FINAL REPORT

Conservation Voltage Reduction

June 2021

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1.0 Executive Summary

NB Power conducted a Conservation Voltage Reduction (CVR) research and demonstration pilot project in partnership with the National Research Council (NRC), Natural Resources Canada (NRCan), and Siemens Canada. The project was initiated in 2018 to study how NB Power can reduce community energy consumption and shift peak demand through dynamic voltage control strategies. The preparatory work by the project team from 2018 to 2020 involved setting up four substations with automated voltage control technology, installing smart meters at 688 homes and commercial buildings, and confirming the measurement and verification (M&V) methodology.

The CVR experiment began at the end of November 2019 and ended on November 30th, 2020. In preparation for the CVR field experiment the following four substations in the province were equipped with Beckwith (M-2001D) load tap changers (LTC) controls with the substation bus voltage levels determined by the Dominion Voltage International (DVI) 'EDGE®' software:

1. Priestman Street, Fredericton Substation (6124): Four Feeders
2. Elliot Road, Quispamsis Substation (6233): Two Feeders
3. Bathurst West, Bathurst Substation (6418): Two Feeders
4. Commercial Street, Moncton Substation (6503): Two Feeders

A total of 5506 residential and 527 commercial buildings from the above four substations and their ten feeders were part of the study. To monitor voltages and gather energy usage at the service connections for this study, NB Power installed smart meters at 10% of residential buildings (559 out of 5506) and 25% of commercial buildings (129 out of 527). The monitoring and feedback mechanisms via the System Operator's Supervisory Control & Data Acquisition System (SCADA) and smart meters ensured visibility of voltage levels through all feeder circuits and ensured that minimum voltage levels were maintained for all customers. It thus allowed for greater confidence that voltage levels were maintained, and therefore enabled greater voltage reduction.

The CVR experiment was set up such that the substations in the study were operated at normal voltage, and at CVR-reduced voltage, on alternate days, with 4:00 AM as the transition time throughout the evaluation period. This experimental design did not require a separate control group such as matched substations/feeders because, with the capability of turning CVR ON and OFF on alternate days, the studied application group acted as the control group for CVR OFF days and as the experimental group for CVR ON days. The energy savings from CVR ON/OFF evaluation were computed using statistical techniques of Mean and Multivariate Regression to normalize for the outdoor temperature. The energy savings from CVR are season dependent and hence the savings estimates were made separately for the winter, spring, summer, and fall seasons.

The following table shows the number of days in the one-year experiment for which CVR control was either turned on or off. The Moncton substation was not available during the fall season for the CVR experiment due to planned maintenance and the summer CVR ON days were limited at the Fredericton substation due to a customer related issue.

Substation	CVR Status	Number of days				
		Winter	Spring	Summer	Fall	Total
Quispamsis 6233	CVR OFF	30	26	31	30	117
	CVR ON	25	25	28	31	109
Moncton 6503	CVR OFF	25	25	38	-	88
	CVR ON	22	24	21	-	67
Bathurst 6418	CVR OFF	30	25	31	30	116
	CVR ON	25	24	26	30	105
Fredericton 6124	CVR OFF	30	25	37	30	122
	CVR ON	23	22	16	24	85

Table 1.1: CVR Operational Status Summary

LTC controls regulated substation bus voltages to 125V (on a 7200-120V basis) during CVR off days and 118-120V on CVR on days. NB Power follows the CAN3-C235-83 Standard by the Canadian Standards Association (CSA) which specifies the normal operating voltage range at the service entrance to be from 110 to 125 V. The CVR controls exploit this voltage spread by reducing the service voltages towards the lower end without affecting the performance of the end user's devices in a detrimental way.

One of the concerns for the pilot study was how the CVR savings would be impacted by New Brunswick's cold winters and prevalence of electric heat. Prior to this study, Kinetrics Inc. had estimated an average annual voltage reduction of 2.5% for the province. The yearlong CVR experiment demonstrated average voltage reduction of 5% for all substations with the corresponding reduction in annual active energy (kWh) consumption of 3.4%. The maximum voltage reduction of 5.6% was observed at the Quispamsis substation during the summer and the minimum of 3.4% at the same substation during the winter. The reduction in the average voltage for each substation for all seasons is shown in the following table:

Substation	Voltage	Winter 2020	Spring 2020	Summer 2020	Fall 2020
6233T001, Quispamsis	Avg. Voltage (CVR OFF)	125.65	125.77	125.70	125.48
	Avg. Voltage (CVR ON)	121.39	119.77	118.63	119.01
	ΔV [V]	4.25	6.00	7.06	6.47
	$\Delta V[\%]$	3.4	4.8	5.6	5.15
6503T001, Moncton	Avg. Voltage (CVR OFF)	125.18	125.31	125.27	Planned Maintenance
	Avg. Voltage (CVR ON)	118.76	118.63	118.47	Planned Maintenance
	$\Delta V[V]$	6.42	6.68	6.80	Planned Maintenance
	$\Delta V[\%]$	5.1	5.3	5.4	Planned Maintenance
6418T002, Bathurst	Avg. Voltage (CVR OFF)	125.35	125.53	125.48	125.36
	Avg. Voltage (CVR ON)	119.23	118.97	118.94	118.45
	ΔV[V]	6.12	6.56	6.54	6.91
	$\Delta V[\%]$	4.88	5.22	5.21	5.52
6124T002, Fredericton	Avg. Voltage (CVR OFF)	124.58	124.47	124.57	124.60
	Avg. Voltage (CVR ON)	119.16	118.66	118.99	118.75
	ΔV[V]	5.42	5.81	5.58	5.85
	$\Delta V[\%]$	4.4	4.7	4.48	4.70

Table 1.2: Average Substation Voltage Reduction

Energy savings resulting from CVR cannot be directly measured and percentage savings are relatively small (1% to 3% in most circuits), therefore accurate estimates require the use of rigorous statistical methods. The energy savings are estimated at the substation and feeder level and depend on a variety of factors that include the load mix of customer classes (e.g. residential, commercial, and small industrial load mix, etc.), percent loading, day of the week, outdoor temperature, and other pseudo-random factors driven by customer activities. The energy savings were evaluated from the measurement data by applying the statistical methods of mean and multivariate linear regression to normalize for outdoor temperatures. The regression method was applied with three variations: (i) Modeling the dependency of energy use on daily CVR status and; (ii) Bus voltage, (iii) Bus voltage and COVID related public health phases. COVID-19 related health phases were introduced as additional predictors of energy for the spring, summer and fall analysis to filter out the effects of the reduced and fluctuating economic activity on energy consumption as certain regions in the province alternated between yellow and orange phases. One may ask the question which of the applied methods is the most accurate? The second and third variants of multivariate regression methods model the impact of multiple variables on energy use and normalize the energy usage against outdoor temperatures. The CVR savings are expected to lie somewhere between the estimates arrived at from the second and the third multivariate regression model.

A key metric in the evaluation of energy savings is the CVR energy factor which is expressed as the percent savings in energy usage as a result of a one percent voltage reduction. The following chart shows a comparison of estimated CVR factors for active energy through bar graphs for each of the four substations over the winter, spring, summer, and fall season evaluated through the following models:

1. Mean method
2. Multivariate regression method that treats energy usage being dependent on the bus voltage and the outdoor temperature {regression method (model 1)}
3. Multivariate regression method that treats energy use as dependent on the bus voltage, the outdoor temperature and New Brunswick health phases {regression method (model 2)}

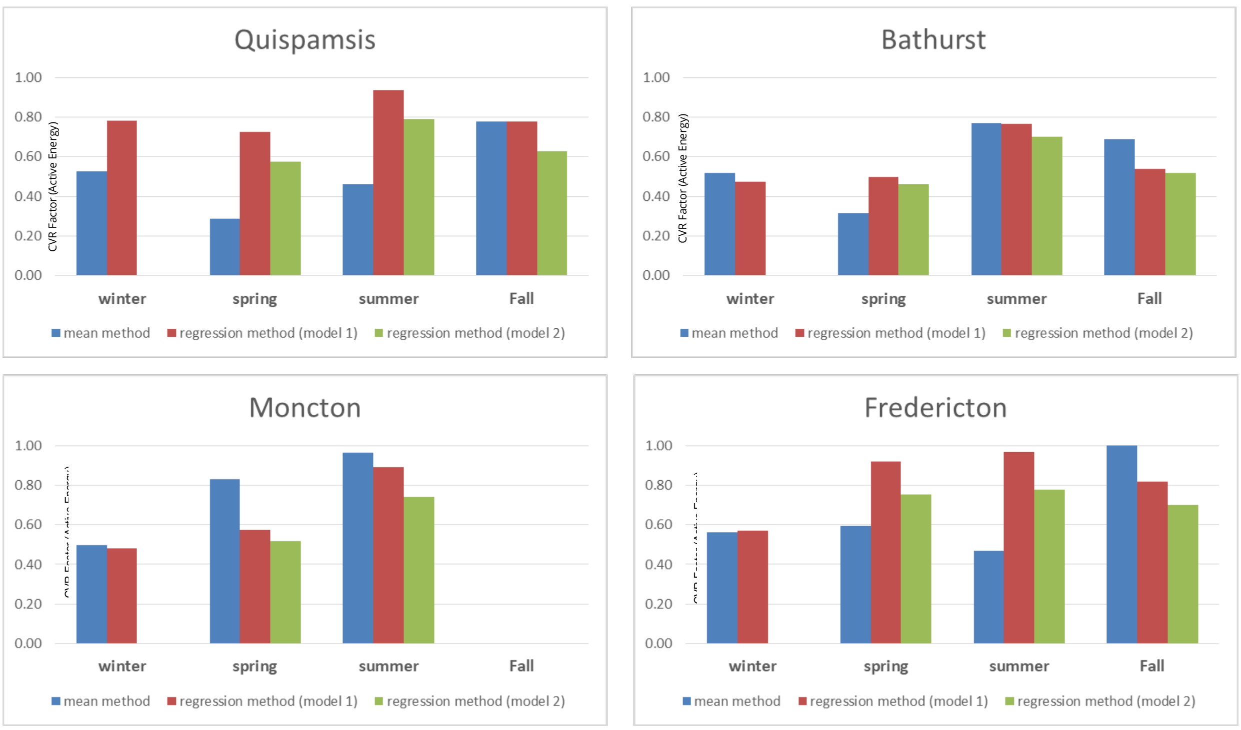


Figure 1.1: CVR Factors by Season

All multivariate linear regression methods yielded similar estimates of savings. Considering that New Brunswick is a winter peaking province with a large proportion of residential and commercial loads being thermostatically controlled due to water and space heating, the observed CVR factor ranging from 0.50 (Moncton, Bathurst and Fredericton) to 0.80 (Quispamsis) for the winter is considered very reasonable. Thermosatically controlled loads respond to the lowering of voltage by reducing immediate demand, but ultimately use the same amount of energy to reach a target setting. As expected, the CVR factor increased slightly for the spring as the thermostatically controlled loads dropped. The CVR factor increased significantly for the summer season when space heating loads are absent. The CVR factor for the summer ranged from 0.7 to 0.8 as estimated through the regression method (model 2) that also accounted for the public health phases. The CVR factors for spring and fall were somewhat similar.

The annual CVR factors for all substations estimated using the three methods are shown in the following chart.

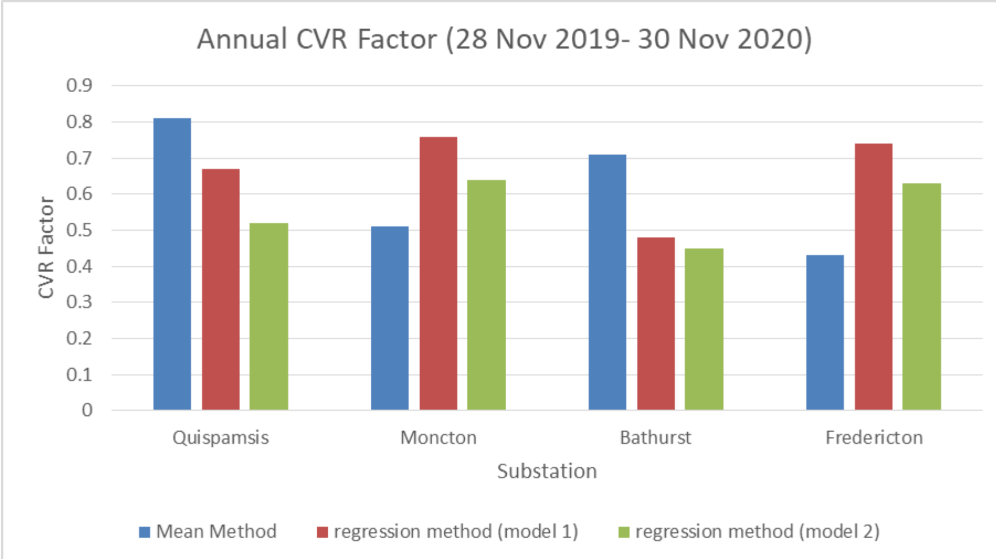


Figure 1.2: Average Annual CVR Factors

The CVR experiment resulted in energy savings of 1.67 GWh (3.4%) across all ten feeders over the one year period with a 5% average reduction in voltage, with an associated reduction of 459 tons of greenhouse gas (GHG) emissions as estimated by the regression method (model 1). Whereas, regression method (model 2), that also includes provinces health phases as predictors of energy usage, returns a more conservative estimate with 1.4 GWh of energy savings and 386 tonnes of GHG reduction.

<u>The average CVR factor for the pilot study is estimated to be in the range of 0.6 to 0.7.</u>

How do these CVR energy savings realized by NB Power compare to the savings realised by other utility companies in Canada and US?

The evaluation of CVR at the national level in the USA, conducted in 2010 by the Pacific Northwest National Laboratory (PNNL) under a contract with the Department of Energy (DoE), reported that CVR has the potential to provide peak load reduction and annual energy consumption reduction of approximately 0.5%-4% per feeder. A total reduction of 3.04% in annual energy consumption at the national level was estimated if CVR was deployed on 100% of distribution feeders.

The US National Energy Technology Laboratory (NETL) compiled data from 30 utilities which reported CVR performance metrics. Their findings, published in 2015, estimated the average energy savings at 1.9% and the average reduction in peak load at 2.5%.

Since the majority of buildings in New Brunswick use electricity for water and space heating, a fair comparison of winter savings requires comparing to geographical regions that experience similar winter temperatures and use electricity as the primary source for winter heating. Québec is very similar in its winter heating characteristics to New Brunswick. Hydro-Québec reported an average energy savings of 0.4% per 1% reduction in voltage (CVR factor of 0.4) in a voltage and reactive power control study in 2005. BC Hydro estimated a CVR factor of 0.7 based on the direct comparison of the demand profile of the experimental substation to the reference substation using SCADA-based telemetry. Considering that British Columbia (BC) has milder winters, a higher CVR factor than that in Québec is expected.

CVR has been studied by electric utilities and regulators over the past four decades in many geographical regions through numerous pilot studies aimed to test the CVR technology and evaluate the savings. During the earlier CVR implementations, the reduction of voltage in CVR was achieved through conventional methods including load tap changer (LTC) and SCADA-based telemetry. The lack of visibility of voltages at the edge of distribution circuits, manually operated distribution assets and regulatory issues, prevented the full realization of benefits and wide scale deployment of CVR. With the emergence of Advanced Metering Infrastructure (AMI), smart grid technologies and changes to the regulatory structures in some geographical regions, CVR is now scalable and cost competitive to other sources of energy efficiency or generation. In this context, 0.7% estimated savings for 1% reduction of voltage from this one-year demonstration study at ten representative feeders in four cities by NB Power is very a promising and an economical method of energy saving.

2.0 Introduction

2.1 Current Challenges

The future of energy is changing and NB Power, like other electric utilities throughout the world, must adapt. Customer expectations, climate change, and new technologies are causing significant change to the future of energy.

NB Power is committed to a greener future. We must reduce the use of greenhouse gas (GHG) emitting conventional generation, welcome renewable customer owned generation, and reduce the use of energy through behavioural and direct demand side management.

If we do nothing, our customers will. They'll take the initiative themselves to reduce GHG and become more energy self-sufficient. We want to be part of their energy future, and we'll do this by offering not only electricity, as we've been doing for over 100 years, but instead a suite of energy solution offerings to help our customers on this new journey.

At the same time our environmental and customer challenges raise concerns about how we'll operate our power system in the future. Changes in customer load profiles due to Distributed Energy Resources (DER) and Electric Vehicles (EV) need to be anticipated and monitored so the system is designed or postured to accommodate. We can't influence what we can't see so we need to rapidly expand our telemetry and control capability into our distribution system and beyond to the customer edge.

We need to understand the impact through more frequent distribution system modeling, and advanced tools in the control room. And finally, we can't stop learning. One big question remains as to how far we need to go with our new energy solution offerings. For example, do we let the proliferation of all DER happen naturally and react, or do we influence some through customer programs and rate structures?

2.2 CVR Project and Why Now

NB Power started its Energy Smart NB Program in the summer of 2012 in partnership with Siemens Canada. The program follows a methodology called Smart Grid Compass which broke the effort of building NB Power's Smart Grid into five working domains called Network Operations, Customers Service, Asset & Workforce Management, Smart Energy, and Smart Organization. The program's latest targets are an annual energy reduction of 103 GWh and a winter peak demand reduction of 90 MW by the year 2040.

Initially, CVR was not one of the technologies envisioned, but would have been loosely part of the Network Operations capability involved in managing network load. Soon after, as NB Power was building its business case for upgrading from its analog and short-range radio meters, it was clear that CVR should be considered as it would benefit greatly from the many voltage measurement points provided by a modern Advanced Metering Infrastructure (AMI), likewise CVR strengthen the business case to deploy AMI.

NB Power was aware of the CVR efforts elsewhere; it wasn't a new concept. Many utilities have tested and deployed CVR to some extent. Our initial analysis was done based on the work of others and a 3% voltage drop and CVR factor of 0.5 would yield an annual energy reduction benefit of 74 GWh; a significant portion of the ESNB energy reduction target. A more detailed analysis was conducted later to support the AMI business case. The work by Kinectrics Inc. validated NB Power's prior assumptions but did recommended a more conservative 2.5% voltage reduction resulting in a lower yield of 64 GWH annually.

Neither the NB Power, nor the Kinectrics study, addressed the use of voltage reduction for reducing demand. NB Power's requirement for demand reduction is due to winter system peaks where a large electric heating component makes any reduction effort short lived.

Faced with a future that will see more customer owned renewable generation sources being added, the deployment of CVR also means the introduction of voltage control technologies that would allow for the continuous optimization of feeder voltage to ensure localized grid efficiency and stability.

All of the work up to this point did highlight the fact that both the energy and demand reduction benefits from CVR are highly dependent on geography, the environment, and load make-up; hence the need for this demonstration pilot and study in New Brunswick.

2.3 Project Participants

This Project is a joint initiative between the New Brunswick Power Corporation and the Department of Natural Resources Canada under the Energy Innovation Program. NB Power successfully executed a leadership role responsible for all aspects and phases of the project including vendor selection, procurement and installation of hardware/software, solution design, network configuration, meter configuration, meter installation, testing and implementation, customer engagement, process improvement, change management, training, and communications.

NB Power engaged the following external participants to assist with the design, implementation and execution of the project:

National Research Council: The National Research Council of Canada (NRC) is Canada's largest federal research and development organization. The NRC partners with Canadian industry to take research impacts from the lab to the marketplace, where people can experience the benefits. This market-driven focus delivers innovation faster, enhances people's lives and addresses some of the world's most pressing problems. Each year NRC's scientists, engineers and business experts work closely with thousands of Canadian firms, helping them develop and de-risk new solutions and technologies.

