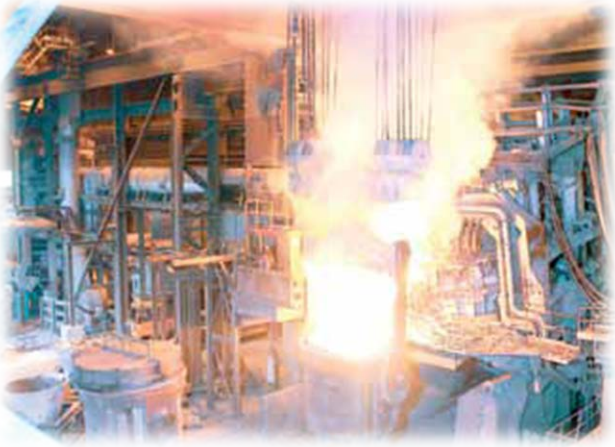
Joe Warner, Electric Power Industry Conference (EPIC), November 15, 2016

Advances in Grid Equipment
Transmission Shunt Compensation

Advances in Transmission Shunt Compensation
Excerpt from the BoA

- BoA: Book of Acronyms
- MSC/MSR: Mechanically Switched Capacitor/Reactor
- SVC: Static Var Compensator
- TCR: Thyristor Controlled Reactor
- TSR/TSC: Thyristor Switched Reactor/Capacitor
- STATCOM: Static Synchronous Condenser
- NPC: Neutral-Point Clamped
- MMC: Multi-level Modular Converter
- IGBT: Insulated-Gate Bipolar Transistor

Advances in Transmission Shunt Compensation
Network Challenges



- Shifting transmission system
  - Synchronous generation retirement
  - Penetration of distributed renewables and dynamic load
- Resulting in
  - Weak networks with a resonance approaching fundamental frequency
  - Increased vulnerability to disturbance
  - Increased requirements for mitigation solutions

Advances in Transmission Shunt Compensation
Network Challenges

Figure 5.23
Installed Capacity of Synchronous vs Asynchronous Generation Contributing to 30GW demand in Gone Green Scenario at different regions

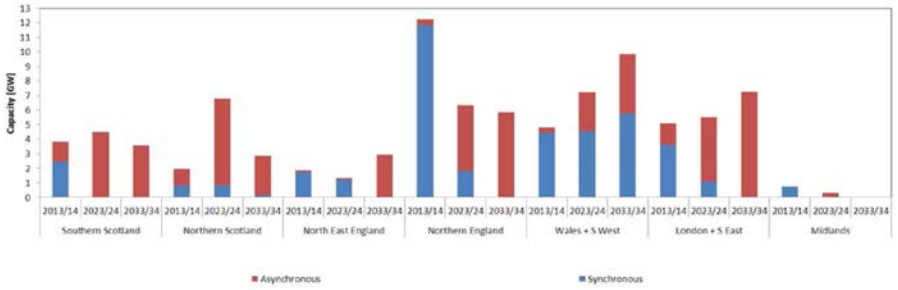


Figure 5.24
Contribution of Synchronous Generators to Short-Circuit level in Gone Green Scenario at different regions

