Targeted Application of STATCOM Technology in the Distribution Zone

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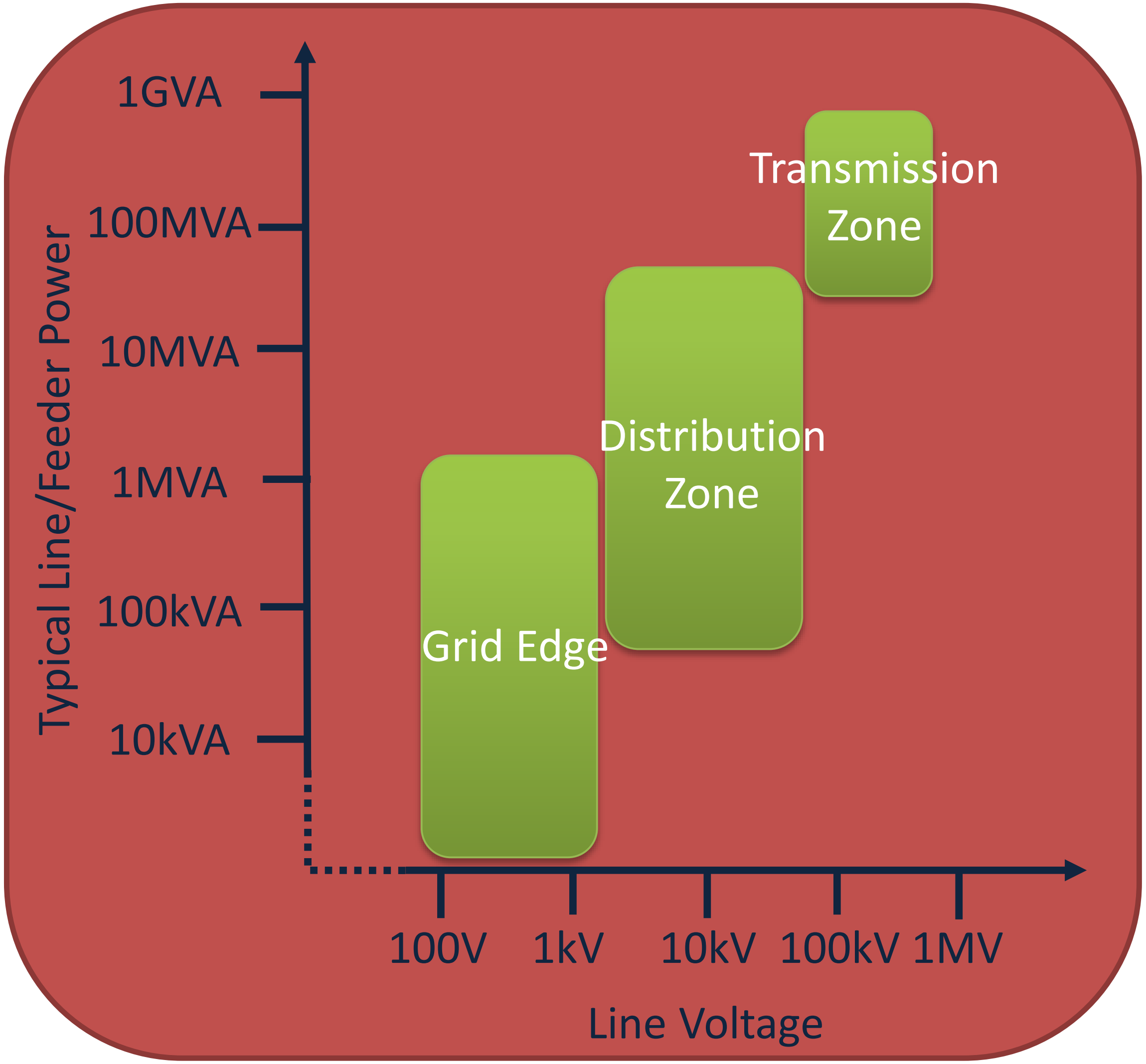
Outline

- Overview of Relevant Grid Compensation Areas and Technology
- Application of STATCOM in IEEE 34 Node Distribution Feeder
- Application of using Distributed STATCOMs in a Residential Feeder
- Advantages of Cascaded H-bridge vs Smart Inverter

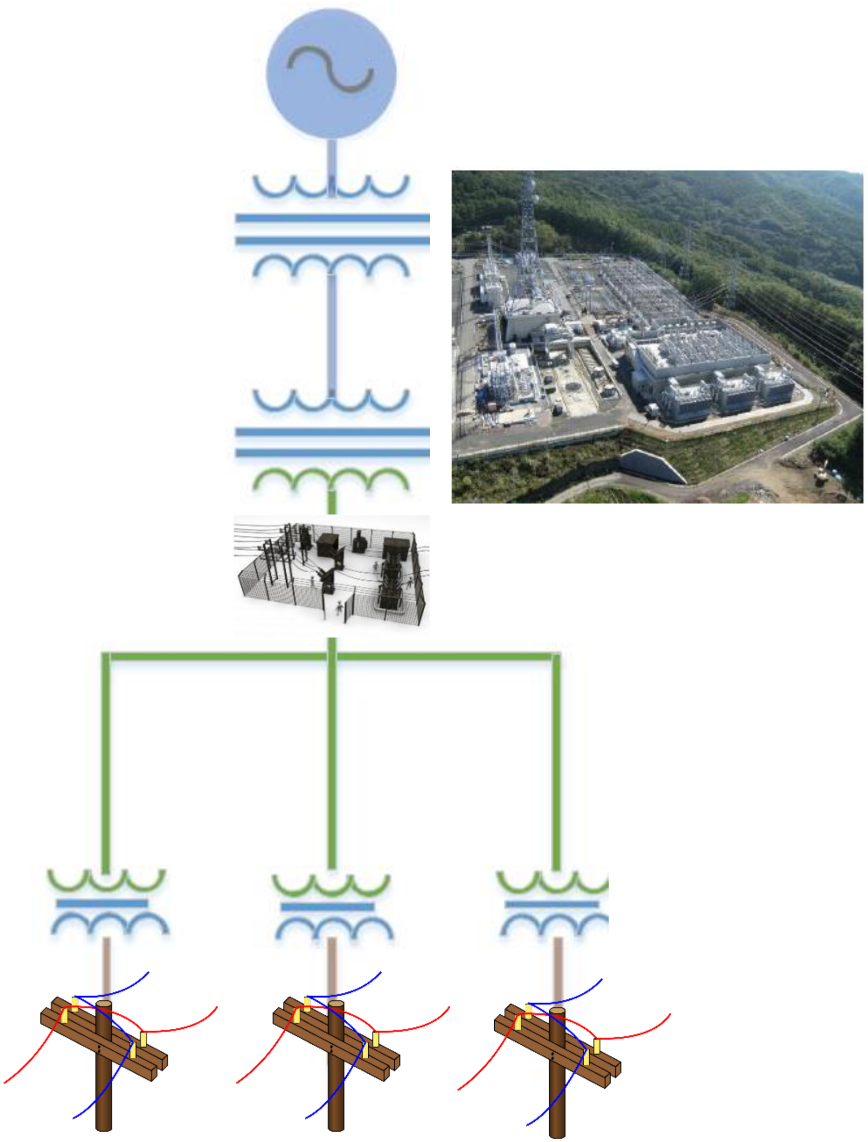
3 “Zones” of Delivery

for a greener tomorrow

Zone	Line Voltage	Description
Transmission	69kV - above	High power transmission prior to primary step down transformer
Distribution	4.76kV -69kV	Portion from secondary of step down transformer to service transformers
Grid Edge	4.76kV -below	Area of grid after step down transformers to home/consumers. Referring to pole mount service distribution



Current Power Quality Solutions



Simplified Power System One Line

Broken into 3 main zones for power quality management

1) Centralized Solution (Transmission Zone)

- STATCOM/SVC/Shunt Capacitor/Reactor solutions
- STATCOM closely coupled to Generator performance
- Voltage Support/Fault Recovery/Reactive Power Support
- Zone Overview
  - High Voltage/High Power between Generator/Step Up, and Step down transformer
  - Minimal nodes and branches

2) Distributed Solution (Distribution Zone)

