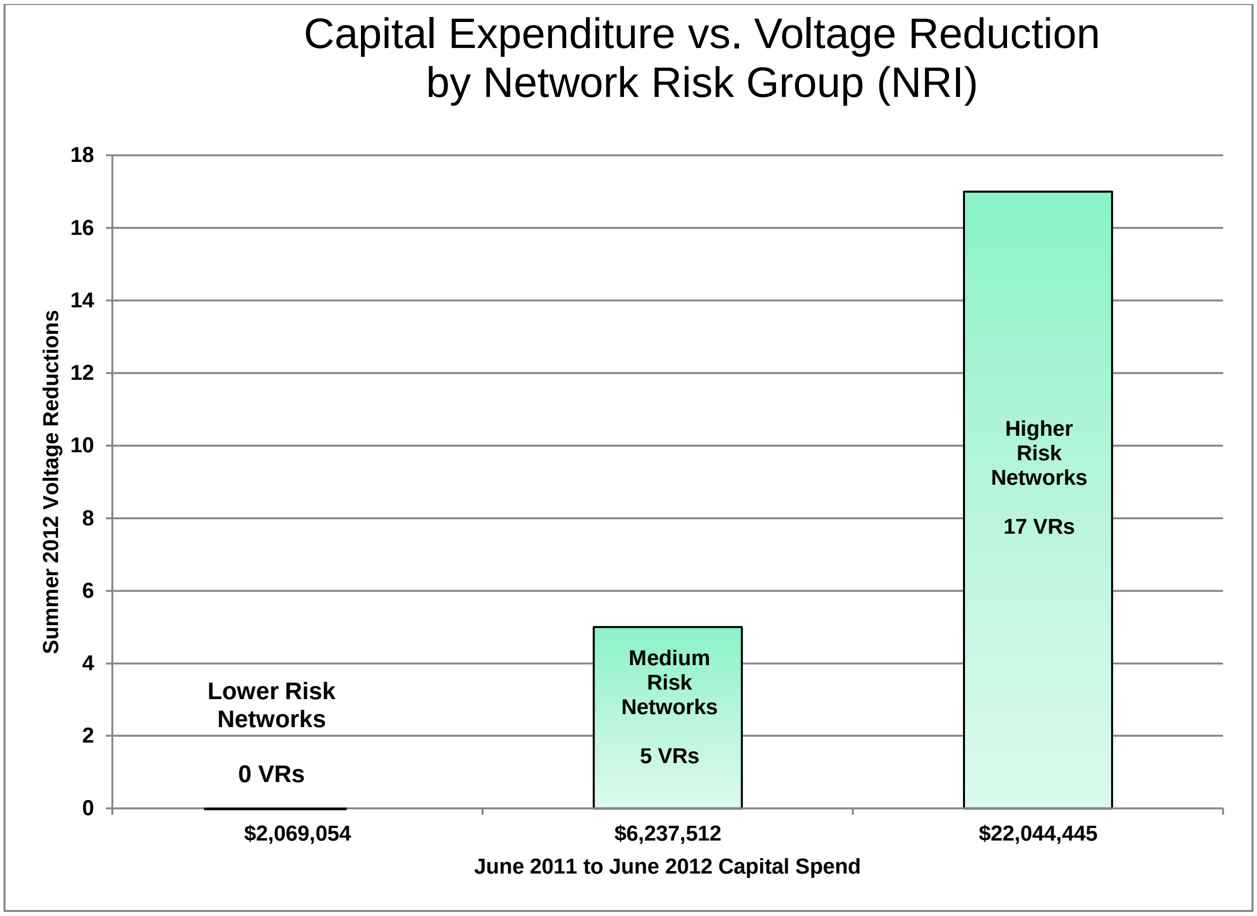


Figure 12

Figure 13 shows all networks that experienced a voltage reduction from 2010 to 2013. Networks are grouped in rows by the number of voltage reductions they experienced. Network NRI is shown on the horizontal axis increasing (corresponding to lower reliability) to the right. The average NRI for a given group is shown as a vertical "tick mark." From the figure, we see that network groups that experienced more voltage reductions have corresponding higher NRI values and lower reliabilities. The average NRI of the networks that experienced four voltage reductions is seven times worse than the average NRI of the zero-voltage reduction group.

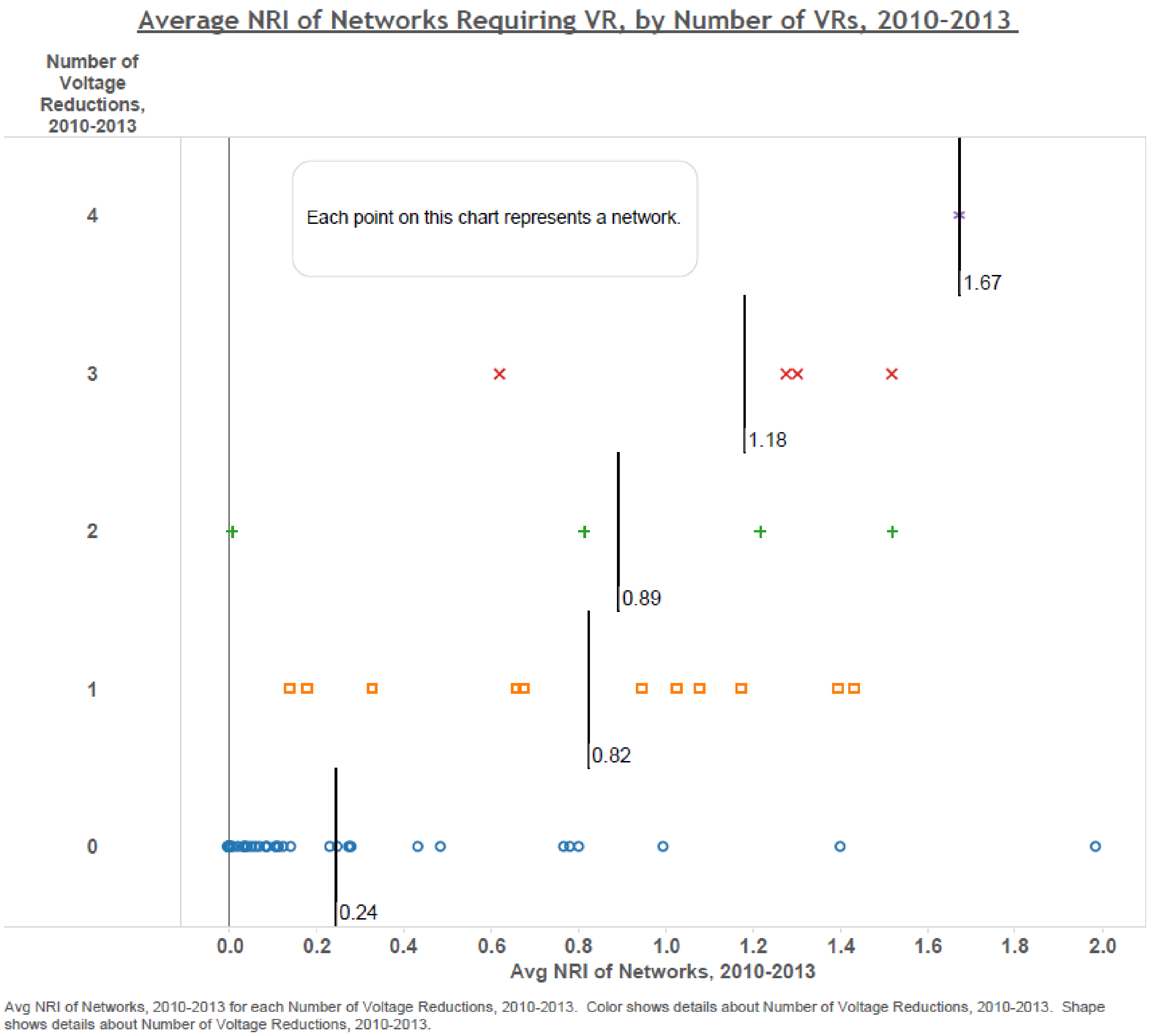


Figure 13

The Company addresses network NRI through its primary feeder reliability program which incorporates three components: PILC replacement, underground sectionalizing switches and installation of new feeders. The Company has an established a 1.0 NRI target that all networks should meet. Since 2010, the Company has made significant progress such that only three networks are above the 1.0 NRI target. The goal is to bring all networks below the target by 2015. These improvements in NRI will correspondingly reduce the instances of voltage reductions.

From Figure 13, we see that the Company targets network reliability expenditure towards networks with higher NRI. From Figure 13, we see that networks with higher NRI are more likely to experience a voltage reduction. Consequently, the Company's capital programs aimed at reducing NRI to target levels for all networks also act to reduce voltage reductions.

Task 6: Impacts of 5% and 8% Voltage Reduction on Customer Service Voltage and Compliance with PQ Standards

The impact of 5% and 8% voltage reduction on customer service voltage and its compliance with power quality standards may be examined in two ways. The first computes the Con Edison design minimum service voltages, reduced by 5% and 8%, and then compares them to the ANSI minimum service voltage standard. The second models a network under voltage reduction to characterize the service voltage received by customers under the specific modeled conditions.

The first of the two methods is outlined in Table 4 which shows Con Edison's design minimum service voltages under normal, contingency (with feeders out of service) and contingency with voltage reduction as compared to the ANSI C84.1 service voltage standards.

It should be noted that considering the Con Edison design minimum service voltages under contingency conditions with voltage reduction provides the minimum voltage that *some* customers would see during voltage reduction. Since at any given time, service voltages vary across the network, the minimum service voltage standard reflects the service voltage for only a fraction of customers at any given time.

CONDITION	**Con Edison**		**ANSI**
	1st Contingency Areas	**2nd Contingency Areas**	
Normal	114	114	114
N-1	110	110	110
N-1 with 5% VR	104.5	N/A*	110
N-1 with 8% VR	101.2	N/A*	110
N-2	N/A**	105	N/A
N-2 with 5% VR	N/A**	99.75	N/A
N-2 with 8% VR	N/A**	96.6	N/A

Table 4

*VR not implemented at N-1 state in second contingency areas
**No design value for N-2 condition in first contingency areas

As can be seen from Table 4, in first contingency design areas, Con Edison's design minimum service voltage meets the ANSI C84.1 minimum service voltage standard under normal and N-1 conditions. It does not meet the ANSI C84.1 minimum service voltage standard during N-1 conditions and simultaneous voltage reduction. ANSI does not have a comparable standard for systems incorporating an additional level of resiliency such as Con Edison's second contingency design. Under N-2 conditions and during simultaneous N-2 conditions and voltage reduction, service voltage for some customers will be below 110V.

Figure 14 and Figure 15 both show a graphical view of the Con Edison design minimum service voltages under N-1 and N-2 conditions both with and without simultaneous 5% and 8% voltage reduction as compared to the ANSI C84.1 standard.