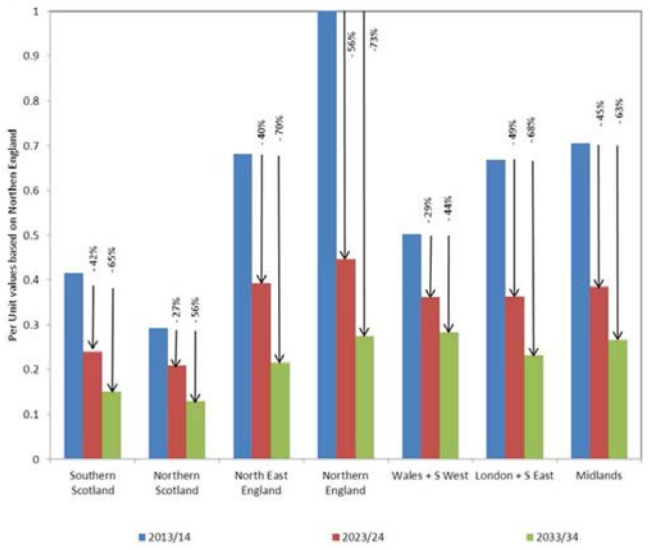
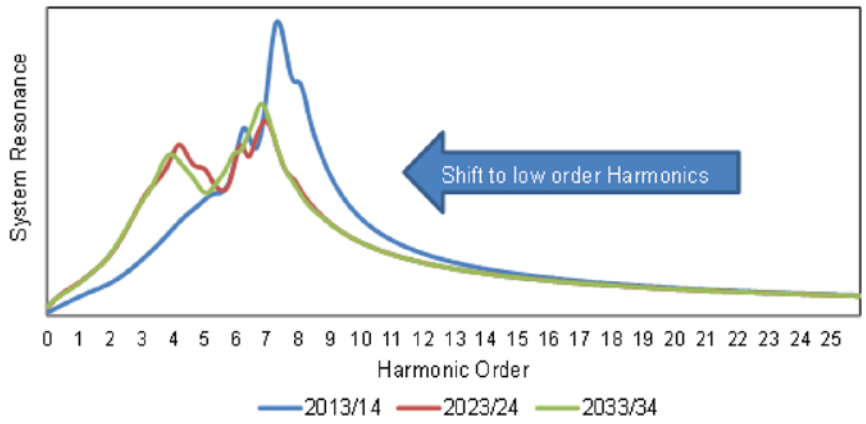
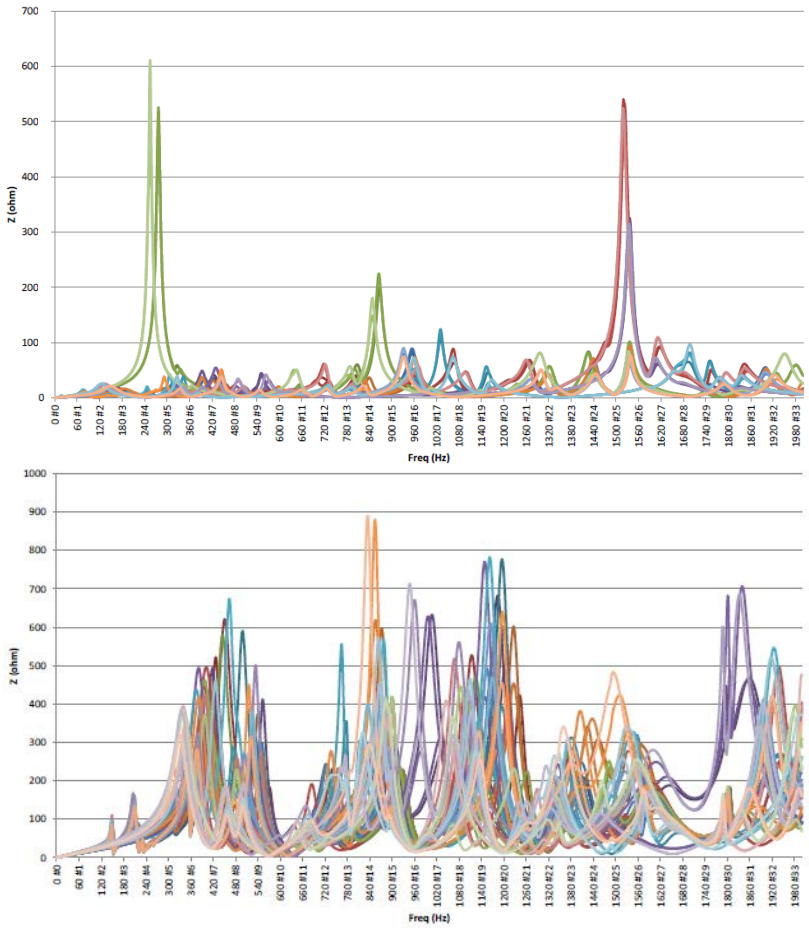


Figure 5.27
Shift of System Resonance to Low Order Harmonics



- National Grid Electric, Ten Year Statement

Advances in Transmission Shunt Compensation
Network Challenges



- Network resonances are shifting due to system changes
- Resonance frequencies and system damping affected by:
  - Number of un-tuned shunt capacitor banks (over-compensation)
  - Cable and T-line charging
  - Parallel FACTS and HVDC installations (filters)
  - System loading (active and reactive)

Advances in Transmission Shunt Compensation
Mechanically Switched Capacitors

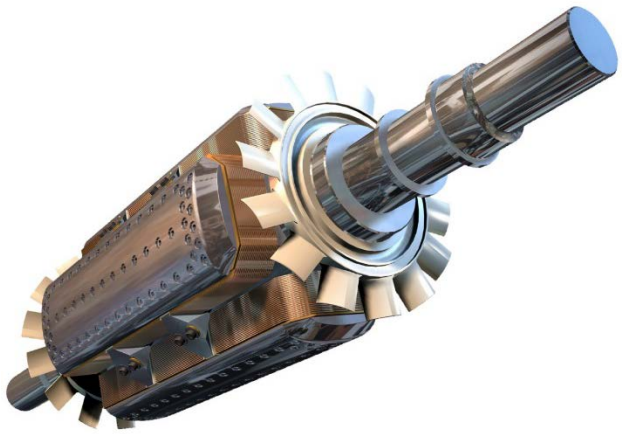
- Solutions:
  - Cheap and low-loss for steady-state compensation
- Challenges:
  - Slow switch-in/out and discharge
  - Network dependent voltage step

$$\frac{\Delta U}{U} \approx \frac{Q}{S}$$

  - Overcompensation leads to low network resonance and has resulted in inadvertent network collapse