The NRC began by devising measurements and data analytics methodology to gauge savings from residential, commercial, and industrial buildings when an electrical distribution system operates at the lowest voltage allowed by the standard of the Canadian Standards Association (CSA).

The NRC also did an exhaustive international literature search of state-of-the-art CVR methods used by electric utilities. It was combined with interviews of project teams in Canadian electric utilities to help develop best practice guidelines for the CVR experiment. The NRC team gathered and analyzed data from the substations, feeders, and smart meters and estimated the savings from the CVR measures. The results from the pilot study were jointly presented by NB Power and NRC in February 2021 at a workshop for electric utilities organized by NRC.

Dominion Voltage Inc: DVI is a subsidiary of Virginia USA-based Dominion Energy a leading provider of Volt/VAR Optimization (VVO) smart grid technologies. Its EDGE® software delivers advanced software solutions to electric utilities across North America for Conservation Voltage Reduction (CVR), demand response, distribution system compliance and reliability, as well as DER hosting capacity. DVI holds 28 U.S. and foreign patents for its specialized approach to perform distribution grid control and analytics. EDGE® dynamically incorporates voltage measurements from advanced metering infrastructure (AMI) with its adaptive control algorithms to optimize the electric distribution system.

With 25 VVO deployments at electric utilities across North America, including NRCan-funded CVR programs in Alberta and New Brunswick and a provincially funded CVR project through the Ontario Conservation Fund of the IESO, DVI's software enables utilities to make the case for AMI and other grid investments, all while achieving energy savings, carbon emission reductions and lower customer bills. For more information about DVI, please visit www.dvigridsolutions.com.

Utilismart Corporation: Based in London Ontario, Utilismart Corporation provides advanced MDM-driven analytics, along with a wide range of Advance Metering Infrastructure (AMI) software solutions and data services for Utilities, Municipalities, Industrial, Commercial and Residential customers across Canada and North America. The company assists small and medium-sized utilities in improving system reliability, drive operational efficiencies and reduce distribution system management costs. Utilismart strives to deliver comprehensive solutions that accelerate digital transformation, including meter data management, outage management, engineering analysis, billing, asset management, grid visualization, rate analysis, and energy management. Please visit their website at www.utilismartcorp.com

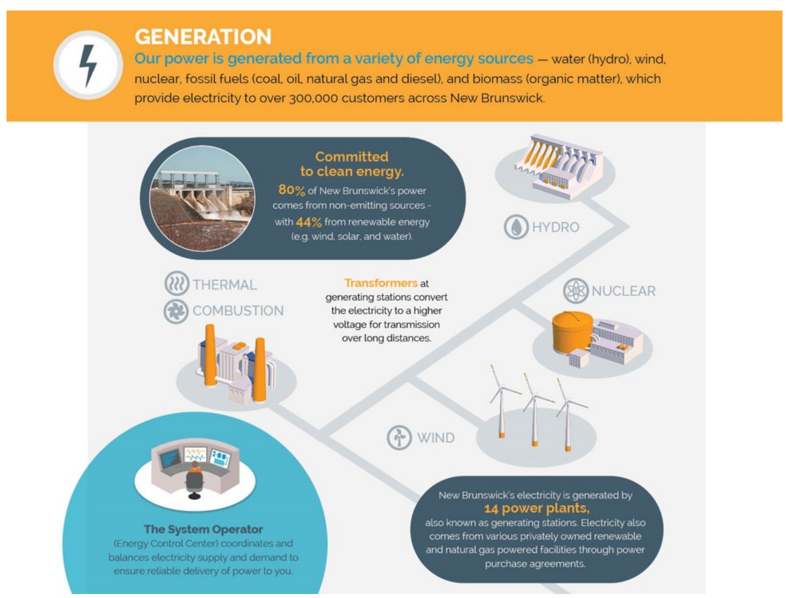
2.4 NB Power Characteristics

For 100 years, NB Power has been a part of the fabric of New Brunswick, Canada. The provincial electric utility is responsible for the generation, transmission, and distribution of electricity that powers the lives and livelihoods of more than 400,000 customers across New Brunswick.

NB Power has one of the most diverse generation fleets in North America, with a combined total generating capacity of 3,790 MW, plus additional installed capacity of 355 MW of wind and 259 MW of other renewable capacity provided by third parties through Purchase Power Agreements (PPAs).

Our employees, more than 2,600 energy experts, provide safe and sustainable energy to our customers by way of 21,358 km of distribution lines, substations, terminals and switchyards that are interconnected by 6,905 km of transmission lines.

By using a customer-centric approach, NB Power is committed to developing sustainable energy for future generations of New Brunswickers. Part of this commitment includes investments in energy efficiency programs, energy solutions, renewable energy sources and smart grid technology.



The New Brunswick Energy Marketing Corporation, a wholly owned subsidiary of NB Power, conducts energy trading activities in markets outside of New Brunswick.

In 2019/2020, the utility provided 44 per cent of the total in-province electricity sales from renewable resources, which exceeded the provincial goal of 40 per cent. When coupled with the approximately 36 per cent of our in-province demand from nuclear power, we achieved an 80 per cent non-emitting electricity supply for our customers.

3.0 CVR Project Objectives

The primary objective of this Project is to demonstrate dynamic voltage control by installing advanced and responsive devices and control systems on select substations. Dynamic voltage control increases system stability and increases the capacity for the electrical grid to accommodate variable renewable and distributed energy generation.

Project outcomes include:

- Enabling the increased penetration of renewable and distributed energy sources which can reduce GHG emissions by offsetting emitting sources.

- Demonstrating a business case for NB Power to continue rollout of this solution to 70+ substations as stated in supporting business case.

The goal of this project is to demonstrate a scalable smart grid solution to dynamically monitor and control voltages at the feeder level needed for the large-scale deployment of renewables in both urban and rural environments. The following benefits are identified:

- Enabling increased renewable and distributed generation penetration which will displace GHG emitting plants;
- Reducing community energy consumption by enabling dynamic voltage conservation strategies; and
- Shifting peak demand by enabling peak reduction voltage control strategies which reduces the need for GHG emitting peaker-plants.

In addition, there will be benefits to Canadians and the electricity sector by:

- Increasing the availability of scientific and technical knowledge from report documentation, promotions at target conferences, and publications; and
- Contributions and collaboration between the utility, industry and the public sector (i.e. NB Power, Siemens Canada and National Research Council, respectively).

4.0 Project Evolution

4.1 Deviations from original project concepts

There were no major deviations from the original project concepts however there were some external variables that resulted in a change to the project schedule. These included:

1) The original CVR Pilot concept includes the use of AMI (smart meters). In Q4 FY18, NB Power senior management directed that any AMI deployment and related customer engagement involving Smart Meters be deferred until the fall of 2018. This executive decision was directly related to the General Rate Application (GRA)

Hearing which includes a review of Capital Projects valued above $50 Million. NB Power's AMI project falls into this category. All external project announcements related to this project were also deferred to Fall 2018. This resulted in a seven (7) month delay in the project schedule specific to customer recruitment and meter install activities. This was formally recognized by NRCan through an amendment to the Contribution Agreement to move the project closure date form March 31, 2020 to March 31, 2021.

2) The original project plan proposed an eight (8) month pilot with three substations. Based on industry best practice identified by the National Research Council (NRC), this was expanded to a twelve (12) month pilot to collect data from all four seasons. At the same time a 4th substation was also added increasing the geographical region involved and moving the target meter installs from 550 meters to 700 meters.
3) The lockdown measures by the Canadian provinces initiated in the middle of March 2020 to slow down the spread of COVID-19 virus immediately reduced the economic activity and impacted the electricity usage profile. The impact on load profiles varies from feeder to feeder depending on the residential, commercial and industrial load mix. While the residential loads increased during the daytime, the commercial and industrial load decreased. This presented some Measurement & Validation (M&V) challenges for the NRC.

   NRC has implemented a solution to ensure that M&V analysis for savings correctly attributes the changes in electricity usage to the voltage reduction and not to the periodic downturn in economic activity. Refer to section 6.4 of this report for information on steps taken by NRC to address the impact of the on-going pandemic.

4.2 Project Timeline

This project submission was initiated in Oct 2017 and the Contribution Agreement with NRCan formally approved in Feb 2018. The CVR pilot was started Nov 6th, 2019 and successfully completed Nov 30th, 2020. The project completion date was Mar 30th, 2021 with some final project closure and NRCan reporting commitments completed in Q1 of fiscal year 21/22.

The following Table 4.1 provides a summary of the project timeline and key activities by fiscal Year.

FY17/18	FY18/19	FY19/20	FY20/21	FY21/22

• Proposal submission Oct 2017
• High Level Solution Design
• NRCan Contribution Agreement Feb 2018
• Finalize Stakeholder Contracts
	• Stand up MV90 Head end
	• Meter ordered, installed
	• Substation fieldwork
	• Establish technical environment at ECC
	• NRC Industry scan USA and Canadian Utility CVR
	• M&V confirmed
	• State of the Art
	• Customer notification & recruitment
	  • Validate workflow - notification thru to billing
		• CA Amendment project end date Mar 31, 2021.
		  • Move to 12-month pilot
		  • Added 4th substation
		• End-to-end system test of technical solution
		• Complete meter installs
		• User Training
		• EDGE software and environment running "monitoring mode" Aug 23 – Nov 5
		• CVR 12-month pilot started Nov 6, 2019
			• CVR Pilot completed
			• NRC CVR Analysis 4 seasons
			• Periodic refresh of bellwether meter set
			• Issue resolution – technical and customer
			• Develop CVR Roadmap
			• Pilot Decommission
			• Stakeholder Communications
				• Complete NRCan Reporting Commitments
				• Progress CVR Roadmap
				• CVR Outcome Report (Mar 31, 2022)

Table 4.1: Project Timeline

4.3 Project Challenges

Table 4.2 below provides a summary of the project challenges encountered throughout the project life cycle. This alignment with the Project Timeline in section 4.2 demonstrates how the nature of the challenges experienced typically relate to the types of activities underway in the project. For example, initial challenges were related to the turnaround time to finalize the Contribution Agreement and get stakeholder contracts in place. The bolded items represent the key challenges and are described in more detail in other sections of this document.

FY 17/18	FY 18/19	FY 19/20	FY 20/21	FY 21/22

• Contract negotiation turnaround
• CA signoff
	• **In Q1 external customer engagement related to the use of smart meters deferred until Nov 1, 2018**
	  • 7-month delay for the CVR pilot
	  • Led to CA amendment
	  • Pilot expanded from 8 to12 months
	  • Added a 4th substation
	• Streamlined our customer recruitment
	• Customer Billing Process
		• **Distribution of meter installs across substation feeders**
		• Minimizing time between meters on the home and pilot start-up
		  • Additional hosting/ cellular costs
		  • SAT and Training
		• Shared MV90 performance issue
		  • Bellwether set size
		• Technical Issues
			• **Maximizing the number of CVR On Days**
			  • Technical issues resulting in sporadic return to 125V default
			  • Planned Maintenance on participating substations
			  • Commercial Customer issues
			  • Unplanned Outages, school closure etc.
			• **COVID 19**
				Progressing the CVR Roadmap – many dependencies

Table 4.2: Project Challenges Summary

See Appendix A for further information on Customer Recruitment.

5.0 CVR Architecture

This section provides a description of the CVR Pilot architecture implemented, a high level overview of the CVR methodology followed, the data sources, and the roles and responsibilities of the primary stakeholders involved. A more detailed description of the CVR methodology and measurement & verification strategy followed is provided in Section 6.0.

This pilot involved 4 substations located across New Brunswick involving a total of approximately 5000 residential and commercial customers.

Figure 5.1: Map of CVR substations

- Priestman St Substation located in Fredericton, NB
- Commercial St Substation located in Moncton, NB
- Elliot Road Substation located in Quispamsis, NB
- Bathurst West Substation located in Bathurst, NB

The CVR project pilot went live on Nov 6, 2019 for a 12-month period ending on Nov 30, 2020 enabling data collection across all four seasons. An AMI based solution was implemented with approximately 700 Itron Gen 2 cellular based AMI meters installed across the 4 substations. Fifteen (15) minute interval data was collected once daily for all AMI meters. A subset of the AMI meters installed (~165) were treated as a Bellwether meter set and were polled every 15 minutes. The AMI meter data is collected through a cloud based hosted platform managed by Utilismart. All AMI data is transferred to NB Power via SFTP.

The CVR methodology implemented applied an alternating CVR On/CVR Off day approach. Starting with a CVR Off day, at 4:00 am an automated control message is sent to the substation Load Tap Changers to transition from the 125V default to a recommended set point but no lower than 118V. This triggers the start of a CVR On Day.

Based on AMI meter data collected from the Bellwether set and substation data received from SCADA, DVI's EDGE® control software issues setpoint recommendations to the SCADA system which communicates to the substation tap-changer controller to raise or lower the substation transformer output voltage by 1V increments. This control logic runs continuously for 24 hour period with an immediate transition back to the 125V default at 3:59 am triggering end of the CVR On day and start of a CVR Off day. AMI data is collected during the CVR off day but no EDGE® control recommendations are issued.

Figure 5.2 provides an overview of the infrastructure implemented for the CVR pilot, the interfaces required to enable data collection and the stakeholder areas of responsibility. The substation meter data and AMI meter data collected is sent on a regular basis via SFTP to the NRC for input into their data warehouse for their analysis. Figure 5.3 provides an overview of the data flow between the various stakeholders implemented to support the CVR Pilot.

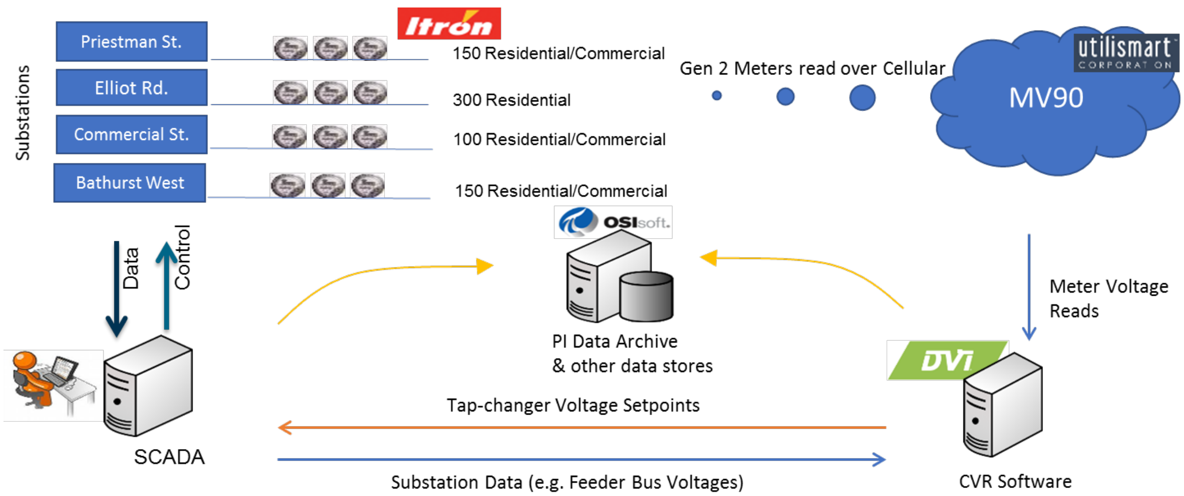


Figure 5.2: CVR Pilot Infrastructure Overview

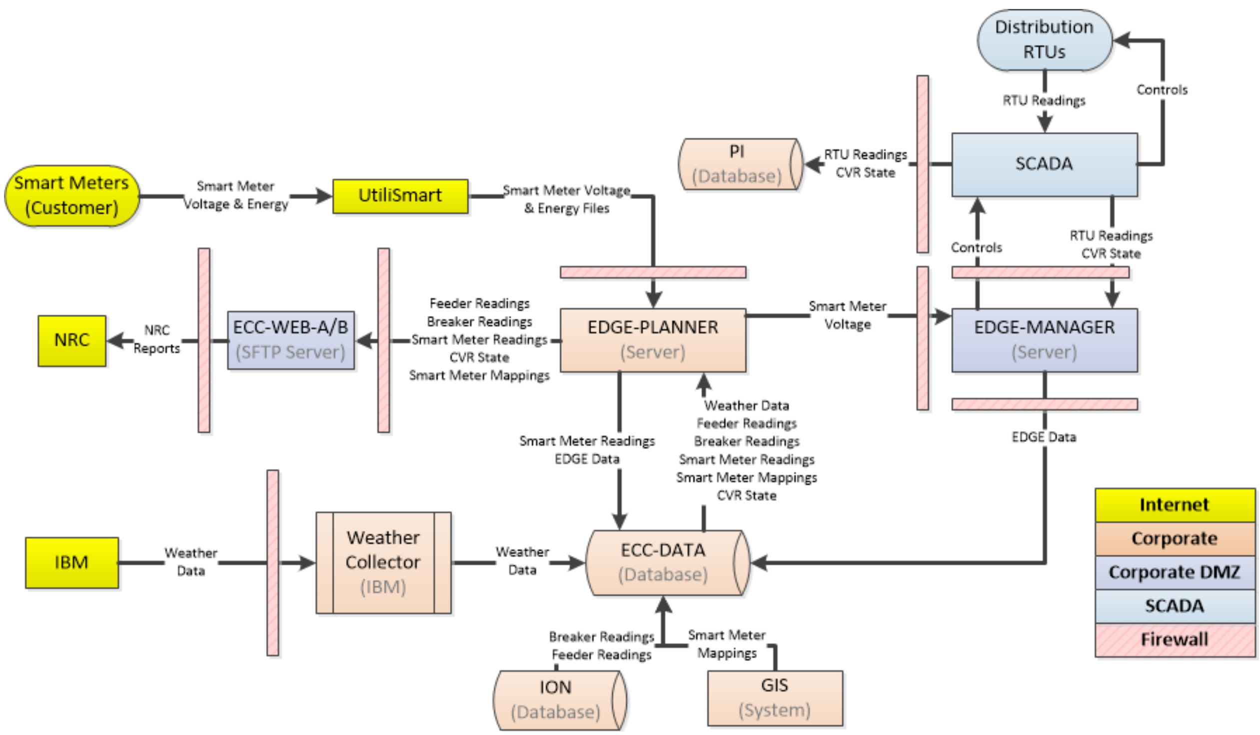


Figure 5.3: CVR Data Flow Model

6.0 CVR Results

6.1 CVR Measurement & Verification Methodology

The savings from CVR are measured at the system level and depend on a variety of factors that include the load mix from customer classes (e.g. residential, small commercial, industrial load mix, etc.), level of loading, season, day of the week, time of the day, outdoor temperature, humidity, and other factors driven by customer activities.

The key metric in the evaluation of savings from CVR is the CVR factor, which is defined as the ratio of the power or energy savings expressed in percent and the voltage reduction expressed in percent as follows:

$$Power\ CVR\ factor\ (\mathrm{CVR_{power}}) = \frac{\text{Power Change (\%)}}{\text{Voltage Change (\%)}} = \frac{\frac{\Delta\text{Power(kW)}}{\text{Power(kW)}}x100}{\frac{\Delta\text{Voltage(V)}}{\text{Voltage(V)}}x100}$$

$$Energy\ CVR\ factor\ (\mathrm{CVR_{energy}}) = \frac{\text{Energy Change (\%)}}{\text{Voltage Change (\%)}} = \frac{\frac{\Delta\text{Energy(kWh)}}{\text{Power(kW)}}x100}{\frac{\Delta\text{Voltage(V)}}{\text{Voltage(V)}}x100}$$

Apart from the active power and energy CVR factors, there are other ratios that are useful in the evaluation of CVR operations, such as the reactive power (kvar) and reactive energy (kvarh) CVR factors with definitions analogous to the above.
See Appendix B for additional industry related CVR information.