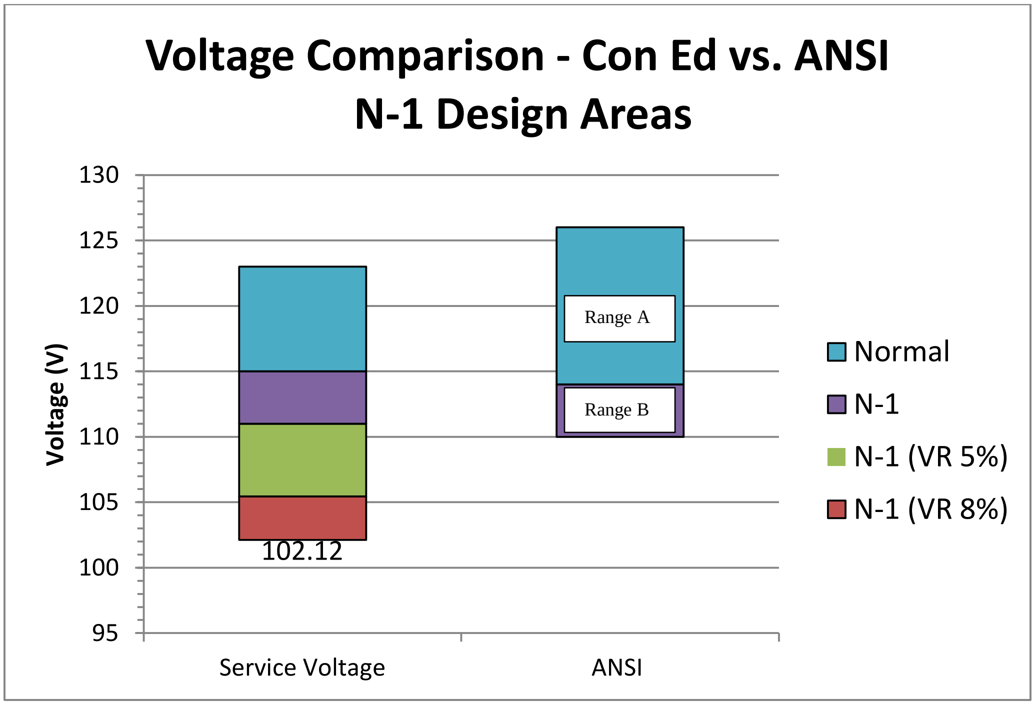


Figure 14

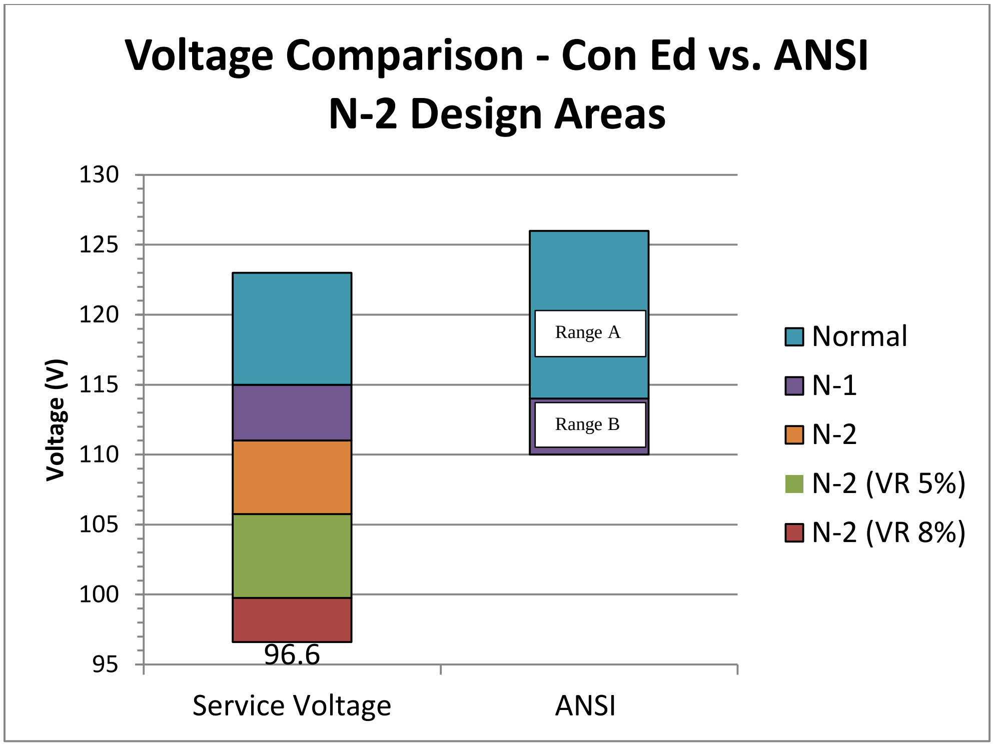


Figure 15

The second of the two methods to examine the impact of 5% and 8% voltage reduction on customer service voltage is to model a network under voltage reduction to characterize the service voltage received by customers. Con Edison uses the Poly Voltage Load Flow (PVL) program to plan, design and analyze its distribution system. The PVL program contains three major components:

- A distribution system model extracted from our mapping systems with characteristics of primary feeders, transformers and secondary mains along with their associated connectivity
- A load model that assigns a peak demand for each service point
- Actual historical voltage readings from distribution transformers

PVL computes loading on all primary sections, transformers and secondary mains. The program compares loading to component ratings and identifies overloads. PVL also computes voltages at all structures and identifies instances of voltage below Company standards.

The Triboro network was selected for analysis of service voltages using the PVL program. The network serves approximately 38,500 customers in upper Manhattan. The network contains 24 feeders, 301 transformers and has a peak load of 143MW. Figure 16 is a graphic showing the boundaries of the Triboro network.

A PVL load flow analysis was performed on the network for the N-2 condition as well as N-2 with simultaneous 5% and then 8% voltage reductions. The PVL model for Triboro contains 6251 individual connection points and 7651branches from those connection points.

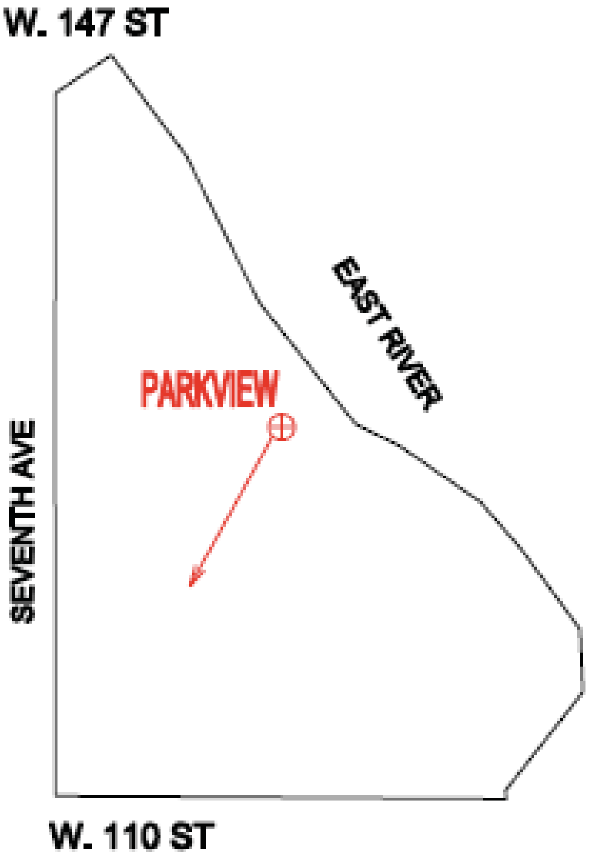


Figure 16

With 24 primary feeders supplying the network, there are 276 possible combinations of the N-2 state. The PVL program considers each combination and solves the network for loading and voltage. Power flows and voltages in the network under any particular condition are dependent on a number of variables including loading at each service point, number of primary feeders out of service and the particular secondary branches onto which power flow is shifted as a result of the unavailability of primary feeders. Because of the dynamics involved with network power flows, the number of customers experiencing service voltage below the ANSI C84.1 standard is dependent on the particular combination of feeders out of service. Table 5 shows a sample of the PVL outputs for five of the 276 possible combinations for each of the conditions, N-2, N-2 with 5% VR and N-2 with 8% VR.

For the N-2 condition without voltage reduction, the number of customers experiencing service voltage below 110V ranges from 276 to 27. For the N-2 condition with 5% voltage reduction, the range is 293 to 66, and for the N-2 condition with 8% voltage reduction, the range is 187 to 61. The total number of customers experiencing low voltage across the five sampled contingencies is 694 for no voltage reduction and 479 for 8% voltage reduction. This counterintuitive result is due to the fact that voltage reduction reduces network loading and current flow which reduces the voltage drop in the feeders and mains, partially counteracting the voltage impact of voltage reduction.

N-2 Condition, NO Voltage Reduction			
N-2 combination		**No. Buses with V < 113**	**No. Customers with V < 110**
44M16	44M21	36	267
44M17	44M18	13	145
44M18	44M19	1	66
44M18	44M21	19	189
44M19	44M20	2	27
Sample Average		**14.2**	**139**
N-2 Condition, 5%Voltage Reduction			
N-2 combination		**No. Buses with V < 113**	**No. Customers with V < 110**
44M16	44M21	15	114
44M17	44M18	25	293
44M18	44M19	1	66
44M18	44M21	13	135
44M19	44M20	10	134
Sample Average		**12.8**	**148**
N-2 Condition, 8% Voltage Reduction			
N-2 combination		**No. Buses with V < 113**	**No. Customers with V < 110**
44M16	44M21	6	61
44M17	44M18	17	187
44M18	44M19	1	66
44M18	44M21	8	97
44M19	44M20	6	68
Sample Average		**7.6**	**96**

Table 5

To better understand the likelihood of customers in the Triboro network actually experiencing low voltage as a result of a voltage reduction, we consider the specific N-2 combination of feeders 44M17 and 44M18 which would affect 187 customers. The Triboro network experienced one voltage reduction over the period 2010 to 2013. Considering only the summer period of 92 days (June 1st to September 1st), over the four-year period, there were a total of 368 days during which a voltage reduction could have been implemented in Triboro. The single instance of voltage reduction occurred on July 22, 2011.[8] Using this experience from the four-year period, the daily probability of a voltage reduction in Triboro is therefore 1/368 or 0.0027. Since the Triboro network has 24 feeders and 276 possible N-2 combinations, the probability of a second contingency involving exactly 44M17 and 44M18 is 1/276 or 0.0036.

Determining the probability of a simultaneous voltage reduction occurring in Triboro and that the N-2 contingency specifically involves feeders 44M17 and 44M18 is found by the product of the two probabilities, (0.0027)(0.0036)=0.00000972 or 1 chance in 103,000. This result can be interpreted using the standard reliability definition of mean time between failures (MTBF). An MTBF for this event is 103,000 days. For a summer period of 92 days, this corresponds to 1,120 summer periods or 1,120 years. Hence the mean time between occurrences of low voltage for the 187 customers that would be affected by the specific N-2 contingency of 44M17 and 44M18 with 8% voltage reduction is 1,120 years.

It is this dependence on a specific N-2 contingency occurring in order to impact a specific group of customers and the relative rarity of that N-2 occurring that result in the relatively few low voltage complaints the Company receives during implementation of voltage reductions.

---

[8] During the period 2010 to 2013, of the 32 networks that reached N-2 or greater and experienced a simultaneous voltage reduction, 19 or 60% of them experienced only a single voltage reduction. Accordingly, the single voltage reduction in Triboro is not unusual. (Excludes Hurricane Sandy and voltage reductions implemented due to external causes like contractor damage)

Customer Complaints of Low Voltage

Another way to gauge the impact of voltage reduction on customers is to examine customer complaint data. Low-voltage complaints are logged in the Company's Emergency Control System (ECS). Records are recorded as "tickets" with an associated "trouble type." The trouble type associated with low voltage is denoted as "LV." We examined a representative summer day in which voltage reductions were implemented in multiple networks providing a reasonable dataset for analysis. On July 22, 2011, voltage reductions were implemented in 14 distinct distribution networks. We compared the number of low-voltage tickets received from networks in which voltage reduction was implemented to those in which it was not. A summary of this analysis is shown in Table 6 . There were 472 low-voltage tickets received on that day which corresponds to .014 % of customers served or an overall incident rate of one low-voltage ticket for every 7,053 customers served.[9] For networks in voltage reduction, there was one low-voltage ticket for every 3,180 customers served. For networks not in voltage reduction, there was one ticket for every 10,330 customers served. Both incident rates are small, particularly in comparison to the customer interruption rate on that same day. During the same 24 hour period, 41,101 customers were interrupted making the customer overall customer interruption rate for that day approximately one interruption for every 81 customers served. The low-voltage ticket rate for networks in voltage reduction for that day was 39 times lower than the interruption rate.

Low Voltage Tickets Received July 11th, 2011			
Status	**Number of Networks With LV Tickets**	**Number of Tickets Received**	**LV Tickets Incident Rate**
In Voltage Reduction	14	298	1 ticket /3180 customers
Not in Voltage Reduction	33	174	1 ticket / 10,330 customers

Table 6

---

[9] In 2011, Con Edison served 3,329,307 electric customers

Task 7: Review of Existing Studies Regarding Impact on Customer Equipment

This section discusses the impact of voltage reduction on customer equipment. The Company has partnered with NYU/Polytechnic for a number of years to conduct studies of the impact of voltage reduction on customer equipment. The partnership included field surveys to determine the types of equipment and appliances used by customers, obtaining a representative sample set of such equipment and subsequent laboratory tests to understand the performance of that equipment under various conditions of supply including low voltage. It also included a review of medical equipment types and their voltage tolerance specifications, as well as instrumenting various customer facilities to understand the impact of service voltage on customer equipment in those facilities.

Field surveys and Laboratory Tests

Field Surveys

Field surveys were conducted at both commercial and at residential sites. Information noted included power consumed by each type of device and the part of the day each was used. In this way, a typical "commercial" load and a typical "residential" load could be defined. The survey locations are listed below.

Commercial Site Surveys

The large commercial sites that were surveyed are listed below:

(1) Disney Building – 500 Park Ave.

(2) Rockefeller University Tower (Weiss) Building – 1230 York Ave.

(3) Bloomingdale's – 59th Street and Lexington Ave.

(4) General Motors (Trump) Building – 767 5th Ave.