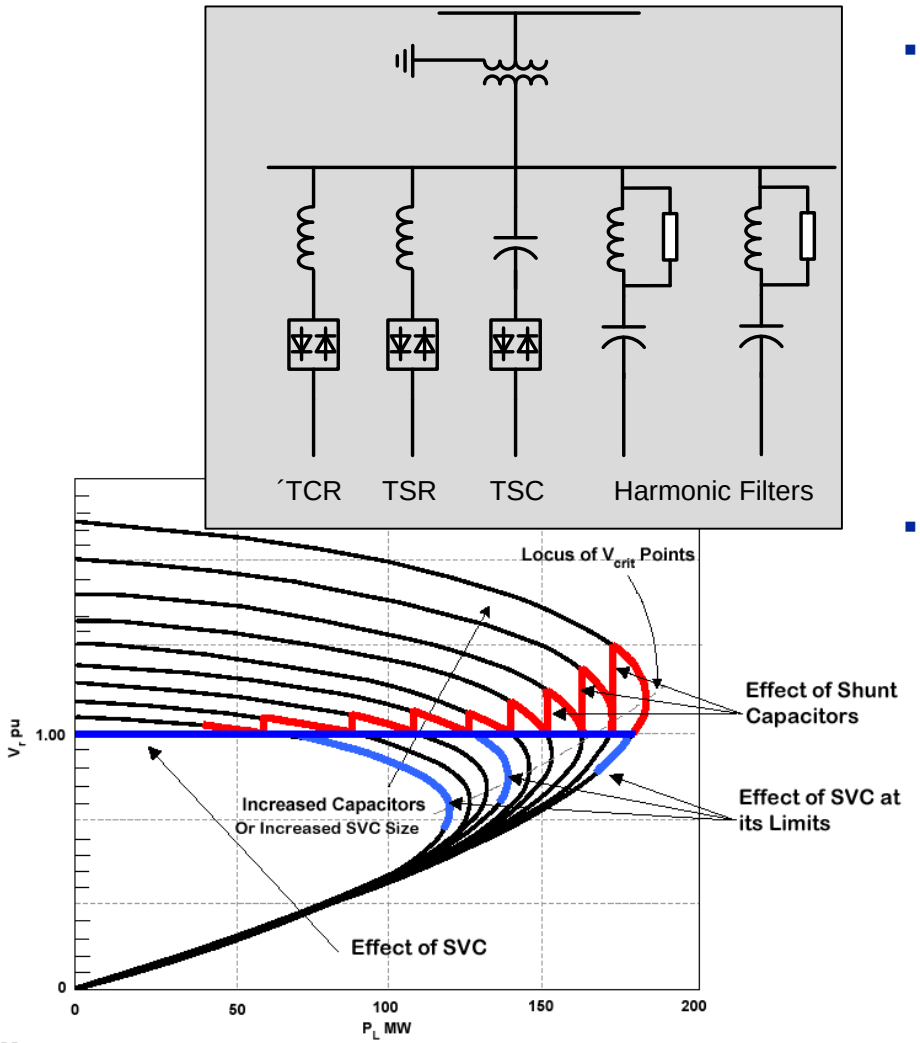
$$r = \sqrt{\frac{S}{Q}}$$

Advances in Transmission Shunt Compensation
Synchronous Condensers



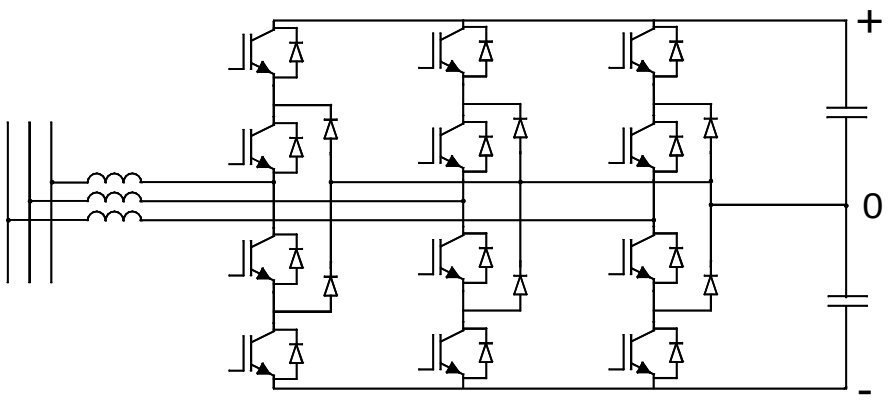
- Solutions:
  - Inertia increases system strength and provides fault current
  - Reactive power compensation without generating harmonics
  - Natural thermal overload capacity
- Challenges:
  - Smaller output range (< 100 MW)
  - Var support provided by automatic excitation control, medium speed
  - Maintenance
  - Losses

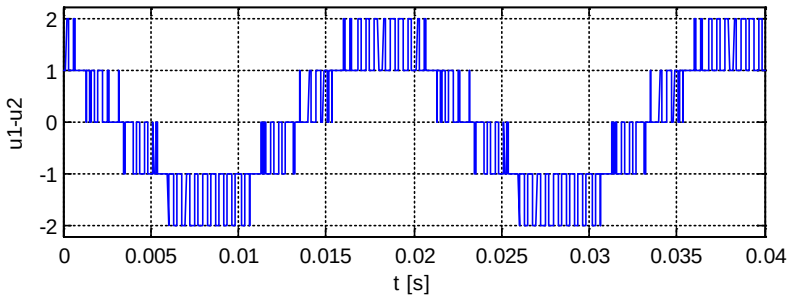
Advances in Transmission Shunt Compensation
Static Var Compensator (SVC)



- Solutions:
  - Fast, continuously variable output
  - Large sizes available (> 400 Mvar)
  - Robust overvoltage capability
  - Configurable to maximize value
- Challenges:
  - TCR generates harmonics
  - Filter design dependent on network harmonic impedances
  - Difficulty operating in a weak network
  - Output varies with V^2

