November 30, 2011

Office of Electricity Delivery & Energy Reliability

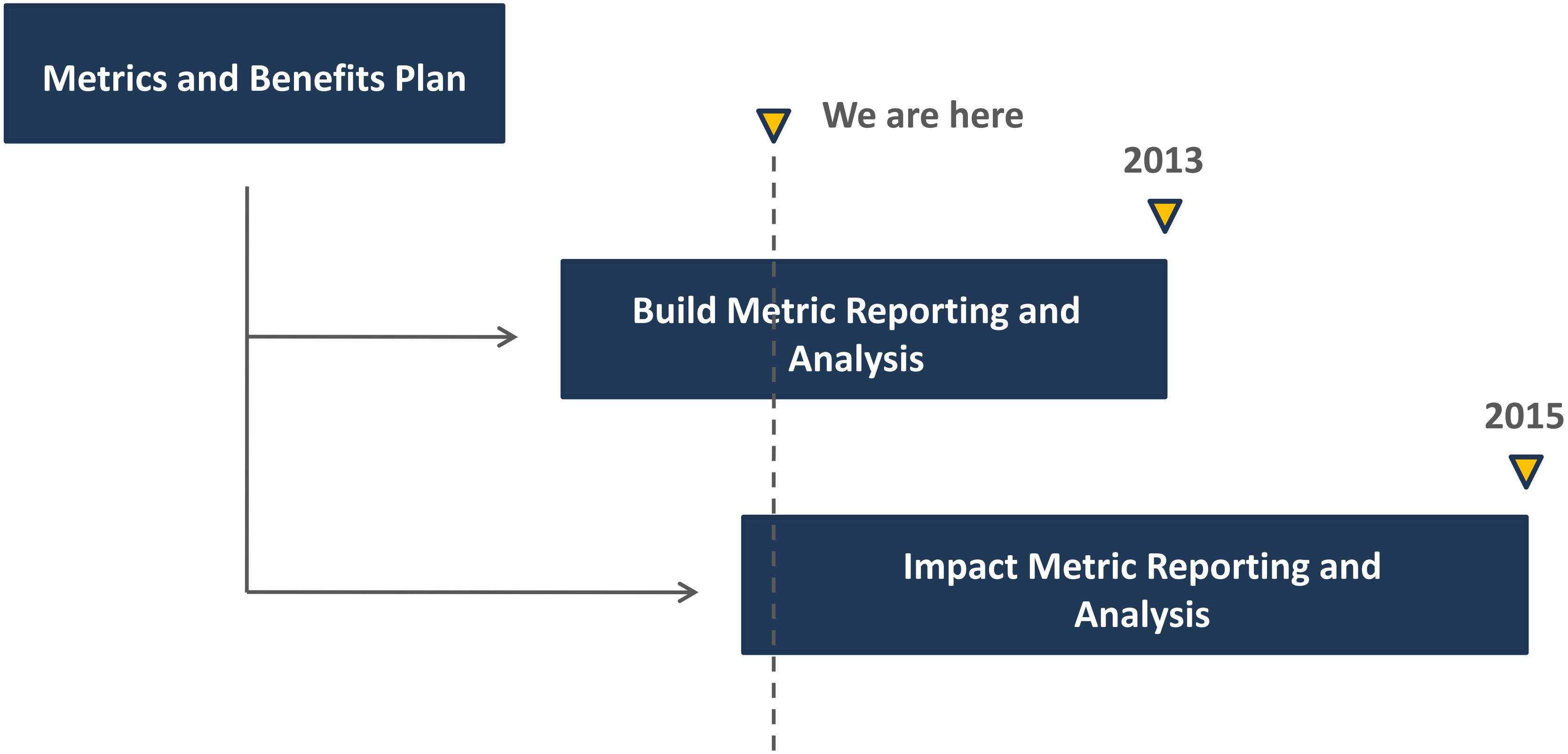
Energy Efficiency in Distribution Systems

DOE/Recipient Forum

SMARTGRID.GOV
RECOVERY ACT SMART GRID PROGRAMS

Introduction

The DOE Metrics and Benefits work is transitioning into the reporting and analysis of impact metrics. Build metric reporting and analysis will continue.



Metrics and Benefits Plan

We are here

2013

Build Metric Reporting and Analysis

2015

Impact Metric Reporting and Analysis

Six Primary Analysis Focus Areas

Today our discussion will focus on Energy Efficiency in Distribution Systems.

Peak Demand and Electricity Consumption

- Advanced Metering Infrastructure
- Pricing Programs and Customer Devices
- Direct Load Control

Operations and Maintenance Savings from Advanced Metering

- Meter Reading
- Service changes
- Outage management

Distribution System Reliability

- Feeder switching
- Monitoring and health sensors

Energy Efficiency in Distribution Systems

- Voltage optimization
- Conservation voltage reduction
- Line losses

Operations and Maintenance Savings from Distribution Automation

- Automated and remote operations
- Operational Efficiency

Transmission System Operations and Reliability

- Application of synchrophasor technology for wide area monitoring, visualization and control

DOE/Recipient Dialogue

DOE would like to establishing a forum to explore energy efficiency in distribution systems using voltage and VAR control technologies.

DOE's Interests	Recipients' Interests
1. Analysis Approach: Working through issues relating to measuring impacts a. Analytical methodology b. Baseline/control groups c. Underlying factors leading to results d. How to convey the results and to whom? 2. Lessons-Learned/Best-Practices: Internally and externally conveyed a. What can we learn from each other? b. How do we want to document lessons-learned and best practices for external communication? c. Are there detailed case studies that can be developed?	1. What would you like to address in a group setting? 2. What do you want to learn or share? 3. How would you like to exchange information? a. In smaller or more focused groups? b. How should we structure and support the discussion? 4. Are there issues you are NOT interested in addressing here?

DOE's Analysis Objectives

The Metrics and Benefits Team is trying to determine how voltage and VAR control assets can reduce distribution losses and end-use energy consumption.

