D-STATCOM Technology and Principles

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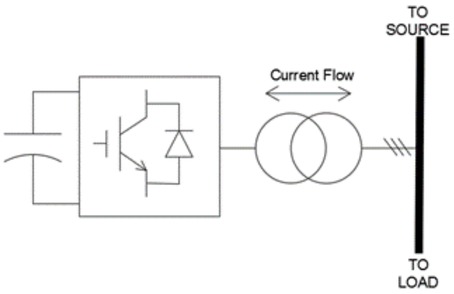
MITSUBISHI ELECTRIC POWER PRODUCTS, INC.

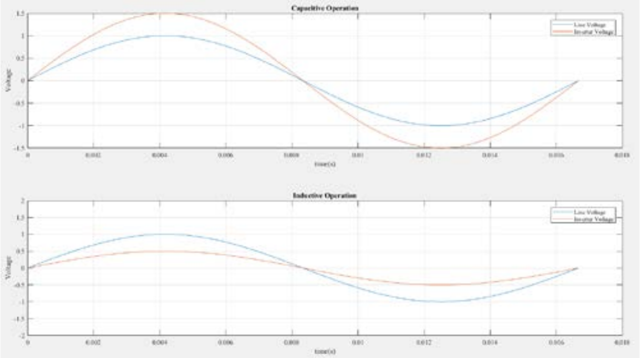
D-STATCOM Intro

- Applying Distribution STATCOM
- Operating and Control Modes
- Distribution Applications
- Topology Selection

WHAT IS A STATCOM?

- Static Synchronous Compensator
  - Replaces unloaded synchronous machines to control reactive power
- Comprised of: IGBT based voltage source converter to convert DC to AC voltage at its terminals in order to control bi-directional power flow
- By regulating the output voltage of the STATCOM, the inverter can source or absorb vars with respect to the connected power system.
- Utilizing high switching frequencies in the kHz, can respond to rapidly changing grid conditions and offer increased dynamic reactive compensation





Capabilities

- Volt-Var Optimization (VVO)
- Conservation Voltage Reduction (CVR)
- Current Phase Balancing
- Harmonic Mitigation
- var Regulation
- Power Factor Correction
- Voltage Stability
- Transient Over/Undervoltage Reduction

Applications

- Distributed Generation Integration
- Voltage Imbalance Situations
- IEEE519 Compliance (Harmonics)
- Peak Demand Shaving
- Power Quality Requirements
- Asset Life Maximization
- Industrial Load Compensation (Arc Furnace, Inductive Pulsed Loads)

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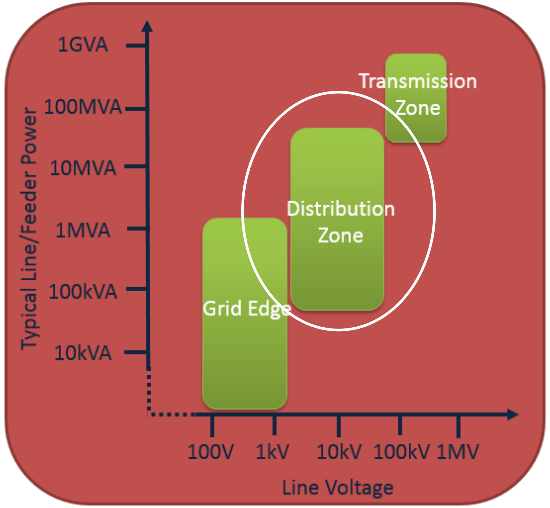
TARGETING the 3rd "ZONE" of DELIVERY

Zone	Line Voltage	Description
Transmission	69kV - above	High power transmission prior to primary step down transformer
Distribution	4.16kV -69kV	Portion from secondary of step down transformer to service transformers
Grid Edge	4.16kV -below	Area of grid after step down transformers to home/consumers. Referring to pole mount service distribution



Transmission vs Distribution STATCOM

Transmission STATCOM

- Typically >100MVAR
- Centralized solution applied at transmission side, typically single STATCOM/SVC for entire transmission line
- Power Flow Support
- Generator Support
- Voltage instability issues
- Over voltage issues
- Utility scale substation installation and cost

VS

Distribution STATCOM

- Typically >500kvar
- Interface directly at the same zone with utility DER
- Cover total feeder length with VVO, CVR, imbalance compensation, and provide transient stability
- Smaller capacity system allows for single cycle or less response time
- Harmonic mitigation at the load
- Can replace or reduce need for traditional VVO/CVR equipment(Cap banks, LTCs, etc..)