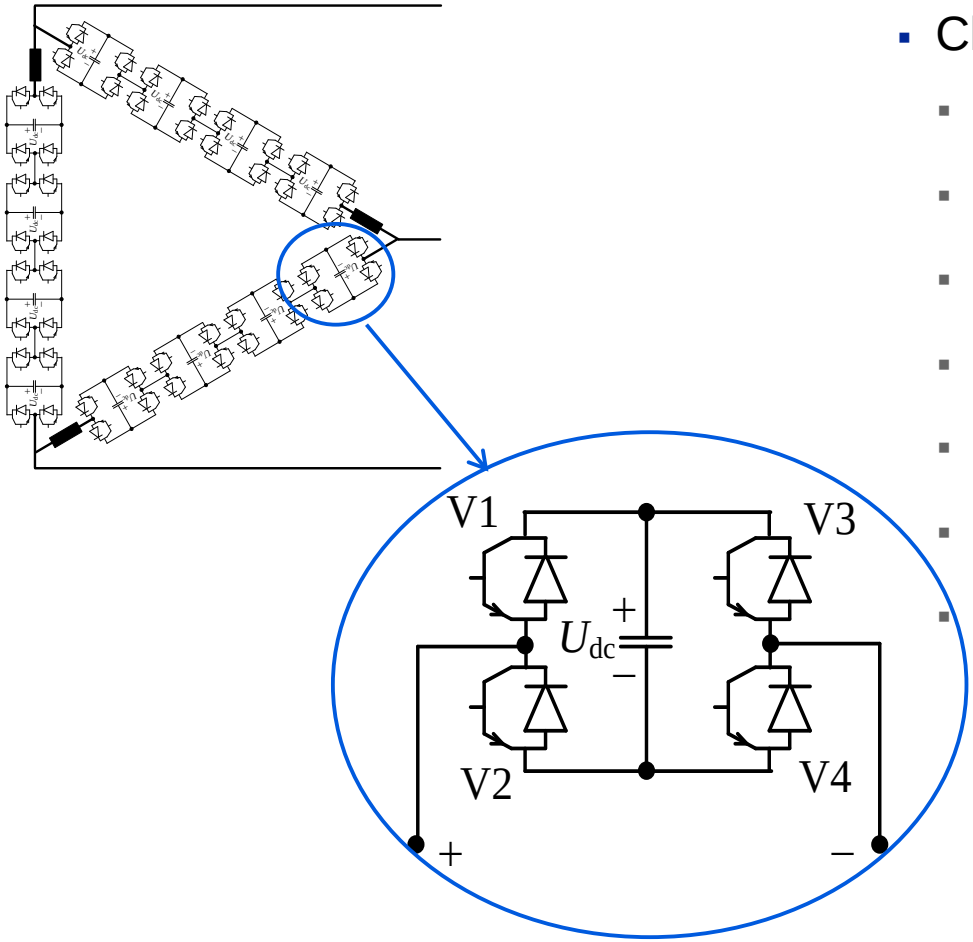
Advances in Transmission Shunt Compensation
STATCOM Converter Topologies





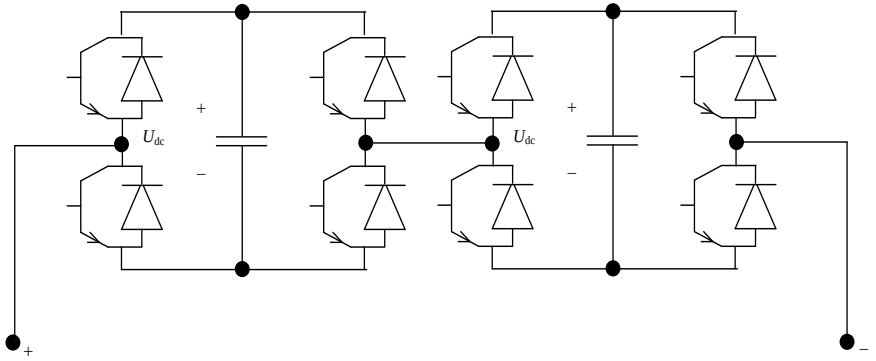
- Three-level NPC concept
  - Pulse Width Modulation
  - High Switching frequency (≥1.5 kHz)
  - Maximum rating of 100 MVA
  - IGBT units in series
  - With IGBTS no voltage grading circuits (snubber circuits)
  - Common dc-link
  - Well suited for energy storage
  - High harmonic generation
  - Substantial power losses

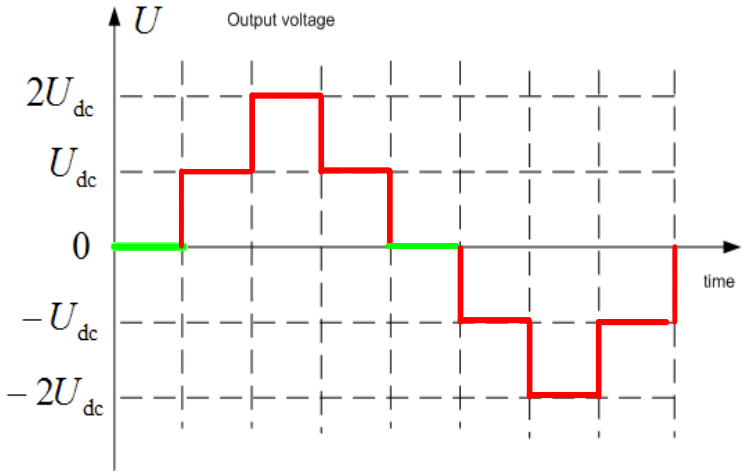
Advances in Transmission Shunt Compensation
STATCOM Converter Topologies