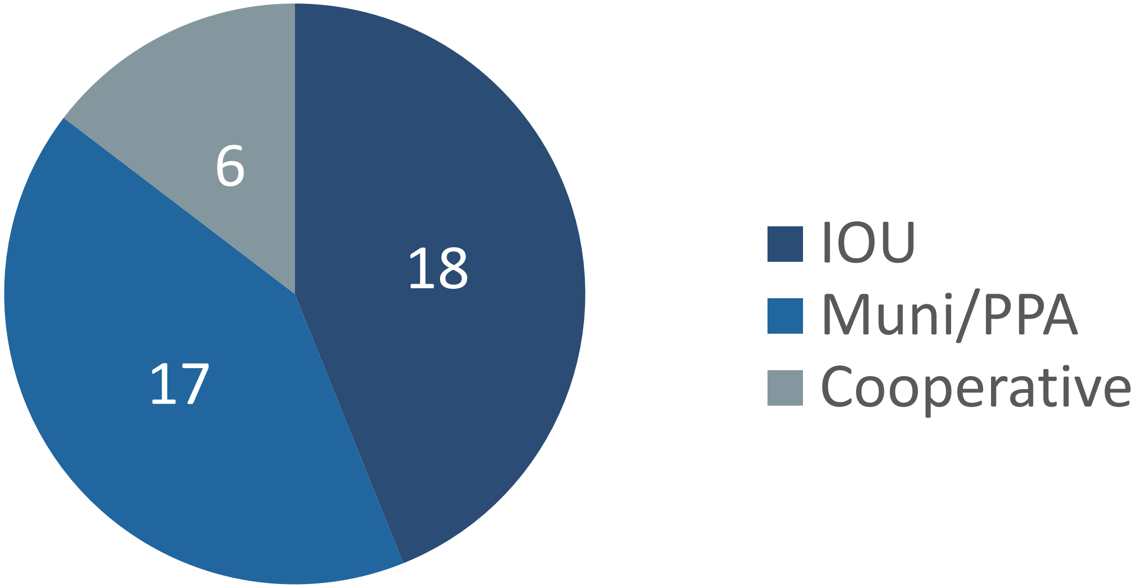
Analysis Objectives

- Determine the improvement in energy efficiency from the application of technology used to optimize circuit voltage and implement conservation voltage reduction.
- Determine what technology configurations are most important for delivering measurable results.
- Quantify the value of energy and capacity savings for utilities, electricity savings for customers, and lower emissions.

SGIG Projects

41 SGIG projects and several SGD projects include technology to control voltage and reactive power.

SGIG Projects Implementing
Voltage and VAR Control Functionality



Source: SGIG Build metrics and Navigant analysis

Technologies

Project teams are deploying a variety of different technologies.

Line voltage sensor

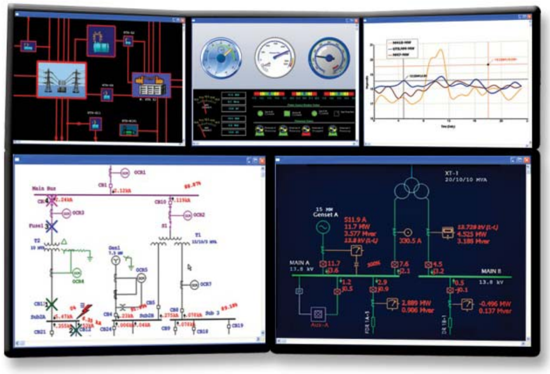
Automated Capacitor Bank

Control package

Smart meter

Automated Voltage Regulator

Distribution Management System



Applications for Distribution Energy Efficiency

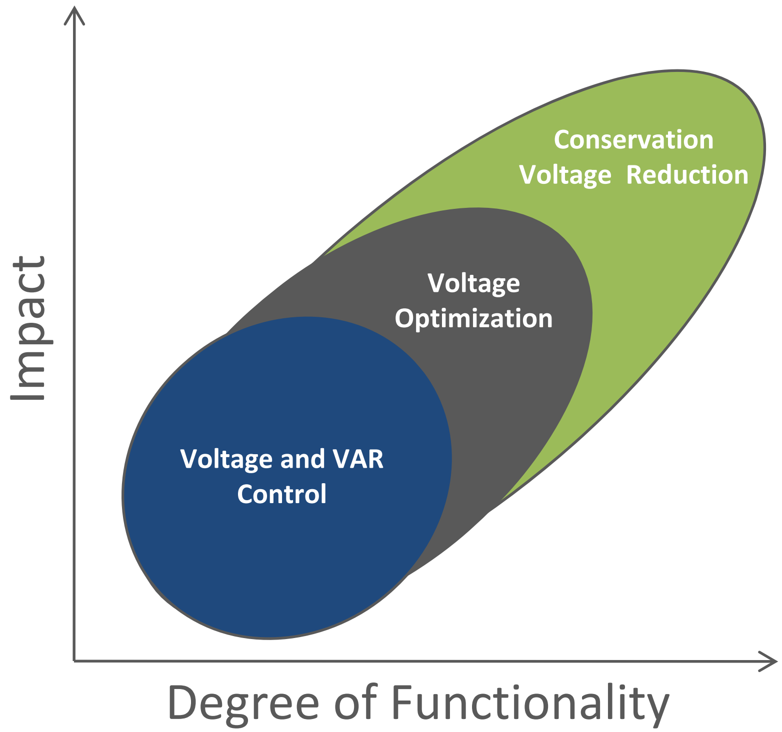
DOE has seen three general applications within projects that are conducting smart grid projects related to distribution energy efficiency.

Voltage and VAR Control (VVC)	Operating transformer load tap-changers, line voltage regulators and/or capacitor banks to adjust voltage along a distribution circuit and/or compensate load power factor.
Voltage Optimization (VO)	Coordinating VVC devices to achieve voltage profiles that meet the utility's operational objectives, including energy delivery efficiency, power quality, and reliability.
Conservation Voltage Reduction (CVR)	Utilizing VVC and VO functionality to lower distribution voltages for energy savings, without causing customer voltages to fall below minimum operating limits.

Functionality and Impact Hypothesis

Our hypothesis is that relative benefits will increase with higher functionality from voltage and VAR control technologies and applications.

Hypothesis…



Applications/Functionality	SGIG Projects
Voltage and VAR Control	17
Voltage Optimization	11
Voltage Optimization and CVR	13
Total	41

Source: SGIG Proposals, MBRPs Build metrics and Navigant analysis

Do you agree with this general characterization and approach?

Build and Impact Metrics

Build and Impact metrics will track the deployment of technology and how it affects distribution load and energy efficiency.

Build Metrics (Technologies)