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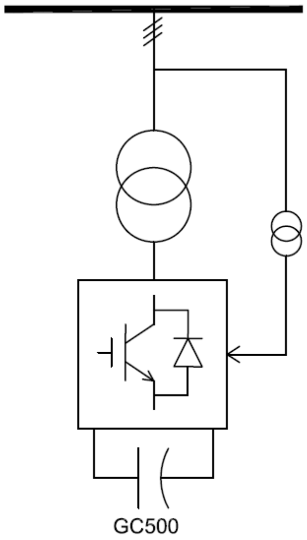
WHY DISTRIBUTION?

- Distribution Zone typically less than 30MVA
- Distribution feeders present unique challenges compared to transmission
  - Direct interconnect with DERs, Bidirectional power flow, Industrial Loads, and three and single phase faults and imbalanced loads
- An opportunity exists to support high power distribution zone with a medium power solution (>500kvar), providing inductive and capacitive correction
- Implement advanced power electronics technology at distribution voltages, minimizing system current
- Interface directly at the same zone with utility DER
  - Previous IEEE 1547 covered distributed energy resources up to 10MVA
  - Provide voltage stability at the source
  - Support renewable integration
- Can integrate with traditional VVO/CVR equipment(Cap banks, LTCs, etc..) while increasing asset life or replace exsiting equipment while delaying re-conductoring

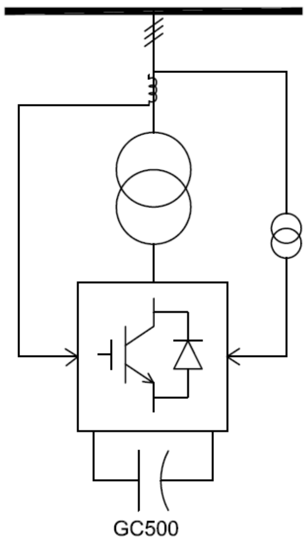
D-STATCOM: OPERATIONAL MODES

- 3 typical Distribution STATCOM control modes:

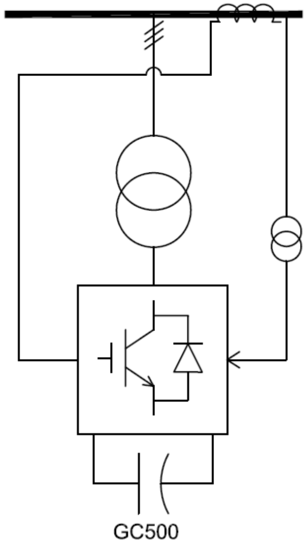
Voltage Control



VAR Control



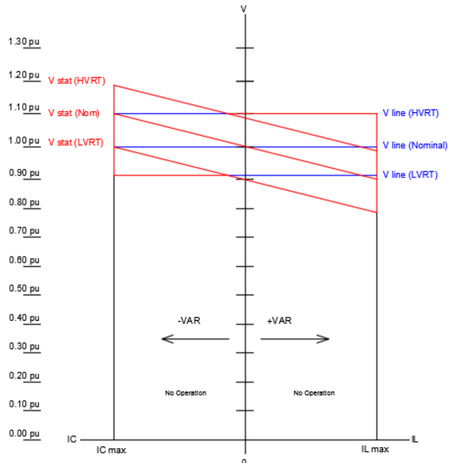
PF Control



- Each control mode will regulate a different aspect at the point of common coupling (PCC) or within the distribution feeder
- D-STATCOM output characteristics will vary depending on the control mode selected
- In all cases, D-STATCOM will regulate current to ensure current remains under control