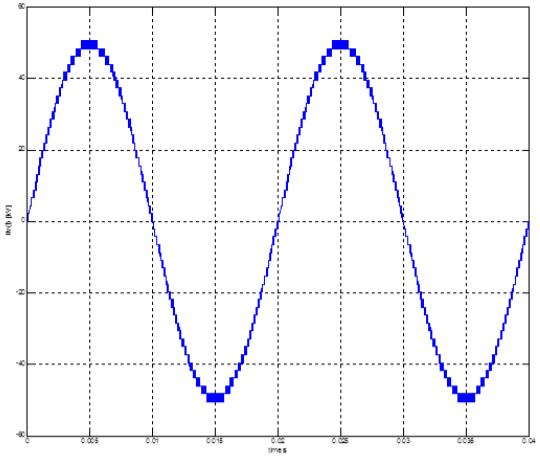


- Chainlink MMC concept
  - Cascaded H-bridges.
  - Modular in # of cells
  - 1 cell = 4 semiconductors (V1 – V4)
  - Number depends on required output.
  - Distributed dc-link
  - Low switching frequency (~300 Hz)
  - Lower power losses

Advances in Transmission Shunt Compensation
STATCOM – How MMC works

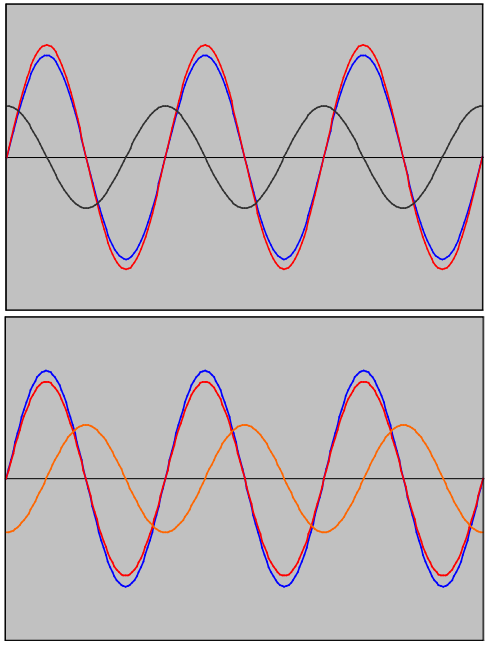






20 cells vs. 2 cells above

Advances in Transmission Shunt Compensation
Static Synchronous Compensator (STATCOM)