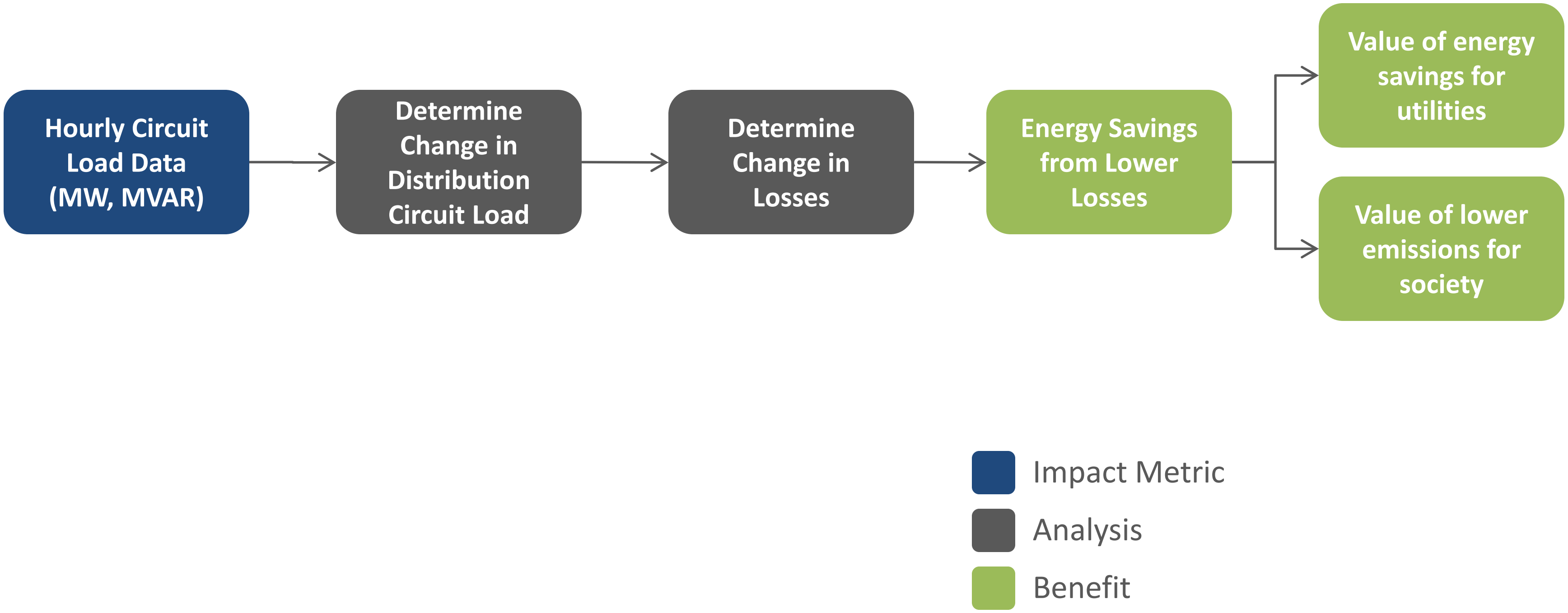
- Automated capacitors
- Automated regulators
- Distribution circuit monitors or SCADA
- Distribution Management Systems (DMS)
- DMS integration with Advanced Metering Infrastructure
- Others
    - CVR algorithms
    - Load balancing
    - Reconductoring

Impact Metrics

- Distribution feeder load (hourly and/or average)
- Distribution power factor (hourly and/or average)
- Distribution losses (average/peak, % of load, or MWh for reporting period)
- Emissions reductions from energy savings
- Energy savings from CVR

Logic for Analyzing Losses

Analyzing the change in hourly circuit load can contribute to determining how much energy is saved by reducing distribution losses.



Hourly Circuit Load Data (MW, MVAR)

Determine Change in Distribution Circuit Load

Determine Change in Losses

Energy Savings from Lower Losses

Value of energy savings for utilities

Value of lower emissions for society

🟦 Impact Metric

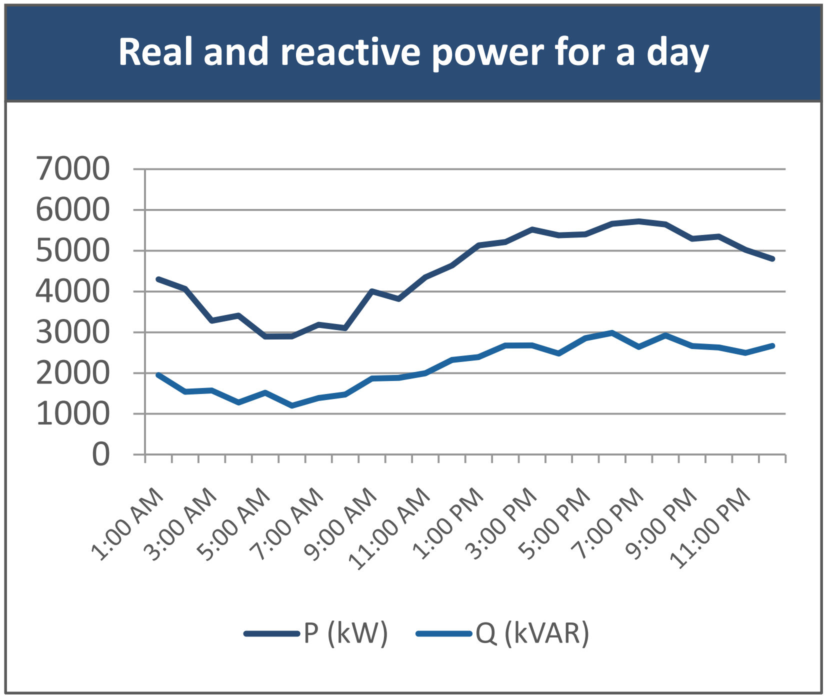
⬛ Analysis

🟩 Benefit

Hourly Circuit Load Data

Many projects are reporting hourly circuit data for real and reactive power, and this data can be used to determine other parameters.