Seasonal Savings

The savings from CVR are dependent on the season. The CVR experiment began on 28th of November 2020. The original plan was to estimate the seasonal savings according to the astronomical period but the analysis of spring CVR experiment data revealed that using the meteorological season classification would be a better indicator of seasonal savings. The astronomical seasons are defined by the position of the Earth compared to the Sun, whereas the meteorological seasons are based on the annual cycle of temperatures. The winter period was extended to 13th March 2020 to coincide with the onset of the province wide lockdown due to COVID-19. The astronomical, meteorological, and adjusted seasonal periods for the CVR study are shown in Table 6.1 below:

Seasons	Astronomical Seasons	Meteorological Seasons	Adjusted Seasonal Periods for the CVR Study
Winter	21 Dec'19 - 19 Mar'20	1 Dec'19 - 29 Feb'20	28 Nov'19 - 13 Mar'20
Spring	20 Mar'20 - 19 Jun'20	1 Mar'20 - 31 May'20	16 Mar'20 - 31 May'20
Summer	20 Jun'20 - 21 Sep'20	1 Jun'20 - 31 Aug'20	1 June'20 – 31 Aug'20
Fall	22 Sep'20 - 20 Dec'20	1 Sep'20 - 30 Nov'20	1 Sep'20 – 30 Nov'20

Table 6.1: Periods for annual seasons for the CVR Study

Estimation Methods

For the NB Power CVR study the experimental design did not require a separate control group, because with turning CVR ON and OFF, the studied group acted as the control group for CVR OFF days and the experimental group for CVR ON days. The system was operated on lower and higher voltage levels on alternate days and CVR OFF days provide the baseline data. The verification period of one year was broken down into several measurement segments each lasting a season (i.e. Winter, Spring, Summer, and Fall). These seasonal segments were expected to capture a variety of load profiles, economic activity, weather conditions, and all of the potential load variability.

The following methods, each of which are described in the sub-sections below, were used to estimate the seasonal CVR Savings for active and reactive energy:

1. Mean Method
2. Multivariate Linear Regression

Mean Method

The mean method is a straightforward method that was used to average the energy savings data over a period of time. Since energy savings from CVR are of the order of 1 to 3 %, and with transformer loads being highly variable (i.e. dependent on the time of the day, weather conditions, and seasons), it would take many months of data to arrive at a statistically significant result (i.e. the estimated savings are a result of CVR measures and not attributed to chance).

Multivariate Linear Regression

Multivariate linear regression is used to model the relationship of more than one independent variable (predictors) on a dependent variable (response). The multivariate regression decomposes the demand into basic and other dependent components (e.g. demand being dependent on the independent variables such as weather, season, weekday/weekend, voltage, etc.). The substation and feeder demand data is temperature normalized using heating degree day (HDD) and cooling degree day (CDD) variables. In this project the method was applied to estimate energy savings separately for each season to estimate the reduction in electricity usage for CVR ON days based on the assumed relationships between the outdoor temperatures, voltage and the electricity demand. A separate multivariate regression model for CVR savings was constructed for each substation and feeder.

See Appendix C – Additional Information on Multivariate Linear Regression for further information on this analysis method.

6.2 CVR Voltage Reduction – Seasonal Comparison

The voltage measurements at 15-minute time intervals were averaged for each season for CVR ON and OFF days to arrive at the mean voltage values for all substations in the study. The percent change in voltage is shown in **Error! Reference source not found.**Table 6.2 for different seasons.

Substation	Voltage	Winter 2020	Spring 2020	Summer 2020	Fall 2020
6233T001, Quispamsis	Avg. Voltage (CVR OFF)	125.65	125.77	125.70	125.48
	Avg. Voltage (CVR ON)	121.39	119.77	118.63	119.01
	ΔV	4.25	6.00	7.06	6.47
	$\%\Delta V$	3.4	4.8	5.6	5.15
6503T001, Moncton	Avg. Voltage (CVR OFF)	125.18	125.31	125.27	x
	Avg. Voltage (CVR ON)	118.76	118.63	118.47	x
	ΔV	6.42	6.68	6.80	x
	$\%\Delta V$	5.1	5.3	5.4	x
6418T002, Bathurst	Avg. Voltage (CVR OFF)	125.35	125.53	125.48	125.36
	Avg. Voltage (CVR ON)	119.23	118.97	118.94	118.45
	ΔV	6.12	6.56	6.54	6.91
	$\%\Delta V$	4.88	5.22	5.21	5.52
6124T002, Fredericton	Avg. Voltage (CVR OFF)	124.58	124.47	124.57	124.60
	Avg. Voltage (CVR ON)	119.16	118.66	118.99	118.75
	ΔV	5.42	5.81	5.58	5.85
	$\%\Delta V$	4.4	4.7	4.48	4.70

Table 6.2: Average Voltages for CVR ON and OFF Days

6.3 CVR Savings using Multivariate Regression Model based on Voltage Measurements

CVR Savings for Substations

Savings in active energy estimated using voltage measurement from the substation transformer PT as an independent variable in addition to the outdoor temperature are shown in Table 6.3.

Substation	Voltage	Winter 2020	Spring 2020	Summer 2020	Fall 2020
6233T001, Quispamsis	Avg. Energy/hr (CVR OFF), kW	7,775	5,507	3,351	8,214
	Avg. Energy/hr (CVR ON), kW	7,569	5,316	3,174	7,898
	% kW Savings	2.65	3.46	5.28	3.84
	CVR Energy Factor	0.78	0.73	0.94	0.82
6503T001, Moncton	Avg. Energy/hr (CVR OFF)	6521.98	4,696	4,295	x
	Avg. Energy/hr (CVR ON)	6361.13	4,552	4,087	x
	% kW Savings	2.47	3.07	4.84	x
	CVR Energy Factor	0.48	0.58	0.89	x
6418T002, Bathurst	Avg. Energy/hr (CVR OFF)	7,011	4,659	3,210	4,070
	Avg. Energy/hr (CVR ON)	6,849	4,538	3,082	3,914
	% kW Savings	2.31	2.60	3.99	3.83
	CVR Energy Factor	0.47	0.50	0.77	0.69
6124T002, Fredericton	Avg. Energy/hr (CVR OFF)	12,024	8,834	7696.31	8213.51
	Avg. Energy/hr (CVR ON)	11,725	8,455	7362.97	7897.77
	% kW Savings	2.49	4.29	4.33	3.84
	CVR Energy Factor	0.57	0.92	0.97	0.82

Table 6.3: Savings in active energy using voltage measurement as an independent variable

Savings for Feeders

CVR factors for active energy by feeders using voltage measurement as an independent variable are shown in Table 6.4.

Substation	Feeder	Winter	Spring	Summer	Fall	Load Composition %	
						Residential	C&I
Quispamsis	6233R001	0.84	0.71	0.88	0.79	99	1
	6233R002	0.60	0.64	0.94	0.72	84	16
Moncton	6503B004	0.54	0.64	0.78	x	16	84
	6503B005	0.37	0.51	1.17	x	4	96
Bathurst	6418B007	0.44	0.44	0.75	0.52	58	42
	6418B008	0.47	0.50	0.72	0.46	48	52
Fredericton	6124B009	0.46	0.75	0.46	0.38	61	39
	6124B010	0.47	0.99	1.01	0.72	31	69
	6124B011	0.77	0.93	0.89	0.79	74	26
	6124B012	0.50	0.90	1.12	1.02	0	100

Table 6.4: Savings in active energy by feeders using voltage measurement as an independent variable

6.4 Impact of COVID-19 and related Public Health Measures on the study

This section describes the estimation of savings observed at the substations by applying the multivariate regression model that uses voltage measurements and COVID-19 related public health measures in addition to the HDD and CDD as independent variables. This analysis was performed to account for the reduced economic activity, and thus reduced energy consumption during the various health phases associated with COVID-19. The key CVR savings indicators using this method for Quispamsis, Moncton. Bathurst, and Fredericton are shown in Table 6.5.

* There were no public health phases for the winter season and hence the values in the winter column are left blank.

Substation	Voltage	Winter 2020	Spring 2020	Summer 2020	Fall 2020
6233T001, Quispamsis	Avg. Energy/hr (CVR OFF), kW		5,286	3,271	4,186
	Avg. Energy/hr (CVR ON), kW		5,140	3,126	4,051
	% kW Savings		2.75	4.44	3.22
	CVR Energy Factor		0.58	0.79	0.63
6503T001, Moncton	Avg. Energy/hr (CVR OFF)		4,387	4,345	x
	Avg. Energy/hr (CVR ON)		4,266	4,170	x
	% kW Savings		2.76	4.03	x
	CVR Energy Factor		0.52	0.74	x
6418T002, Bathurst	Avg. Energy/hr (CVR OFF)		4,474	3,208	4,021
	Avg. Energy/hr (CVR ON)		4365.90	3,091	3,907
	% kW Savings		2.40	3.66	2.84
	CVR Energy Factor		0.46	0.70	0.52
6124T002, Fredericton	Avg. Energy/hr (CVR OFF)		8,413	7,704	8,159
	Avg. Energy/hr (CVR ON)		8,118	7,435	7,892
	% kW Savings		3.52	3.49	3.28
	CVR Energy Factor		0.75	0.78	0.70

Table 6.5: Savings in active energy through multivariate regression model based on the voltage and public health measures

6.5 Green House Gas Emission Results

The CVR measure achieves reduction in Green House Gas (GHG) emissions as a result of reducing the energy usage. Table 6.6 shows the computation of GHG emission reductions first by aggregating the total yearly energy savings at the substation level and then for the whole study. A marginal emission factor of 275 tonnes/GWh is then applied to the whole energy savings to estimate the GHG reductions.

Parameters	Quispamsis	Moncton	Bathurst	Fredericton	Pilot Study
	6233T001	6503T001	6418T002	6124T002	Aggregated
Avg kWh (CVR OFF)	5,087.35	5,043.20	4,657.13	9,108.08	23,895.76
Avg kWh (CVR ON)	4,924.70	4,840.23	4,540.76	8,801.87	23,107.56
Delta kWh/hr	162.65	202.97	116.37	306.21	
Number of CVR OFF days	117	88	116	122	
Number of CVR ON days	109	67	105	85	
CVR ON days energy savings (kWh)	425,485	326,371	293,264	624,659	1,669,779 kWh
CVR ON days energy savings (GWh)					1.67 GWh
Green House Gas Reductions					**459 tonnes**
marginal emission factor	275	tonnes/GWh			

Table 6.6: Computation of GHG Emission Reductions Using Regression Method (Model 1)

Regression model based on voltage and outdoor temperature estimates the energy savings of 1.67 GWh (3.4%) across all ten feeders over a one-year period with a 5% average reduction in voltage, and an associated reduction of 459 tons of greenhouse gas emissions. Whereas, regression model that also includes provinces health phases, returns a more conservative estimate with 1.4 GWh of savings and 386 tonnes of GHG reduction.

6.6 Reduction in Reactive Power Requirement due to CVR

In some cases, during light load conditions, the effects of CVR and associated reduction in voltage and reduction in the reactive power requirement of the load, resulted in a diminished power factor. From a Distribution Planning perspective, the goal is to install the proper balance of fixed vs. switched capacitor banks in an effort to provide adequate reactive power compensation, but not over-compensate during times when there is less load present. In some cases, feeders studied at Winter peak, show a near unity power factor at the substation bus, with a small positive Var requirement for the Transmission system to supply. However, as the load is reduced, the Var flow changes and we begin to see a scenario where the capacitor banks are overcompensating, resulting in a negative Var value at the bus, or Vars being absorbed at the substation. When CVR is implemented, the voltage is reduced, the active energy is reduced, and the reactive power required by the feeder(s) is also reduced. Less Vars being consumed by the load resulted in increased Var flow back toward the substation from the capacitor banks. The outcome was a negative CVR (reactive energy) factor. These Vars will be consumed by the Distribution substation transformer, and the remaining Vars will contribute to the reactive power requirements on the Transmission system. Due to Distribution system losses, it is not economical to provide Vars to the Transmission system from capacitor banks installed on the Distribution feeders.

6.7 Demand Response Analysis

6.7.1 Background

During the 'ON' transition time when entering CVR control, the substation voltage drops from the default value of 125V (on a 120V base) to as low as 118V within a one-minute period. When this occurs, the substation demand is temporarily reduced. This reduction, known as 'demand response' (DR) is primarily due to the reduction in demand of downstream resistive loads, such as electric heating, incandescent lights, appliances, etc. In general, after an initial reduction in demand, downstream load diversity will eventually be re-established and the demand curve will re-establish its pre-DR shape

In an effort to observe the effects of this temporary reduction in demand and its potential use in shaving the substation peak demand, the 'day-on', 'day-off' CVR pilot schedule was suspended and a series of DR tests were initiated on February 3, 4 and 5. During these tests, the 'fast transition' time to enter CVR mode was chosen to target the local morning peaks at each of the four substations. The substation meters (ION 7550's) were set to record substation demand (kW) and 12.47kV bus voltage on a 1-minute average basis.

NB Power is a winter peaking utility, with local substation peaks typically occurring between 7AM-9AM and a second, smaller peak occurring in the evening. The local substation peaks are not necessarily coincident with the system peak. Due to the limited number of substations participating in the pilot project, the local morning peak at each substation was targeted.

As can be seen from the typical daily load profiles in Figure 6.1, the shape, duration, and magnitude of the morning peak can vary greatly from day to day, even with all other factors seemingly similar (temperature, weekday vs. weekend, etc.). This makes any comparison between a typical 'baseline day' with a 'DR test day' extremely difficult, considering the limited number of DR test days.

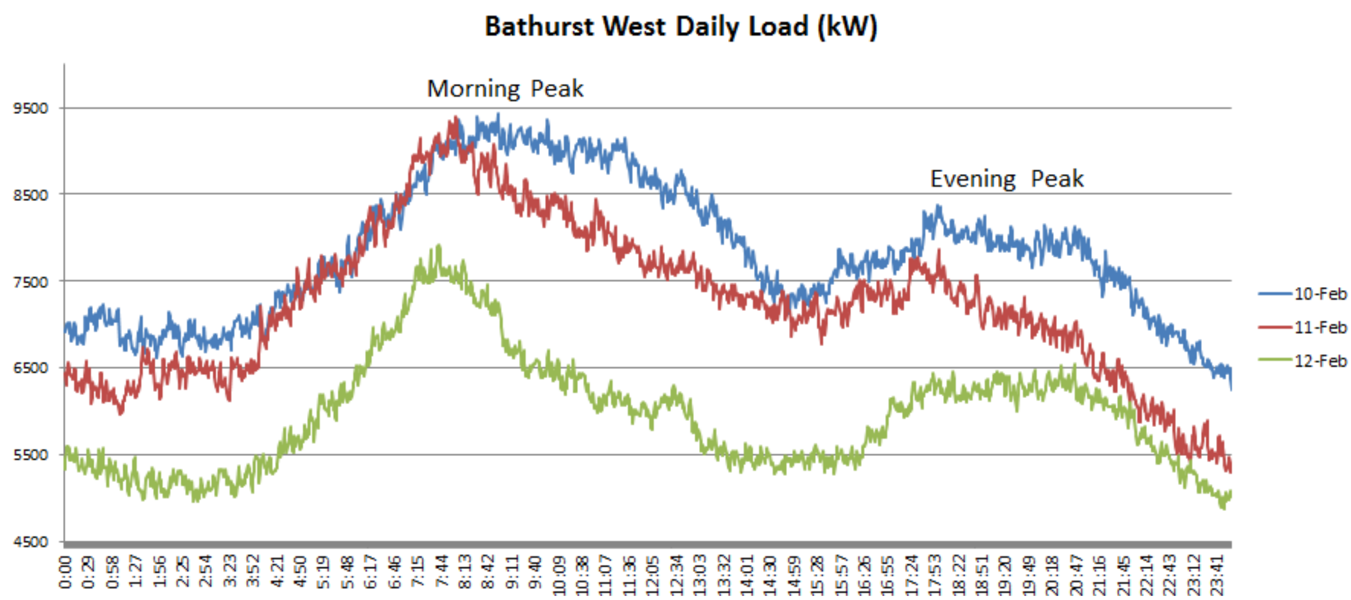


Figure 6.1: Typical Winter Daily Load Profile at Bathurst West T002

6.7.2 Results

Figure 6.2 shows the typical effect that a step reduction in substation bus voltage has on the substation load profile. As can be seen, there is a noticeable drop in load when the substation bus voltage is reduced. Across the four substations, this immediate decrease in load ranged from 3.8% - 9.4% and the window lasted between 12-49 minutes before the pre-DR load curve was re-established.

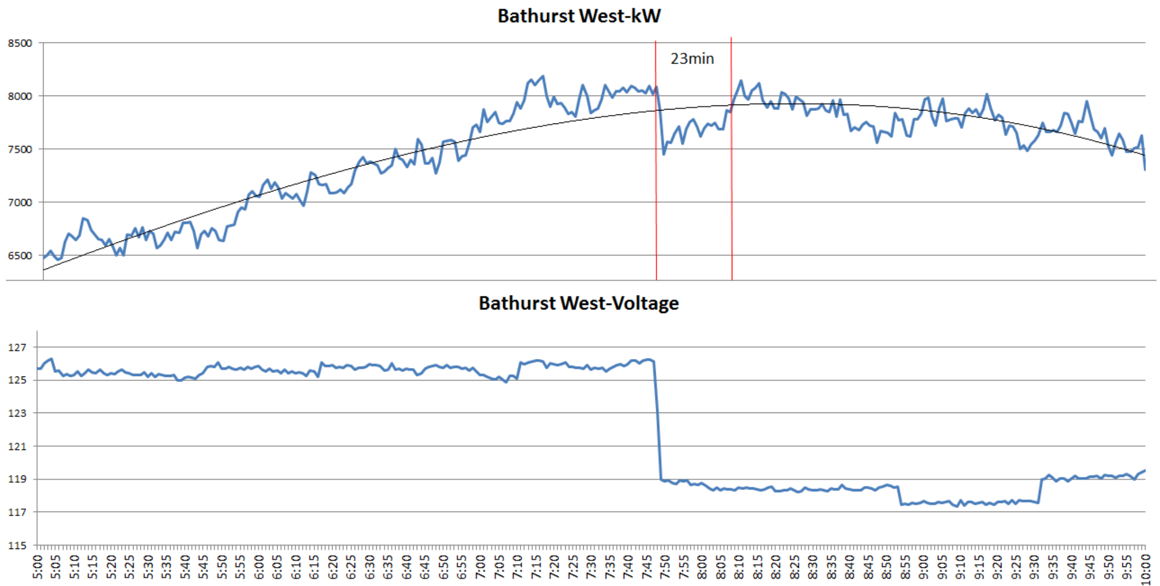


Figure 6.2 – Substation demand response to step change in voltage
(ΔV=-5.4%, ΔkW=-7.9%, Time to re-establish load diversity=23min)

Table 6.7 shows a summary of the average load reductions in the first 1 minute and in the first 15 minutes following the voltage setpoint change. The table also shows the average length of time before load diversity was re-established (average duration of reduction) and the average load reduction over this time frame.