Similarly, the following small commercial sites were visited:

(5) El Gigante Mini Supermarket - 3856 Broadway

(6) Grocery store - 53 Vermilyea Ave.

(7) CVS Pharmacy – 630 Lexington Ave.

(8) 117/119 East 55th Street - Brownstone

(9) KAI Tea and Sushi Restaurant – 822 Madison Ave.

Residential Site Field Surveys

In the same manner, a number of “large” residences were visited, and their electrical equipment was inventoried.

(1) Regent Apartments – 45 West 60th Street

(2) The Capri – 231/235 East 55th Street

“Small” residences that were inventoried were:

(3) Brownstone – 161 East 63rd Street

(4) Brownstone – 272 East 10th Street

Data for the large residences were consolidated to define the term “large residential load” Similarly the small residences data were combined to define the term “small residential load.”

Selection of Load Categories

From the results of surveys, laboratory tests and search of the literature, a list of 17 basic loads was constructed, each having its own individual type of electrical characteristic. This list is given in Table 6, which also includes the numbers of devices tested in the NYU/Poly Power Laboratory, and the voltage range of the tests.

List of 17 Basic Loads Tested In Laboratory Tests		
LOAD	Number Tested	Voltage Range (%)
Air Conditioners (Window)	4	63-110
Pumps-Variable Speed	1	91-110
Fans-Constant Speed	2	50-110
Fans-Variable Speed	1	65-110
*Elevator- Variable Speed	1	85-110
#Elevator/Escalator-Motor Generator Set	1	75-110
**Const. Torque motor-load	1	85-110
Fluorescent Lights-Magnetic	3	76-110
Fluorescent Lights-Electronic	2	50-110
Fluorescent Lights-U-shape	2	50-110
Fluorescent Lights-Spotlight	2	83-110
Halogen	1	83-110
Incandescent	4	87-110
Resistive Load	2	75-110
TV; Printers; Fax	10	83-110
Computers	4	50-110
Microwave Oven	2	75-110
UPS	1	77-110

Table 7

*: Elevator- Variable Speed was simulated with AC/DC Converter and DC motor set at constant shaft torque.
#: Elevator M/G set and escalators were simulated in our lab with AC-DC M/G set also at constant shaft torque.
**Constant torque motor-loads include small motor loads such as: cutters, mixers, meat slicers, ice-cream makers, meat grinders, brand-new cutters, compactors and small conveyers. These were simulated in our laboratory with AC-DC M/G set also at constant torque.

Laboratory Experiments

Each load was subjected to a range of voltages, varying stepwise in a slow ramp, from 50% below to 10% above its rated value. For small loads, several devices could be tested simultaneously in parallel. The step tests were performed in accord with the recommendations of the IEEE Working Group on Load Representation for Steady State Performance.

Thirty loads in 17 categories were tested. The emphasis was on modern loads, such as heat pumps, computers, laser printers and microwave ovens. Large loads, such as three-phase industrial induction motors, were not tested because well-documented simulation models exist for these motors.

Power lab of NYU/Polytechnic has facilities to test small industrial and residential loads over a range of voltage, frequency and loading conditions. Each facility is fully instrumented, and was designed and operated according to recognized test standards (i.e. ASHRAE, AMCA, IEEE, CSA).

The laboratory tests were carried out for at least ten voltage levels. For a 120V device, voltages of 60V, 70V, 80V, 90V, 100V, 105V, 110V, 115V, 120V, 125V and 130V were used. For a 208V device, voltages of 160V, 170V, 180V, 190V, 200V, 205V, 210V, 215V, 220V, 225V and 230V. At each voltage level, the real power, reactive power, current and power factor were measured along with the devices effective "cutoff voltage," *i.e.*, the voltage at which the device would no longer operate. Each test was performed three times, and each device was turned on over one half hour before the data were recorded to make sure that the device operated in steady state.

Figure 17, Figure 18, and Figure 19 show actual equipment cutoff voltages as found from the laboratory results. Those voltages are superimposed over calculated utilization voltage as a function of feeder contingency and voltage reduction. The voltage calculation takes into account the voltage drop from Con Edison's distribution structure to the point where Con Edison's wiring connects to the customer wiring and also the voltage drop due to the internal customer wiring.[10] As can be seen from the figures, most equipment would not be affected during simultaneous voltage reduction and feeder contingencies.

---

[10] The National Electric Code allows up to a 5% drop in voltage for internal wiring from the service entrance equipment to the point of utilization. This analysis used a 2.5% nominal value for that voltage drop.

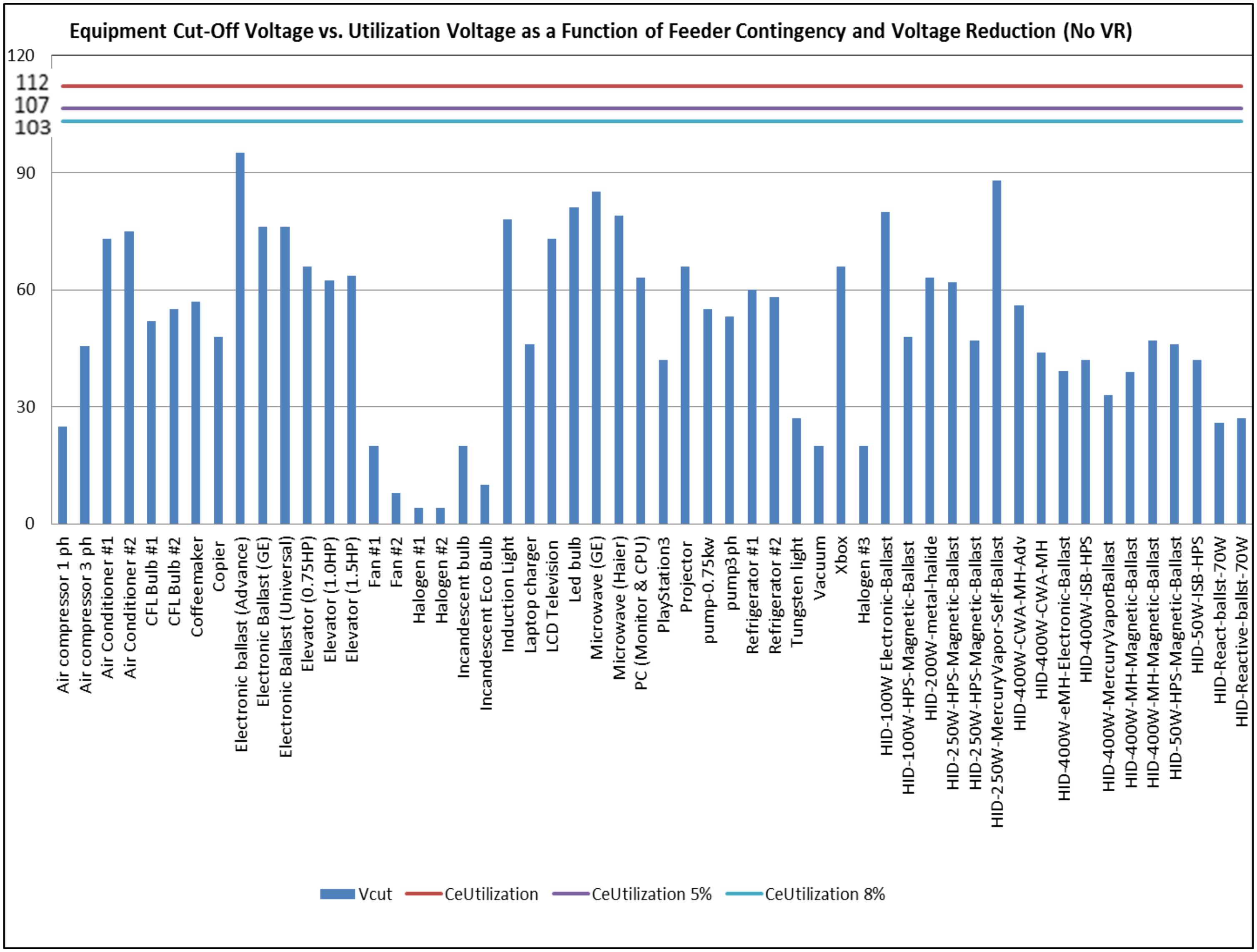

Equipment Cut-Off Voltage vs. Utilization Voltage as a Function of Feeder Contingency and Voltage Reduction (No VR)
120
112
107
103
90
60
30
0
Air compressor 1 ph
Air compressor 3 ph
Air Conditioner #1
Air Conditioner #2
CFL Bulb #1
CFL Bulb #2
Coffeemaker
Copier
Electronic ballast (Advance)
Electronic Ballast (GE)
Electronic Ballast (Universal)
Elevator (0.75HP)
Elevator (1.0HP)
Elevator (1.5HP)
Fan #1
Fan #2
Halogen #1
Halogen #2
Incandescent bulb
Incandescent Eco Bulb
Induction Light
Laptop charger
LCD Television
Led bulb
Microwave (GE)
Microwave (Haier)
PC (Monitor & CPU)
PlayStation3
Projector
pump-0.75kw
pump3ph
Refrigerator #1
Refrigerator #2
Tungsten light
Vacuum
Xbox
Halogen #3
HID-100W Electronic-Ballast
HID-100W-HPS-Magnetic-Ballast
HID-200W-metal-halide
HID-250W-HPS-Magnetic-Ballast
HID-250W-HPS-Magnetic-Ballast
HID-250W-MercuryVapor-Self-Ballast
HID-400W-CWA-MH-Adv
HID-400W-CWA-MH
HID-400W-eMH-Electronic-Ballast
HID-400W-ISB-HPS
HID-400W-MercuryVaporBallast
HID-400W-MH-Magnetic-Ballast
HID-400W-MH-Magnetic-Ballast
HID-50W-HPS-Magnetic-Ballast
HID-50W-ISB-HPS
HID-React-ballst-70W
HID-Reactive-ballst-70W
Vcut
CeUtilization
CeUtilization 5%
CeUtilization 8%