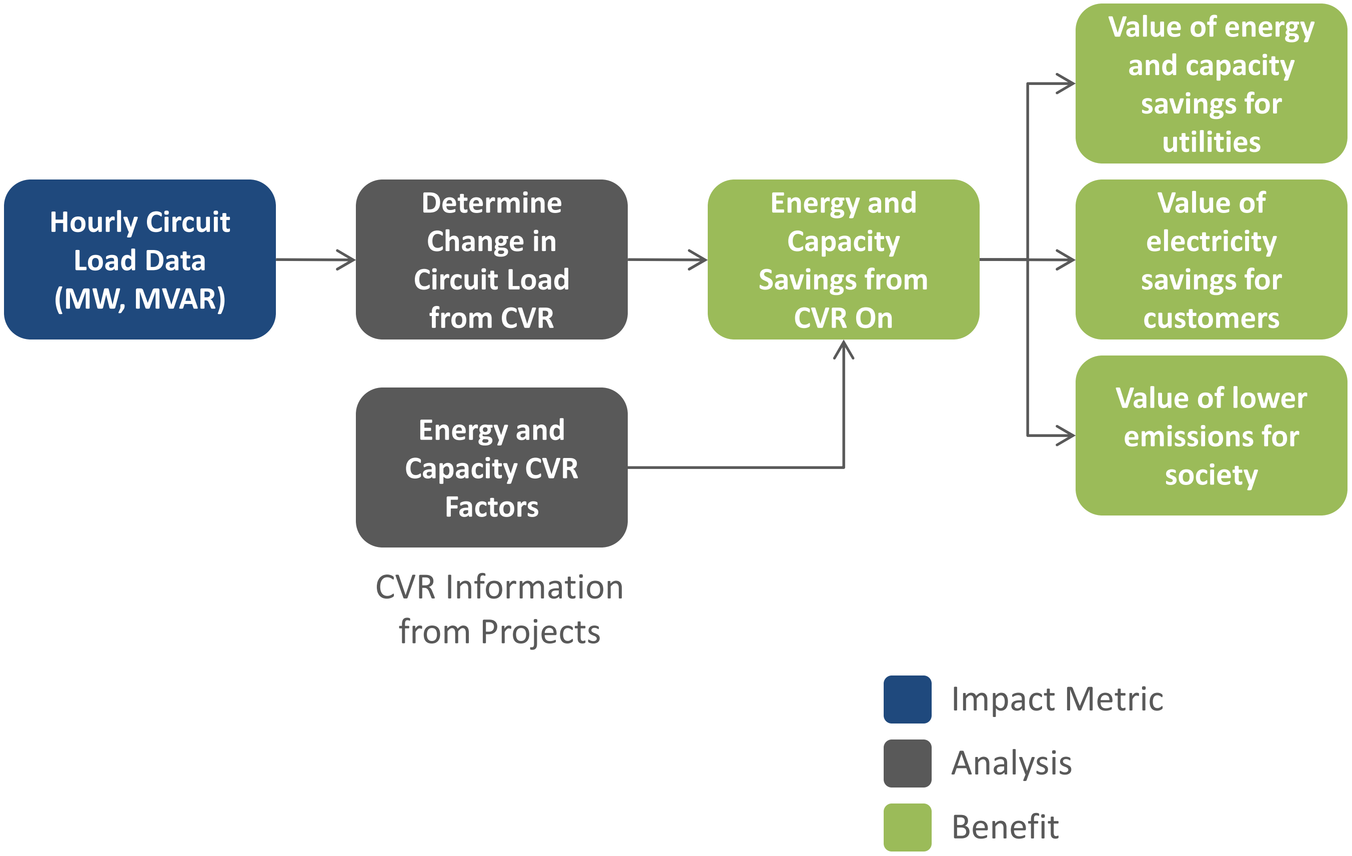
Time	P (kW)	Q (kVAR)
1:00 AM	4298	1949
2:00 AM	4061	1542
3:00 AM	3284	1574
4:00 AM	3408	1277
5:00 AM	2896	1519
6:00 AM	2900	1200
7:00 AM	3185	1388
8:00 AM	3103	1476
9:00 AM	4006	1868
10:00 AM	3817	1884
11:00 AM	4351	1997
12:00 PM	4635	2323
1:00 PM	5129	2390
2:00 PM	5213	2673
3:00 PM	5517	2677
4:00 PM	5378	2478
5:00 PM	5400	2855
6:00 PM	5658	2986
7:00 PM	5720	2638
8:00 PM	5643	2922
9:00 PM	5290	2664
10:00 PM	5346	2628
11:00 PM	5019	2496
12:00 AM	4801	2667


Real and reactive power for a day

Source: Illustrative results from Navigant analysis

Logic for Analyzing CVR

We will work closely with projects implementing CVR to determine how implementation is creating energy and capacity savings.



Hourly Circuit Load Data (MW, MVAR)

Determine Change in Circuit Load from CVR

Energy and Capacity CVR Factors

CVR Information from Projects

Energy and Capacity Savings from CVR On

Value of energy and capacity savings for utilities

Value of electricity savings for customers

Value of lower emissions for society

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Moving Forward

Additional Questions	Logistics
• What other kinds of impacts are project teams expecting, and how should we be looking for them in the metrics data? • What other kinds of data or information can be shared to help the group understand impact? • How are utilities operating the voltage and VAR control equipment and systems, and how can that shared? • How are baselines and control group circuits being established? • How might circuit topology and configuration affect results? • What kinds of “experiments” can the forum projects perform together?	• What type of format should we use for future meetings? • Who should participate in these meetings? • What type of schedule should we follow? • Suggested topics for the next discussion?

Appendix

Lower Losses
Benefits Logic

Analyzing the change in hourly circuit load can contribute to determining how much energy is saved by reducing distribution losses.

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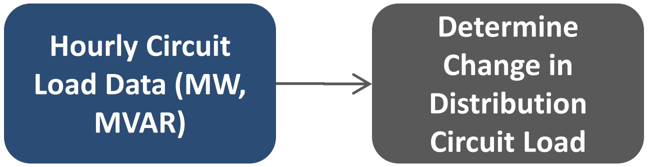
⬛ Analysis

🟩 Benefit

Lower Losses
Hourly Circuit Load Data

Many projects are reporting hourly circuit data for real and reactive power, and this data can be used to determine other parameters.


Hourly Circuit Load Data (MW, MVAR)

Determine Change in Distribution Circuit Load

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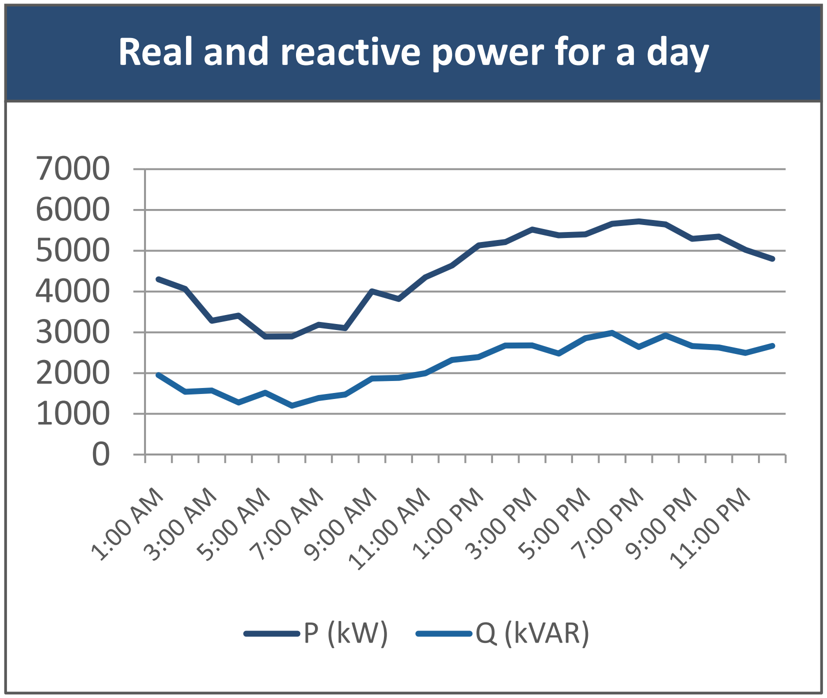


Source: Illustrative results from Navigant analysis

Lower Losses
The Meaning of Line Losses

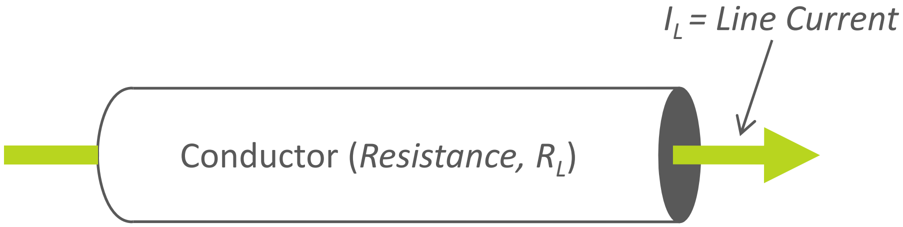
Energy is wasted as electricity flows through distribution lines. This wasted energy is known as “line losses”.