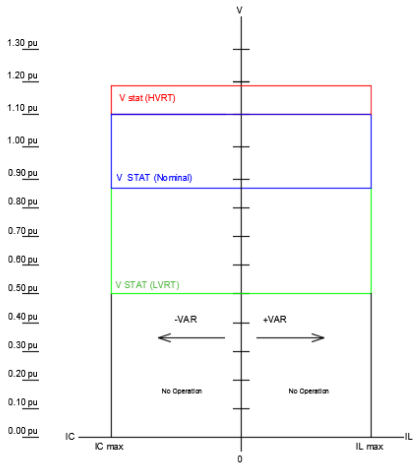
D-STATCOM: OUTPUT CURVES

Voltage Control



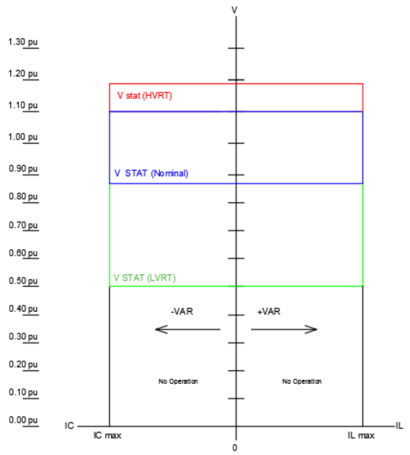
- Voltage control mode will regulate the input terminals of the GC500 to a constant voltage
- As the line voltage increases or decreases the D-STATCOM will provide a proportional reactive or capacitive current providing voltage control and sag mitigation

VAR Control



- Controller will regulate output voltage with respect to input voltage to provide constant vars
- Operationally similar to installed capacitor banks or shunt reactors, but with variable output power, allows for var optimization with respect to grid conditions

Power Factor Control



- D-STATCOM will regulate reactive output power to a power factor set point at the terminals of the STATCOM
- D-STATCOM will adjust voltage to provide appropriate vars to system to correct for reactive power offset

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D-STATCOM: HARMONIC MITIGATION

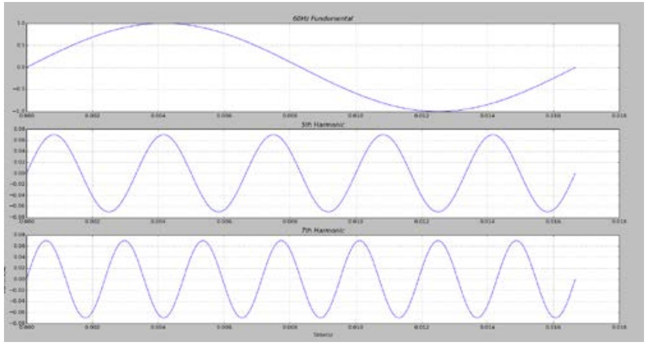
Why Use Harmonic Mitigation?

- Modern electric loads utilizing power electronics produce harmonics due to device switching

- IEEE-519 Std. sets power quality recommendations for industry, but is not regulated

- High harmonics can cause issues with motor/generator heating, cable heating, electronic equipment disoperation, and potential resonance issues with tuned capacitor filter banks

- 5th and 7th harmonics are lowest harmonics typically targeted for harmonic mitigation
  - 2nd -Even Harmonics
  - 3rd -Triplen harmonics
  - 4th -Even Harmonics
  - **5th -Negative Sequence Harmonics**
  - **7th -Positive Sequence Harmonics**



60Hz, 1st,5th, & 7th Harmonics

Table 2—Current distortion limits for systems rated 120 V through 69 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)[a, b]						
I_{SC}/I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
$< 20^c$	4.0	2.0	1.5	0.6	0.3	5.0
$20 < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < 100$	10.0	4.5	4.0	1.5	0.7	12.0
$100 < 1000$	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

IEEE-519 Current Harmonic Limits

Source: IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems, IEEE Standard 519, 2014.