Figure 17

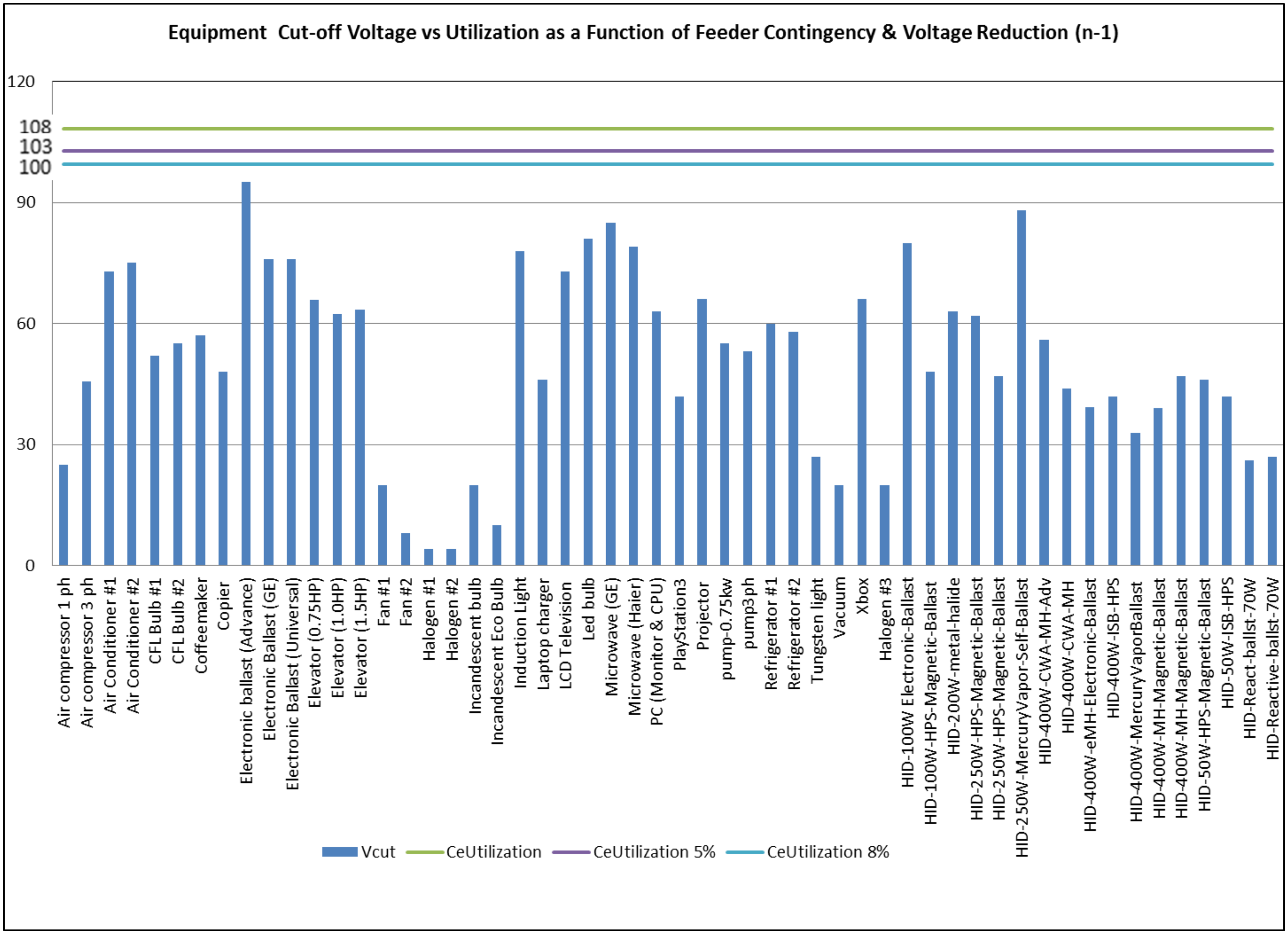

Equipment Cut-off Voltage vs Utilization as a Function of Feeder Contingency & Voltage Reduction (n-1)
120
108
103
100
90
60
30
0
Air compressor 1 ph
Air compressor 3 ph
Air Conditioner #1
Air Conditioner #2
CFL Bulb #1
CFL Bulb #2
Coffeemaker
Copier
Electronic ballast (Advance)
Electronic Ballast (GE)
Electronic Ballast (Universal)
Elevator (0.75HP)
Elevator (1.0HP)
Elevator (1.5HP)
Fan #1
Fan #2
Halogen #1
Halogen #2
Incandescent bulb
Incandescent Eco Bulb
Induction Light
Laptop charger
LCD Television
Led bulb
Microwave (GE)
Microwave (Haier)
PC (Monitor & CPU)
PlayStation3
Projector
pump-0.75kw
pump3ph
Refrigerator #1
Refrigerator #2
Tungsten light
Vacuum
Xbox
Halogen #3
HID-100W Electronic-Ballast
HID-100W-HPS-Magnetic-Ballast
HID-200W-metal-halide
HID-250W-HPS-Magnetic-Ballast
HID-250W-HPS-Magnetic-Ballast
HID-250W-MercuryVapor-Self-Ballast
HID-400W-CWA-MH-Adv
HID-400W-CWA-MH
HID-400W-eMH-Electronic-Ballast
HID-400W-ISB-HPS
HID-400W-MercuryVaporBallast
HID-400W-MH-Magnetic-Ballast
HID-400W-MH-Magnetic-Ballast
HID-50W-HPS-Magnetic-Ballast
HID-50W-ISB-HPS
HID-React-ballst-70W
HID-Reactive-ballst-70W
Vcut
CeUtilization
CeUtilization 5%
CeUtilization 8%

Figure 18

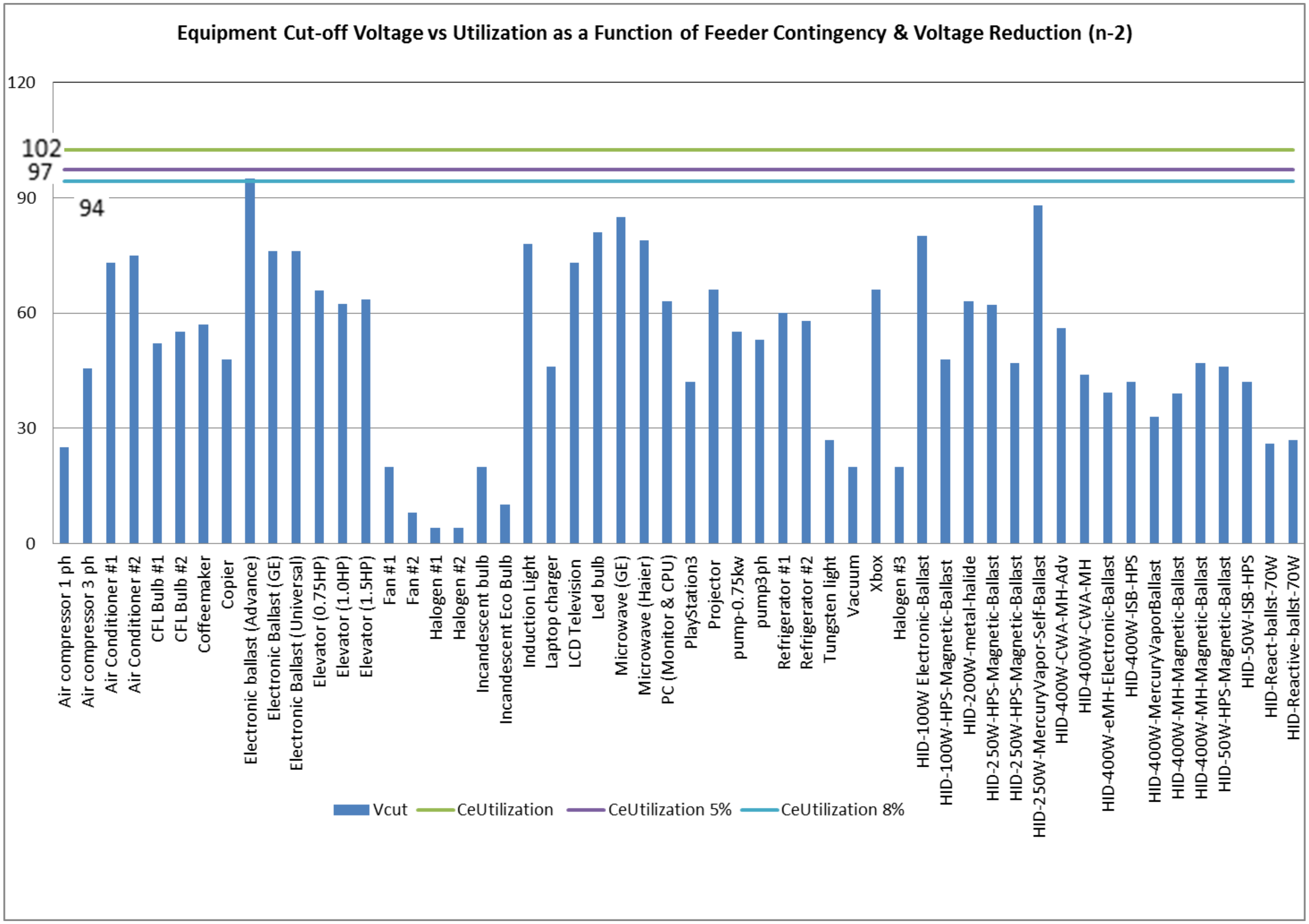

Equipment Cut-off Voltage vs Utilization as a Function of Feeder Contingency & Voltage Reduction (n-2)
120
102
97
90
94
60
30
0
Air compressor 1 ph
Air compressor 3 ph
Air Conditioner #1
Air Conditioner #2
CFL Bulb #1
CFL Bulb #2
Coffeemaker
Copier
Electronic ballast (Advance)
Electronic Ballast (GE)
Electronic Ballast (Universal)
Elevator (0.75HP)
Elevator (1.0HP)
Elevator (1.5HP)
Fan #1
Fan #2
Halogen #1
Halogen #2
Incandescent bulb
Incandescent Eco Bulb
Induction Light
Laptop charger
LCD Television
Led bulb
Microwave (GE)
Microwave (Haier)
PC (Monitor & CPU)
PlayStation3
Projector
pump-0.75kw
pump3ph
Refrigerator #1
Refrigerator #2
Tungsten light
Vacuum
Xbox
Halogen #3
HID-100W Electronic-Ballast
HID-100W-HPS-Magnetic-Ballast
HID-200W-metal-halide
HID-250W-HPS-Magnetic-Ballast
HID-250W-HPS-Magnetic-Ballast
HID-250W-MercuryVapor-Self-Ballast
HID-400W-CWA-MH-Adv
HID-400W-CWA-MH
HID-400W-eMH-Electronic-Ballast
HID-400W-ISB-HPS
HID-400W-MercuryVaporBallast
HID-400W-MH-Magnetic-Ballast
HID-400W-MH-Magnetic-Ballast
HID-50W-HPS-Magnetic-Ballast
HID-50W-ISB-HPS
HID-React-ballst-70W
HID-Reactive-ballst-70W
Vcut
CeUtilization
CeUtilization 5%
CeUtilization 8%

Figure 19

The cutoff voltages for almost all types of equipment tested are well below the lowest expected voltage during an N-1 or N-2 feeder contingency and 8% voltage reduction. Only the "Advance Electronic Ballast" was affected (at a voltage of approximately 94 volts).

Instrumentation of Facilities

Several customer locations were selected for the installation of power quality monitoring devices. Monitors were installed at the utility service point and also at electrical panels within the facilities. At each location, a number of electrical parameters were recorded including the steady state voltages at each of the instrumented locations. The internal voltage drops between the utility service point and the electrical panels were also calculated.

The locations were:

- Bellevue Hospital (462 1st Ave, New York, NY)
- Lincoln Hospital (234 E 149th St, Bronx, NY)
- Vornado Realty Trust (11 Penn Plaza, New York, NY)
- Vornado Realty Trust (150 E 58th St, New York, NY)
- Bloomberg LP (731 Lexington Ave, New York, NY)

At **Bellevue Hospital**, power quality monitors were installed in four locations:

- The point of service entry (POE) where the Con Edison transformer equipment is located (Utility Power CT-Service D)
- The MRI Main MDB subpanel that feeds the MRI machine magnets (A1)
- The ATT communications equipment panel on the 22nd floor (ATT Panel 22nd Fl.)

- The 13th floor CT South West cabinet that feeds the ATT equipment panel on the 22nd floor (Utility Power CT-13th Fl.)

A schematic of the Bellevue Hospital internal distribution system is shown in Figure 20.

Figure 21 and Figure 22 show voltages for the utility supply points and MRI and ATT panels measured over a two week period.

Table 8 shows the steady state voltages measured at the various measured points. Table 9 shows the internal voltage drops calculated from the measurements.