- High concentration of voltage regulators, capacitor banks
- Minimal STATCOM products
- Zone Overview
  - High concentration area of distributed energy resources (DER)
  - Large number of nodes

3) Distributed Solution (Grid Edge)

- Zone Overview
  - Area after service transformers
  - 3 Phase, but often separated into 1 or 2 phases with unequal loading on each phase
  - Highest number of nodes
- Low power pole mount solutions
  - Peak Demand Management
  - Voltage Conservation

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Centralized and Edge Solutions

Centralized

- Centralized solution applied at transmission side, typically single STATCOM/SVC for entire transmission line
- Power Flow Support
- Generator Support
- Steady state instability issues
- Over voltage issues
- Utility scale installation and cost
- Large undertaking due to space and regulation requirements
- Slower response due to magnitude of equipment power

High Power Zone

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High Power Solution

Distributed Solution At the Grid Edge

- Typically Pole Mounted
- Single or Two Phase Solution
- Low power servicing a few loads, requiring high numbers for substantial impact
- Power Factor Control
- Volt/Var Optimization(VVO) (Typically 25kvar or less)
- Fast response for voltage stability
- Peak demand management
- Conservation Voltage Reduction (CVR)
- May delay conductoring 2-3 years
- Not for use in distributed generation voltage stability

Low Power Zone

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Low Power Solution

Application of Distribution STATCOM

- Distribution Zone typically less than 30MVA
- An opportunity exists to support high power distribution zone with a medium power solution (>500kvar)
- Implement advanced power electronics technology at distribution voltages, minimizing system current
- Interface directly at the same zone with utility DER
  - IEEE 1547 covers distributed energy resources up to 10MVA
  - Provide voltage stability at the source
- 3 phase solution, providing inductive and capacitive correction
- Cover total feeder length with VVO, CVR, and provide transient stability
- Smaller capacity system allows for single cycle or less response time
- Can replace or reduce need for traditional VVO/CVR equipment(Cap banks, LTCs, etc..)

High Power Zone

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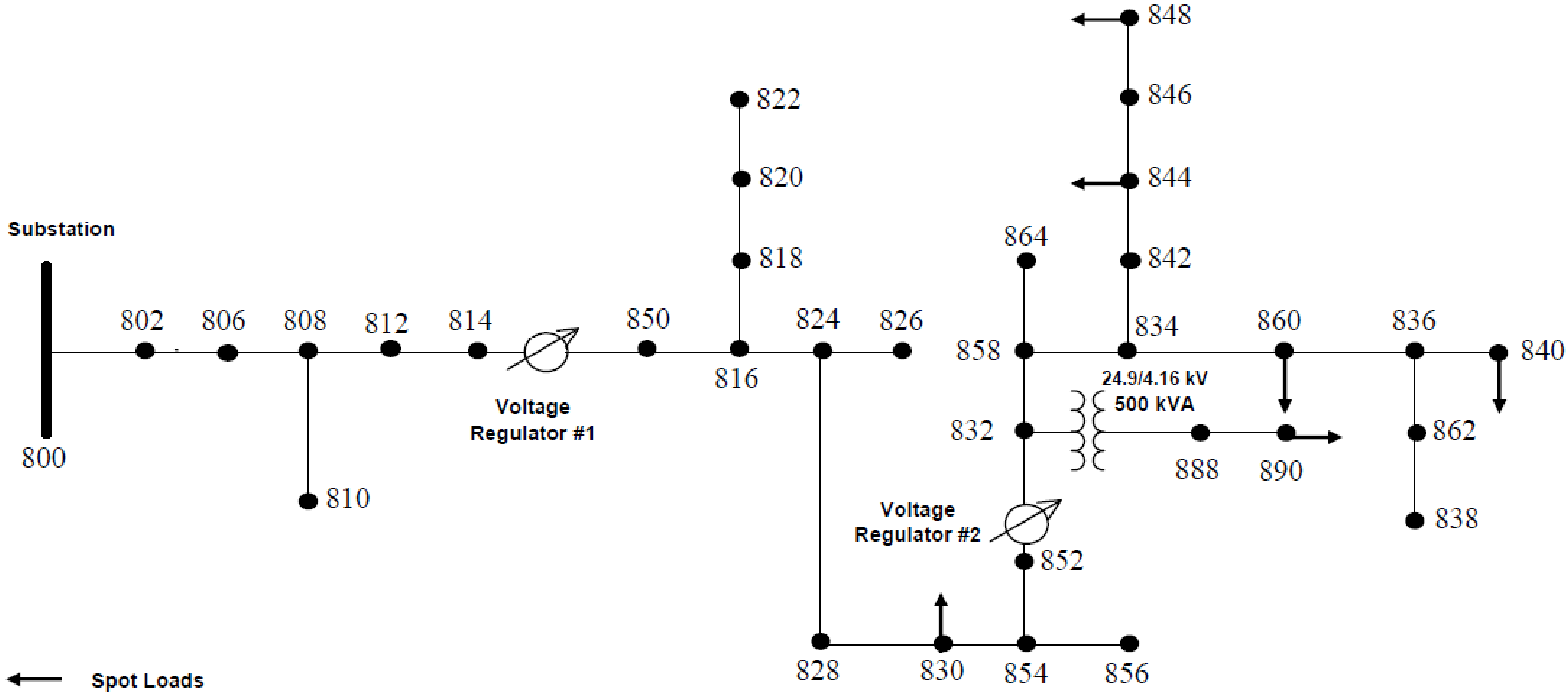
Medium Power Solution

IEEE 34 Feeder Study

- IEEE 34 node sample feeder study performed by MEPPI PSES
- Investigation of STATCOM operability at distribution level using medium sized building blocks in typical higher power feeder location
- 2.5 MVA substation with nominal operating voltage of 24.9kV
- 36 Mile feeder length
- Current traditional compensation techniques
  - Two in-line voltage regulators required to maintain acceptable voltage profile.
  - Two shunt capacitors are used to maintain an acceptable range for voltage profile
- Line Characteristics
  - An in-line transformer reduces the voltage to 4.16 kV for a short section of the feeder.
  - Unbalanced loading with both "spot" and "distributed" loads. Distributed loads are assumed to be connected at the center of the line segment.

IEEE Feeder Study

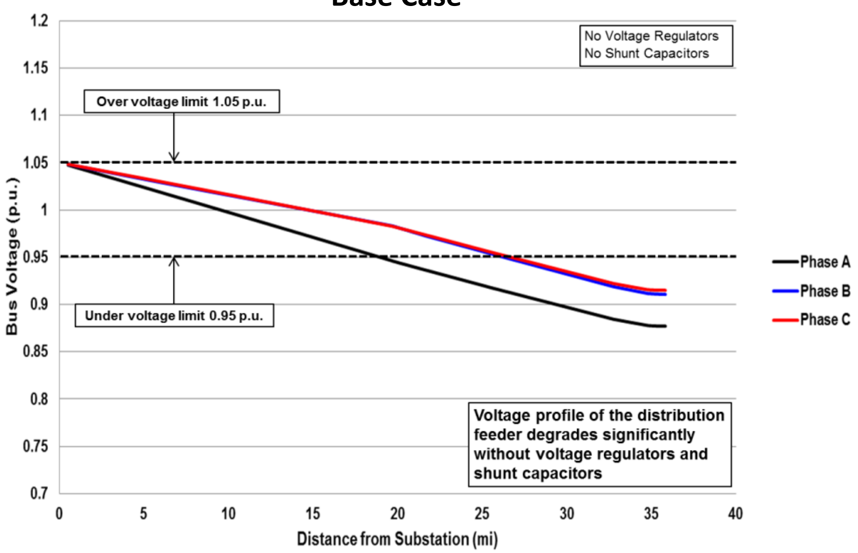


Sample Circuit -Published IEEE 34 Node Radial Distribution feeder based on data from test feeder in Arizona