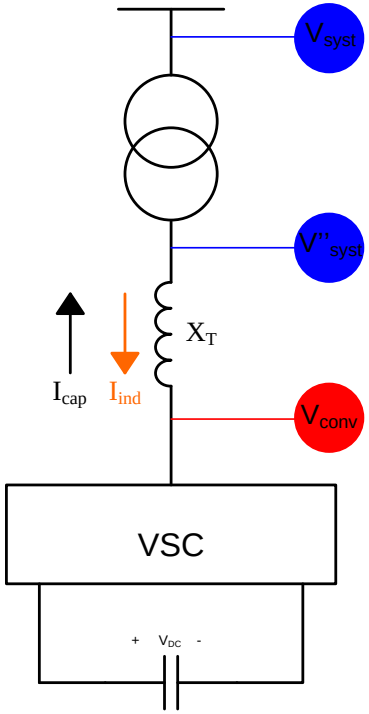


System Voltage

Converte Voltage

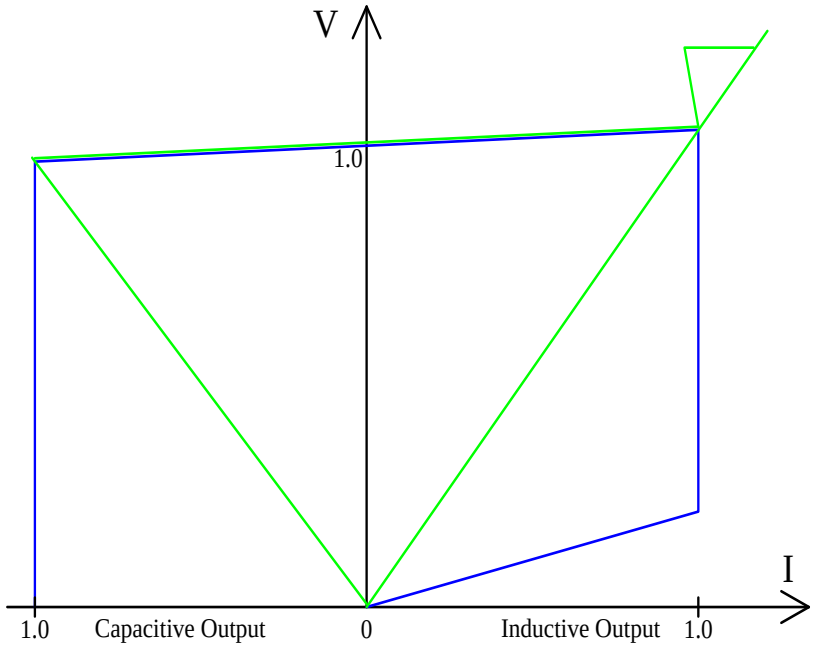
Capacitive Current

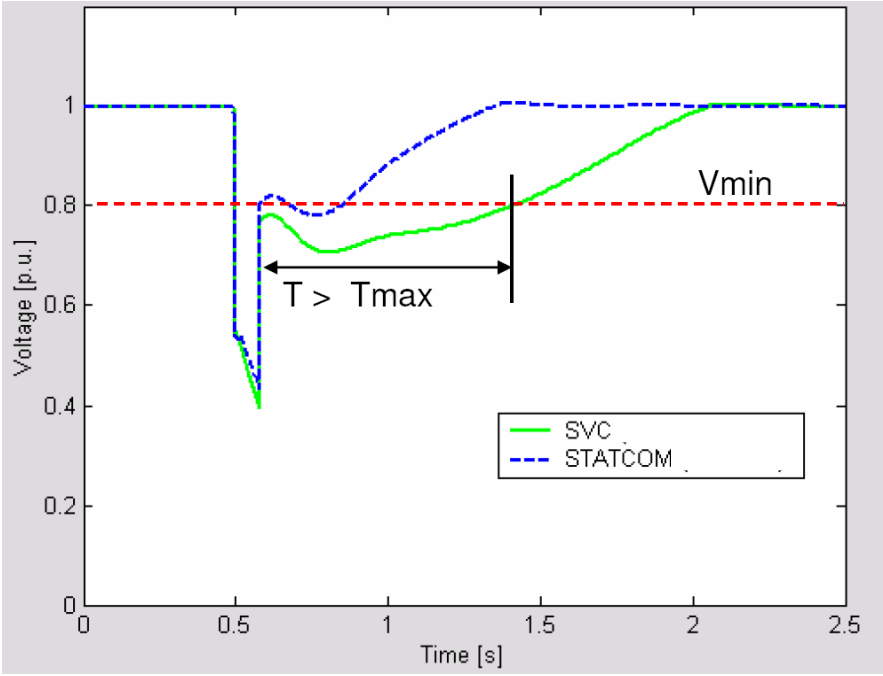
Inductive Current



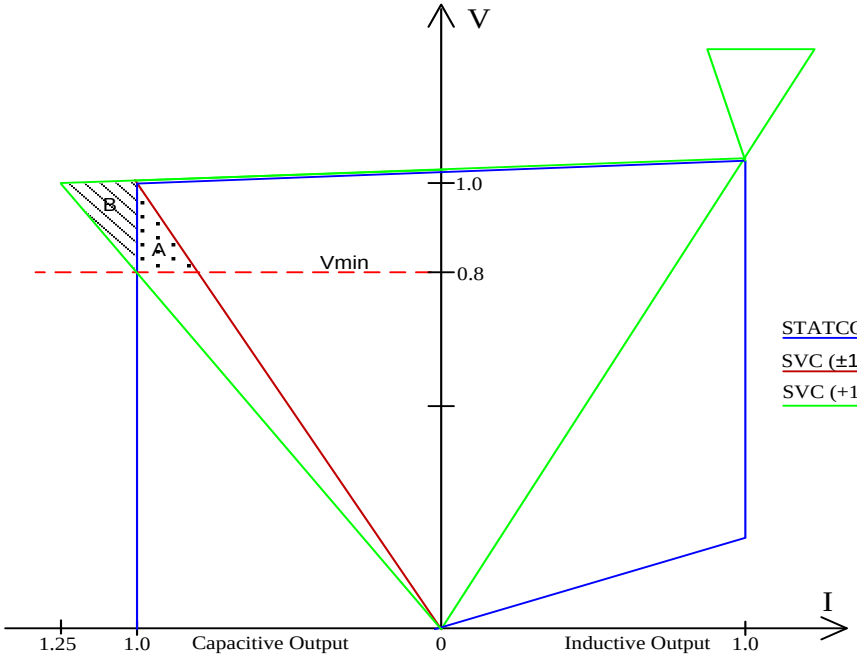
- Solutions:
  - Fast, continuously variable output
  - MMC configuration typically filterless
  - Operates in a weak network
  - Output varies directly with voltage
  - Small footprint
- Challenges:
  - Limited overvoltage capability