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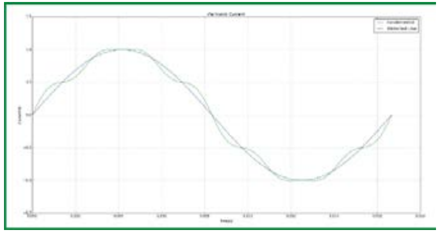
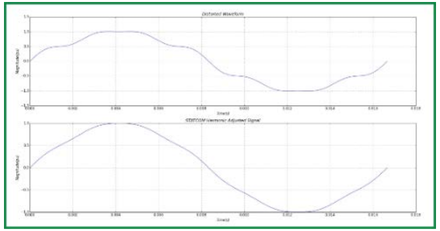
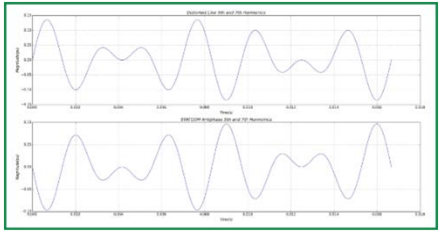
HARMONIC MITIGATION: CASE STUDY



Step 1) *Measure line currents and decompose into harmonics*

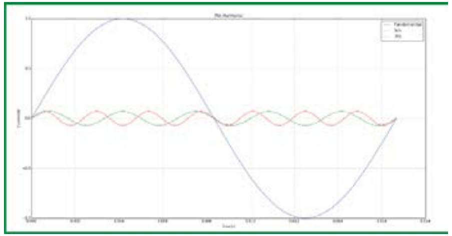




Step 2) *Synthesis antiphase waveforms at set harmonic frequencies*

5th and 3rd Harmonics
Original (Left) STATCOM (RIGHT)

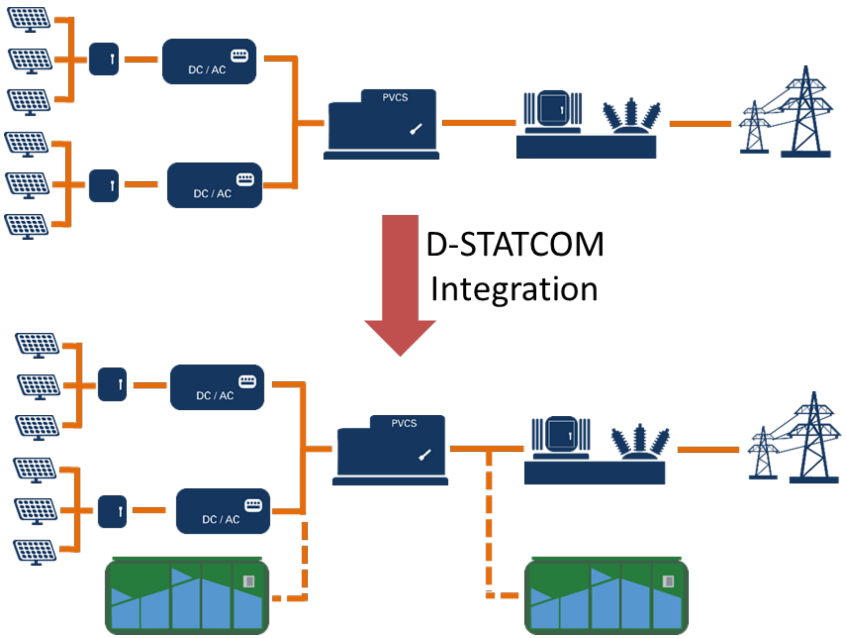
Step 3) *Produce combined waveform at output of the inverter to created compensated line waveform*



Case Study

- Existing customer load contains individual 5th and 7th harmonics at 7% at rated load for short circuit ratio of 50
- Total THD would be 14%, not IEEE-519 compliant
- After 5% reduction on 5th and 7th harmonic using with full GC500 harmonic mitigation Total THD=2.8%

DER INTEGRATION



- Modern grid codes require a PV Plant to control reactive power at the point of interconnect (POI) with dedicated smart PV inverters or capacitor banks.
- By applying D-STATCOMs within the PV plant, additional PV inverters can be removed, while obtaining the same output performance.
- The use of D-STATCOMs also provide the potential benefit of harmonic mitigation, adjustable reactive power output, and other dynamic capabilities not available from traditional reactive compensation methods.