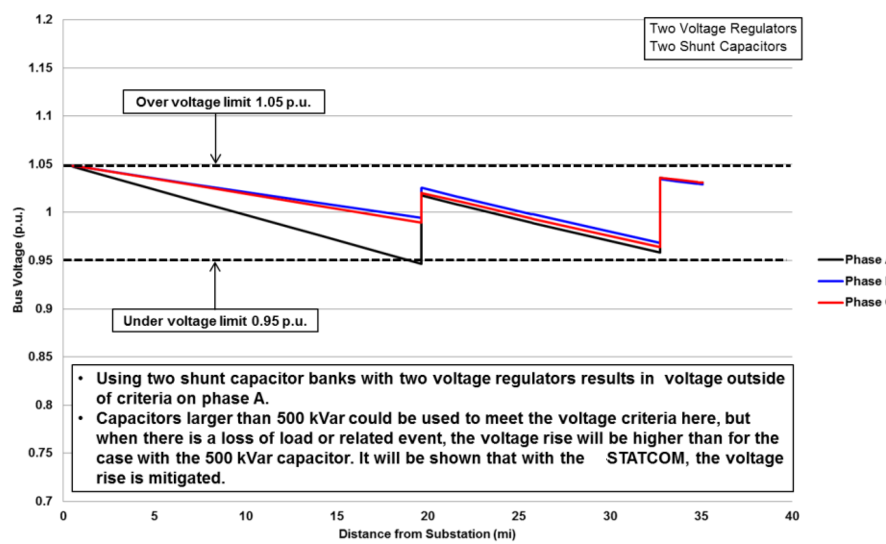
IEEE 34 Distribution Voltage Profile

- The voltage profile of a distribution feeder decreases as it extends away from the substation.
- Traditional voltage compensation techniques do not account for voltage increases along the feeder
- Low load conditions will result in voltages near the maximum acceptable range close to voltage regulation equipment
- The use of DERs will result in the voltage at the point of common coupling to rise and exceed the maximum voltage range.
- Dynamic reactive devices provide voltage support for feeder operation at various loading conditions to prevent voltage violations.

Base Case

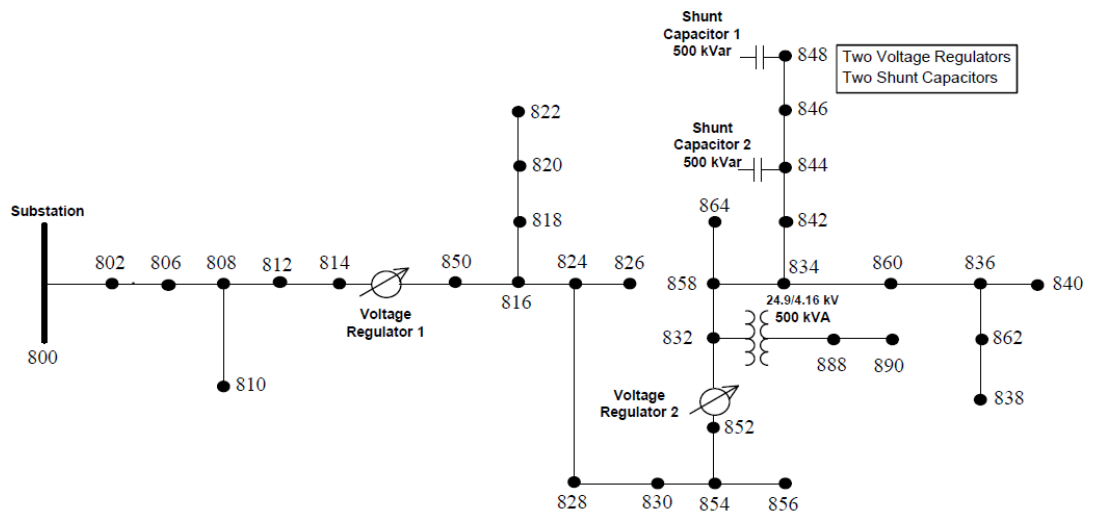


Traditional Methods

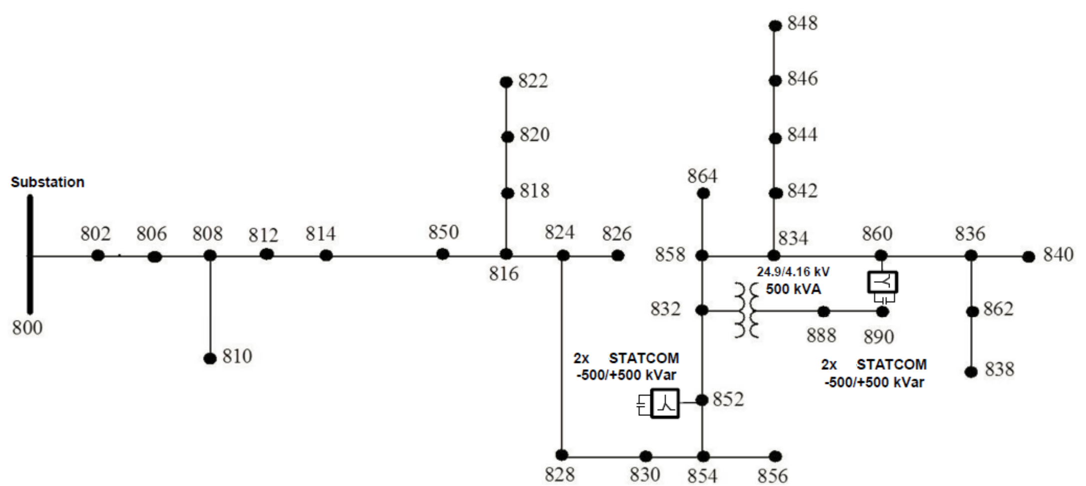


* Shunt Capacitor and Voltage Regulators

IEEE 34 Distribution Voltage Profile



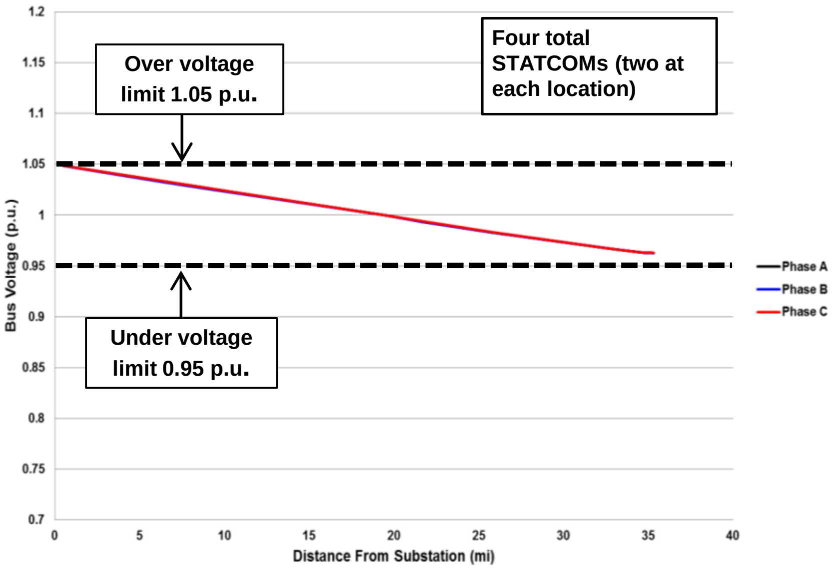
Shunt Capacitor Solution



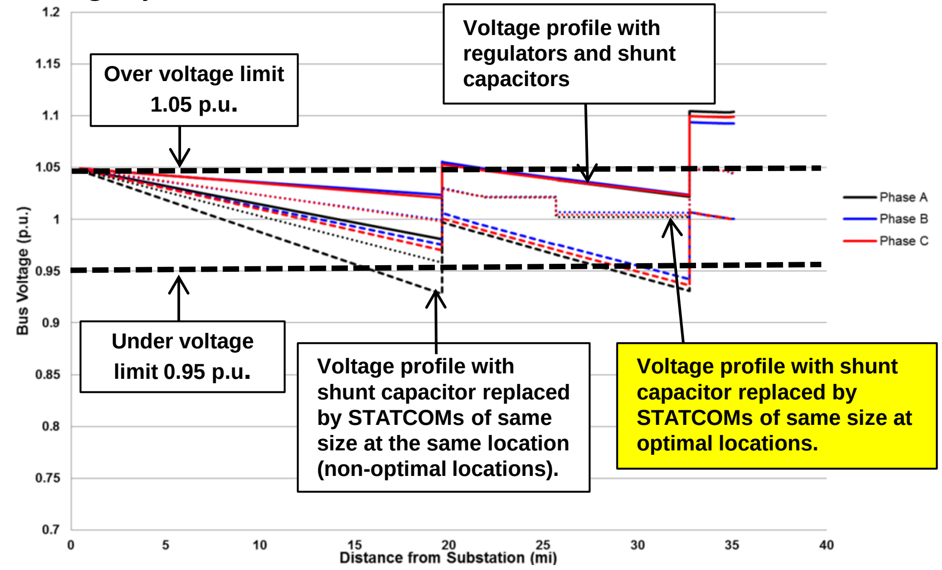
STATCOM Solution

IEEE 34 Distribution Voltage Profile

Distribution STATCOMs



Lightly Loaded Feeder: STATCOMs + Traditional Methods



Using STATCOMs exclusively improves the voltage profile of the distribution feeder. Note that the scheduled voltage at the substation is 1.05 p.u. As the distance increases, voltages along the nodes in the test feeder decreases, and slopes down near 0.95 p.u. at 35 miles.