Advances in Transmission Shunt Compensation
SVC vs. STATCOM Performance

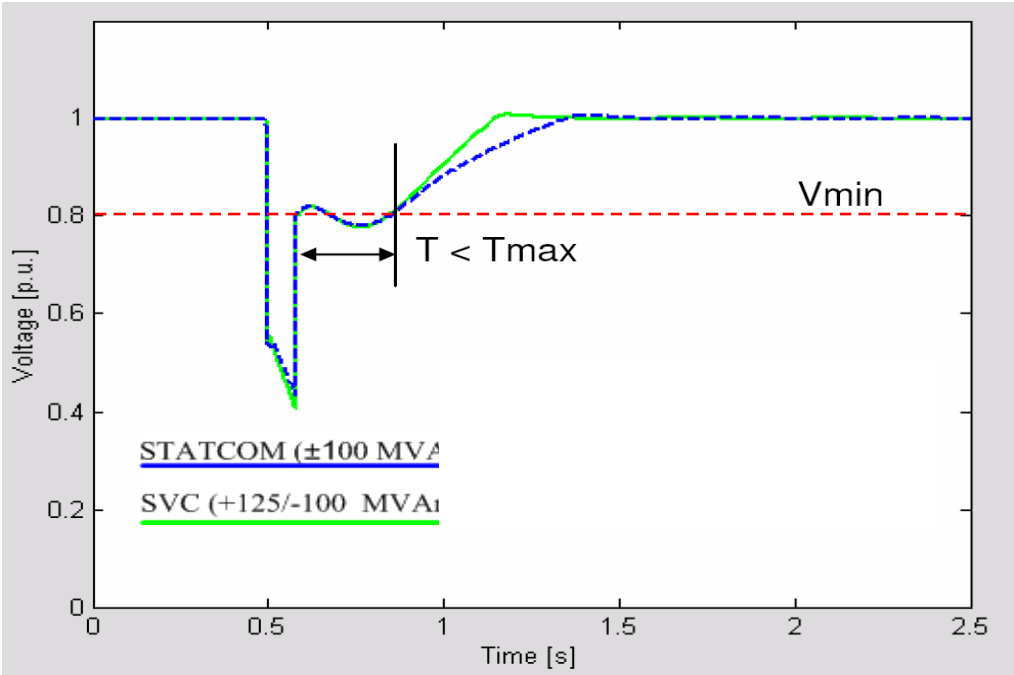




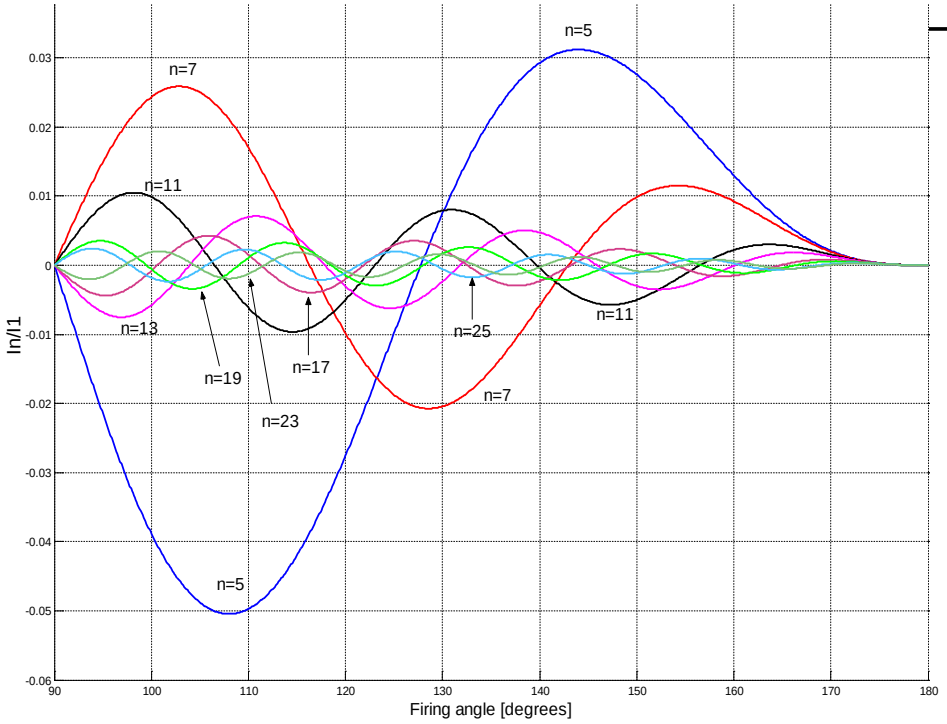
Advances in Transmission Shunt Compensation
SVC vs. STATCOM Performance