						Substation Load Makeup		
Substation	**Voltage Reduction**	**Initial 1-min Ave. Load Reduction**	**Initial 15-min Ave. Load Reduction**	**Ave. Duration of Reduction (min.)**	**Total Ave. Load Reduction**	**Commercial Load Makeup**	**Residential Load Makeup**	**Industrial Load Makeup**
Bathurst West T002	5.2%	7.8%	6.3%	23	5.6%	46.4%	53.4%	0.2%
Commercial St T001	4.8%	4.8%	1.7%	32	1.4%	81.6%	12.2%	6.2%
Elliot Rd T001	5.1%	7.0%	1.8%	22	0.2%	7.5%	85.1%	7.4%
Priestman St T002	5.7%	7.1%	3.0%	26	2%	66.6%	32.8%	0.6%

Table 6.7 – DR Testing results (average of 3 test days)*

*Due to a technical issue on Feb.4, Elliot Rd did not enter DR mode. The data in this section includes test results for Feb. 3 and Feb. 5 only for Elliot Rd.

The data from the three test days shown in Figure 6.3 depicts a correlation between the % decrease in load and the time to re-establish load.

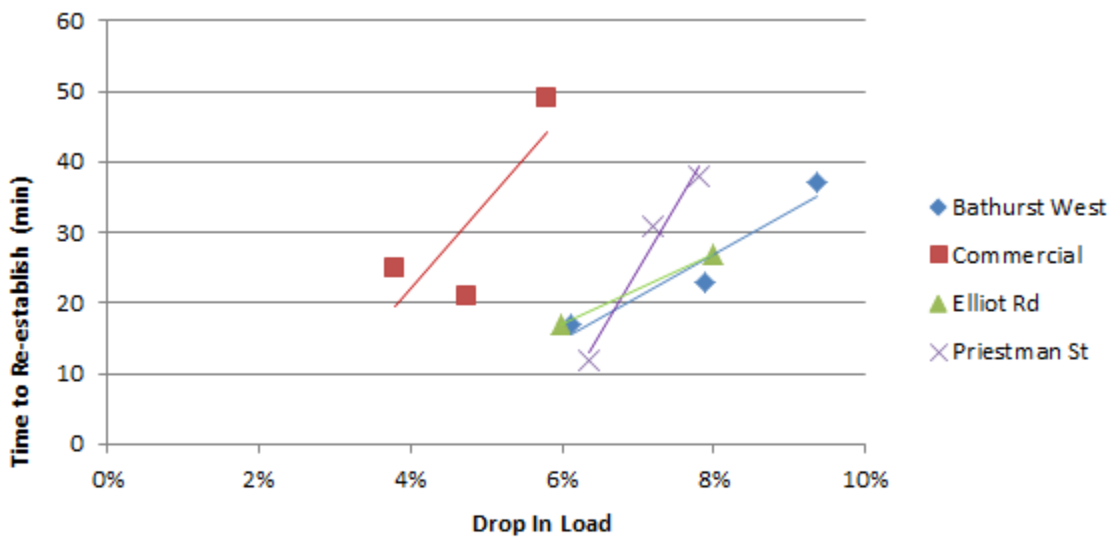


Figure 6.3 – Drop in Load vs. Time to Re-establish Load

Figure 6.4 shows a correlation between the load makeup of the substation and the average time to re-establish load. In general, the greater percentage of the load that was made up of residential loads, the faster the total load was re-established after the DR event.

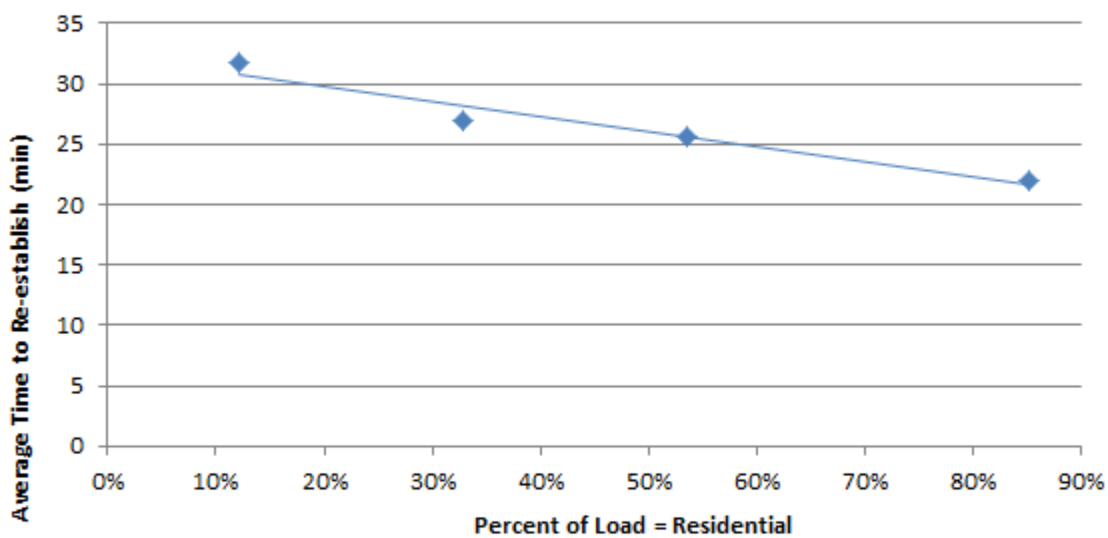


Figure 6.4 – Load Makeup vs. Time to Re-establish Load

Significantly more substations would need to be participating in the pilot project to have an observable effect on the overall system peak. To obtain results with a high degree of statistical confidence, more days of DR testing and baseline days would be required.

It is apparent the reduction in voltage caused a temporary additional reduction in load across the four substations. In all instances, this additional reduction in load lasted less than 50 minutes and varied from day to day at each substation. There appears to be a correlation between the substation load makeup and the drop in load as well as the time to re-establish the natural load curve.

Depending on the required duration, it could be possible to reduce the system peak demand by using demand response. Due to the relatively short duration of time that it can take for load diversity to be re-established, a staged DR approach would likely be required to ensure a certain amount of load reduction over the entire duration of the system peak (a system peak event can range from 1-2 hours). In this type of approach, the CVR enabled substations could be divided into subsets and enabling of DR would be staged such that voltage is reduced at the next subset before load diversity of the previous subset is fully re-established. Such an approach could allow for a temporary reduction in load beyond the reduction offered by CVR alone. Further testing would be required to determine the best system wide DR approach and to form further conclusions.

Refer to *Appendix D - Demand Response Daily Test Data* for plots showing effect that a reduction in substation bus voltage has on the substation load profile for each of the 4 substations involved in the pilot.

6.8 Tap Changer Wear and Tear

During a scheduled transition to turning CVR 'ON', the EDGE® issues a new setpoint to the tap changer controller that causes it to drop from default (125 V) to the lowest acceptable voltage based on the bellwether set data (typically 118 V). During a scheduled transition to 'OFF', the setpoint is changed back to 125 V.

During a typical CVR On day, the EDGE control logic determines if the voltage should be raised (1 V every 30 minutes) or lowered (1 V every 60 minutes). If for any reason the bellwether data is lost, the EDGE® software starts to 'backout' of the CVR control by raising the setpoint by 1 V every half hour until it has returned to 125 V. If bellwether data is re-established, the EDGE® will return to operating in CVR mode raising or lowering the setpoint as described above.

Analysis was conducted to evaluate if operating the four substations on an alternating CVR On/Off day strategy for an extended period of time had any adverse impact on the wear and tear of the LTC.

Table 6.8 provides a summary of the wear and tear for each LTC (actual and historic).

	Priestman 6124T002	Commercial 6503T001	Elliot 6233T001	Bathurst West 6418T002
Operation Count Nov 6, 2019	7130	13088	5986	103157
Operation Count Feb 13, 2020	10418	17672	8104	104291
Average Operations Per Day	*16.4*	*22.9*	*10.6*	*10.1*
Operation Count Nov 7, 2020	18742	26092	12552	107502
Average Operations Per Day	*15.5*	*15.7*	*8.3*	*11.3*

Table 6.8: LTC Wear and Tear Analysis

Note:
For every individual tap operation, the Beckwith Control counter increments by two.
Beckwith Control at Bathurst West Sub not wired correctly to monitor number of operations; therefore, LTC dial counter was used.

Based on the analysis that was completed in mid-February, and again in early November, average number of operations per day at Elliot and Bathurst West was as expected. Commercial and Priestman were slightly higher than what Asset Management typically see, but acceptable as both power transformers supply sections of urban centers, with some heavy commercial loading that varies throughout the day.

6.9 DVI Validator Results

The **EDGE®** software suite that was used for CVR control has a built-in tool for calculating CVR savings, called **EDGE® VALIDATOR**. This tool was used as an alternate method for calculating the CVR factors and the associated savings. The table below provides a summary by season for each substation.

Refer to *Appendix E – EDGE Validator* for a more detailed description of the **EDGE® VALIDATOR** methodology used to calculate the results.

Winter Season

Node	Period	# Pairs	CVR Factor	σ	95% Confidence	Savings
Bathurst West	11/29 - 03/13	131	0.55	0.44	0.47-0.62	2.83%
Commercial St	11/29 - 03/13	138	0.3	0.53	0.22-0.39	1.66%
Elliot Rd	11/29 - 03/13	356	0.5	0.73	0.43-0.58	1.67%
Priestman St	11/29 - 03/13	330	0.44	0.55	0.38-0.5	1.99%

Spring Season

Node	Period	# Pairs	CVR Factor	σ	95% Confidence	Savings
Bathurst West	03/16 - 05/31	310	0.28	0.52	0.22-0.33	1.44%
Commercial St	03/16 - 05/31	122	0.3	0.13	0.28-0.32	1.59%
Elliot Rd	03/16 - 05/31	137	0.06*	0.15	0.03-0.08	N/A*
Priestman St	03/16 - 05/31	130	0.43	0.58	0.33-0.53	1.97%

*Results for Elliot Road inconclulsive.

Summer Season

Node	Period	# Pairs	CVR Factor	σ	95% Confidence	Savings
Bathurst West	06/01 - 08/30	161	0.58	0.12	0.56-0.6	3.15%
Commercial St	06/01 - 08/30	139	0.53	0.14	0.51-0.55	2.90%
Elliot Rd	06/01 - 08/30	207	0.53	0.42	0.48-0.59	2.45%
Priestman St**	07/28 - 08/30	101	0.48	0.51	0.37-0.58	2.10%

**CVR was disabled at Priesmtan St for part of the summer season.

Fall Season

Node	Period	# Pairs	CVR Factor	σ	95% Confidence	Savings
Bathurst West	09/01 – 11/30	301	0.54	0.44	0.49 – 0.59	3.03%
Commercial St***	09/01 - 11/30	N/A	N/A	N/A	N/A	N/A
Elliot Rd	09/01 – 11/30	364	0.49	0.56	0.43 – 0.55	2.49%
Priestman St	09/01 – 11/30	144	0.7	0.52	0.62 – 0.79	3.41%

***Commercial St was offline for maintenance.

Table 6.9: Edge Validator CVR Results

6.10 Adjacent Substation Transformer Comparison

NB Power employed an 'Adjacent Substation' comparison method as an alternate way to estimate CVR savings for the pilot project. For this method, nearby substations with similar load makeups and sizes to the CVR substations were chosen. The Adjacent Substations chosen are located geographically close to their associated CVR Substation to minimize the effects of varying weather on the data analysis.

CVR Substation	Adjacent Substation	Distance
Bathurst West T002	Bathurst West T001	0.1km
Commercial St T001	Church St T002	1.7km
Elliot Rd T001	Westfield T001	26km
Priestman St T002	Priestman T001	0.1km

Table 6.10: Adjacent Substation List

For this analysis, the 15-minute average kW and Voltage data from the ION substation meters was used. A ratio of the average CVR Substation daily load to the average Adjacent Substation daily load was calculated for CVR ON days and CVR OFF days:

$$R_{CVR\ ON} = [\text{CVR Sub. kW}_{ave} / \text{Adjacent Sub. kW}_{ave}](\text{ON DAYS})$$

$$R_{CVR\ OFF} = [\text{CVR Sub. kW}_{ave} / \text{Adjacent Sub. kW}_{ave}](\text{OFF DAYS})$$

These CVR ON and CVR OFF ratios were used to calculate a projected CVR substation load value, if CVR had not been active during the CVR ON days (Proj. CVR Sub. kW_{ave}). This was then used to calculate the CVR factor and associated savings.

$$\text{Proj. CVR Sub. kW}_{ave}\,(\text{ON DAYS}) = \text{CVR Sub. kW}_{ave}\,(\text{ON DAYS}) \times R_{ave\ CVR\ OFF} / R_{ave\ CVR\ ON}$$

$$\Delta\ \text{kW}_{ave} = [\text{Proj. CVR Sub. kW}_{ave} - \text{CVR Sub. kW}_{ave}](\text{ON DAYS})$$

$$\Delta\ \text{Volt}_{ave} = \text{CVR Sub. Volt}_{ave}\,(\text{OFF DAYS}) - \text{CVR Sub. Volt}_{ave}\,(\text{ON DAYS})$$

The following plot shows the CVR substation to Adjacent substation load ratios for CVR ON and CVR OFF days for the summer season at Commercial St substation. The area between these two curves represents the average savings realized by CVR. The two curves intersect in a few locations due to variability in load at the two substations, but in general the CVR OFF day ratio is greater than the CVR ON day ratio.

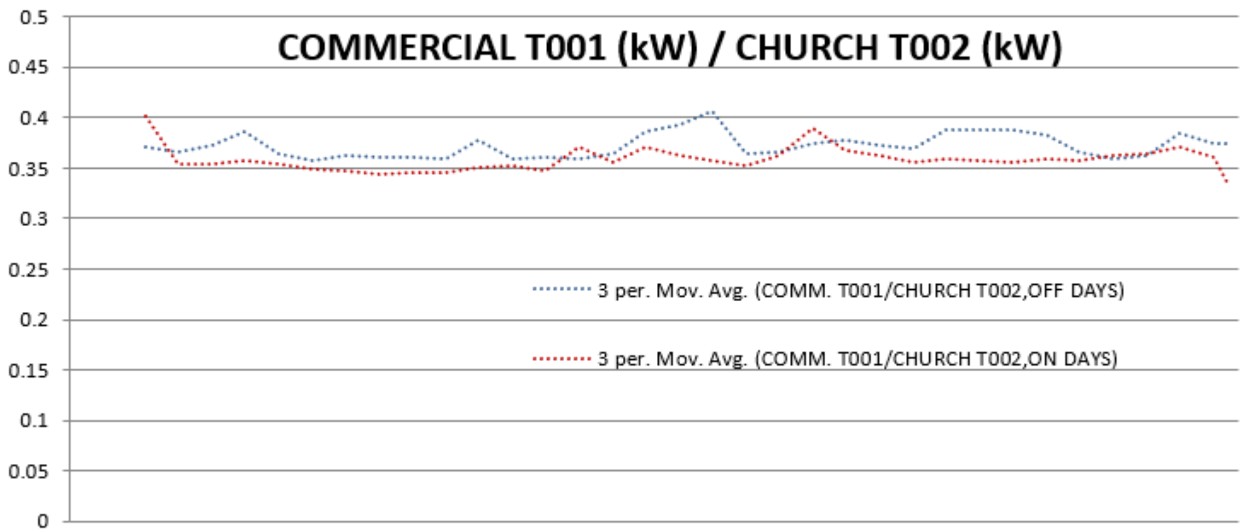


Figure 6.5: Commercial St. and Adjacent Substation ON/OFF Day Ratios

Only data from complete CVR ON and CVR OFF days were used in this analysis. Data from days where the CVR state changed midway through the day and otherwise anomalous data was discarded. A similar number of CVR ON and CVR OFF days were used, and adjacent CVR ON and CVR OFF days were chosen as much as possible to minimize the effects of temperature differences over time.

The CVR factors calculated using the Adjacent Substation comparison method are noted below. Due to the variable nature of the load at the two comparison substations, and the more basic calculation method used, the below results have less of a degree of confidence than those achieved using more rigorous statistical analysis methods in other sections of this report.

Bathurst West:

	Winter	Spring	Summer	Fall
Average Volt. Reduction	4.9%	5.3%	5.3%	5.5%
Average CVR Factor	0.3	0.44	0.56	0.33
Average Load Decrease	1.5%	2.4%	3.02%	1.86%

Commercial St:

	Winter	Spring	Summer	Fall
Average Volt. Reduction	4.9%	5.4%	5.1%	N/A
Average CVR Factor	0.45	0.53	0.64	N/A
Average Load Decrease	2.3%	2.9%	3.4%	N/A

Elliot Road:

	Winter	Spring	Summer	Fall
Average Volt. Reduction	3.4%	4.8%	5.3%	5.2%
Average CVR Factor	0.4	0.34	0.55	0.46
Average Load Decrease	1.4%	1.7%	3.01%	2.43%

Priestman St:

	Winter	Spring	Summer	Fall
Average Volt. Reduction	4.2%	4.5%	4.5%	4.8%
Average CVR Factor	0.42	0.6	0.53	0.32
Average Load Decrease	1.81%	2.77%	2.4%	1.56%

Table 6.11: Adjacent Substation Comparison CVR Factors

6.11 CVR Factor Comparison

This section shows a comparison of the CVR factors and energy savings as calculated by the various methods outlined in this report. Due to the variability in substation load and the small effect that CVR has on load, calculating an exact CVR factor and the corresponding energy savings is difficult. The results from the NRC linear regression methods have the highest degree of confidence. The other calculation method results are presented for comparison only.

From the results, the more lightly loaded summer months yield a higher CVR factor than the colder, higher loaded months. This is due primarily to the large percentage of thermostatically controlled baseboard heating in the province in the wintertime. The more the total load consists of this type of heating, the larger the immediate drop in load due to demand response; however, load diversity is quickly re-established and the same total energy is required for these loads since the thermostats' setpoints didn't change. The heaters will cycle on for a longer period to compensate for the lower thermal output due to the lowered voltage, and the overall energy used to keep the building heated is the same with CVR on or off. As such, the months with a lower percentage of thermostatically controlled heating loads in their load makeup yield higher CVR factors.