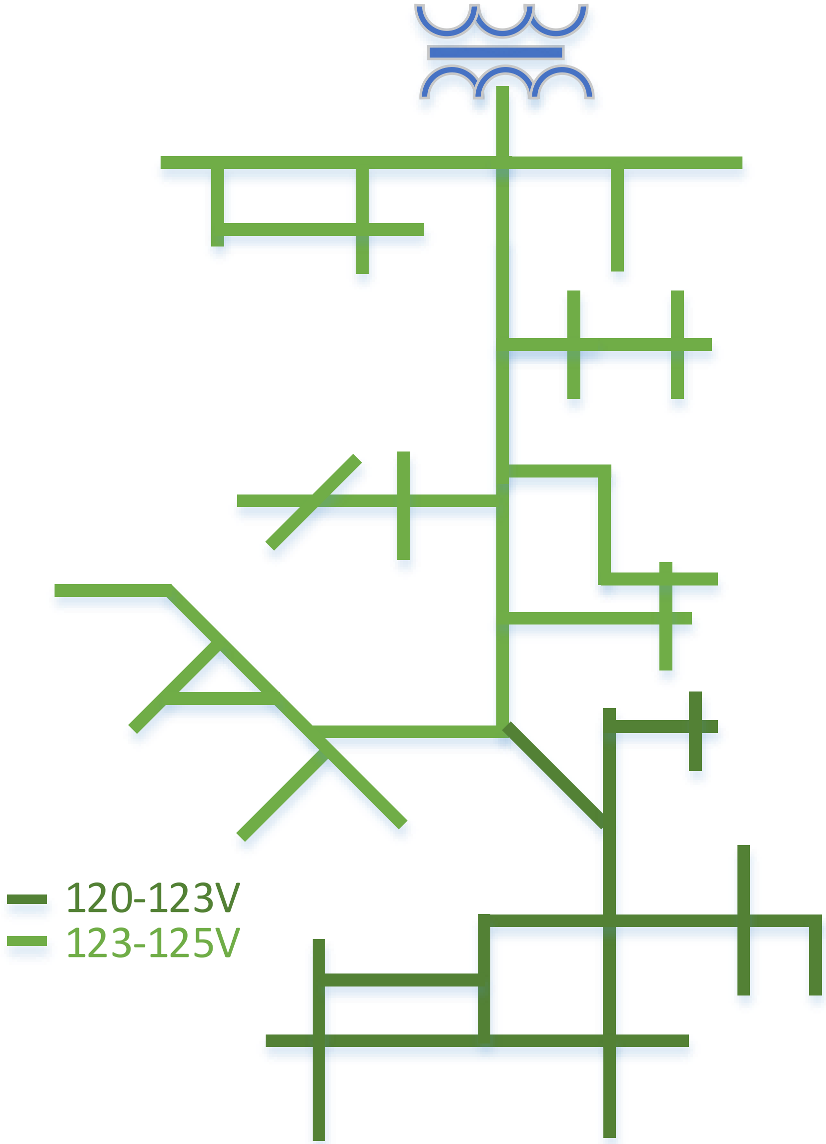
Locating STATCOMs at optimal sites removes the need of shunt capacitors and drives the voltage to within an acceptable voltage profile.

- For new feeders, or the expansion of existing feeders, optimally located STATCOMs can be effectively used to improve the voltage profile and regulate the voltage according to user-defined levels.
- STATCOMs can be used in conjunction with existing voltage regulators and capacitor banks to improve the voltage profile on existing distribution feeders.

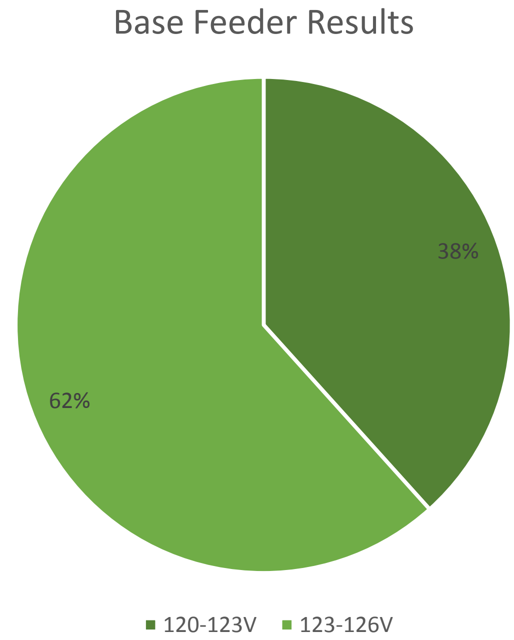
Residential Feeder Studies

- Several studies performed on residential distribution feeders
- Simplified model representing studies of consumer 120V feed
- Evaluated with respect to ANSI C84.1-2006
  – Max Voltage before Violation-125V
- Average Model Properties
  – ~25MVA
  – Total conductor length - 60 Miles
  – Maximum distance from substation - 12 Miles
  – Available DER - 5MW Solar
  – Reactive devices - 4x 400 kvar Capacitor Banks