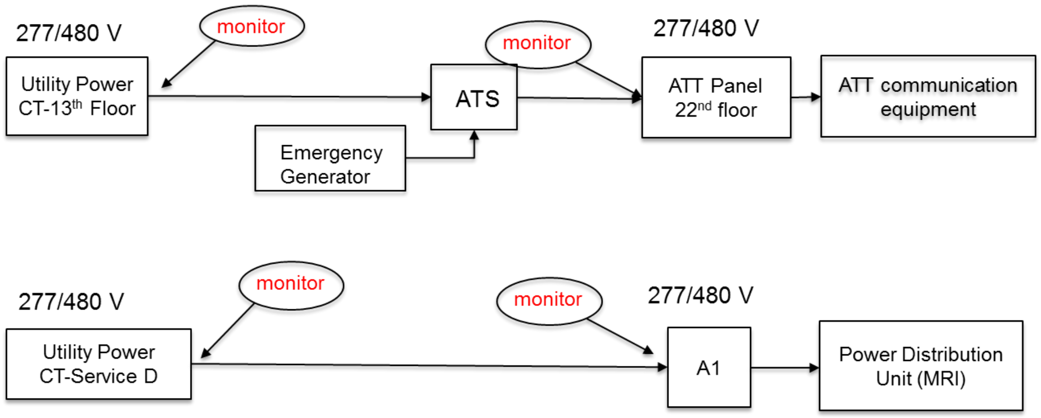


Figure 20

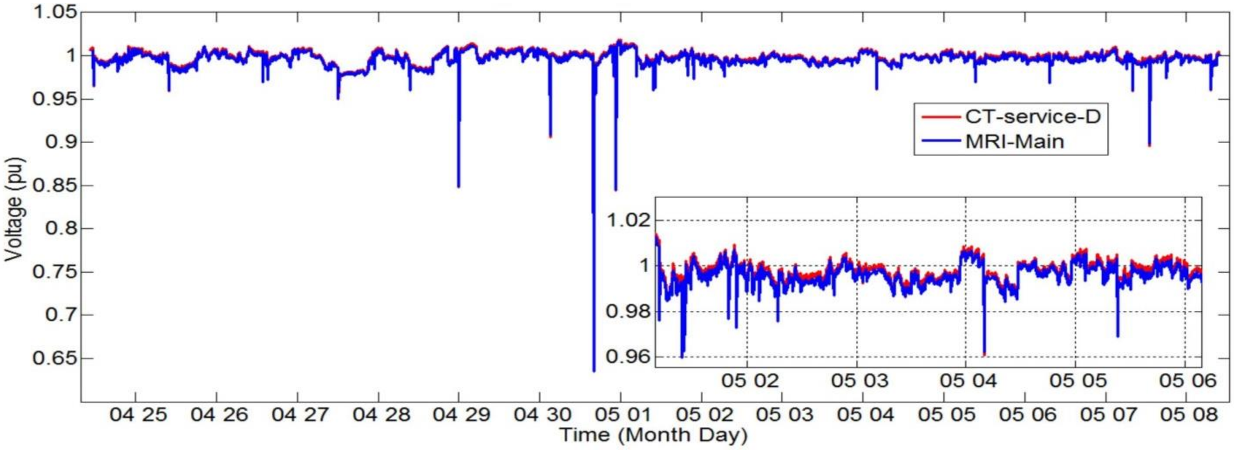


Figure 21

Minimum voltage comparison at feeder’s POE and ATT equipment in phase AB

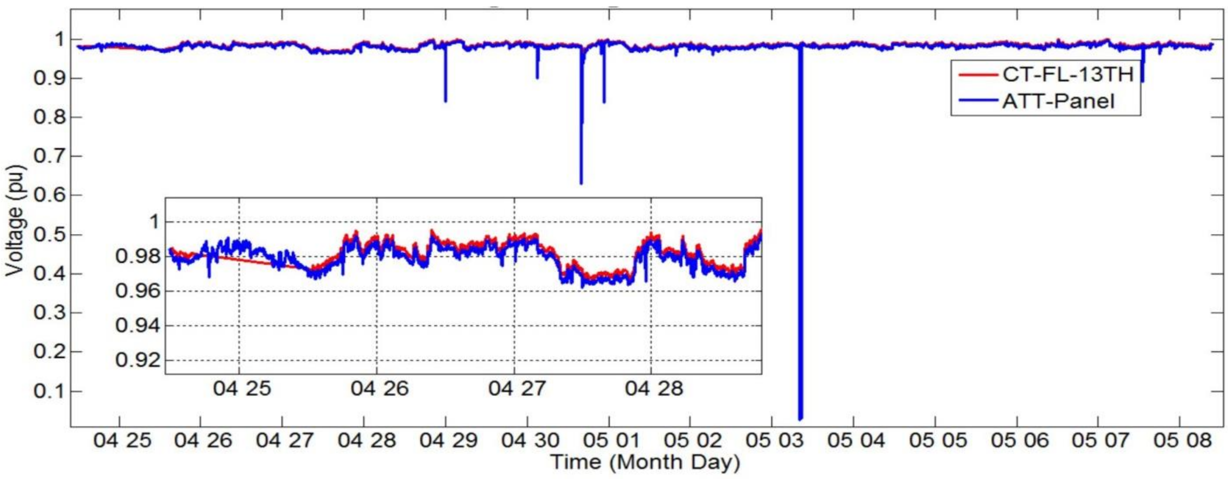


Figure 22

Minimum voltage comparison at feeder’s POE and ATT equipment in phase AB

Node	Phases	Average Voltage	ANSI C84.1
Utility Power CT-Service D	AB	480.57	Pass
	BC	481.35	Pass
	CA	481.48	Pass
MRI	AB	480.18	Pass
	BC	481.22	Pass
	CA	479.34	Pass
Utility Power 13fl	AB	474.11	Pass
	BC	475.48	Pass
	CA	472.76	Pass
ATT	AB	472.67	Pass
	BC	474.62	Pass
	CA	471.53	Pass

Table 8

Equipment	Phase	Maximum voltage drop (V)	Average voltage drop (V)	ANSI Standard (5 %)
ATT Communication Room	AB	3.57	1.45	Pass
	BC	3.58	0.89	Pass
	CA	3.51	1.23	Pass
MRI Machine	AB	3.63	0.35	Pass
	BC	3.93	0.20	Pass
	CA	6.80	2.10	Pass

Table 9

For Bellevue hospital, the steady state voltages measured were within the ANSI standards, and the voltage drops due to the internal wiring were within the 5% ANSI standard.

At **Lincoln Hospital**, power quality monitors were installed in three locations:

- The point of service entry (POE) where the Con Edison transformer equipment is located (West Bronx Lincoln Hospital Vault)
- A 480V equipment panel (EMCC_3A panel)
- A 480V equipment panel (MCC_3C panel)

A schematic of the installation for Lincoln Hospital is shown in Figure 23. Figure 24 and Figure 25 show voltages for the utility supply point and the two 480V distribution panels measured over a one week period. Table 10 shows the steady state voltages at the various measured points. Table 11 shows the internal voltage drops calculated from the measurements.

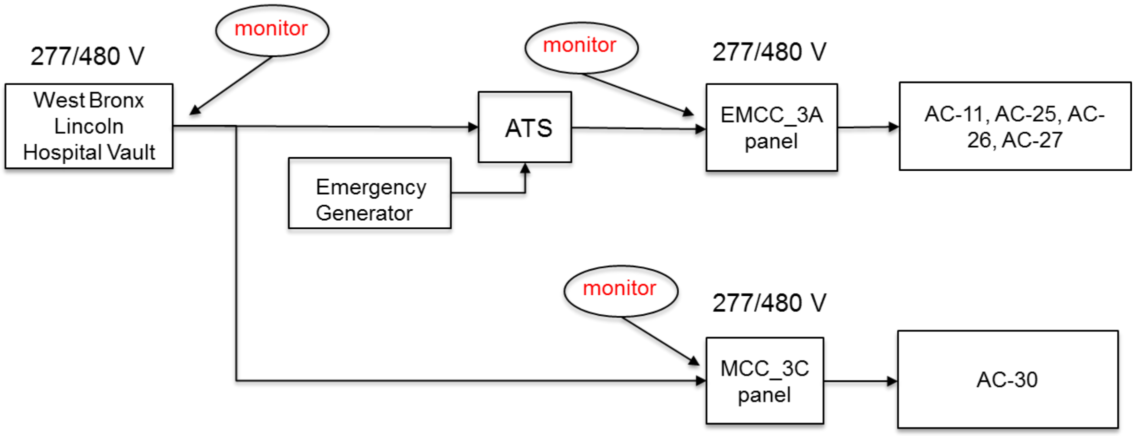


Figure 23

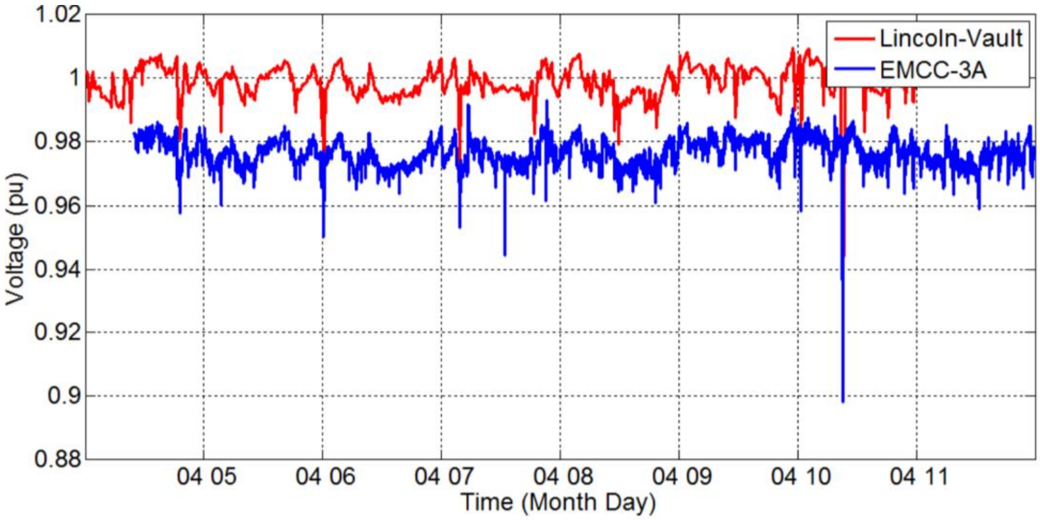


Figure 24

Minimum Voltage comparison at vault and EMCC_3A in Phase AB

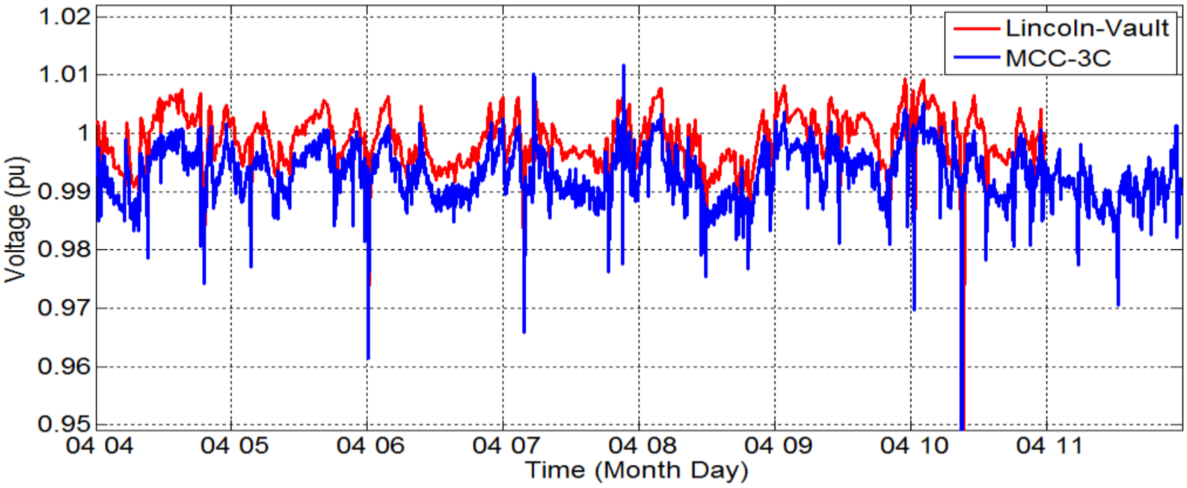


Figure 25

Minimum Voltage comparison at vault and MCC_3C in Phase AB

Node	Phases	Average Voltage	ANSI C84.1-2006 Table 1 Standard
EMCC_3A	AB	473.27	Pass
	BC	474.80	Pass
	CA	472.77	Pass
MCC_3C	AB	478.73	Pass
	BC	479.54	Pass
	CA	478.39	Pass
Vault	AB	481.80	Pass
	BC	481.63	Pass
	CA	481.21	Pass

Table 10

Equipment Panel	Phase	Maximum voltage drop (V)	Average voltage drop (V)	ANSI C84.1 Standard
EMCC_3A	AB	24.86	8.46	Pass
	BC	39.27	6.77	Pass
	CA	17.61	8.39	Pass
MCC_3C	AB	9.98	2.90	Pass
	BC	6.51	1.93	Pass
	CA	8.76	2.67	Pass

Table 11

For Lincoln hospital, the steady state supply voltages measured were within the ANSI standards, and the average voltage drops due to the internal wiring were within the 5% ANSI standard. The maximum voltage drop for the EMCC_3A panel exceeded the 5% ANSI standard. This can be seen in Figure 24 where the red trace is the Con Edison supply voltage and the blue trace is the voltage at the EMCC_3A panel. The spacing between the traces is indicative of the internal voltage drop in the facility wiring.

At **Vornado Realty Trust (11 Penn Plaza),** power quality monitors were installed in two locations:

- The point of service entry (POE) where the Con Edison transformer equipment is located (Utility Power Level B2 Switchboard)
- Panel "A", 15th Floor which supplies the building elevators

A schematic of the installation for 11 Penn Plaza is shown in Figure 26. Table 12 shows the steady state voltages at the measured points. Data to produce a table of voltage drops was not available, but Figure 27 indicates a maximum voltage drop between 4 and 4.5%. Consequently, for 11 Penn Plaza, the steady state supply voltage at the utility point of entry, as well as the internal voltage drop, were both measured to be within the ANSI standard.