WINTER SEASON	Edge Validator		NRC Mean Method		NRC Linear Regression (Volt. As Independent Variable)		NRC Linear Regression (Volt.+Health Phase As Independent Variable)		NBP Adjacent Substation Comparison	
	CVR Factor	Savings	CVR Factor	Savings	CVR Factor	Savings	CVR Factor	Savings	CVR Factor	Savings
BW	0.55	2.83%	0.52	2.53%	0.47	2.31%	0.47	2.31%	0.3	1.50%
Commercial	0.30	1.66%	0.5	2.56%	0.48	2.47%	0.48	2.47%	0.45	2.30%
Elliot	0.50	1.67%	0.53	1.78%	0.78	2.65%	0.78	2.65%	0.4	1.40%
Priestman	0.44	1.99%	0.56	2.45%	0.57	2.49%	0.57	2.49%	0.42	1.81%

SPRING SEASON	Edge Validator		NRC Mean Method		NRC Linear Regression (Volt. As Independent Variable)		NRC Linear Regression (Volt.+Health Phase As Independent Variable)		NBP Adjacent Substation Comparison	
	CVR Factor	Savings	CVR Factor	Savings	CVR Factor	Savings	CVR Factor	Savings	CVR Factor	Savings
BW	0.28	2.83%	0.32	2.53%	0.5	2.31%	0.46	2.31%	0.44	1.50%
Commercial	0.30	1.66%	0.83	2.56%	0.58	2.47%	0.52	2.47%	0.53	2.30%
Elliot	0.06	1.67%	0.29	1.78%	0.73	2.65%	0.58	2.65%	0.34	1.40%
Priestman	0.43	1.99%	0.6	2.45%	0.92	2.49%	0.75	2.49%	0.6	1.81%

SUMMER SEASON	Edge Validator		NRC Mean Method		NRC Linear Regression (Volt. As Independent Variable)		NRC Linear Regression (Volt.+Health Phase As Independent Variable)		NBP Adjacent Substation Comparison	
	CVR Factor	Savings	CVR Factor	Savings	CVR Factor	Savings	CVR Factor	Savings	CVR Factor	Savings
BW	0.58	3.15%	0.77	3.99%	0.77	3.99%	0.7	3.66%	0.56	3.02%
Commercial	0.53	2.90%	0.96	5.23%	0.89	4.84%	0.74	4.03%	0.64	3.40%
Elliot	0.53	2.45%	0.46	2.60%	0.94	5.28%	0.79	4.44%	0.55	3.01%
Priestman	0.48	2.10%	0.47	2.09%	0.97	4.33%	0.78	3.49%	0.53	2.40%

FALL SEASON	Edge Validator		NRC Mean Method		NRC Linear Regression (Volt. As Independent Variable)		NRC Linear Regression (Volt.+Health Phase As Independent Variable)		NBP Adjacent Substation Comparison	
	CVR Factor	Savings	CVR Factor	Savings	CVR Factor	Savings	CVR Factor	Savings	CVR Factor	Savings
BW	0.54	3.03%	0.69	3.83%	0.69	3.83%	0.52	2.84%	0.33	1.86%
Commercial	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Elliot	0.49	2.49%	0.78	4.02%	0.82	3.84%	0.63	3.22%	0.46	2.43%
Priestman	0.70	3.41%	0.9	5.28%	0.82	3.84%	0.7	3.28%	0.32	1.56%

Table 6.12: CVR Calculation Method Comparison

Refer to *Appendix F – CVR Factor Comparison Plots by Season* for a graphical representation of the various methods identified in this report.

7.0 Lessons Learned

The lessons learned coming out of the project were categorized into 3 areas: General, Customer, and Technical. There were many lessons learned on what the project team may do differently if doing this type of pilot project again. This section focuses more on the lessons learned that are applicable to NB Power moving forward with a larger deployment of CVR across New Brunswick. It should also be noted that the alternating CVR day On/Off approach used for this pilot introduced challenges that would not carry over to a broader deployment where CVR would run daily.

7.1 General

General lessons learned on the project include:

- *CVR Worked* – recognizing that CVR is not a new concept, the AMI based solution implemented in this pilot enabled moving to a lower voltage on CVR On days without impacting customer or service level quality. The energy voltage reduction savings did vary across seasons as expected.

- *NRC Findings support NBP Business Case for broader deployment.* The results determined through NRC analysis (Sections 6.1-6.6) show the calculated average annual voltage energy savings in this project support the CVR cost/benefit projections submitted by NB Power as part of their AMI Business Case submission approved through the Energy Utility Board. Having the CVR voltage energy savings determined through a respected unbiased 3rd party research partner such as the NRC adds credibility to the utility's pilot project results.

- *Involve Customer Account Managers* –At NB Power, communication to commercial customers is facilitated primarily through commercial Key Account Managers (KAM). Ensuring the KAM was informed on the project timeline, how CVR worked, and impact to the customer was critical for commercial recruitment into the pilot. The

KAM can play an important role with customer education, awareness and adoption as NB Power lays the groundwork for an expanded implementation of CVR.

7.2 Customer

Customer related lesson learned include:

- *Residential Customer acceptance of AMI Smart Meter installation.* Residential customers selected to receive a new AMI were informed through an email and phone campaign that their existing meter was scheduled to be replaced with an AMI Smart Meter as part of the CVR pilot research project. The customer had the option to opt out and not receive the smart meter. Through this campaign NB Power experienced a less than 1% opt out by residential customer to receiving the AMI smart meter. Commercial customer recruitment was done via the Key Account Managers.

- *Customers want access to meter data*. There were multiple requests from both residential and commercial customers for the ability to access to their smart meter data. Commercial Customers in particular were hoping to access their smart meter data. Providing this capability was not in scope for this project. Having clear communication materials (FAQs, Website, Customer information sheets etc.) are important tools to help with managing customer expectations coming from participation in a larger CVR deployment. Although not part of this project, customer access to smart meter data is part of the functionality to be delivered through NB Power's AMI project currently underway.

- *Voltage Outlier Analysis.* Prior to enabling CVR, AMI data was collected for a two-week period. This data was analyzed to identify voltage outliers. Both high and low voltage issues, resulting from defective equipment and non-standard construction were discovered. It is important to resolve low voltage issues to eliminate constraints on CVR and ability to lower voltage. There is certainly value in completing this exercise with respect to a larger CVR rollout. AMI will provide engineering staff with visibility at the customer level that they have not had in the past and allow these types of issues to be discovered and addressed, resulting in a more impactful CVR program.

- *Effective Communication/Awareness.* As NB Power plans for a larger CVR rollout, communication strategies will need to be developed to support this initiative. Ensuring that all customers and electrical contractors impacted by CVR are informed, and clearly understand the scope of the project will be essential. A higher penetration of AMI meters will provide NB Power staff with increased visibility and will help to ensure service entrance voltages remain within acceptable limits. The CVR On/Off day strategy will not be required, making the program much more tolerable and transparent to the customer.

7.3 Technical

- Maximizing CVR On days: If the meter data was missing for some time periods of a 24-hour CVR day (i.e. 4:00 am to 3:59 AM the following day) that day was dropped from the CVR savings analysis. If the voltage was not held down for the complete 24 hours for CVR ON days, those days were excluded from the CVR status regression model but were included in the bus voltage regression model

- *Initial transition from 125V to 118V on CVR On Day may be too aggressive*. Depending on the type of customers served by the Distribution Substation, and the loading levels at specific times of the year, NB Power Distribution Engineering may recommend a less aggressive voltage reduction.

  While the alternating CVR On/Off day strategy was essential with respect to analyzing the data and being able to quantify the effectiveness of the program, this strategy contributed to customer complaints. The alternating transition from 125V to 118V was disruptive to a few customers with sensitive equipment. Malfunction occurred when equipment was regularly exposed to the upper and lower limits of the acceptable voltage range specified as per the CSA standard for Service Entrance Voltage. It was necessary that NB Power staff promptly address these issues.

  Larger customers may be more sensitive to low voltage and may require the occasional tap-up at their pole/padmount transformer.

- No significant additional wear and tear on Load Tap Changers due to CVR On/Off strategy. (refer to section 6.8)

- In some cases, during lighter load conditions (night), the effects of CVR, and associated reduction in voltage, and reduction in the reactive power requirement of the load, resulted in a diminished power factor. (refer to section 6.6 *Reduction in Reactive Power Requirement due to CVR*)

- Demand Response testing was completed as part of the Research Project with a limited sample size. Results showed a decrease in demand of 3.8% - 9.4% and lasted 12-49 minutes before re-establishing the 'pre-DR event' values based on the demand curve. (Refer to section 6.7)

8.0 CVR Path Forward

8.1 CVR Roadmap

An enterprise-wide Conservation Voltage Reduction (CVR) implementation at NB Power is a complex engineering, software, and communications solution.

NB Power has several projects, both in-flight and planned as-of fall 2020, which individually will deliver components of the planned CVR system.
The specific projects that contribute to the overall CVR solution include the following:

- Advanced Meter Infrastructure (AMI) *(In Progress)*
- Advanced Distribution Management System (ADMS) *(In Progress)*
- Distribution SCADA (DSCADA) *(In Progress)*
- Digital Communications Network (DCN/COMMS) *(In Progress)*
- Conservation Voltage Reduction Technology Implementation *(Scheduled FY23)*
- Conservation Voltage Reduction Process Implementation *(Scheduled FY24)*

The purpose of this CVR Roadmap is to describe how the enterprise CVR implementation can be realized in New Brunswick, in consideration of the above projects that each provide one or more components of the CVR solution. The CVR Roadmap provides a very high-level overview of how CVR can be achieved. More detailed plans and designs will be delivered within the constituent projects identified in the roadmap. Figure 8.1 below provides a graphic visualization of the project relationships and the proposed timeline for completion.

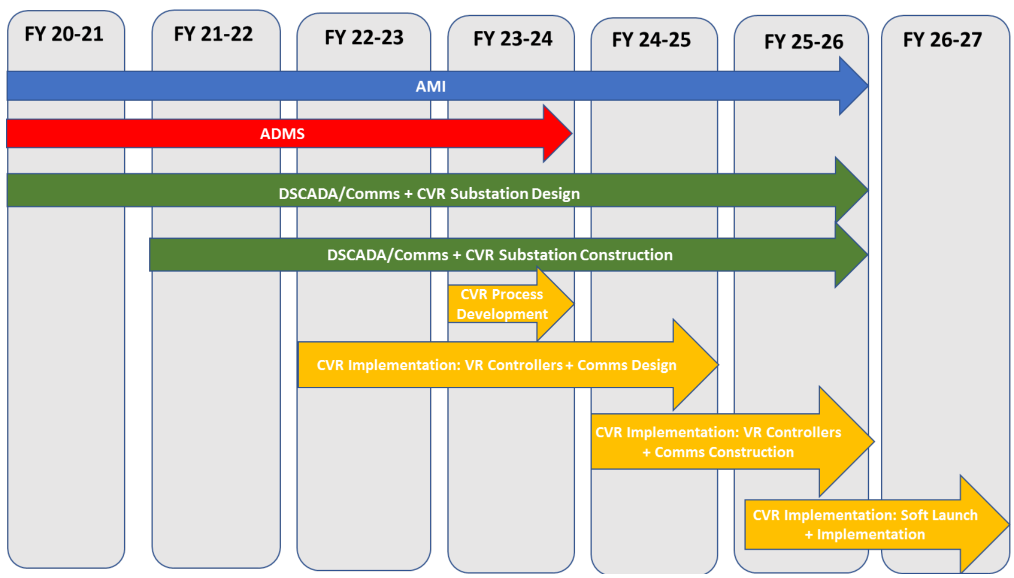


Figure 8.1: CVR Roadmap and Timeline

The CVR pilot involved four (4) substations. For NB Power, the implementation of CVR to a larger scale envisions the implementation to approximately seventy (70+) substations located across New Brunswick.

8.2 CVR Substation comparison of Characteristics

As an immediate follow-up activity to this project, NB Power has further engaged NRC to scale-up the CVR experiment findings to qualifying selected feeders in the province. NRC will conduct analysis to extrapolate the CVR benefit to 70+ substations targeted for CVR scale-up by conducting similarity analysis based on characteristics of the 4 substations involved in the CVR pilot. Target feeders that are

similar in characteristics to the feeders in the CVR experiment are assigned similar CVR benefits. The goal is to provide a more detailed analysis using substation/feeder characteristics to support CVR pilot findings and to determine projected benefits for the broader deployment of CVR in New Brunswick.
The feeders under the CVR experiment would be considered model/reference feeders. Characteristics of target feeders will be analyzed using statistical clustering algorithms to group similar feeders together and these groups will then be matched to the feeders in CVR experimental study. The necessary base data for the 70+ substations has been collected and provided to NRC. Their analysis is expected to be completed in Q3 FY22.

9.0 Conclusion

NB Power upgraded four substations in Bathurst, Fredericton, Moncton, and Quispamsis with automated LTC, and installed approx. 700 smart meters at residential and commercial buildings so customers' voltage could be monitored and fed back to the CVR control system. In November 2019, the one-year CVR experiment was initiated with the control scheme of CVR being turned ON and OFF for 24 hour periods on alternate days at 4 am.

One of the key questions from the pilot study was how much CVR savings could be realized in the cold winters of New Brunswick with its prevalence of electric heat. In a study prior to this pilot, Kinetrics Inc. had estimated an average annual voltage reduction of 2.5% for the province. The yearlong CVR experiment demonstrated an average voltage reduction of approximately 5% for all substations with the corresponding reduction in active energy (kWh) of 3.4%. The reduction in the average voltage for each substation over the year is shown in Figure 9.1.

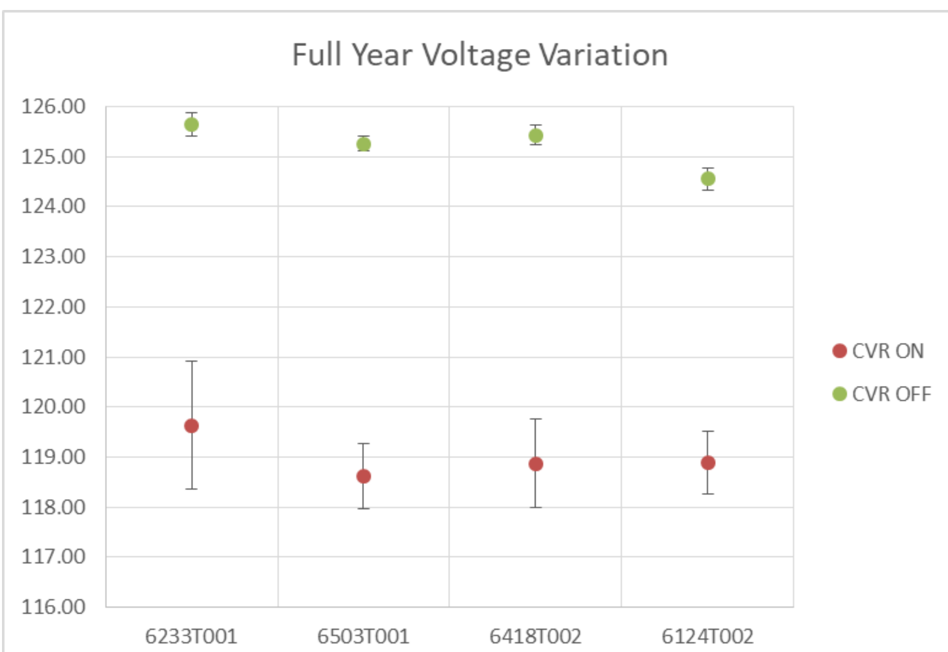


Figure 9.1: Voltage Spread for CVR ON and OFF Days

Savings from the CVR experiment were estimated using statistical methods to normalize for outdoor temperature. All multivariate linear regression methods yielded similar savings. Considering that New Brunswick is a winter peaking province with a large proportion of residential and commercial loads being thermostatically controlled due to the water and space heating, the observed CVR factor ranging from 0.50 (Moncton, Bathurst and Fredericton) to 0.80 (Quispamsis) for the winter is considered very reasonable. As expected, the CVR factor improved slightly for the spring as heating loads dropped and saw a significant increase for the summer season when space heating loads are absent. CVR factor for the summer ranged from 0.7 to 0.8 as estimated through the regression method (model 2) that also accounted for the public health phases. The CVR factors for spring and fall are comparable as expected due to similar heating requirements.

The results from regression analysis are to be interpreted within the observed space of data. For example, if during the CVR experiment the outdoor temperature varied from -20°C to 5 °C, during the winter, then the CVR savings can be reliably estimated within this temperature range.

Annual CVR factor for all substations using the mean method and two variants of multivariate regression method are shown in Figure 9.2 below.

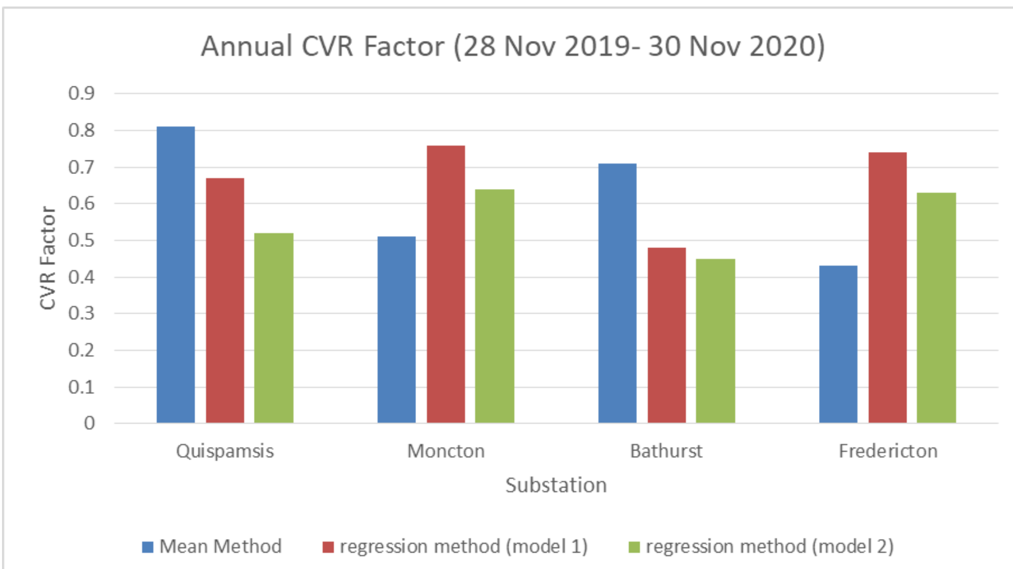


Figure 9.2: Annual CVR factor for all substations

The CVR measure achieves reduction in Green House Gas (GHG) emissions as a result of reducing the energy usage. Table 9.1 shows the computation of GHG emission reductions first by aggregating the total yearly energy savings at the substation level and then for the whole study. A marginal emission factor of 275 tonnes/GWh is then applied to the whole energy savings to estimate the GHG reductions.

Parameters	Quisispamsis	Moncton	Bathurst	Fredericton	Pilot Study
	6233T001	6503T001	6418T002	6124T002	Aggregated
Avg kWh (CVR OFF)	5,087.35	5,043.20	4,657.13	9,108.08	23,895.76
Avg kWh (CVR ON)	4,924.70	4,840.23	4,540.76	8,801.87	23,107.56
Delta kWh/hr	162.65	202.97	116.37	306.21	
Number of CVR OFF days	117	88	116	122	
Number of CVR ON days	109	67	105	85	
CVR ON days energy savings (kWh)	425,485	326,371	293,264	624,659	1,669,779 kWh
CVR ON days energy savings (GWh)					1.67 GWh
Green House Gas Reductions					**459 tonnes**
marginal emission factor	275	tonnes/GWh			

Table 9.1: Computation of GHG emission reductions using the regression method (model 1)

Regression method (model 1) estimates the energy savings of 1.67 GWh (3.4%) across all ten feeders over a one-year period with a 5% average reduction in voltage, and an associated reduction of 459 tons of greenhouse gas emissions. Whereas, regression model 2, that includes provinces health phases, returns a more conservative estimate with 1.4 GWh of savings and 386 tonnes of GHG reduction.

Appendix A - CVR Customer Recruitment

Customer Recruitment Guiding Principles

This section describes the guidelines followed for recruiting customers to participate in this pilot. The overall objective was to achieve a good distribution of smart meters across the substations/feeders involved in the pilot.