Base Feeder Study

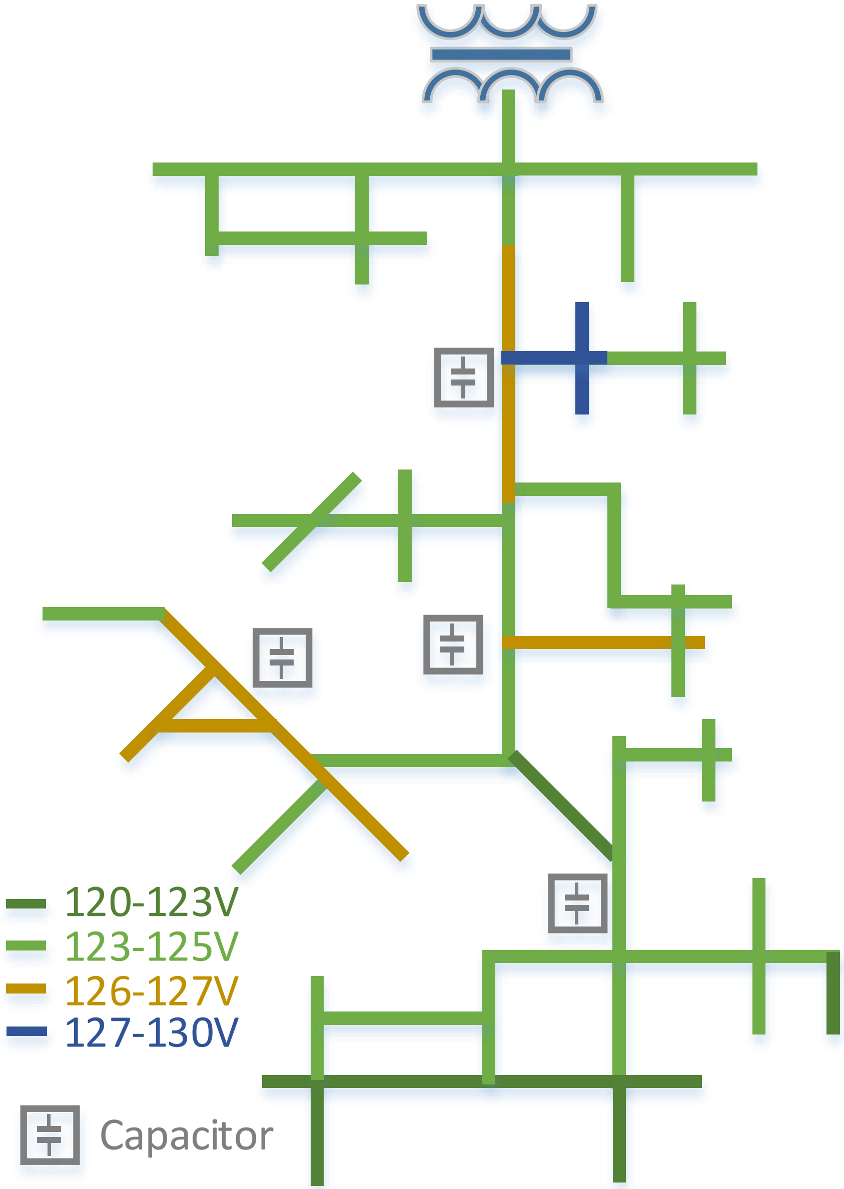


- Normal load
- Solar generation -OFF
- Capacitor banks -OFF
- STATCOM-OFF

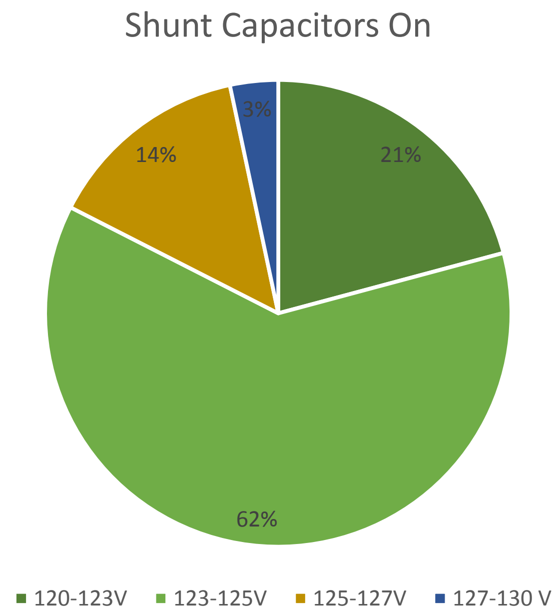


Base feeder conditions show elevated voltage conditions close to the substation

Res. Feeder Online Shunt Capacitors

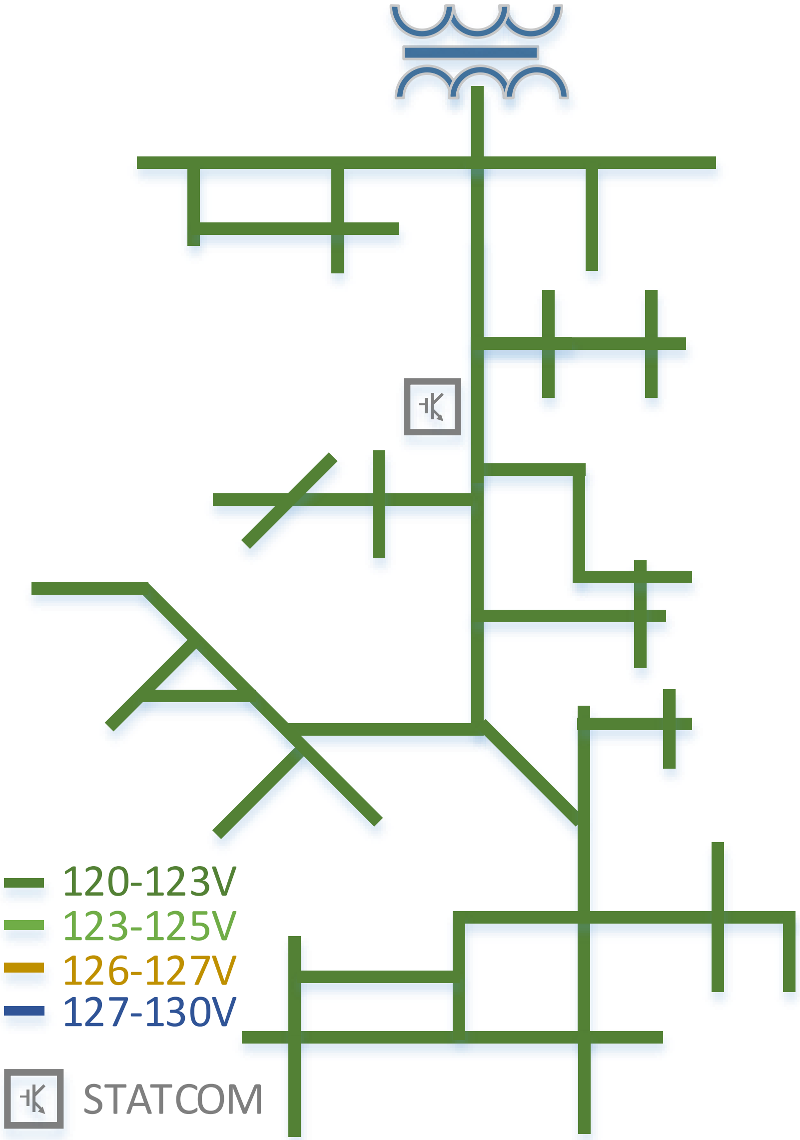


- Normal load
- Solar generation -OFF
- Capacitor banks -ON
  - 4x 400kvar
- STATCOM-OFF