Determine Change in Losses → **Energy Savings from Lower Losses**

Modern overhead distribution conductor is typically made of stranded aluminum wire, sometimes with a steel reinforcing core.

The resistance (R_L) of the conductor is about 0.3 ohms per mile, and decreases with cross sectional area.

As line current flows through the conductor, its resistance dissipates power in the form of “line losses”.

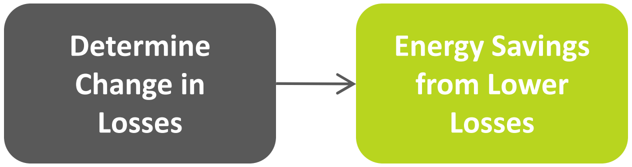


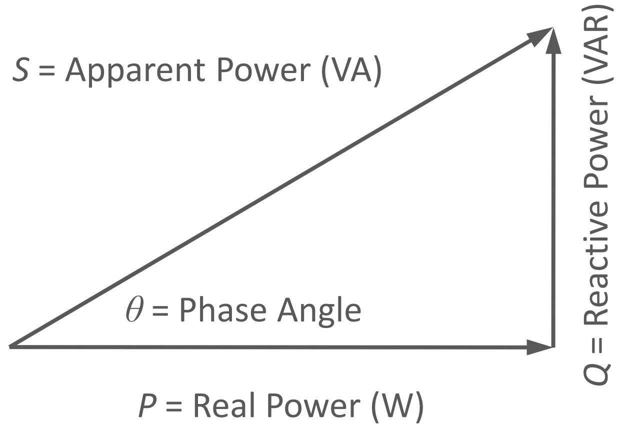
$$P_{line\ losses} = I_L^{\ 2} R_L \text{ watts}$$

Higher line current means higher line losses, and vice versa

Lower Losses
Energy Savings from P/Q Data

Hourly data for real and reactive power will determine hourly line losses, and the difference between baseline and impact losses yields energy savings.





$$S_{3\theta} = \sqrt{{P_{3\theta}}^2 + {Q_{3\theta}}^2} \text{ volt} - \text{amperes}$$

$$\text{power factor} = \cos^{-1}(\theta) = \frac{P_{3\theta}}{S_{3\theta}}$$

Some projects will be reporting hourly circuit load data for real (P) and reactive (Q) power. Using this information we will calculate hourly values for apparent power ($S_{3\theta}$) and power factor, and then calculate hourly line current (I_L):

$$I_L = \frac{S_{3\theta}}{\sqrt{3}V_{LL}} \text{ amperes}$$

With I_L and an assumption of distribution conductor resistance (R_L), we calculate hourly line losses ($P_{line\ losses}$):

$$P_{line\ losses} = {I_L}^2 R_L \text{ watts}$$

For each six-month reporting period (4380 hours) the total line losses per circuit or circuit group are:

$$Energy\ Savings = \sum_{n=1}^{4380} P_{baseline} - \sum_{n=1}^{4380} P_{project} \text{ watt-hours}$$

Lower Losses
Value of Benefits

The energy savings from lower distribution losses saves utilities money on wholesale energy, and reduces carbon emissions and their potential cost.

Energy Savings from Lower Losses

- **Value of energy savings for utilities**

$$Value\ (\$) = Energy\ \ Savings\ (MWh) \times Wholesale\ \ Energy\ \ Cost\ (\$ / MWh)$$

- **Value of lower emissions for society**

$$CO_2\ Emissions\ (tons) = Energy\ \ Savings\ (MWh) \times CO_2\ Emissions\ \ Factor\ \left({}^{tons}\!/_{MWh} \right)$$

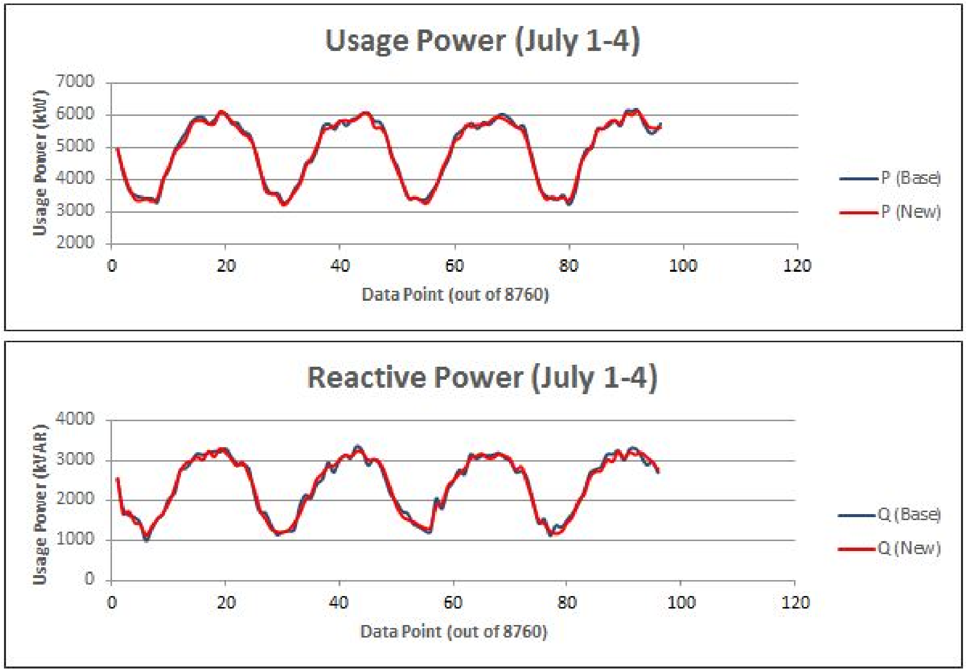
$$Value\ (\$) = CO_2\ Emissions\ (tons) \times CO_2\ Cost\ \left({}^{\$}\!/_{ton} \right)$$

Lower Losses
Example Analysis – Hourly P/Q Data

This project is seeking to improve distribution circuit voltage regulation and reduce losses.

Distribution automation project implementing better voltage regulation to improve power quality and reduce losses. This includes the coordinated operation of a voltage regulator with a transformer load-tap changer at a substation.