Guiding Principles:

- Like for like meter swap. The pilot used 4 specific models of smart meters (2S, 12S, 9S, 16S). Customers that had a different meter type were not eligible.
- Avoided any customers with property access concerns or meter access issues.
- Avoided any customers with a history of disconnects
- Avoided any customers with call escalation history
- Avoided priority customers (e.g. oxygen use in home)
- No customer incentive provided to participate in the pilot
- Customer could opt out at any time during the pilot

Customer Recruitment Challenges

A specific recruitment strategy was developed for both commercial and residential customers.

Residential: Candidate customers were identified by NB Power to ensure a good distribution across the substation feeder. Customers were contacted by telephone to inform them their meter was going to be replaced and the approximate date when the utility would be in the area. Messages were left for those that did not answer providing a number to call if they had any questions/concerns as well as the ability to opt out of the pilot. A "door hangar" information card was left at the customer's residence when the meter was installed providing a number to call if they had any questions or concerns.

Commercial: Candidate customers were identified by NB Power to ensure a good distribution across the feeder. NB Power commercial Key Account Managers (KAM) were utilized to vet the list for potential conflicts based on the guiding principles. The KAM met with the customer to explain the purpose of the pilot and obtain approval to install the new smart meter. Communication materials were prepared for the KAM to leave with the customer. The KAM was also the first point of contact for their customer if they had any questions during the pilot.

All customers receiving the smart meter could opt out at any time during the pilot. As part of opting out they could request to have the smart meter replaced with what they had previously.

Challenges: The main challenge, regardless of the type of customer, was achieving a good distribution of smart meters across the substation feeders.

1) In order to get a good distribution along the feeder, we had to wait to see if the customer would participate. For example, on a street with 10 houses we may only be looking for 1 or 2 customers versus all 10. All 10 customers would technically be in the pilot because their energy is supplied through the same substation/feeder but only 2 of the homes would have a smart meter installed.
2) Replacing "like for like" meters and a limited number of each meter type. In the CVR pilot we deployed both single phase (2S, 12S) and multi-phase (9S, 16S) meters. Single phase normally implies residential and multi-phase implies commercial. This assumption did not always hold

true which led to challenges with fully utilizing all meter types. Because we needed to pre-order it was a challenge to estimate how many of each type we could utilize.

3) Customer selected turns out to be ineligible once NB Power is on site (i.e. access issues, location of meter, complexity of install etc.).

Customer monitoring and Call Volumes

As part of the CVR Pilot, customer contacts were tracked as a means of learning if customers had concerns either with receiving a smart meter (pre-pilot phase), or if customers were experiencing voltage issues (pilot phase). The following table provides a summary of the calls received through NB Power's Customer Care Center at various stages of the project. Contacts in the pre-pilot phase would be almost exclusively residential customers.

Contact Action Name	Total	Timeframe	Definition
CVR - Active Offer	412	During recruitment stage	When attempt was made to reach a customer, but we didn't actually speak with them. Ex. Left a message, email or letter. Since they did not opt out, we made an assumption they were ok to participate
CVR - Active Offer Accepted	332	During recruitment stage	When we spoke with a customer and they accepted the offer to participate
CVR - Active Offer Rejected	28	During recruitment stage	When we spoke with the customer and they refused to participate
CVR - Inquiry	98	Entire pilot	When customer called and the Advisor who answered the inquiry was able to handle the inquiry with the general FAQ's provided
CVR - Escalation	27	Entire pilot	When customer called and the Advisor who answered the inquiry could not handle the inquiry with the general FAQ's provided, call was escalated to Tier 2
CVR - Acct Mgr: Customer Relationship	40	After recruitment stage, during pilot	Key Account Managers used this log contact when speaking with their customers during pilot. Some may be the same customer with multiple inquiries
Grand Total	**937**	Entire pilot	

Figure A.1: Customer Care Center Call Summary

The primary reasons for contact in the case of the 27 CVR Escalation calls can be categorized as follows:

- Customer did not want their meter changed
- Customer questioning why their meter was now being manually read versus radio frequency with previous meter
- Requesting additional information around the pilot

In addition to tracking calls received through the customer call center, a CVR Feeder Report was generated from NB Power's Outage Management System to capture information on all calls related to outage reported by any customer serviced by the substations/feeders involved in the CVR Pilot. This report was produced twice weekly and allowed us to proactively monitor any calls that may be voltage related and conduct customer follow-up if warranted.

Customer Issues

While the alternating CVR On/Off day strategy was essential with respect to analyzing the data and being able to quantify the effectiveness of the program, this strategy contributed to customer complaints. The alternating transition from 125V to 118V was disruptive to customers with sensitive equipment. Malfunction occurred when equipment was regularly exposed to the upper and lower limits of the acceptable voltage range specified as per the CSA standard for Service Entrance Voltage. It was necessary that NB Power staff promptly address these issues.

As NB Power plans for a larger CVR rollout, communication strategies will be developed to support this initiative. Ensuring that all customers and electrical contractors impacted by CVR, are informed, and clearly understand the scope of the project will be essential. A higher penetration of AMI meters will provide NB Power staff with increased visibility and will help to ensure service entrance voltages remain within acceptable limits. The CVR On/Off day strategy will not be required, making the program much more tolerable and transparent to the customer. Depending on the type of customers served by the Distribution Substation, and the loading levels at specific times of the year, NB Power Distribution Engineering may recommend a less aggressive voltage reduction.

Appendix B – Additional Industry Related CVR Information

CVR Industry Scan on CVR across North America:

An important part of gathering information about conservation voltage reduction/regulation (CVR) studies in Canada was establishing contacts with the key players at three major Canadian electric utilities that have either completed, or are in the midst of, their CVR pilot projects. Interviews were conducted with the project leaders at BC Hydro, Hydro Ottawa and Hydro-Québec, who were directly involved in the implementation of the voltage regulation. Additional information on their pilot projects and experiences was collected by means of e-mail communication and from their publications.

BC Hydro started work on CVR studies in early 1990s and had its first pilot project in 1995. This work has been subsequently extended to include fully automated real time Volt-VAR Optimization (VVO) in the closed loop and has been gradually implemented to most of their substations (presently more than 120 substations) with significant savings to customers and the company. BC Hydro's approach is characterized by the use of: modeling of substations, SCADA-based telemetry, off-the-shelf software, and implementation of a distribution management system (DMS) in 2014 (initially in 6 substations, and currently in 40 substations with VVO). The baseline for CVR was established with data from neighboring substations with similar load composition. Eight 24-hour tests were conducted with CVR alternatively turned ON and OFF at hourly intervals. The savings from the CVR were estimated based on the load mix and CVR factor. The CVR factor was evaluated at about 0.7 on a longer term basis. The lessons learned from the pilot study were: to scan voltages at the beginning of the study and install smart meters (SMs) at the critical points to monitor voltages; and that control based on a set point is better than the direct load tap changer LTC control. As there was no specific provision for the VVO in the budget, the adopted approach was to implement VVO on a normal asset planning/upgrade schedule where possible. The residential and commercial customers were not specifically informed that their feeders were part of the BC CVR/VVO pilot study. No major concerns were received from commercial customers during CVR implementation. BC Hydro did not conduct surveys of the customers who were part of the CVR/VVO study. BC Hydro not only accounted for the increase in efficiency for their distribution system from CVR/VVO measures, their models also accounted for the loss reduction in the transmission system.

Hydro-Québec started their first CVR pilot project in 2005, it included reactive power control and has been implemented at a number of substations. For the evaluation of the impact of CVR/VVO, Hydro-Québec used a combined method known as "CATVAR" (Contrôle asservi de la tension et des vars). The intelligent monitoring and control system maintained end-of-line voltage closer to the lower allowable thresholds. Reactive power was managed with capacitor banks to reduce power losses and better manage the voltages along the feeders. An average energy saving of 0.4% for every 1% voltage reduction was reported. A typical substation selected to investigate the impact of voltage reduction was located in a residential area, but it had mixed residential, commercial and industrial loads on each feeder. In the Hydro-Québec pilot project, high accuracy measurement transformers were used. The voltage corrections for CVR were applied via an automatic setup in the substation changing the transformer tap at midnight every day. The voltage was kept at a reduced level for 24 hours (ON days) and then a normal level for the next 24 hours (OFF days), for evaluation purposes. The final results of the Hydro-Québec pilot project are expected to be published in the near future, with details for all seasons and for all categories of customers (residential, commercial and industrial).

Hydro Ottawa's CVR pilot project started in 2015 and in some aspects the project is still ongoing. It is a joint project with Dominion Voltage Inc. (DVI), and to a smaller extent with Elster Metering. The project is based on the use of smart meters and DVI control software. The project is funded by Independent Electricity System Operator (IESO) of Ontario Conservation Fund as a part of the IESO long-term plan for energy conservation. The primary interest of IESO in this project is the evaluation of energy savings and not the power demand reduction. The project is implemented at the Hydro Ottawa (HO) MTS substation in Kanata with approximately 6,000 customers, mostly residential. CVR is turned on for a period of eight consecutive days and then turned off for the same period by manually enabling and disabling the CVR system. HO runs the project and collects the data, whereas the data analysis is the responsibility of IESO. The customers were not informed that their feeders were part of the CVR study and no surveys were conducted. There were no complaints from the residential customers but there were a few issues with the large commercial customers – these issues were immediately addressed. In retrospect, use of a new generation of SMs with sag alert capability would have been preferred. The voltage outliers should have been scanned and fixed before the project started since they restricted how much the voltage at the substation could be lowered. Also, informing large customers and key accounts on the CVR pilot substation would have avoided a few problems later in the project.

CVR Pilot overview and methodology:

CVR has been studied by electric utilities and regulators in the United States (US) over the past four decades; numerous pilot studies in many geographical regions have aimed to test the CVR technology and evaluate the savings. During the first decade of CVR implementation, the reduction of voltage for CVR was achieved through conventional methods including load tap changer (LTC), line drop compensation (LDC) and home voltage reduction. The lack of visibility of voltages at the edge of distribution circuits, manually operated distribution assets and regulatory issues prevented the full realization of benefits and wide scale deployment of CVR. With the emergence of Advanced Metering Infrastructure (AMI), smart grid technologies and changes to the regulatory structures in some geographical regions, CVR is now scalable and cost competitive to other energy sources in US.

An evaluation of CVR at the national level in the US was conducted in 2010 by the Pacific Northwest National Laboratory (PNNL) under a contract with the Department of Energy (DoE). This evaluation reported that CVR has the potential to provide a peak load reduction and annual energy consumption reduction of approximately 0.5%-4% per feeder, with a total reduction of 3.04% in annual energy consumption at the national level if CVR was deployed at 100% of distribution feeders.

The US National Energy Technology Laboratory (NETL) sponsored a national assessment of CVR in 2013-14 to build a body of knowledge on CVR costs, benefits, deployment models, and industry barriers. Their initial findings, published in 2015, indicated that most US utilities were still in the pilot project stage regarding the exploration of CVR potential. For 30 utilities which reported CVR performance metrics, the average energy saving was 1.9% and the average reduction in peak load was 2.5%. Where cost data was available from the utility companies, the cost of realizing the CVR savings compared favorably to other demand-side energy efficiency options and also to other sources of energy generation, including renewables. The report stresses the need to develop a standard CVR evaluation method as its lack makes it difficult to compare the reported savings across various pilot studies.

The report observed that larger deployments of CVR/VVO offer better savings per unit cost. Regulatory and utility business model issues also complicate the path forward to full CVR deployment. Despite offering huge potential, CVR is not qualified as an Energy Efficiency (EE) resource, but it should be classified as such to allow it to be counted towards mandatory energy savings measures. Utilities incur the cost of CVR implementation while customers receive the benefits in the form of reduced energy costs. CVR regulatory issues are handled differently by different stakeholders across US. The investigators recommended that utility associations and standards setting bodies play a vital role to help develop reliable planning and evaluation tools and protocols.

Lessons learned pointed out that existing voltage imbalance on feeders during summer severely limited the VVO functionality; that new visibility obtained through frequent AMI voltage readings can help weed out feeders that may have existing issues with low voltages or voltage unbalance; and, that 15 min or hourly voltage readings of the customer smart meters will help in the feeder selection for VVO.

Appendix C – Additional Information on Multivariate Linear Regression Analysis

Multivariate Linear Regression

Multivariate linear regression is used to model the relationship of more than one independent variable (predictors) on a dependent variable (response). The multivariate regression decomposes the demand into basic and other dependent components (e.g. demand being dependent on the independent variables such as weather, season, weekday/weekend, voltage, etc.). The substation and feeder demand data is temperature normalized using heating degree day (HDD) and cooling degree day (CDD) variables. In this project the method was applied to estimate energy savings separately for each season to estimate the reduction in electricity usage for CVR ON days based on the assumed relationships between the outdoor temperatures, voltage and the electricity demand. A separate multivariate regression model for CVR savings was constructed for each substation and feeder.

The total energy use in a 24-hour period was modeled as a dependent variable from 4 am to 3:59 am the following day at each substation and feeder with the following independent variables:

- Average voltage for the same 24 hours
- Heating degrees for day i, HDDi (IF dry bulb temp <18° C, 18° C – dry bulb temperature, otherwise 0)
- Cooling degrees for day i, CDDi (IF dry bulb temperature >18 ° C, dry bulb temp – 18 ° C, otherwise 0);
  not applicable to the spring and winter season

The prediction for energy flow for CVR ON days from the regression model is compared to that for the CVR OFF days to estimate the CVR savings at a given outdoor air temperature. It must be noted that CVR saving estimates are outdoor temperature dependent.

For the winter period the following two regression models were created that are further explained in the subsequent subsections:

- CVR Status Multivariate Regression Model
- Bus Voltage Multivariate Regression Model

The lockdown measures by the Canadian provinces initiated in the middle of March 2020 to slow down the spread of COVID-19 virus immediately reduced the economic activity and impacted the electricity usage profile [**Error! Reference source not found.**]. The impact on load profiles varies from feeder to feeder depending on the residential, commercial and industrial load mix. Generally, the residential demand increased during the day-time, the commercial and industrial demand decreased.

The estimation of CVR savings was made more complex as the economy remained in a state of flux with economic activity trending down as the province imposed the restrictions when COVID cases went up and vice-versa when case count decreased. Knowing that electricity usage is linked to the economic activity, the CVR multivariate regression model was extended to include provincial health phases as predictors of economic activity to correctly attribute the changes in electricity usage due to the voltage reduction and not to the periodic downturn in economic activity.

CVR Status Multivariate Regression Model

In this model, CVR status is used as one of the predictors in addition to the heating degree and cooling degree days. The relationship between the dependent variable daily energy flow, and independent (predictor) variables is expressed by the following regression equation:

$$Daily\_Energy_i = \beta_0 + \beta_1[\ CVRStatus_i] + \beta_2[HDD_i] + \beta_3[CDD_i]$$

Similarly, the hourly demand is expressed as:

$$Hourly\ Demand_i = \beta_0 + \beta_1[Hourly\ CVRStatus_i] + \beta_2[Hourly\ HD_i] + \beta_3[Hourly\ CD_i]$$

The above regression equations are solved for regression coefficients β0, β1, β2, β3. The regression coefficient β1 in the regression equation represents the dependency of energy/demand on the CVR status for the measurement period

Only the daily CVR status energy models were created and solved for the winter season.

Bus Voltage Multivariate Regression Model

In this model, bus voltage is used as predictor variable instead of the CVR status. The relationship between the dependent variable *daily energy/hourly demand*, and independent (predictor) variables is expressed by the following regression equation:

$$Daily\_Energy_i = \beta_0 + \beta_1[Daily\ Avg.Voltage_i] + \beta_2[HDD_i] + \beta_3[CDD_i]$$

$$Hourly\ Demand_i = \beta_0 + \beta_1[Hourly\ Avg.Voltage_i] + \beta_2[Hourly\ HD_i] + \beta_3[Hourly\ CD_i]$$

The above regression equation is solved for regression coefficients β0, β1, β2, β3. The regression coefficient β1 in the regression equation represents the dependency of demand on the voltage for the measurement period.

Extending Bus Voltage Multivariate Regression Model to include COVID-19 Public Health Phases as Independent Variables

The multivariate regression models to estimate CVR savings assume a stable economic activity and historical data is normally used to establish the baseline and to predict the electricity usage after compensating for temperature changes. However, the pre-COVID historical data couldn't be used for baseline as $8\frac{1}{2}$ months of experiment happened during the COVID period. Instead data for CVR OFF days was used as the baseline.

The bus voltage multivariate regression model was extended to include public health phases (i.e. red, orange, yellow) as independent variables to reflect and model associated economic activity to estimate the seasonal and annual savings. This scheme of switching CVR ON and OFF on alternate days, breaking down the M&V into four segments, and using a public health measures variable was applied to evaluate the saving from voltage reduction for the COVID period.

$$Daily_{Energy_i} = \beta_0 + \beta_1[Daily\ Avg.Voltage_i] + \beta_2[HDD_i] + \beta_3[CDD_i] + \beta_4[Health\_Phase_{red}] + \beta_5\left[Health\_Phase_{orange}\right] + \beta_6\left[Health\_Phase_{yellow}\right]$$

Appendix D – Demand Response Test Data

These plots show the effect that a reduction in substation bus voltage has on the substation load profile for each of the 4 substations involved in the pilot.