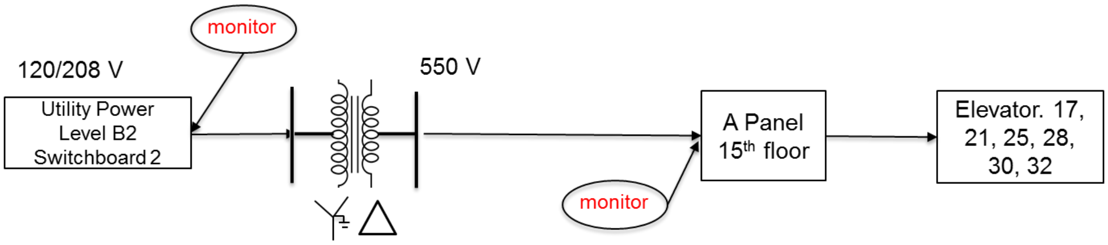


Figure 26

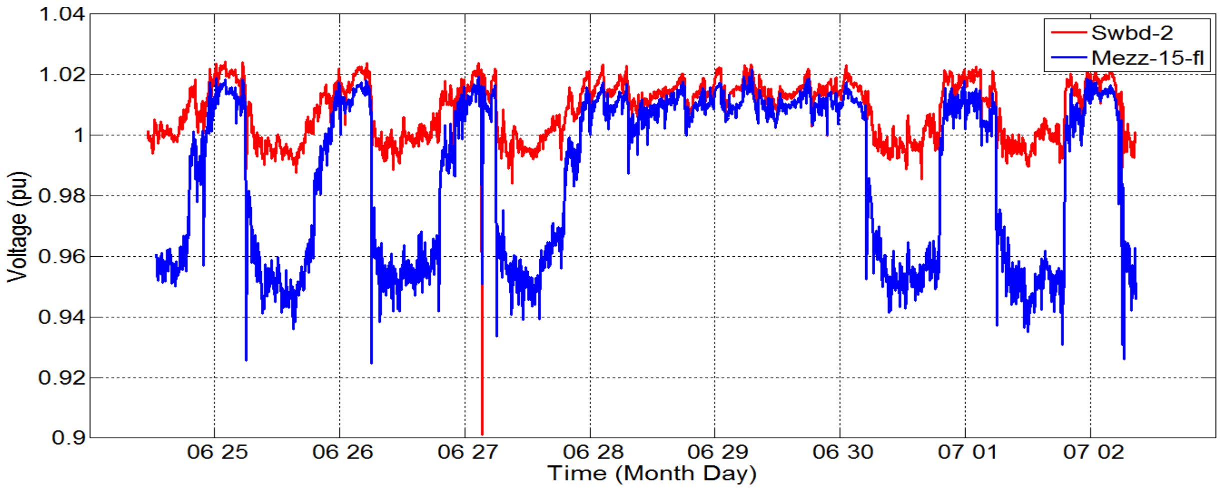


Figure 27

Node	Phases	Average Voltage	ANSI C84.1-2006
Utility Level Swbd_2	AB	210.58	Pass
	BC	211.18	Pass
	CA	211.35	Pass
Mezz_15_fl	AB	549.93	Pass
	BC	550.62	Pass
	CA	550.83	Pass

Table 12

At **Vornado Realty Trust (150 E 58th St.)** power quality monitors were installed in two locations:

- The point of service entry (POE) where the Con Edison transformer equipment is located (Service A SWGR A-02)
- Switchboard Mezzanine DP-A

A schematic of the installation for 150 E 58th St. is shown in Figure 28. Figure 29 shows the voltages for the utility supply point and the monitored panel over the period of a week.

Table 15 shows the steady state voltages at the various measured points. Table 14 shows the internal voltage drops calculated from the measurements. The steady state supply voltage at the utility point of entry and the internal voltage drops were both measured to be within the ANSI standard.

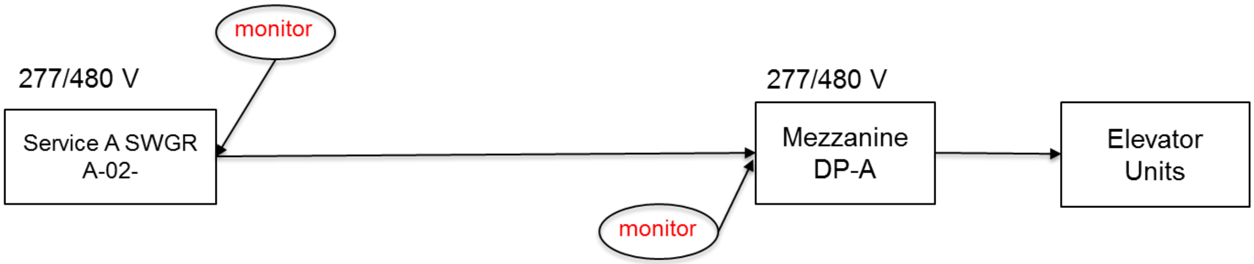


Figure 28

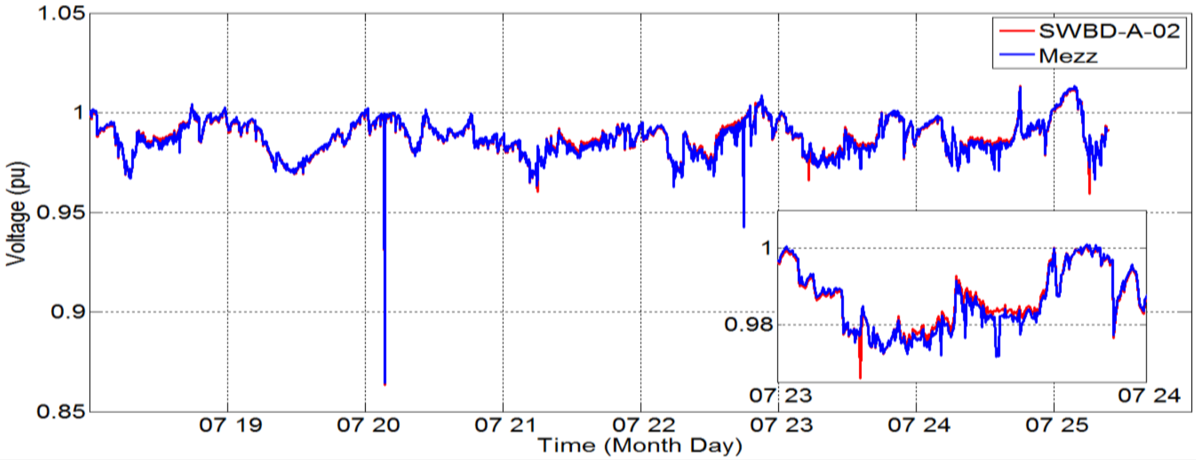


Figure 29

Node	Phases	Average Voltage	ANSI C84.1 Standard
Mezz	AB	475.54	Pass
	BC	475.83	Pass
	CA	475.01	Pass
Swbd_A_02	AB	475.70	Pass
	BC	475.87	Pass
	CA	476.91	Pass

Table 13

Equipment Panel	Phase	Maximum voltage drop (V)	Average voltage drop (V)	ANSI C84.1 (3%)
Mezz	AB	2.181488	0.16397	Pass
	BC	8.056763	0.032844	Pass
	CA	9.513794	1.905213	Pass

Table 14

At **Bloomberg LP (731 Lexington Ave.)** power quality monitors were installed in two locations:

- The point of service entry (POE) where the Con Edison transformer equipment is located (Utility Basement Switchboard 5)
- Switchboard 8-E-2

A schematic of the installation for 731 Lexington Ave. is shown in Figure 30. Figure 31 shows the voltages for the utility supply point and the monitored panel over the period of a week.

Table 15 shows the steady state voltages at the various measured points. Table 16 shows the internal voltage drops calculated from the measurements. The steady state supply voltage at the utility point of entry and the internal voltage drops were both measured to be within the ANSI standard.

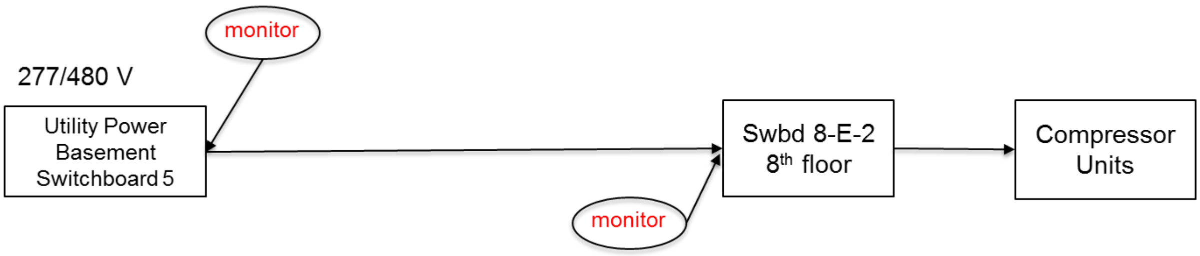


Figure 30

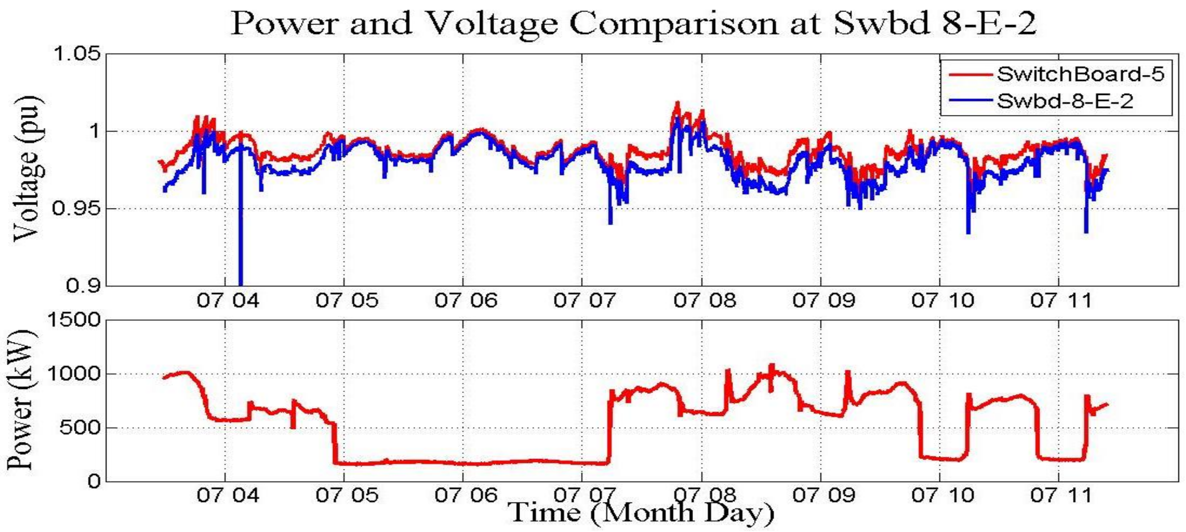


Figure 31

Node	Phases	Average Voltage	ANSI C86.1-2006 Standard
Swbd_8_E_2	AB	471.50	Pass
	BC	472.47	Pass
	CA	471.44	Pass
SwitchBoard_5	AB	475.02	Pass
	BC	475.87	Pass
	CA	474.60	Pass

Table 15

Equipment Panel	Phase	Maximum voltage drop (V)	Average voltage drop (V)	ANSI C84.1 Standard
Swbd_8_E_2	AB	12.30378	3.526001	Pass
	BC	12.8938	3.413256	Pass
	CA	15.35271	3.166268	Pass

Table 16

Network Simulations

Since, during the period of the monitoring, no voltage reductions were implemented in the networks supplying the five facilities where voltage monitoring was conducted, network simulations were performed to evaluate the potential impact of voltage reduction on those facilities. The network simulations were performed using the Poly Voltage Load Flow (PVL) computer application previously discussed in the section on the impact of voltage reduction on customer service voltage. In addition to the model of the Con Edison network system, the model was extended to include the internal distribution systems of the five monitored facilities. The simulations tested all combinations of N-1 and N-2 contingencies under normal conditions, 5% and 8% voltage reduction. A total of 3,204 separate contingencies were considered using the PVL computer application.

Table 17 shows the ANSI C84.1 Range A and B minimum service and utilization voltages in "per-unit" or the fraction of full supply voltage (480V corresponds to 1.0pu for 277/480V supplies and 208V corresponds to 1.0pu for 120/208V supplies).[11] Table 18 shows the *lowest* voltages found from the simulations, listed in per-unit of full voltage. The voltages shown are at the point of interconnection between the Con Edison infrastructure and the customer infrastructure (POE) as well as the voltage at the panel supplying the equipment.

Range	Service (pu)	Utilization (pu)
A	0.95	0.90
B	0.92	0.87

Table 17
ANSI Service and Utilization Voltages in "Per-Unit"

Network	**Location**	**VR % @ N-2**	**Service(POE)**	**Equipment**
Madison Square	Bellevue Hospital	0%	0.99	0.97
		5%	0.93	0.92
		8%	**0.91**	0.89
West Bronx	Lincoln Hospital	0%	0.96	0.93
		5%	**0.91**	0.88
		8%	**0.88**	**0.85**
Herald Square	11 Penn Plaza	0%	1.01	0.94
		5%	0.96	0.89
		8%	0.93	**0.86**
Roosevelt	158 E 58th St.	0%	0.95	0.95
		5%	**0.90**	0.90
		8%	**0.87**	0.87
Roosevelt	731 Lexington	0%	0.95	0.94
		5%	**0.90**	0.89
		8%	**0.87**	**0.85**

Table 18
Lowest Predicted Voltages at POE and Internal Points - Simulation

The instances of voltage below the lowest ANSI C84.1 standard are bolded and highlighted There are seven instances of service voltage below the lowest ANSI standard and three instances of utilization voltage below the lowest ANSI standard.