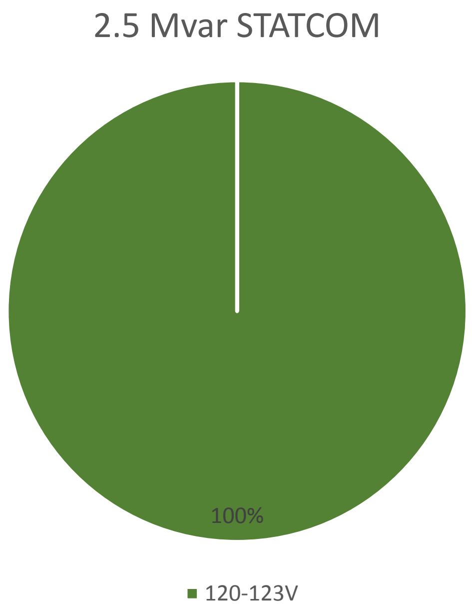


Several branches with high voltage violations occur near capacitor banks

Res. Feeder ±2.5Mvar STATCOM

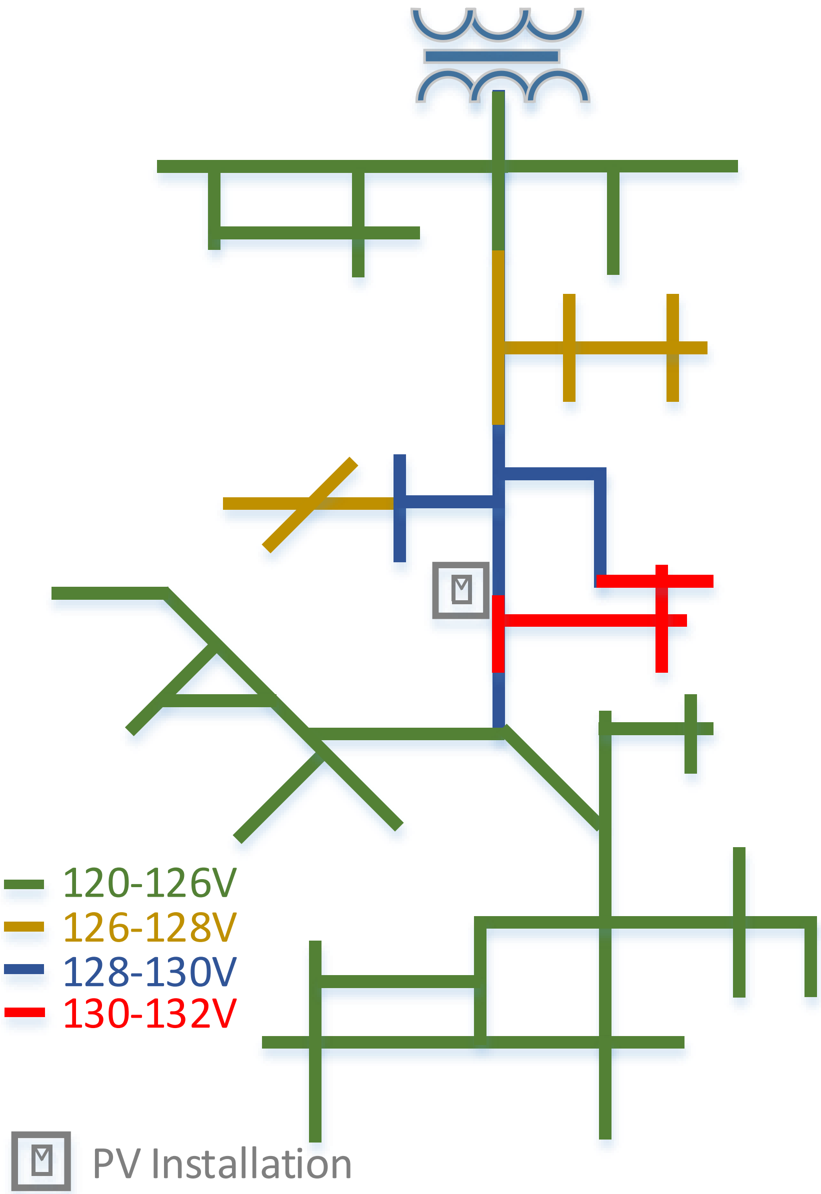


- Normal load
- Solar generation -OFF
- Capacitor banks -OFF
- STATCOM-ON
  - 2.5 Mvar STATCOM

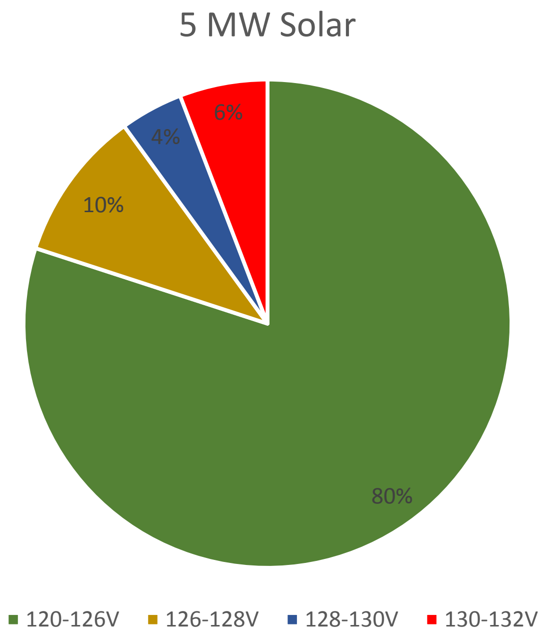


- All voltage violations resolved with centrally located STATCOM

Res. Feeder with 5MW Solar

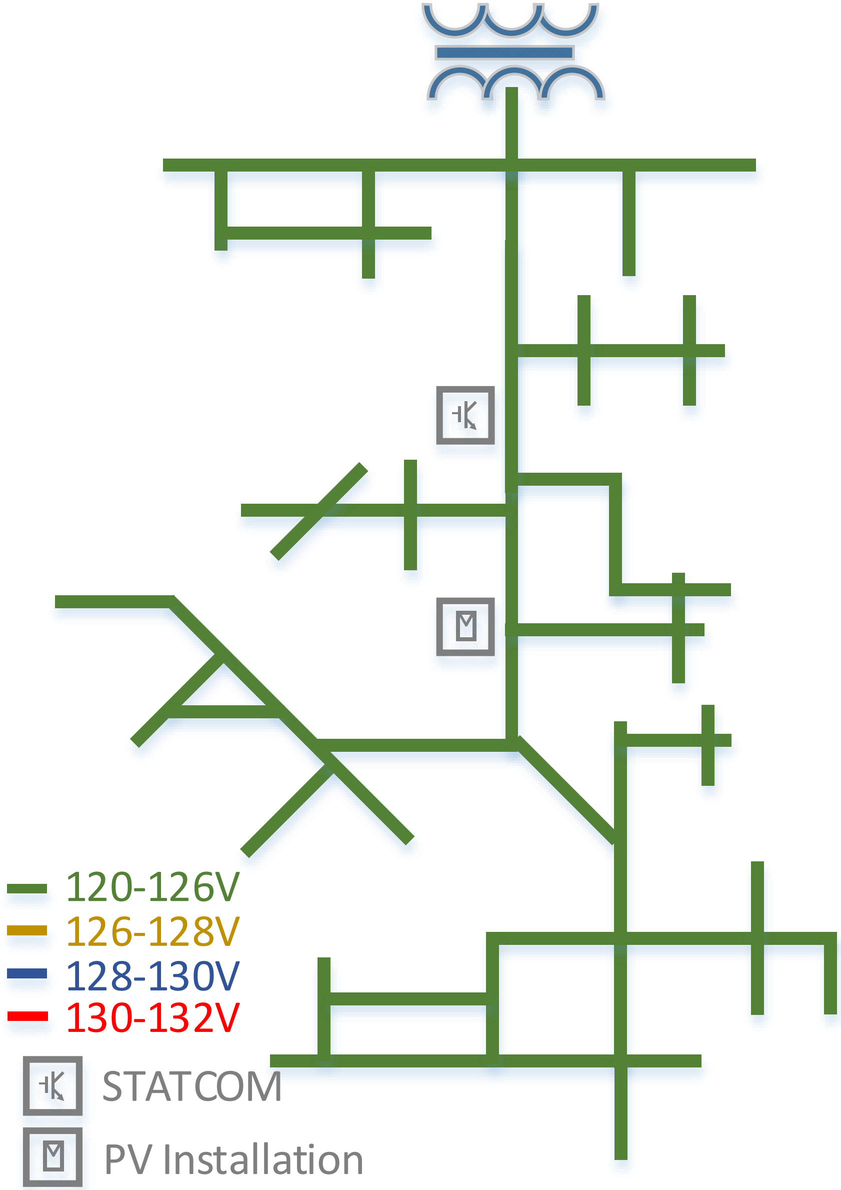


- Normal load
- Solar generation – ON
  - 5 MW Solar
- Capacitor banks - OFF
- STATCOM - OFF

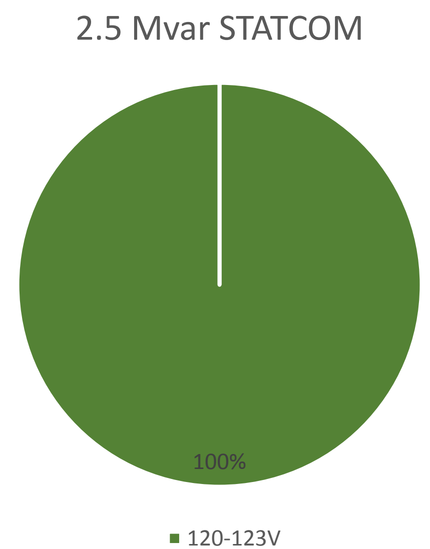


Large portion of feeder in violation due to excess generation PV installation. Small area of voltage violations in excess of 130V