Demand Response Daily Test Data:

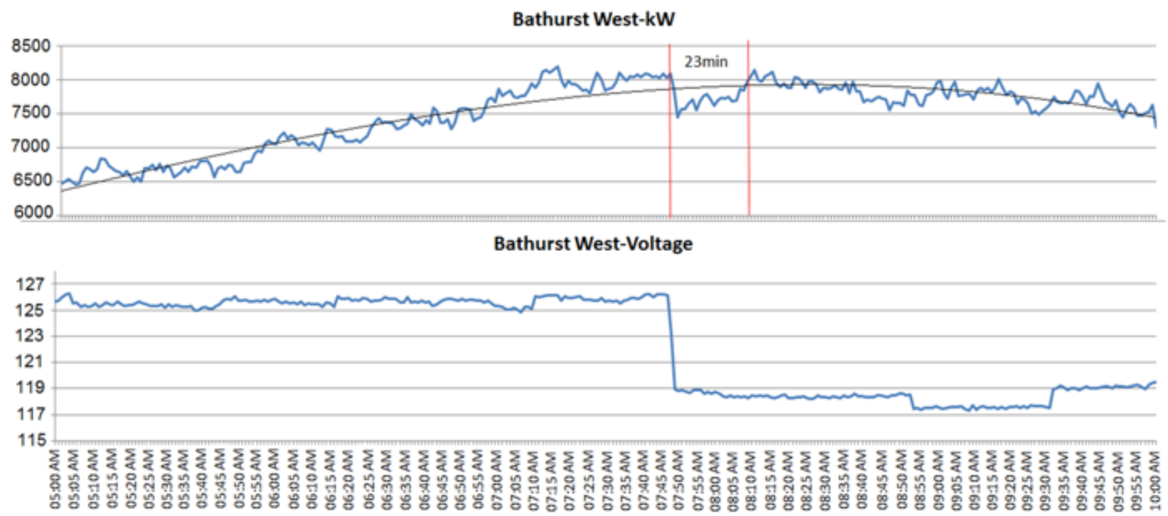


Figure D1 - Bathurst West Feb. 3 DR Test

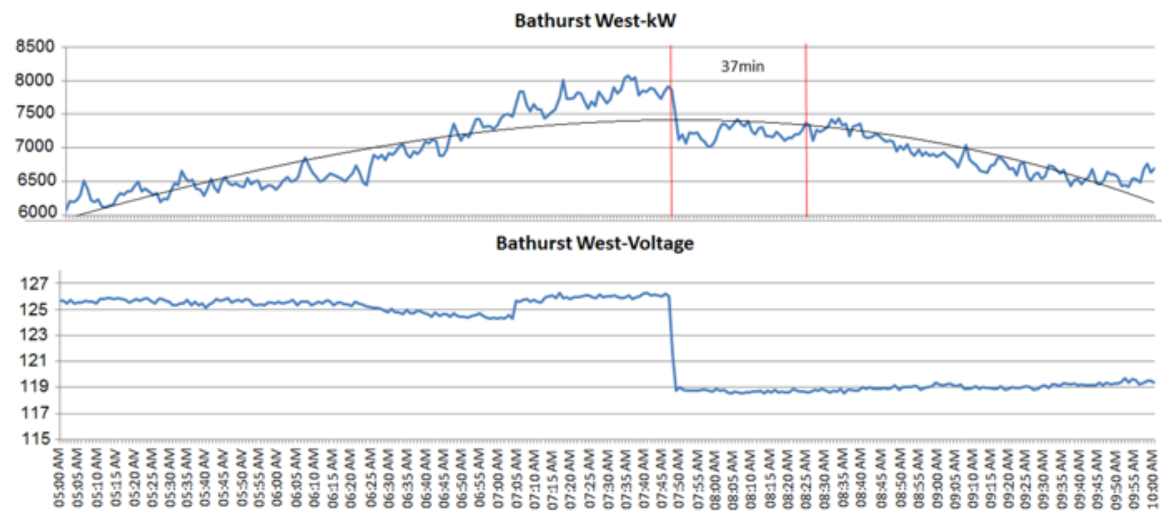


Figure D2 - Bathurst West Feb. 4 DR Test

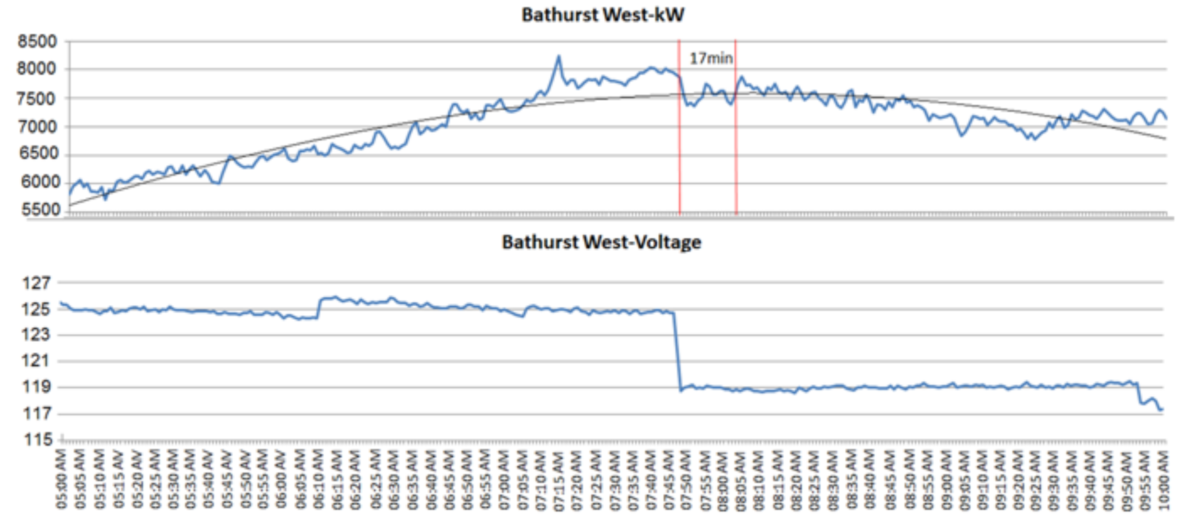


Figure D3 - Bathurst West Feb. 5 DR Test

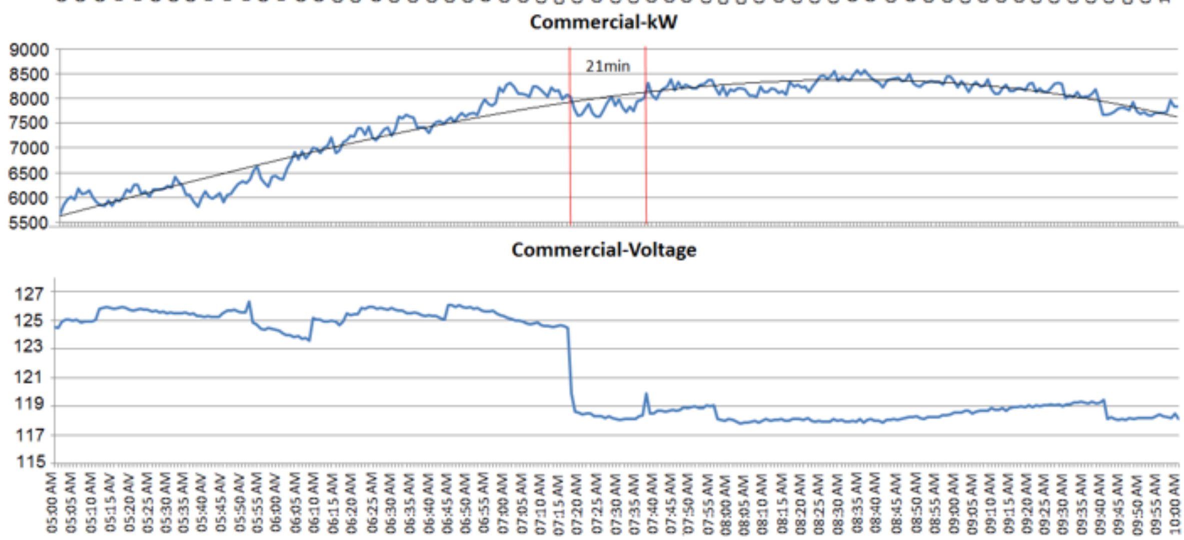


Figure D4 - Commercial St Feb. 3 DR Test

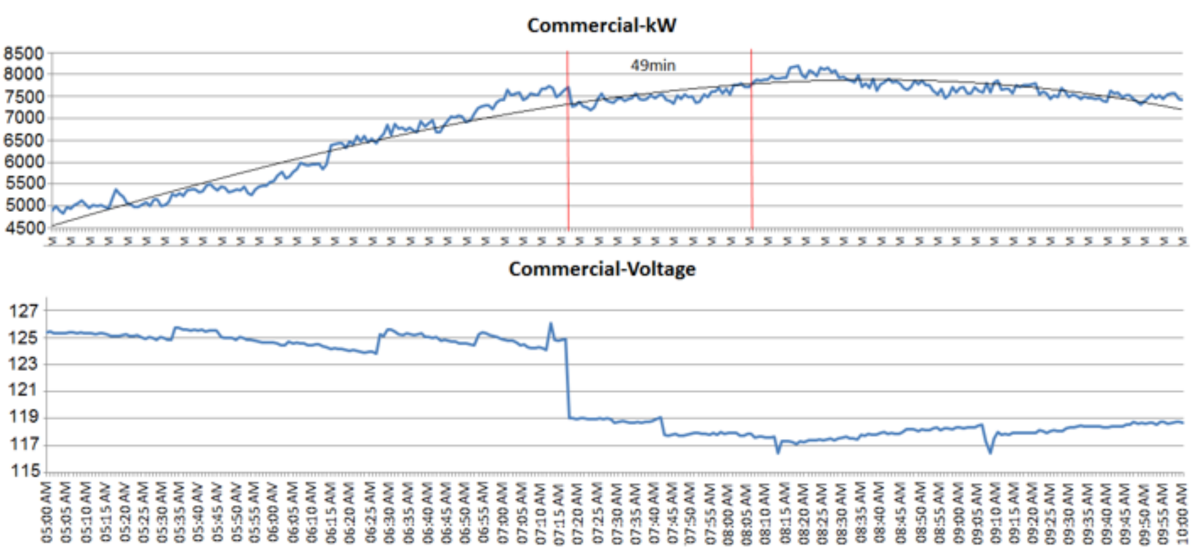


Figure D5 - Commercial St Feb. 4 DR Test

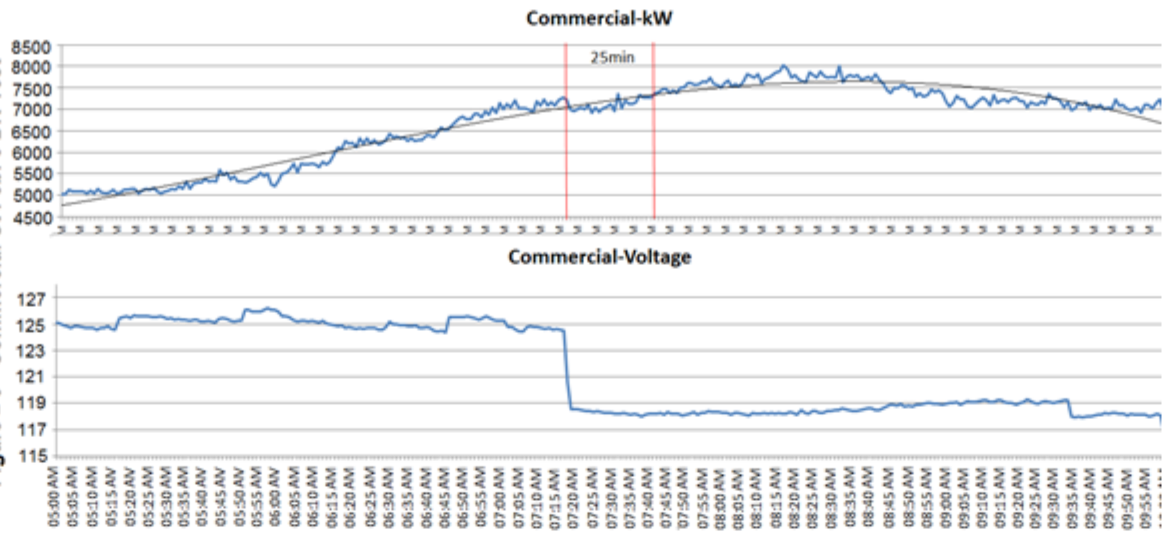


Figure D6 - Commercial St Feb. 5 DR Test

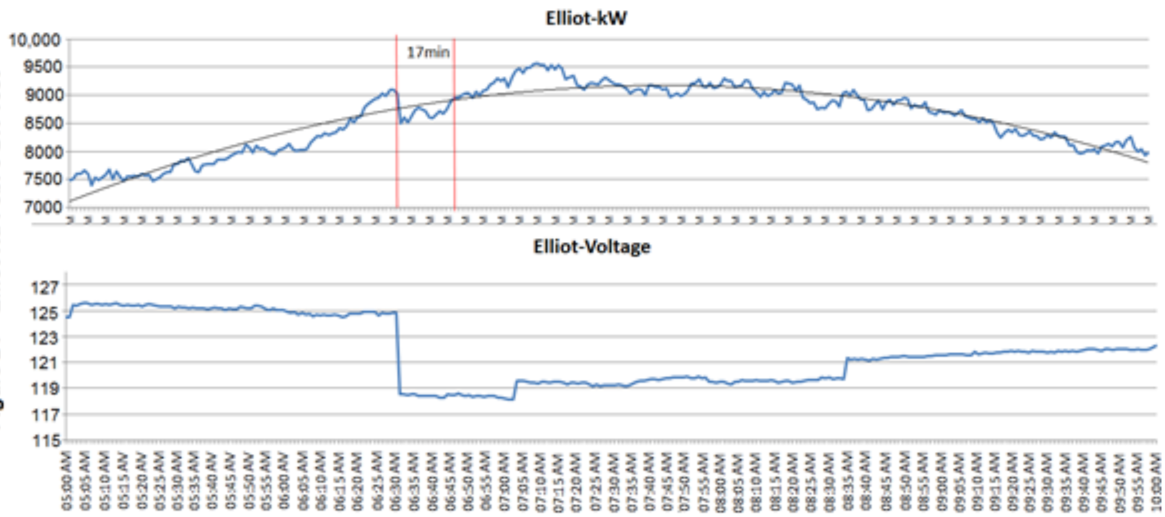


Figure D7 - Elliot Rd Feb. 3 DR Test

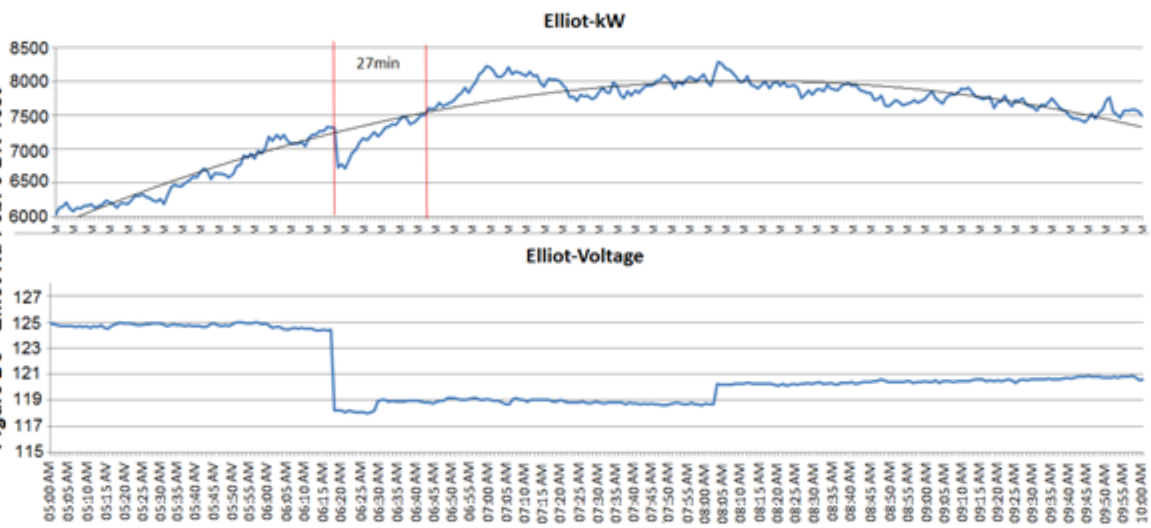


Figure D8 - Elliot Rd Feb. 5 DR Test

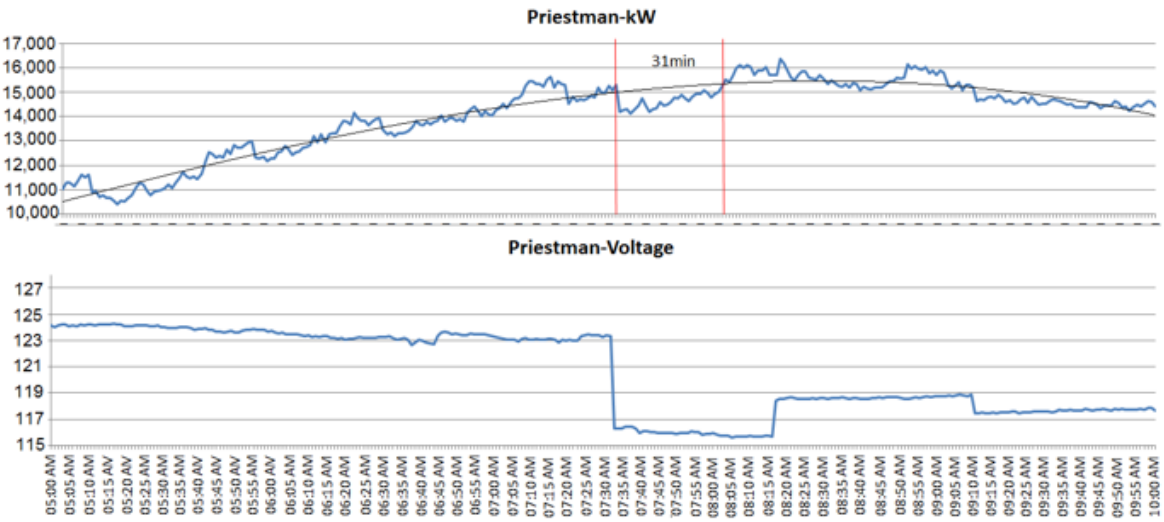


Figure D9 - Priestman St Feb. 3 DR Test

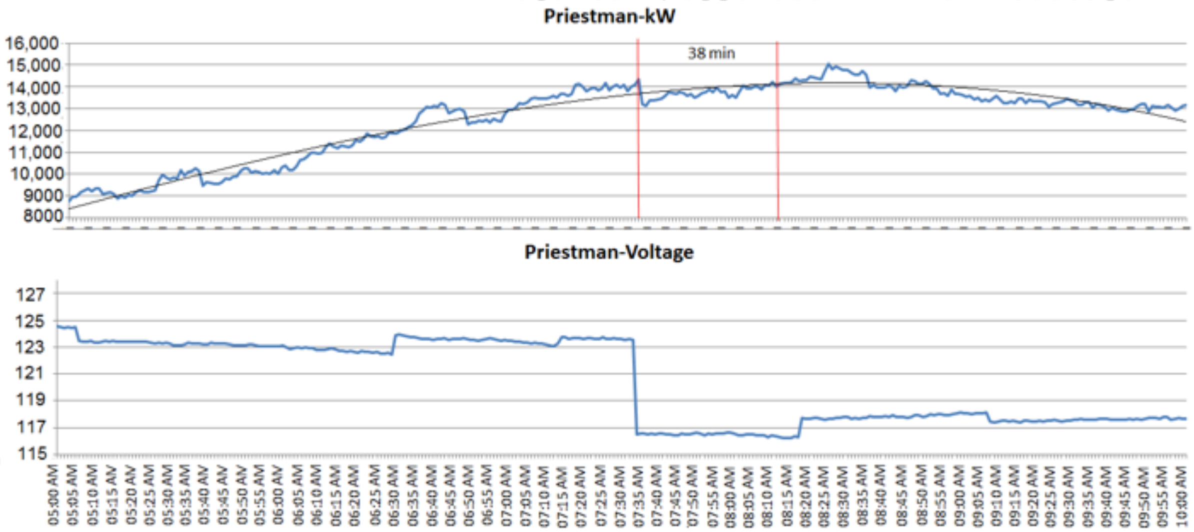


Figure D10 - Priestman St Feb. 4 DR Test

Appendix E – Additional Information on EDGE Validator Analysis

The **EDGE®** software suite that was used for CVR control has a built-in tool for calculating CVR savings, called **EDGE® VALIDATOR**. This tool was used as an alternate method for calculating the CVR factors and the associated savings.

The **EDGE® VALIDATOR** tool uses the following methodology:

Figure E.1: EDGE Validator Methodology

<u>Data Requirements</u>

EDGE® VALIDATOR uses 4 types of data for its analysis.

- Electrical observation data – *hourly substation-level power and voltage*
- Weather data – *hourly temperature, relative humidity, and user-selected variables for a weather station located near the node*
- CVR status data – *the CVR ON/OFF status, exported from* **EDGE® MANAGER**
- Customer count data – *the number of customers on the node at different historical dates, used to normalize load per customer as a method of incorporating new customer growth*

<u>Data Cleanup and Scrubbing</u>

Before importing the data into **EDGE® VALIDATOR**, quality control inspections were performed to ensure the data was in the required formats, no significant amounts of data were missing, duplicate data was not present, and all the required data elements were available. The data provided was formatted correctly then imported into **EDGE® VALIDATOR**.

Suspect data was examined and excluded from the pairing process.