By applying a dedicated set of Distribution STATCOMs (D-STATCOM) at the plant terminals to meet dynamic power factor control requirements, or located within the plant itself to compensate for plant losses, a single product with a diverse set of capabilities can be applied to meet customer requirements

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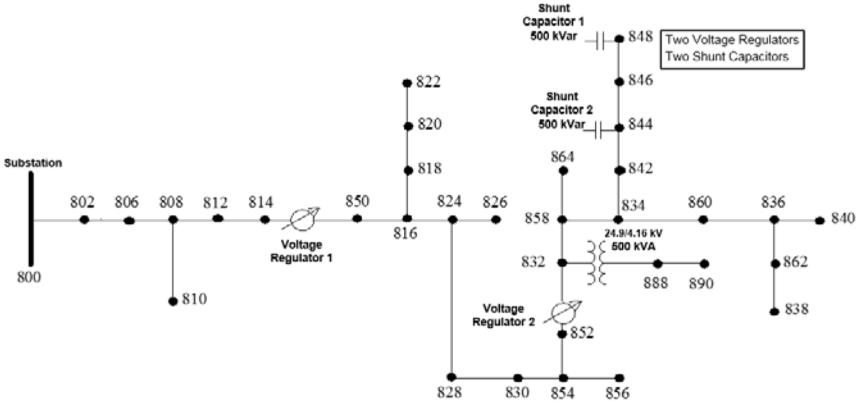
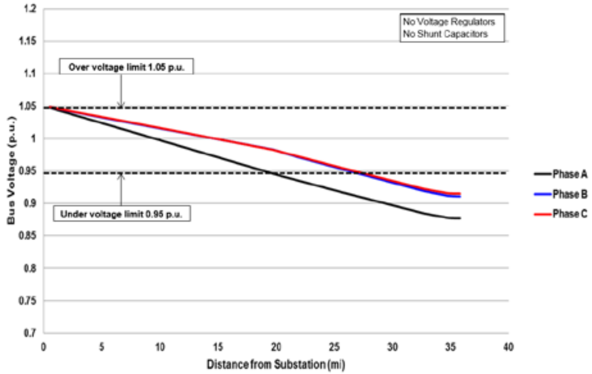
FEEDER STUDY

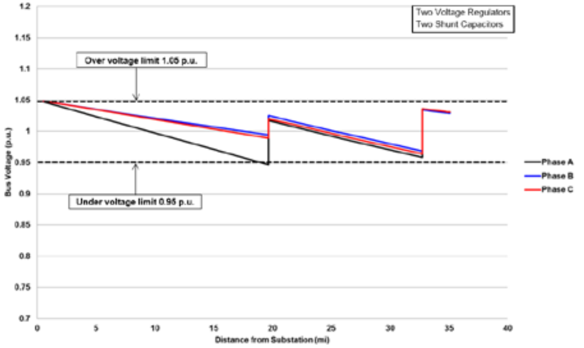
- IEEE 34 node sample feeder study performed by MEPPI PSED
- Sample Circuit -Published IEEE 34 Node Radial Distribution feeder based on data from test feeder in Arizona
- Investigation of STATCOM operability at distribution level using medium sized building blocks in typical higher power feeder location
- 2.5 MVA substation, 24.9kV, 36 mile total feeder
- Traditional compensation techniques to maintain acceptable voltage profile
    - Two in-line voltage regulators
    - Two shunt capacitors
- The voltage profile of a distribution feeder decreases as it extends away from the substation.