Reported hourly data for real and reactive power (four days in July)

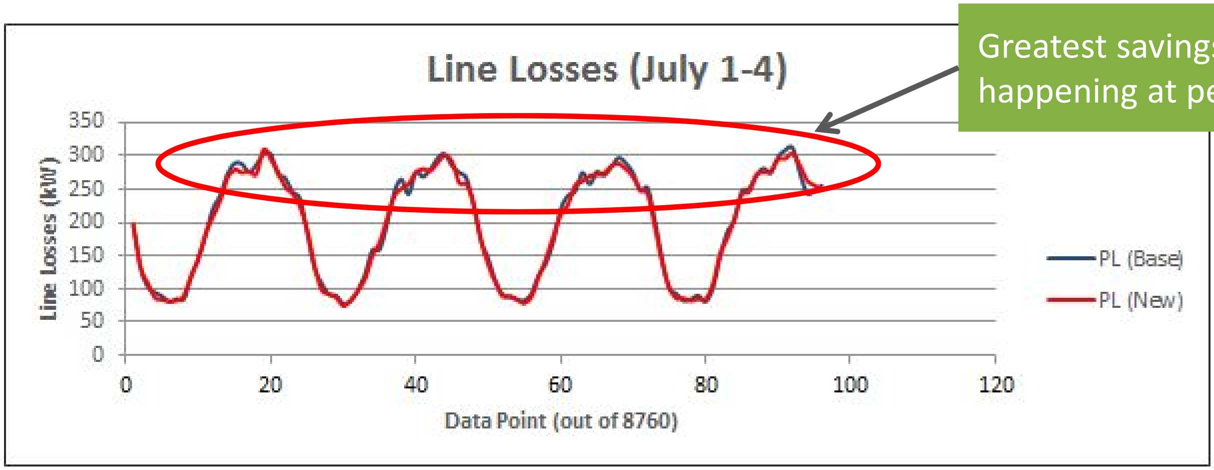


Source: Illustrative results from Navigant analysis

Lower Losses
Example Calculation of Losses Savings

This project was able to reduce line losses by about one percent over a year.

	SELECTED DATA (Jan 1 – Dec 31)					FULL YEAR DATA (Same)			
	Baseline	*New*		*Change*		*Baseline*	*New*		*Change*
Usage Energy	35712.1	35524.1	MWh	-0.5%		35712.1	35524.1	MWh	-0.5%
Reactive Power	17111.8	17094.5	MVARh	-0.1%		17111.8	17094.5	MVARh	-0.1%
Apparent Power	39654.8	39462.0	MVAh	-0.5%		39654.8	39462.0	MVAh	-0.5%
Avg Power Factor	0.904	0.903		0.0%		0.904	0.903		0.0%
Avg Current	209.0	208.0	A	-0.5%		209.0	208.0	A	-0.5%
Total Power Losses	1207.66	1195.50	MWh	-1.0%		1207.7	1195.5	MWh	-1.0%



Greatest savings happening at peak load

Source: Illustrative results from Navigant analysis

Lower Losses
Example Calculation of Monetary Value

Assuming average wholesale prices and a cost for CO2 emissions, the value of reducing losses by one percent is about $840 per year.

$$Value(\$) = Energy\ \ Savings\,(MWh) \times Wholesale\ \ Energy\ \ Cost\,(\$/MWh)$$

At average wholesale market price of $56 per MWh

$$Value(\$) = (1207.66 - 1195.50)\,MWh \times 56\,(\$/MWh)$$

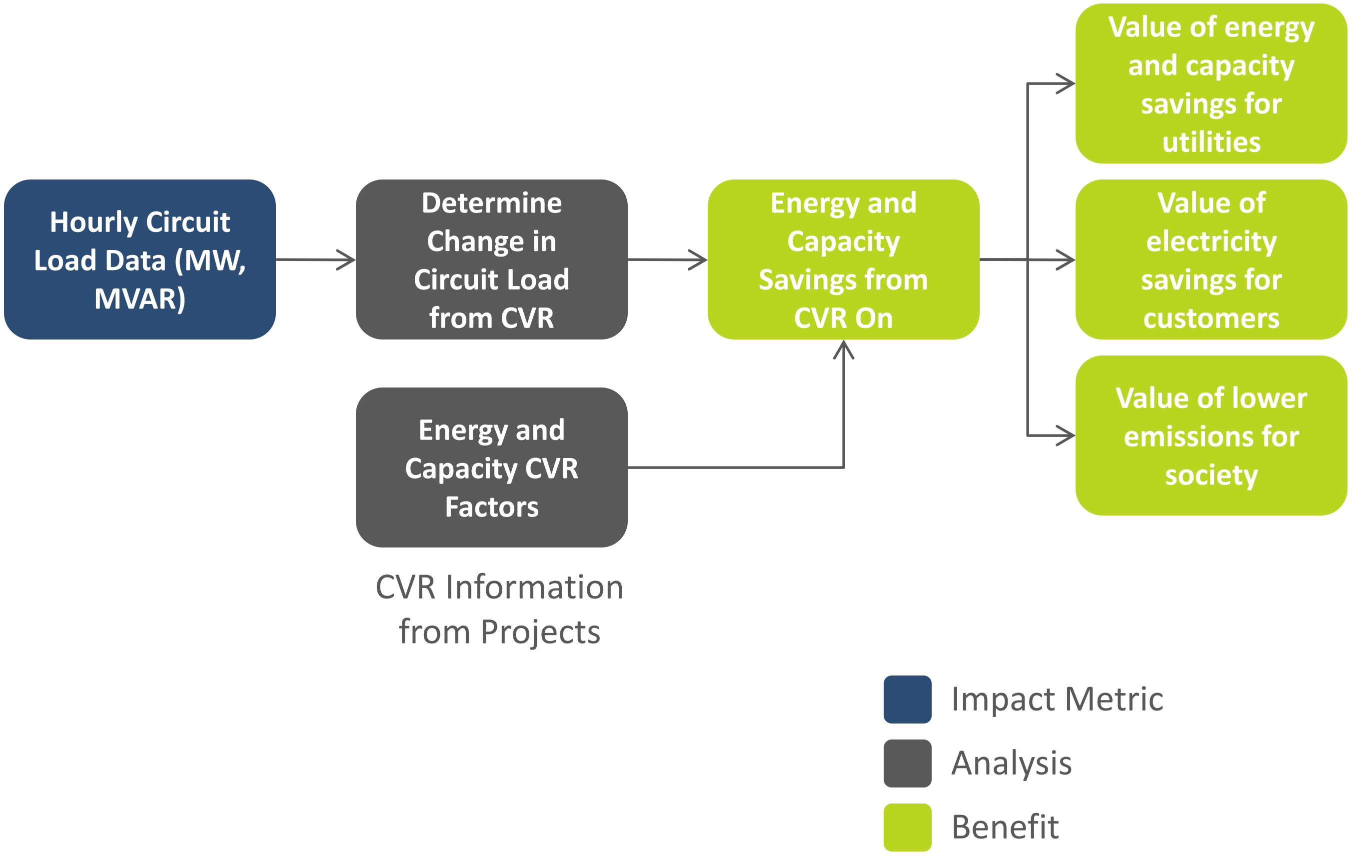
$$Value(\$) = \$680\ \text{ per circuit, per year}$$

Assuming 1.3 lbs/kWh for electricity generation and a price for CO_2 emissions of $20 per ton

$$Value(\$) = 1.3\,(lbs/kWh) \times 12{,}160\,(kWh) \times \frac{20(\$/ton)}{2000\,(lb/ton)} = \$158 \text{ per circuit, per year}$$

Savings from CVR Benefits Logic

We will work closely with projects implementing CVR to determine how its implementation creates energy and capacity savings.