The pairing process uses the *hourly index* to classify the 168 hours of the week based on their non-weather-driven loading characteristics. This eliminates the need for limiting pairing by weekday or weekend status. However, **EDGE® VALIDATOR** does exclude any holidays configured.

Calculations

EDGE® VALIDATOR calculates CVR factor using a process that pairs hours from the CVR ON period with hours from the CVR OFF period. The pairing compares the change in a number of measurements found to be significant in their effect on loading:

- Temperature
- Average temperature over the past 6 hours
- Average temperature over the past 72 hours
- Relative humidity
- Hourly index – *a factor calculated by Validator that measures NON-weather-related loading characteristics for each hour of the week, e.g. load at 10 p.m. on Thursday tends to be higher than weather characteristics would predict*
- Megawatts – *used to exclude pairs with large changes in load due to factor other than CVR (such as switching); normalized by customer count*
- Voltage – *used to ensure a minimum change in voltage, to avoid dividing by near-zero in the* CVR_f *equation*

For all parameters except voltage, the difference between the ON and OFF hours must be *less than or equal to* the configured value in order for the hours to form a pair. For voltage, the difference must be *greater than or equal to* the configured value.

EDGE® VALIDATOR compares every ON hour with every OFF hour, using the pairing parameters in the above list. All candidate pairs that fall within the parameter limits are given a pairing score, with smaller differences (more similar hours) receiving a higher score. **EDGE® VALIDATOR** then selects the pair with the highest score, adds that pair to its collection, and excludes all other candidate pairs that use the same ON and OFF hour as the selected pair. Then it proceeds to select the next highest score. In this way, **EDGE® VALIDATOR** will generate as many pairs as possible such that:

- All pairs meet the specified pairing parameters.
- Each hour belongs to only one pair.
- The highest-scoring pairs are selected first.

Because **EDGE® VALIDATOR** uses the highest score rather than a randomized pairing order, this method also ensures that the same pairing inputs will produce the same results every time the analysis is run.

Once **EDGE® VALIDATOR** has a collection of valid pairs, it will calculate the CVR factor for each pair by dividing the percent change in energy by the percent change in voltage.

$$\mathrm{CVR_f} = \frac{\%\Delta \mathrm{E}}{\%\Delta \mathrm{V}}$$

At this point, outlier pairs are removed from the population, based on the specified Outlier parameter, which uses the median absolute deviation (MAD). From this final population, the mean CVR factor is calculated and displayed in the **EDGE® VALIDATOR** user interface.

By convention in the statistics field, the minimum number of pairs required is 30, but in DVI's experience, the best results come with populations of nearly 100 pairs, or more. Having 100 pairs usually results in representation from all times of day. The standard deviation should not be much larger than the mean. The p-value is calculated to determine whether the difference in load between ON and OFF hours is significant; in this analysis the p-value was expected to be less than 0.05. If the p-value is out of bounds, the standard deviation is too large, or insufficient pairs were found, the analysis may be repeated with relaxed pairing parameters to generate more pairs and a more statistically sound result.

The megawatt filter excludes pairs with a large difference in power (typically > 5% difference), but since the M&V process is *looking for* a difference in power (energy savings), it has an asymmetric effect. Therefore, a calibrating CVR factor is specified for the pairing process, which adjusts the megawatt filter to be symmetrical around the change in power expected from that calibrating CVR_f. The methodology used here is to begin with a calibrating CVR_f of zero and to set the megawatt filter very wide at 30% and the outlier filter to 5 MAD. This initial pairing is considered round 1. The resulting median CVR_f is then used as the calibrating CVR_f in round 2. In addition, the megawatt filter is tightened to 5% and the outlier filter is tightened to 2 MAD. The resulting mean CVR_f from round 2 is used as the result of the pairing process.

In order to find an acceptable answer, at least one result must include at least 75 pairs with a standard deviation no more than double the mean CVR_f. If no answer is accepted, DVI will collaborate with the utility to apply additional statistical techniques in search of a statistically acceptable answer for CVR_f.

Appendix F – CVR Factor Comparison Plots by Season

These plots provide a graphical view of the comparison of the CVR factors and energy savings as calculated by the various methods outlined in this report for each season and substation.

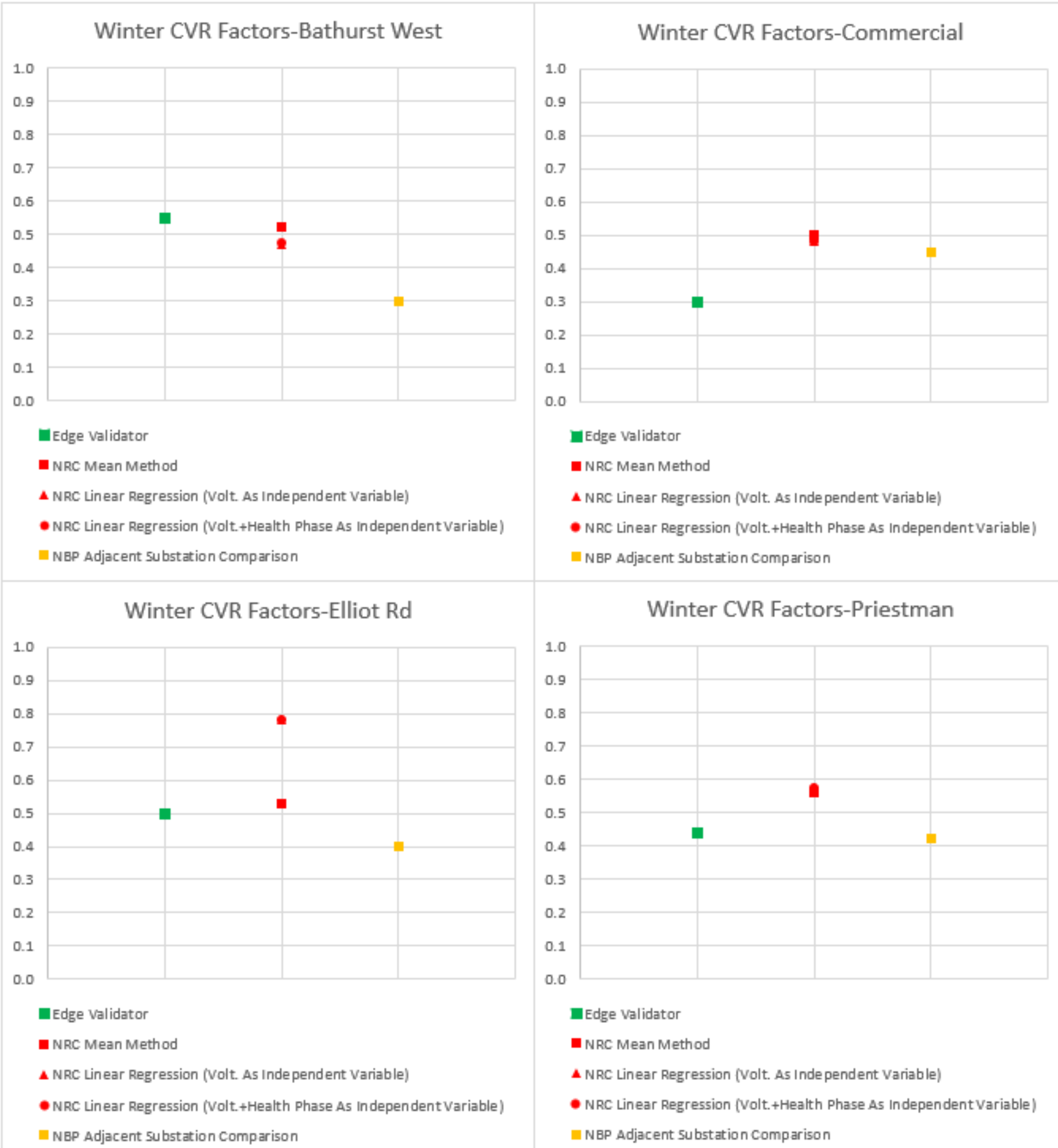


Figure F.1: Winter CVR Factor Calculation Method Comparison

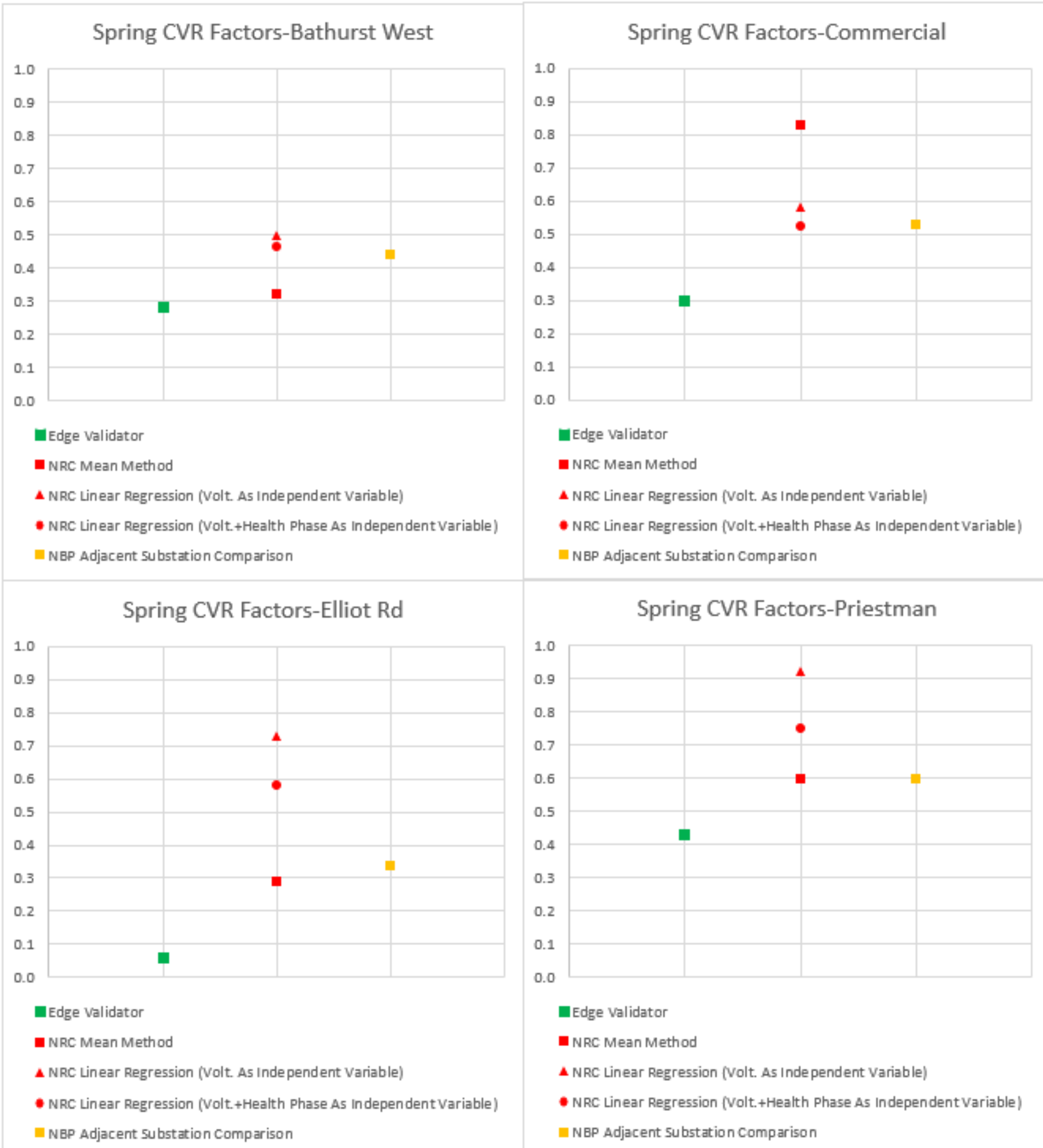


Figure F.2: Spring CVR Factor Calculation Method Comparison

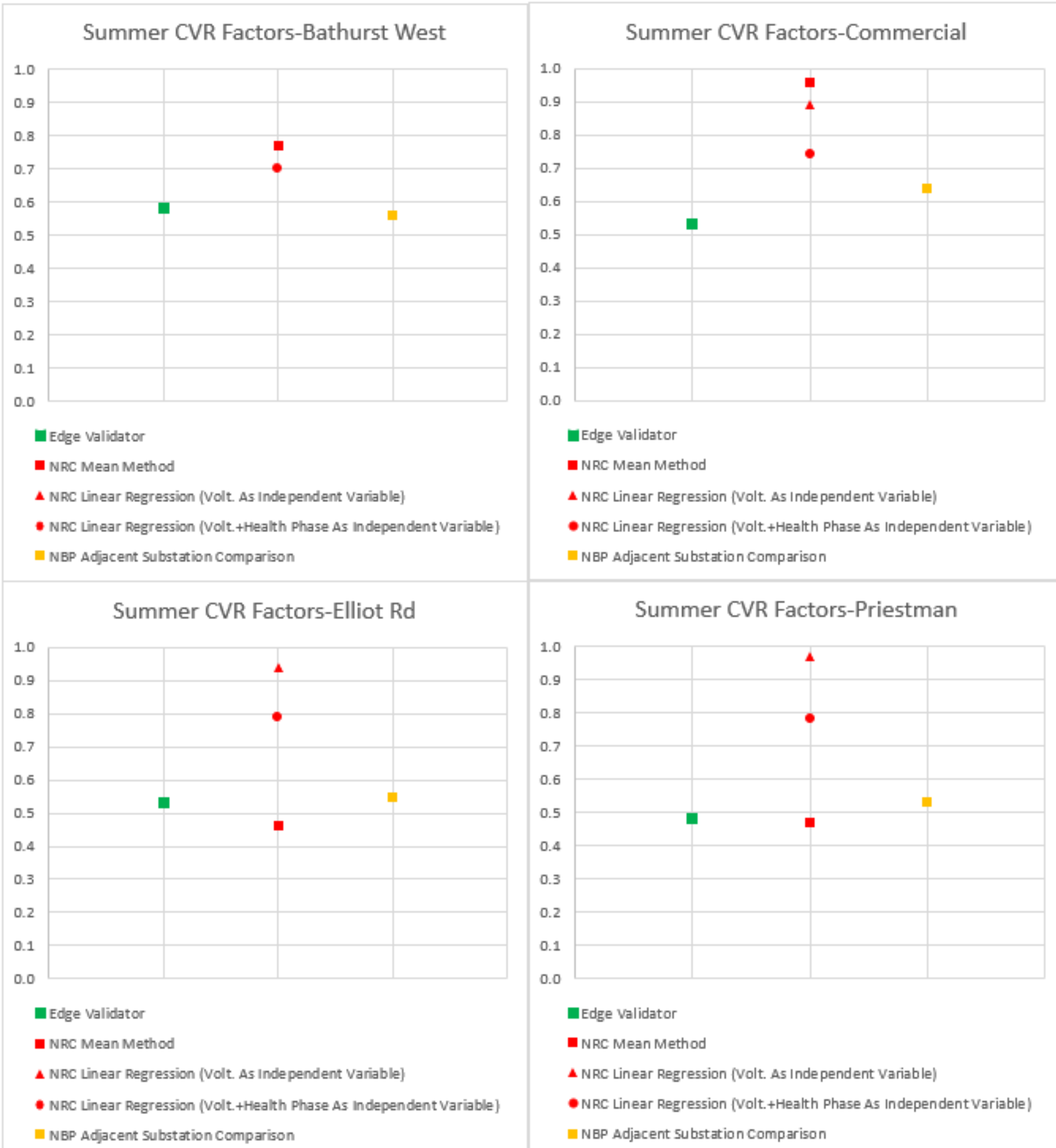


Figure F.3: Summer CVR Factor Calculation Method Comparison

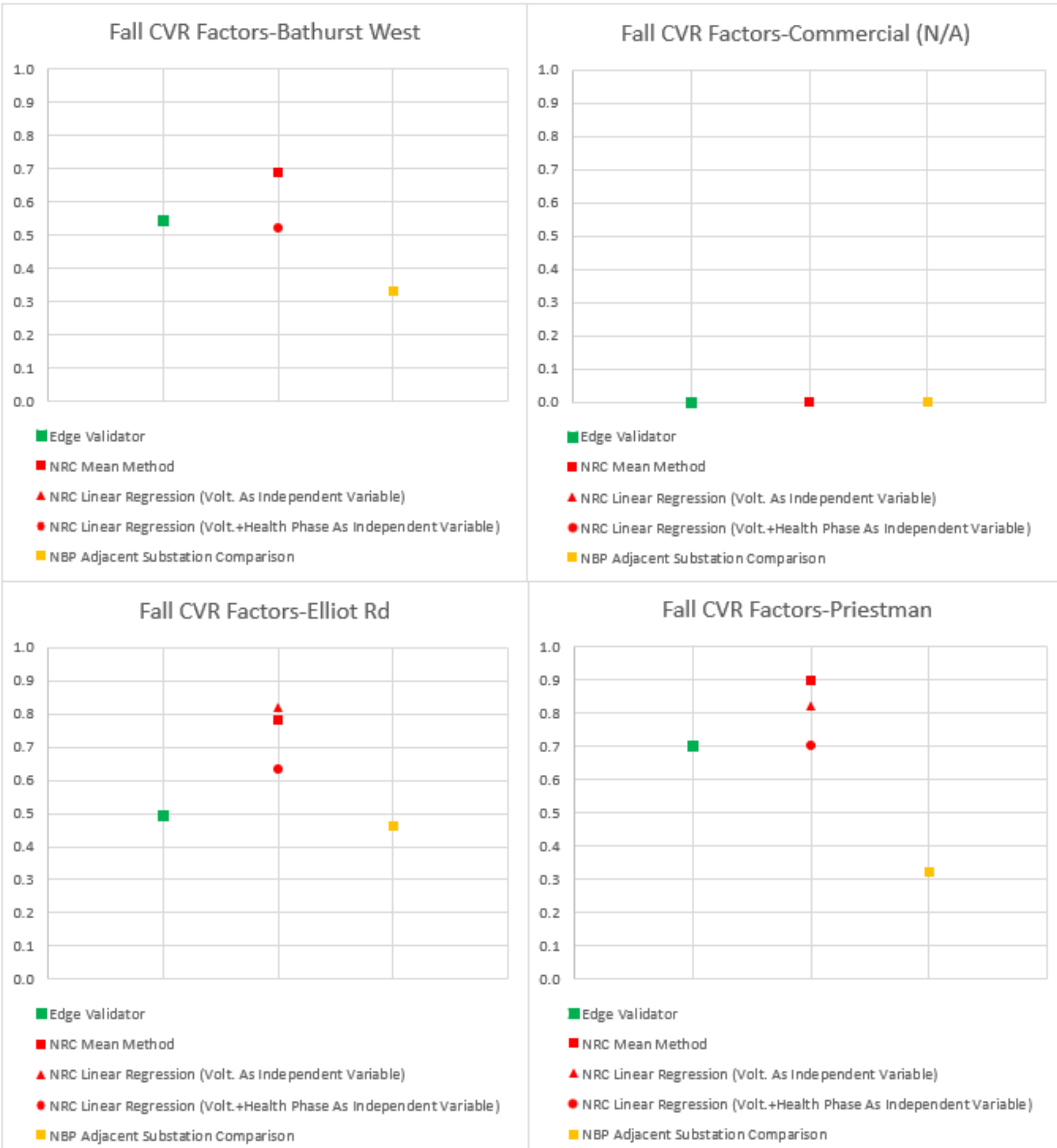


Figure F.4: Fall CVR Factor Calculation Method Comparison