No Reactive Compensation



Voltage Regulator/Capacitor Solution



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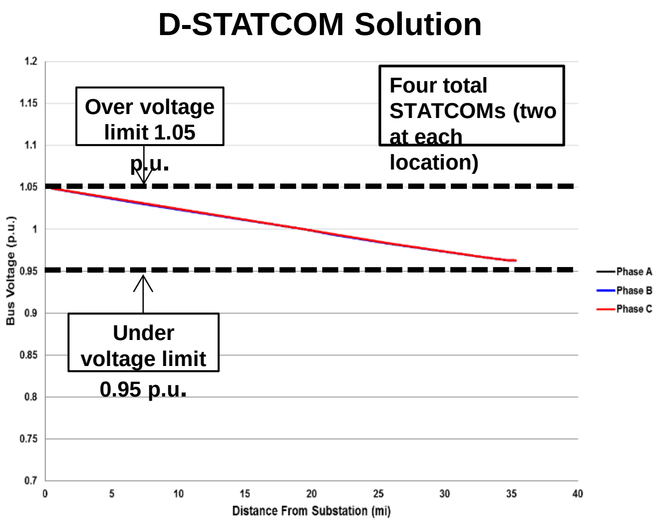
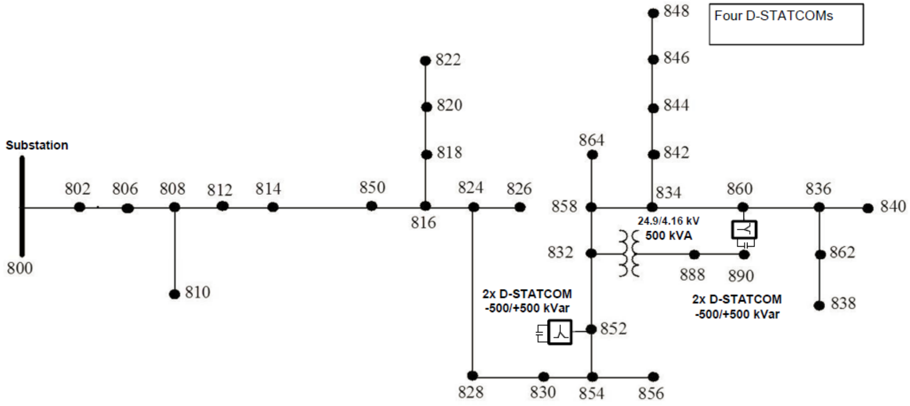
FEEDER STUDY





- 2 D-STATCOM units were placed at Nodes 852 and 860 to compensate for low voltage and imbalance situations
- D-STATCOMs can be used in conjunction with or replace existing voltage regulators and capacitor banks to improve the voltage profile on existing distribution feeders.
- Low load conditions or use of DERs in feeders can result in voltages near the maximum acceptable range close to voltage regulation equipment not compensated by traditional techniques

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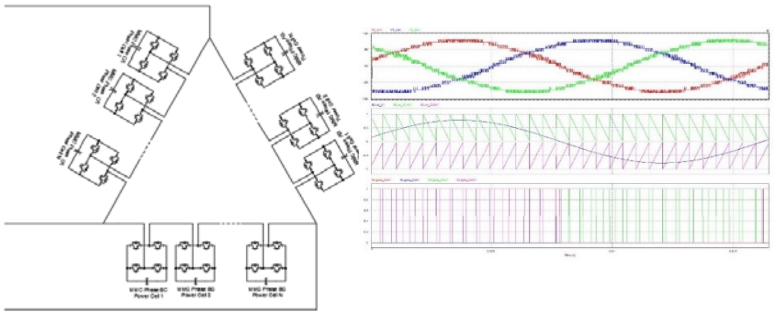
TOPOLOGY APPROACH

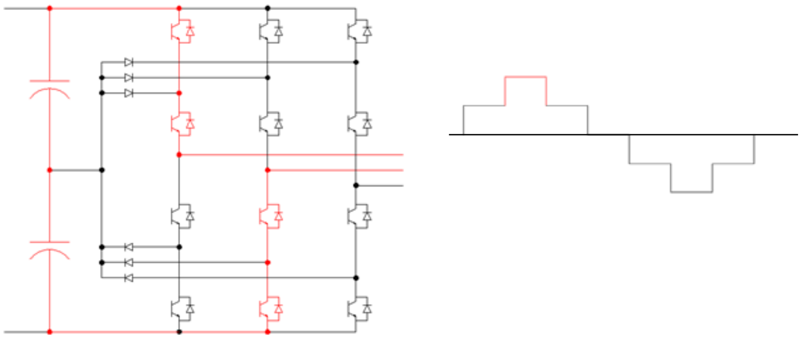
MULTILEVEL CONVERTER (STATCOM)

- 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

MULTILEVEL INVERTER (STATCOM)



TYPICAL "SMART" INVERTER



A smart inverter cannot equal the performance features of a STATCOM

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

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Thank You

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