Hourly Circuit Load Data (MW, MVAR)

Determine Change in Circuit Load from CVR

Energy and Capacity CVR Factors

CVR Information from Projects

Energy and Capacity Savings from CVR On

Value of energy and capacity savings for utilities

Value of electricity savings for customers

Value of lower emissions for society

🟦 Impact Metric

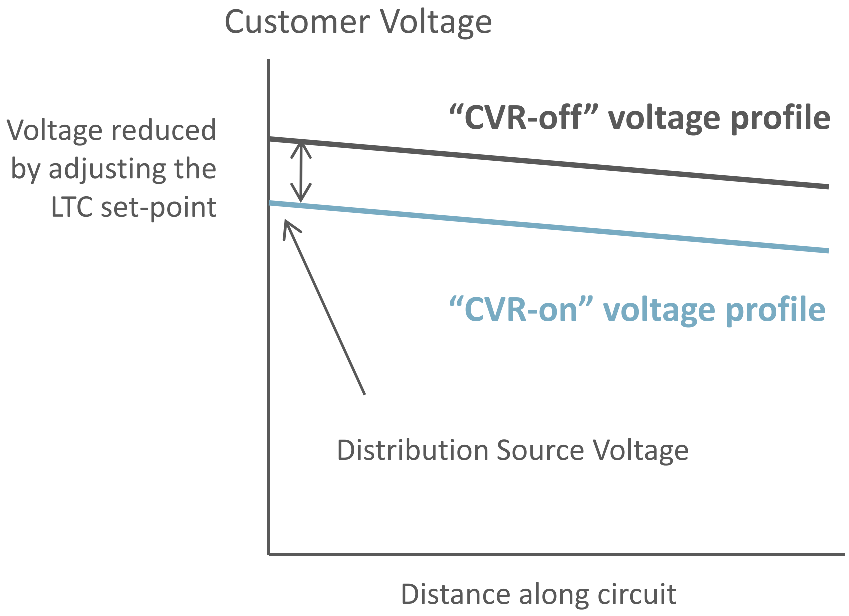
⬛ Analysis

🟩 Benefit

Savings from CVR
The Meaning of CVR

Conservation voltage reduction (CVR) reduces customer voltages along a distribution circuit to reduce electricity demand and energy consumption.

Energy and Capacity CVR Factors



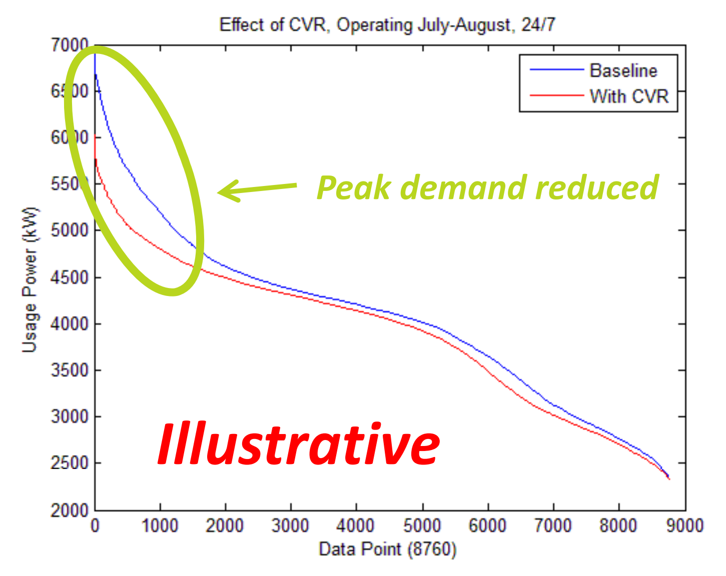
Studies dating back to the 1980s have shown that small reductions in distribution voltage can reduce electricity demand from customer equipment and save energy. This has become known as "conservation voltage reduction (CVR)".

Recent utility pilot programs have demonstrated that lowering distribution voltage by 1% can reduce demand and energy consumption by 1% or more.

Correlating CVR Results with Technology Configurations

By analyzing hourly load data and talking with utilities, we will try to correlate CVR factors with VVC technology configurations.

CVR reduces demand during peak load periods



Source: Illustrative results from Navigant analysis

Some projects who are pursuing CVR will be reporting hourly circuit load data. By analyzing this data we hope to determine how much demand and energy savings each project achieves with its technology configuration.

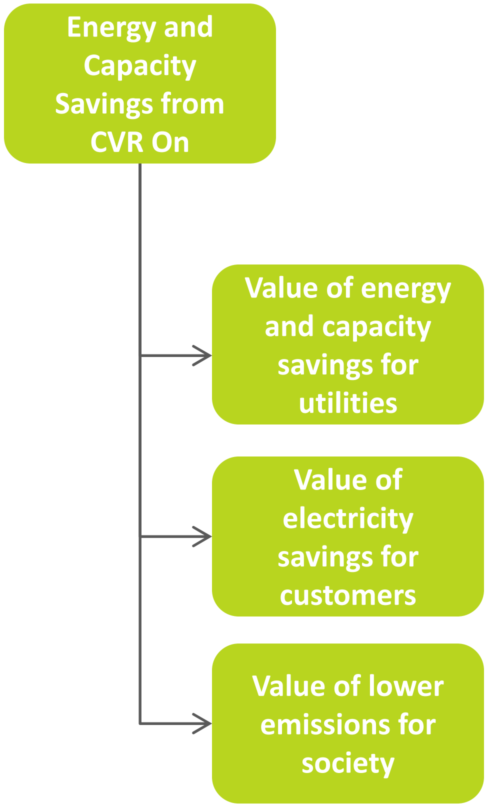
CVR Factor (*CVRf*)

$$CVRf = \frac{\Delta P}{\Delta V} \; watts/volt$$

We will work with project teams in the focus group to understand how much distribution voltage was reduced to achieve the reduction in load.

Savings from CVR
Value of Benefits

The energy savings from CVR saves utilities and their customers money on energy and capacity, and reduces carbon emissions.