---

[11] Per-unit voltages allow a uniform comparison which is necessary because some facilities had internal equipment that converted Con Edison supplied voltage to other voltages.

It is notable that despite the fact that the minimum expected Con Edison service voltage under an N-2 contingency is below the lowest ANSI standard voltage (0.92 per unit), the Con Edison service voltage is actually below 0.92 per unit in only six of the 15 N-2 conditions listed. This is because service voltages are dependent on many factors and vary geographically across the network. The Con Edison design service voltage standard is the minimum service voltage under the stated conditions, *not* the actual service voltage at each customer's service point.

It is also notable that in four of the seven instances of Con Edison service voltage below 0.92 per unit, the equipment utilization voltage is nonetheless adequate (at least 0.87 per unit) being above the minimum ANSI utilization standard. This is because the ANSI standards are based on an assumed voltage drop within a facility. If the voltage drop is less than that assumption, then adequate utilization voltage may be supplied despite inadequate service voltage.

Additionally, one of the three instances of inadequate utilization voltage occurs with adequate service voltage supplied by Con Edison.

Location	No. Voltage Reductions	V.R. Frequency	Contingency Frequency	MTBF (years)
Lincoln Hosp.	1	0.00271	0.21	19.0
11 Penn. Plaza	1	0.00271	0.30	10.4
731 Lexington	2	0.0054	0.67	3.38

Table 19

To better understand the likelihood of actually experiencing utilization voltage below 0.87 per unit at the three facilities identified in the simulation, we computed the mean times between failures (MTBF) for such occurrences and have listed them in Table 19. The number of voltage reductions is taken from the 2010 to 2013 dataset used for other computations in this report. For the Herald Square network (feeding 11 Penn. Plaza), which did not experience any voltage reductions in the four year period of data, the median number of voltage reductions (1) for networks with similar NRI over the four year period was used. Considering only the summer period of 92 days (June 1st to September 1st), over the four year period, there were a total of 368 days during which a voltage reduction could have been implemented in any of the networks. The "V.R. Frequency" is the daily probability of a voltage reduction in each of the networks during the summer period and is computed as the number of voltage reductions divided by the 368 opportunities for a reduction. The "Contingency Frequency" is computed as the number of N-2 contingencies that actually result in utilization voltage below the minimum ANSI utilization voltage divided by the total number of possible N-2 contingencies, that possible number being dependent on the total number of feeders in the network.

The probability of a simultaneous voltage reduction occurring in any network and the probability of the N-2 contingency specifically resulting in utilization voltage below the minimum ANSI utilization voltage is found by the product of the two probabilities. This is shown in the table using the standard reliability definition of mean time between failures (MTBF). The MTBF in "summers" is computed by computing the MTBF in days and dividing by the summer period of 92 days. Since each year contains only one summer, the MTBF in summers is also the MTBF in years.

Only Lincoln Hospital and 731 Lexington Ave. would experience utilization voltage below the minimum ANSI utilization voltage as a result of Con Edison service voltage below the minimum ANSI service voltage during voltage reduction. 11 Penn Plaza would experience utilization voltage below the minimum ANSI utilization voltage, despite adequate Con Edison service voltage. Lincoln Hospital would experience this condition on average once every 19 years while 731 Lexington Ave. would experience this condition on average once every three years.

Task 8: Role of Load Curtailment Programs Including Demand Response and Customer Appeals

In this task we examined the impact of load curtailment programs on the likelihood of implementing voltage reductions. The analysis focused on second contingency design networks. Since the general guidance for initiating voltage reduction is when a network experiences a second contingency, we utilized summer second contingencies as a proxy for voltage reductions. (An N-2 contingency can be used as a proxy for a VR, since a VR may be implemented in the summer when an N-2 contingency occurs.) We examined data from 320 summer weekdays from 2008 to 2013 (2009 was omitted as there were no voltage reductions in 2009). A relationship between system peak load (MWs) and the number of N-2 contingencies, for a given peak load day is shown in Figure 32. The red regression line represents a composite system relationship between load and N-2 contingencies. The upper right quadrant indicates the conditions of load and temperature variable under which VR is implemented according to company procedure EOP-5022.

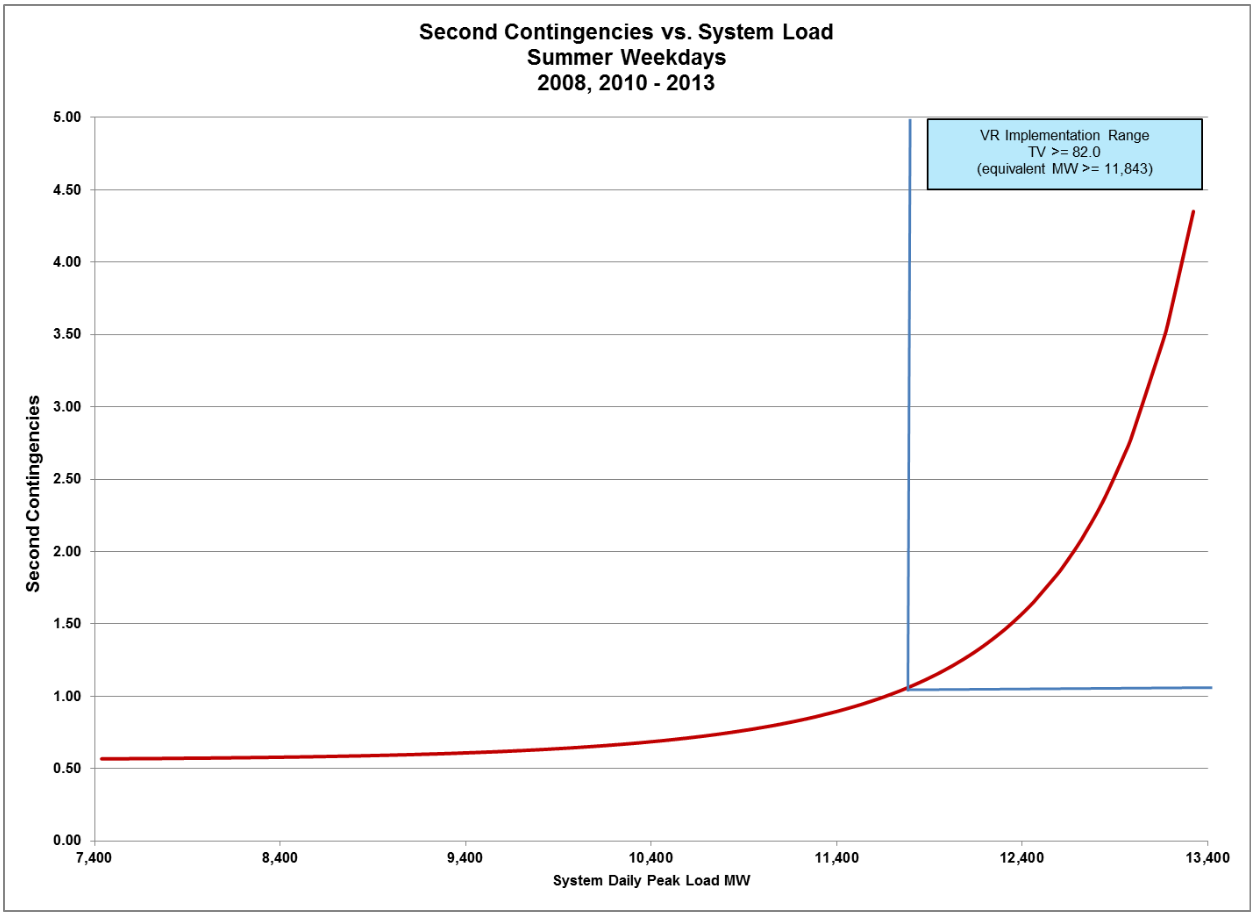


Figure 32
Derived relationship between system daily peak load and daily N-2 contingencies

The upper right corner of the curve corresponds to Con Edison's all-time electric system peak of 13,322 MW, which occurred on July 19, 2013. On that day, over 200 MW of load reduction from the various demand response programs was realized. Without these demand response programs, the electric system peak would have been at least 200 MW higher, or at least 13,522 MW. The regression model predicts six N-2 contingencies at 13,522. At the actual peak experienced on that day, the regression model predicts four N-2 contingencies. This may be interpreted as our demand response measures avoiding two additional N-2 contingencies – or voltage reductions – from taking place on the peak day.

In order to consider the impact of additional demand response on the likelihood of voltage reduction, we note that the regression model defines a relationship between the number of N-2 contingencies and peak demand. Due to the exponential nature of the curve, as the system peak demand is decreased, fewer and fewer N-2 contingencies would be avoided. In other words, more and more MW demand decreases are needed to avoid each additional N-2 contingency as system peak load gets lower and lower.

Following are two specific examples. In order to decrease the number of N-2 contingencies expected on a day similar to the system peak (about four) down to three N-2 contingencies, the system peak would need to decrease by about 187 MW. So a system peak of 13,135 MW would, based on the regression model, result in one fewer N-2 contingency. However, because of the "diminishing returns" nature of the relationship between system load and N-2 contingencies, in order to avoid an additional N-2 contingency above and beyond the one avoided by reducing peak demand to 13,135, *i.e.*, to go from three to two N-2 contingencies, system peak would need to decrease by an additional 298 MW.

Additionally, VR is implemented only above a temperature variable (TV) of 82. Based on the historical relationship between TV and system peak load, this corresponds to an 11,843 MW system demand. Moving from the system all-time peak of 13,322 MW to 11,843 MW (a decrease of 1,479 MW) translates to an expected decrease of three N-2 contingencies. However, as calculated in the previous two paragraphs, two N-2 contingencies were avoided by reducing the all-time system peak by 187 MW + 298 MW = 485 MW. In other words, an additional 994 MWs would be needed to move from two expected N-2 contingencies to one expected N-2 contingency.

In summary, using the all-time system peak of 13,322 as reference point and based on the derived regression model, moving from a day similar to the all-time peak load day down to a MW peak load associated with a TV of 82, which is the trigger point for the use of voltage reduction, we would expect a decrease of three daily N-2 contingencies (or voltage reductions) system-wide.

Task 9: Projected Capital Costs

In this section, we examine the projected capital costs to reduce instances of voltage reduction. In order to compute these costs, we used the Company's Network Reliability Index (NRI) model discussed in Task 5. We also used instances of summer N-2 contingencies as a proxy for voltage reductions. Eight sample networks were selected for analysis. Two networks were selected from each of the four N-2 design areas, Manhattan, Brooklyn, Queens and the Bronx. In each area, the networks were selected such that their NRI values differed enough to provide a reasonable range of reliability for comparative analysis.

The NRI program was run to first determine the MTBF for N-2 contingencies for each network. Then the program was configured to adjust the reliability of each network, and NRI was re-run to assess the change in MTBF for N-2 contingencies. The reliability adjustment used in this analysis was complete replacement of PILC cable and all stop joints in the network.[12] The percent change in N-2 performance and total cost to achieve that change in performance were computed.

Table 20 shows the results of the reliability and cost analysis for the selected networks. The table lists the network, number of PILC sections, number of stop and paper joints and the cost to replace those components.[13] The table also lists the frequencies of occurrence of N-2 contingencies before and after PILC section and joint replacements are completed.

---

[12] PILC and stop joint impact on network reliability are discussed in Task 4 which examined the root cause of feeder failures.

[13] The analysis assumes an average cost of $25,000 for replacement of a section of PILC cable and $25,000 for replacement of a splice.

				Frequency of summer 2nd contingencies				
Network	PILC Sections	Stop Joint + Paper Joints	Replacement Cost	Currently	After PILC Replacement	Reduction	% Reduction	Cost/N-2 Avoided/Yr.
Yorkville	448	596	$ 13,159,000	1.58	1.207	0.373	23.60	35,295,853
Madison Square	248	352	$ 6,440,000	0.40605	0.294	0.112	27.52	57,633,793
Northeast Bronx	295	394	$ 9,551,200	0.5025	0.343	0.160	31.77	59,833,365
Southeast Bronx	549	747	$ 18,834,000	1.1223	0.742	0.381	33.91	49,483,723
Ridgewood	7	8	$ 98,800	0.80624	0.804	0.002	0.28	43,524,229
Bay Ridge	31	37	$ 817,200	0.78449	0.753	0.032	4.06	25,657,771
Maspeth	579	778	$ 19,241,100	1.40356	0.896	0.508	36.19	37,879,909
Flushing	165	213	$ 5,991,000	2.02863	1.854	0.175	8.62	34,277,377

Total Cost	$ 74,132,300
Average % Reduction	21.8%

Table 20
Reliability and Cost Analysis

Currently, across all the eight sampled networks, the frequency of N-2 contingencies ranges from 2.02 to 0.4 occurrences per year with an average of 1.08. After reliability improvement work, the frequency of N-2 contingencies ranges from 1.8 to 0.29 occurrences per year with an average of 0.86. The overall, average improvement in N-2 contingency frequency after PILC and stop joint replacement is 21.8%. The cost to achieve this across the eight selected networks is $74,132,300. The average cost to avoid a single N-2 contingency is $42.9 million.