Res. Feeder with 5MW Solar ±2.5 Mvar STATCOM

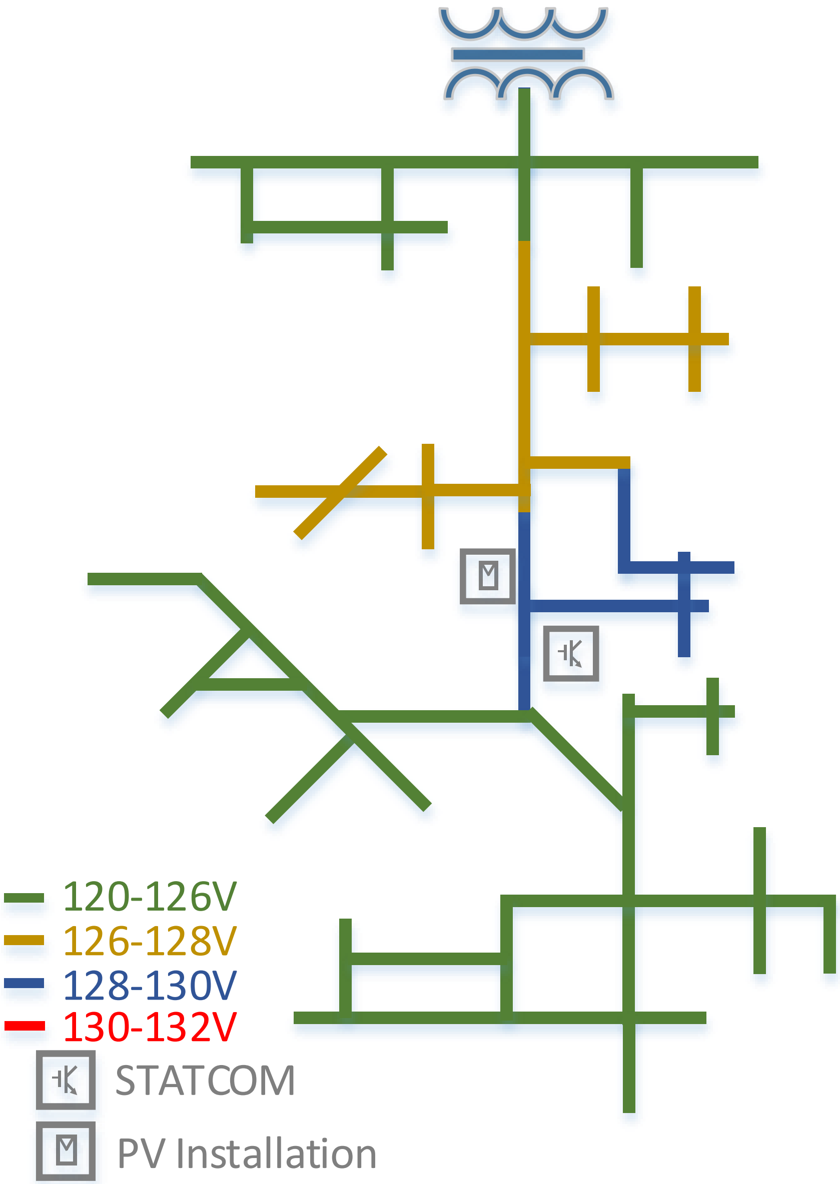


- Normal load
- Solar generation – ON
  - 5 MW Solar
- Capacitor banks - OFF
- STATCOM – ON
  - ±2.5 Mvar STATCOM

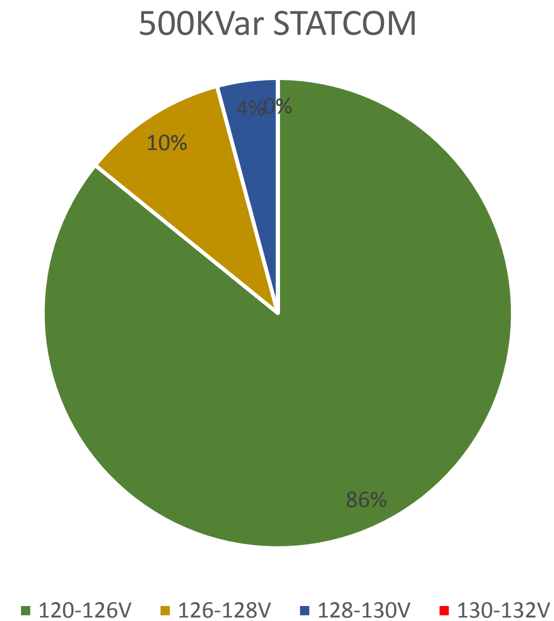


All violations resolved with centrally located STATCOM

Res. Feeder with 5MW Solar ±500 kvar STATCOM

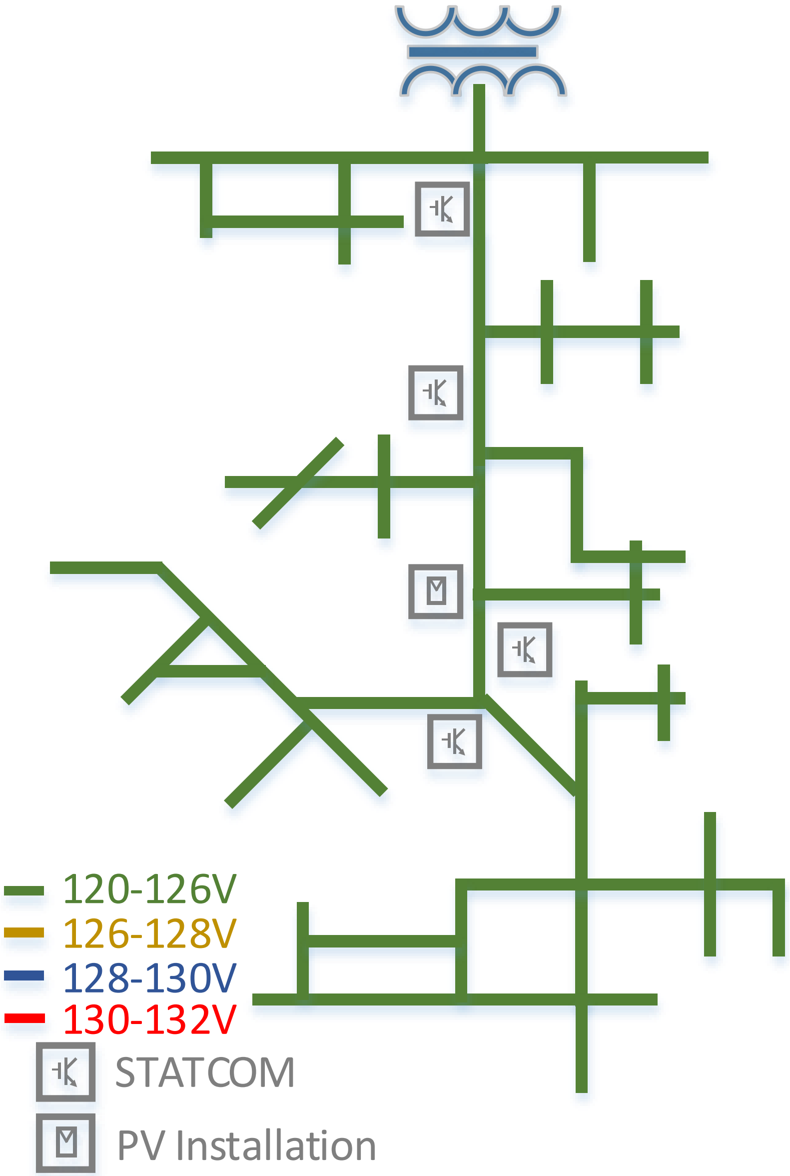


- Normal load
- Solar generation – ON
  - 5 MW Solar
- Capacitor banks - OFF
- STATCOM – ON
  - 4x ±500 kvar STATCOM

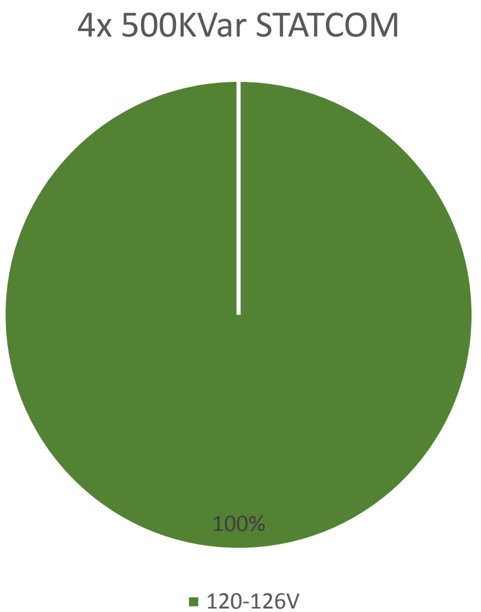


Medium sized STATCOM resulted in 25% decrease in violation. All voltage violations above 130V resolved

Res. Feeder with 5MW Solar 4x ±500 kvar STATCOM



- Normal load
- Solar generation – ON
  - 5 MW Solar
- Capacitor banks - OFF
- STATCOM – ON
  - ±500 kvar STATCOM