Energy and Capacity Savings from CVR On

Value of energy and capacity savings for utilities

$$Value(\$) = Energy\ Savings(MWh) \times Wholesale\ Energy\ Cost(\$/MWh)$$

$$Value(\$) = Capacity\ Savings(MW) \times Wholesale\ Capacity\ Cost(\$/MW)$$

Value of electricity savings for customers

$$Value(\$) = Electricity\ Savings(kWh) \times Average\ Electricity\ Cost(\$/kWh)$$

Value of lower emissions for society

$$CO_2\ Emissions(tons) = Energy\ Savings(MWh) \times CO_2\ Emissions\ Factor\left({}^{tons}\!/_{MWh}\right)$$

$$Value(\$) = CO_2\ Emissions(tons) \times CO_2\ Cost\left({}^{\$}\!/_{ton}\right)$$

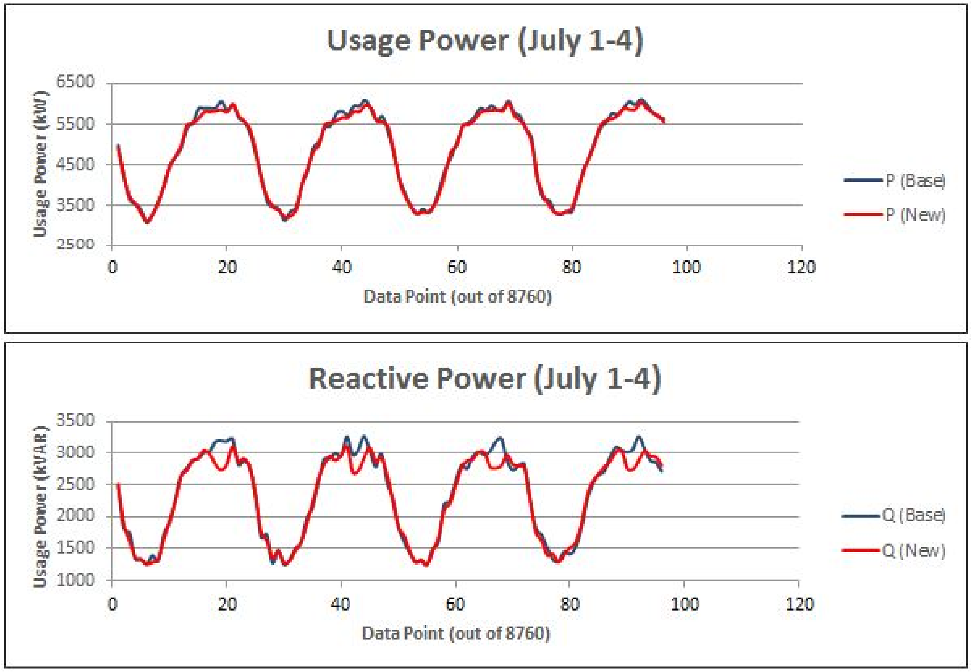
Savings from CVR
Example Analysis – Hourly P/Q Data

This project is seeking to reduce system peak demand with conservation voltage reduction during the summer.

Distribution automation project implementing conservation voltage reduction including the coordinated control of a capacitor bank with a transformer load-tap changer at a substation.

The CVR action was taken as a way to reduce system peak demand during high load periods in July and August.

Reported hourly data for real and reactive power (four peak demand days in July)

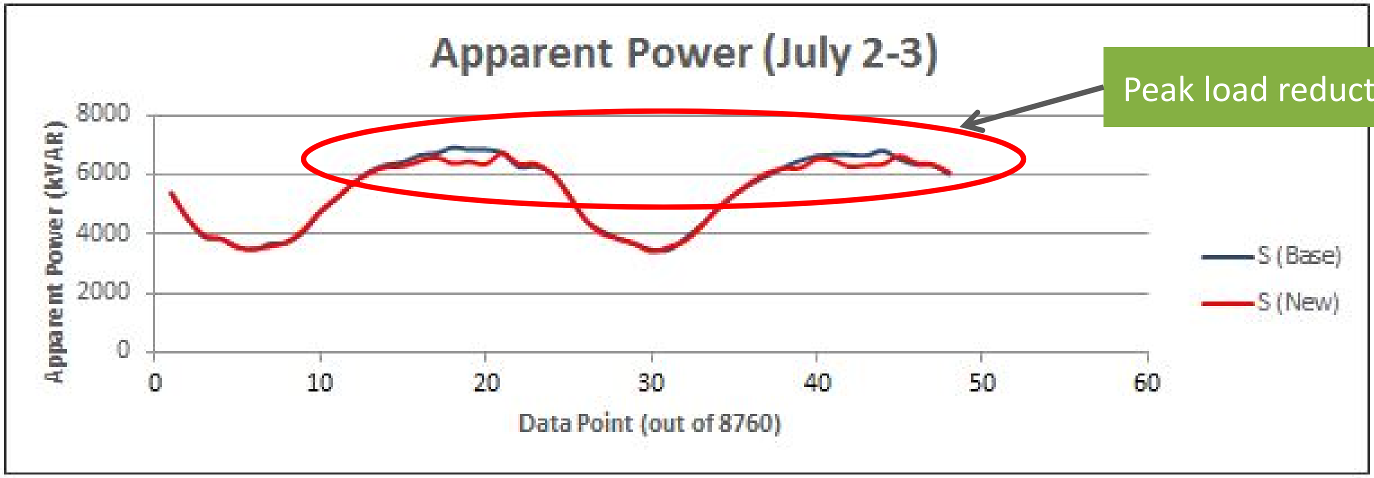


Source: Illustrative results from Navigant analysis

Example Calculation of Capacity Savings

This project achieved about a 2% reduction in demand by performing CVR during a peak period in July.

	SELECTED DATA (July 1-4, 3PM-9PM)			
	Baseline	*New*		*Change*
Usage Energy	5.841	5.770	MW	-1.2%
Reactive Power	3.092	2.891	MVAR	-6.5%
Apparent Power	6.610	6.456	MVA	-2.3%
Avg Power Factor	0.887	0.896		1.0%
Avg Current	304.6	295.4	A	-3.0%
Total Power Losses	280.2	267.1	kW	-4.7%



Peak load reduction

Source: Illustrative results from Navigant analysis

Savings from CVR
Example Analysis

Assuming peak wholesale prices the capacity value of CVR is worth over $15,000 per year, per circuit.

$$Value\,(\$) = Capacity\ \ Savings\ (MW) \times Wholesale\ \ Capacity\ \ Cost\ (\$/MW)$$

At peak whole sale prices

$$Value\,(\$) = (6.610 - 6.456)\ \ MW \times 100\ (\$/kW - yr) = \$15{,}400\ \ per\ year,\ per\ circuit$$

Assuming a large utility implements CVR on 25% of its 2000 circuits

$$Value\,(\$) = 15{,}400\ (\$/circuit) \times 500\ \ circuits\ = about\ \ \$8\ million\ \ per\ \ year$$