We extended the reliability impact and cost analysis for the selected networks to the entire system by valuing the replacement of all PILC and stop joints across all networks. The result is shown in Table 21. System-wide, the estimated cost for replacement cost of all PILC and stop joints is $502.8 million.

Component	Quantity	Cost Per Unit	Total
PILC Cable Sections	14,740	$25,000	$368,500,000
Stop Joints	15,192	$5,000	$75,960,000
Lead Wipe Joints	11,669	$5,000	$58,345,000
Total Cost			$502,805,000

Table 21
Component Replacement Costs

Conclusions

The Company conducted an extensive analysis of its use of voltage reduction and whether additional investment or revisions to current investment plans may reduce or avoid voltage reductions and whether it is in customers' interest to make such investments.

The study found the following:

- Con Edison's service voltage standards comply with the ANSI C84.1 standard.
- Voltage reduction is an operating tool widely used in the energy industry and specified in the NERC and NYISO operating procedures.
- Con Edison used voltage reduction on only 2.5% of all days over a four-year period.
- Con Edison's use of voltage reduction is effective at reducing subsequent feeder failures and preventing cascading failures in our networks.
- The feeder failures that prompt voltage reduction occur at loading well below feeder emergency rating indication showing that the Company is not using voltage reduction in lieu of capital reinforcement.
- The feeder failures that prompt voltage reduction result from the failure of thermally sensitive feeder components (such as PILC and stop joints,) with known elevated failure rates.
- The Company's existing capital reliability programs are targeting the same components that contribute to voltage reduction, and the failure rates of those components are decreasing.
- The Company's spends more capital reliability dollars in networks that experience more voltage reductions.

- Voltage reduction during network contingencies results in low voltage for some customers. The specific customers that experience low voltage depend on the specific feeder contingency that occurs.[14] Those customers experiencing low voltage are a fraction of the customers served in the network and are unlikely to repeatedly experience low voltage.
- Laboratory testing of consumer and commercial equipment demonstrated that such equipment is quite resilient against low voltage and continued to operate reliably despite supply voltage well below the ANSI standard.
- Instrumentation of hospitals and commercial buildings demonstrated that the Company provides adequate supply voltage and that, at in at least one instance, the internal customer wiring did not meet standards and hence would contribute to low utilization voltage at the equipment.
- Modeling showed that although voltage reduction during feeder contingencies had the potential to impact the hospitals and commercial buildings studied, that impact was dependent on the specific feeder contingency occurring and the internal conditions of the facility.
- Additional demand reduction during peak load periods has the potential to reduce the likelihood of voltage reductions; however, the amount of additional load that would need to be enrolled is more than double the current enrollment.
- The estimated capital cost to achieve a 30% reduction in the instances of voltage reduction system wide is in excess of half a billion dollars.

---

[14] In our largest network there are 496 possible combinations of second contingency.

- Given the relative infrequency of voltage reductions, the small number of customers impacted during such reductions, the resilience of consumer and commercial equipment as found through lab testing, the fact that existing capital programs are currently improving reliability and addressing the components that prompt voltage reductions, and the substantial costs to achieve a relatively small improvement in voltage reductions, we conclude that it is not in customers interests to invest additional capital for the sole purpose of reducing the instances voltage reductions.

Appendix 1: Voltage Reduction Log

Legend

Networks in voltage reduction because they are being supplied from the same substation as the network in need of voltage reduction

Substation	Network	Feeder Contingency	Start Time	End Time	Duration	% Voltage Reduction
Water Street	Williamsburg	4	6/28/2010 16:26	6/29/2010 8:58	16:32:00	8
	Prospect Park					
Glendale	Maspeth	2	7/6/2010 18:30	7/7/2010 17:45	23:15:00	8
Corona No. 1	Flushing	2	7/6/2010 19:03	7/7/2010 3:30	8:27:00	8
Greenwood	Park Slope	2	7/6/2010 19:04	7/7/2010 9:34	14:30:00	5
	Bay Ridge					
Plymouth Street	Borough Hall	2	7/6/2010 23:12	7/7/2010 21:04	21:52:00	8
Bensonhurst No. 2	Brighton Beach	3	7/9/2010 21:36	7/10/2010 20:57	23:21:00	8
	Flatbush					
Bensonhurst No. 2	Brighton Beach	3	7/11/2010 18:04	7/12/2010 13:47	19:43:00	5
	Flatbush					
Hell Gate	Yorkville	6	1/1/2011 17:34	1/2/2011 2:42	9:08:00	8
Water Street	Williamsburg	3	6/1/2011 18:24	6/2/2011 2:39	8:15:00	5
	Prospect Park					
Elmsford No. 2	Elmsford	2	7/21/2011 22:30	7/22/2011 11:39	13:09:00	5
Glendale	Maspeth	2	7/22/2011 0:09	7/23/2011 9:10	33:01:00	5
Brownsville No. 2	Richmond Hill	2	7/22/2011 12:30	7/24/2011 0:56	36:26:00	5
Parkview	Triboro	2	7/22/11 14:06	7/22/2011 17:40	3:34:00	5
Fox Hills	Fox Hills	1	7/22/2011 14:26	7/24/2011 7:43	41:17:00	5
Ossining West	Ossining West	2	7/22/2011 15:31	7/24/2011 0:27	32:56:00	5
Bensonhurst No. 1	Sheepshead Bay	2	7/22/2011 16:12	7/23/2011 8:32	16:20:00	8
	Ocean Parkway					

Substation	Network	Feeder Contingency	Start Time	End Time	Duration	% Voltage Reduction
Washington Street	Washington Street	2	7/22/2011 16:33	7/24/2011 0:19	31:46:00	5
Granite Hill	Granite Hill	1	7/22/2011 18:42	7/24/2011 0:23	29:41:00	5
Corona No. 2	Rego Park	1	7/22/2011 19:14	7/24/2011 0:52	29:38:00	5
	Jackson Heights					
Brownsville No. 1	Ridgewood	1	7/22/2011 19:19	7/24/2011 1:27	30:08:00	5
	Crown Heights					
Buchanan	Buchanan	1	7/22/2011 20:18	7/24/2011 0:33	28:15:00	5
Parkview	Triboro		7/22/11 20:27	7/23/2011 14:54	18:27:00	
Bensonhurst No. 1	Sheepshead Bay	2	7/23/2011 10:04	7/24/2011 0:43	14:39:00	8
	Ocean Parkway					
West 110th Street No. 2	Central Park	5	7/29/2011 21:13	7/31/2011 8:18	35:05:00	8
Water Street	Williamsburg	2	6/20/2012 13:59	6/21/2012 1:51	11:52:00	5
	Prospect Park					
Bensonhurst No. 1	Sheepshead Bay	2	6/20/2012 15:25	6/21/2012 18:04	26:39:00	5
	Ocean Parkway					5
Jamaica	Jamaica	2	6/20/2012 16:36	6/21/2012 14:10	21:34:00	5
Glendale	Maspeth	2	6/20/2012 16:56	6/21/2012 15:40	22:44:00	5
Brownsville No. 2	Richmond Hill	2	6/20/2012 18:13	6/23/2012 1:14	55:01:00	5
Corona No. 1	Flushing	2	6/20/2012 22:01	6/22/2012 5:00	30:59:00	5

Substation	Network	Feeder Contingency	Start Time	End Time	Duration	% Voltage Reduction
Greenwood	Park Slope	2	6/21/2012 19:37	6/23/2012 8:35	36:58:00	8
	Bay Ridge					
Bensonhurst No. 1	Sheepshead Bay	3	6/21/2012 20:49	6/23/2012 16:59	44:10:00	8
	Ocean Parkway					
Bensonhurst No. 2	Brighton Beach		6/22/2012 6:02	6/23/2012 1:07	19:05:00	5
	Flatbush	2				
Water Street	Williamsburg	2	6/22/2012 14:02	6/24/2012 17:57	51:55:00	5
	Prospect Park					
Bensonhurst No. 2	Brighton Beach		7/4/2012 20:07	7/8/2012 2:58	78:51:00	5
	Flatbush	2				
Brownsville No. 1	Ridgewood		7/5/2012 12:47	7/8/2012 2:56	62:09:00	5
	Crown Heights	2				
Parkchester No. 1	Southeast Bronx	2	7/5/2012 22:37	7/7/2012 0:49	26:12:00	5
East 63rd Street No. 2	Turtle Bay	2	7/16/2012 13:30	7/16/2012 22:10	8:40:00	5
	Roosevelt					
East 63rd Street No. 1	Sutton	2	7/18/2012 6:34	7/19/2012 5:53	23:19:00	5
	Hunter					
Bensonhurst No. 1	Sheepshead Bay		7/18/2012 16:20	7/19/2012 5:57	13:37:00	5
	Ocean Parkway	2				

Substation	Network	Feeder Contingency	Start Time	End Time	Duration	% Voltage Reduction
Corona No. 1	Flushing	2	7/18/2012 21:05	7/19/2012 17:46	20:41:00	5
Sherman Creek	Riverdale	3	8/2/2012 7:23	8/3/2012 5:10	21:47:00	5
Lenoard Street No. 1	Sheridan	3	8/9/2012 1:26	8/9/2012 19:03	17:37:00	5
	Greenwich					
Bensonhurst No. 1	Sheepshead Bay	4	8/15/2012 17:04	8/16/2012 23:34	30:30:00	5
	Ocean Parkway					
Bruckner	West Bronx	2	8/24/2012 10:57	8/26/2012 14:21	51:24:00	5
	Randall's Island					
West 110th Street No. 2	Central Park	2	8/31/2012 5:26	9/1/2012 11:21	29:55:00	5
Trade Center No. 1	Battery Park City	6	10/31/2012 11:55	11/2/2012 3:15	39:20:00	5
	Freedom					
East 36th Street	Greely Square		11/3/2012 1:23	11/5/2012 4:16	50:53:00	5
	Kips Bay	6				
Seaport No. 1	Cortlandt	6	11/3/2012 8:14	11/9/2012 11:09	146:55:00	5
	Bowling Green	8				
Seaport No. 2	Fulton	11	11/5/2012 5:29	11/9/2012 2:41	93:12:00	5
East 36th Street	Greely Square		11/16/2012 7:06	11/16/2012 22:57	15:51:00	5
	Kips Bay	3				
Hell Gate	Yorkville	4	12/15/2012 11:26	12/15/2012 19:09	7:43:00	5
East 63rd Street No. 2	Turtle Bay		5/24/2013 6:33	5/26/2013 5:05	46:32:00	5
	Roosevelt	5				

Substation	Network	Feeder Contingency	Start Time	End Time	Duration	% Voltage Reduction
Bensonhurst No. 2	Brighton Beach		6/24/2013 16:54	6/26/2013 15:52	46:58:00	8
	Flatbush	3				
Brownsville No. 2	Richmond Hill	2	6/24/2013 18:16	6/25/2013 8:30	14:14:00	5
Fox Hills	Fox Hills	3	7/6/2013 4:22	7/7/2013 21:58	41:36:00	8
Corona No. 2	Rego Park	2	7/7/2013 23:44	7/8/2013 16:34	16:50:00	5
	Jackson Heights					
Fox Hills	Fox Hills	1	7/15/2013 13:20	7/16/2013 10:29	21:09:00	5
Fresh Kills	Fresh Kills	1	7/15/2013 14:59	7/16/2013 21:31	30:32:00	5
Water Street	Williamsburg	2	7/17/2013 22:47	7/18/2013 12:21	13:34:00	5
	Prospect Park					
Fresh Kills	Fresh Kills	1	7/18/2013 16:57	7/19/2013 6:48	13:51:00	5
Washington Street	Washington Street	2	7/19/2013 1:39	7/20/2013 0:57	23:18:00	5
Parkchester No. 1	Southeast Bronx	2	7/19/2013 22:49	7/20/2013 0:52	2:03:00	5
East 179th Street	Fordham	2	7/20/2013 1:17	7/20/2013 18:36	17:19:00	5