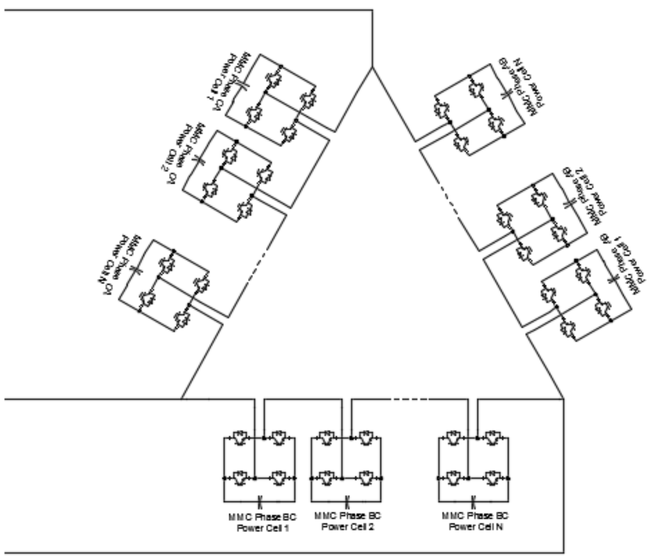
All violations resolved with distributed STATCOM solution

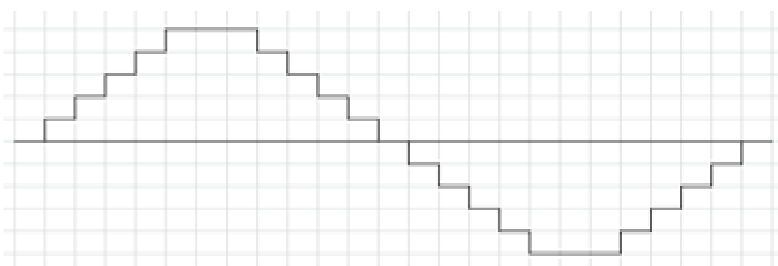
Res. Feeder Study Conclusions

- STATCOM application in 25MVA Feeder showed significant improvement
- Single 2.5Mvar STATCOM was solve voltage issues due to existing equipment and issues to presence of DER
- Single 500kvar STATCOM was able to improve power quality by 25%
- 4 optimally place 500Kvar STATCOMs was able to equal the performance of a single 2.5Mvar solution
- Use of smaller STATCOM size support future feeder growth without increasing size of central STATCOM
- More studies on other distribution grids will need to be performed, but shows promise of further positive results

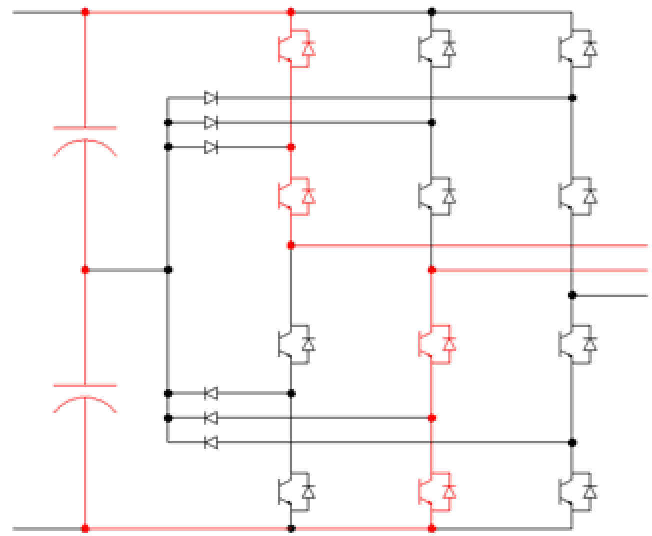
STATCOM Topology Comparison

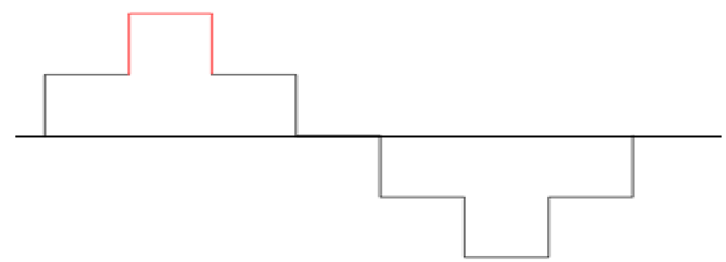
MULTILEVEL INVERTER (STATCOM)





TYPICAL “SMART” INVERTER





A smart inverter <u>cannot</u> equal the performance features of a STATCOM

STATCOM Topology Comparison

MULTILEVEL CONVERTER (STATCOM)

Cascaded H-Bridge topology

Reactive power absorption & injection

- Distributed DC bus
- Low harmonic content due to multiple levels
- Limited or no filters required (limited resonance issues with grid)
- Low voltage stress on FWD & IGBT's
- IGBT, Diode, & cap redundancy
- More overall switching devices
- IGBT matching is not required (lower spare parts cost)
- Faster reaction time to charge / discharge capacitors
- Easier to achieve higher voltage level using common building block

Typical SMART INVERTER

NPC or Flying Capacitor topology

- Reactive power absorption & injection
- Common DC bus
- High harmonic content due to minimum switching levels
- Large inductor / cap filters required (possible resonance issues with grid)
- High voltage stress on FWD & IGBT'S
- Limited redundancy (IGBT & diodes)
- Less overall switching devices
- Matched IGBT's for voltages > 3kV (higher spare parts cost)
- Slower reaction times to charge larger capacitors
- Higher voltages require placing low voltage devices in series or using higher voltage rated device

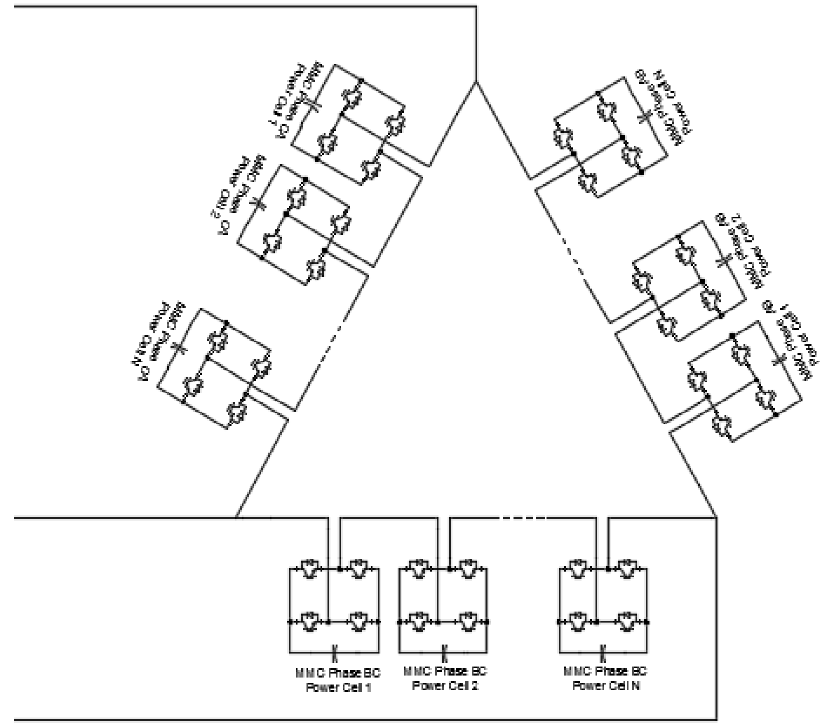
MMC Inverter more suited for STATCOM Technology

Inverter Comparison

Cascaded H-Bridge

Application in Delta Configuration

- Easier fault handling of single phase to ground faults
- Easier unbalanced operation characteristics
- Easier negative sequence control
- Lower current means results in lower conduction loss



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Changes for the Better

Summary

for a greener tomorrow eco Changes

- Distribution zone has not been traditionally targeted with advanced technology for power quality management
- High penetration of DERs in distribution zone provide the opportunity to stabilize the system near the source
- The implementation of medium powered STATCOMs in the distribution feeder shows they significantly affect power quality
- STATCOM technology in the distribution zone provides inductive and capacitive operation, allowing for full range of voltage support
- By decentralizing a single STATCOM and installing throughout the feeder shows significant improvement at the consumer load
- Allows for application of latest low voltage power electronics technology at higher voltage zone

Distributed Solution for a Distribution Problem

Thank you for your attention

Questions?