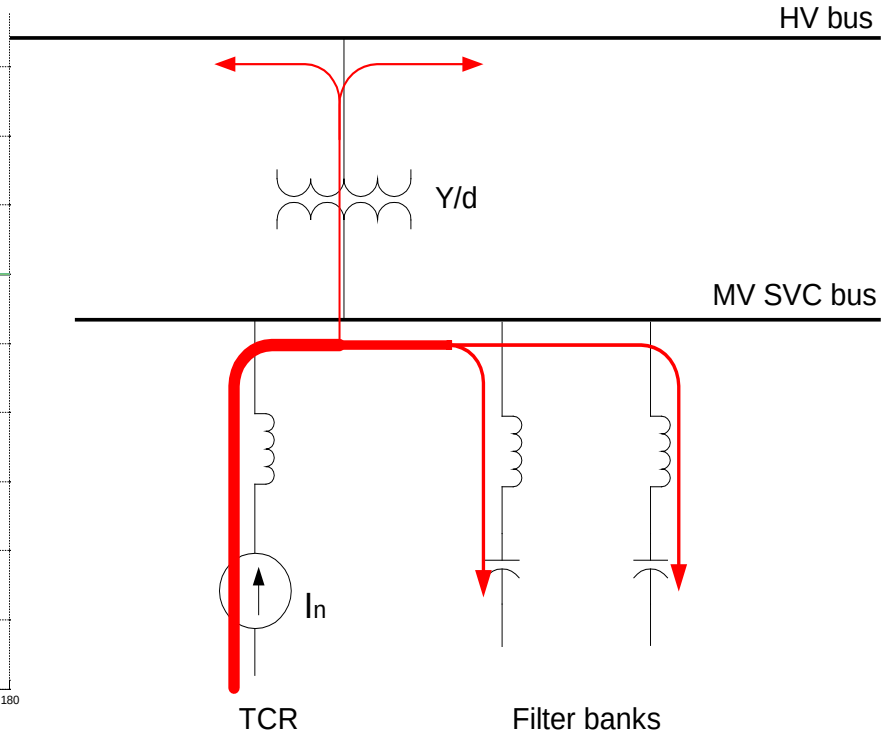


Performance driven by vars, not speed

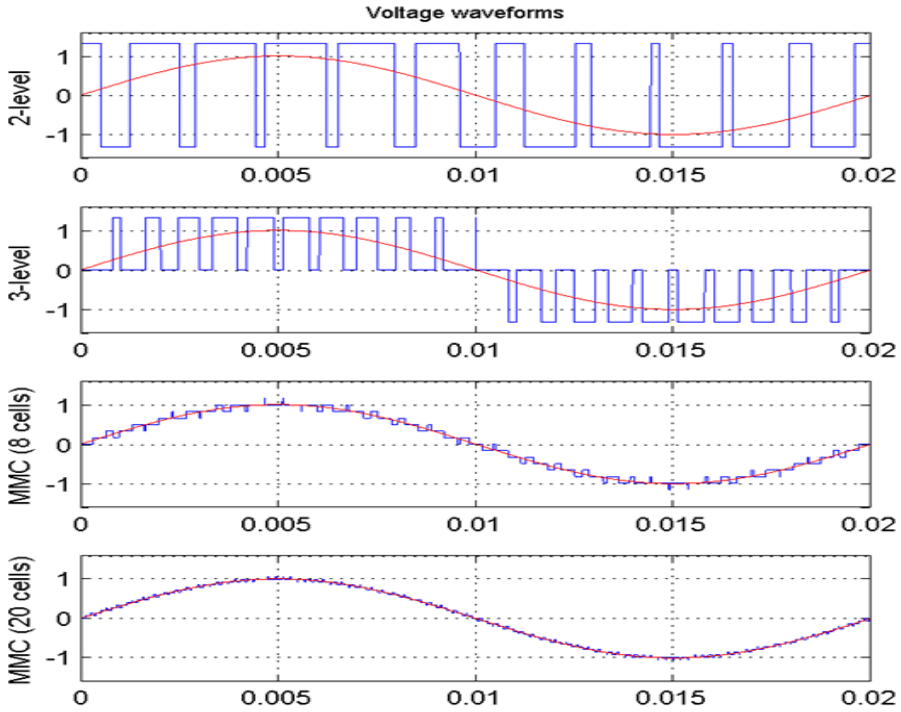


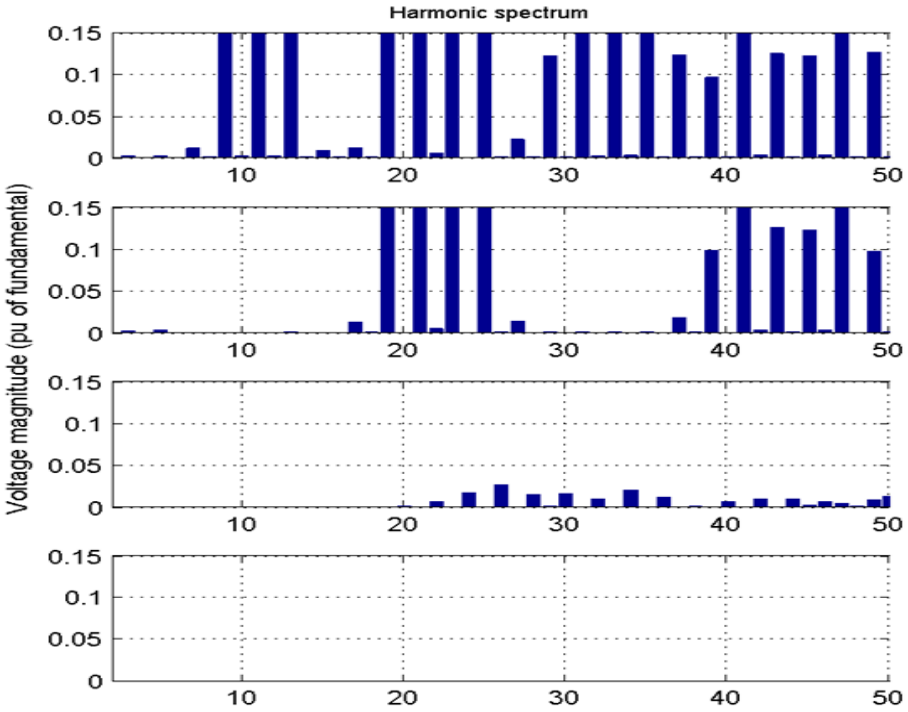
Advances in Transmission Shunt Compensation
SVC TCR Harmonic Generation



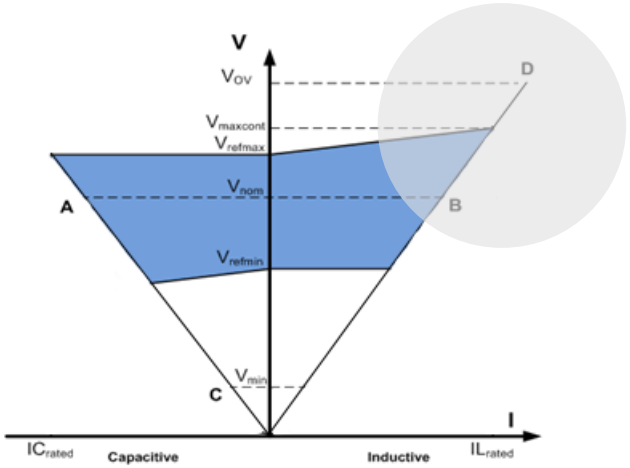


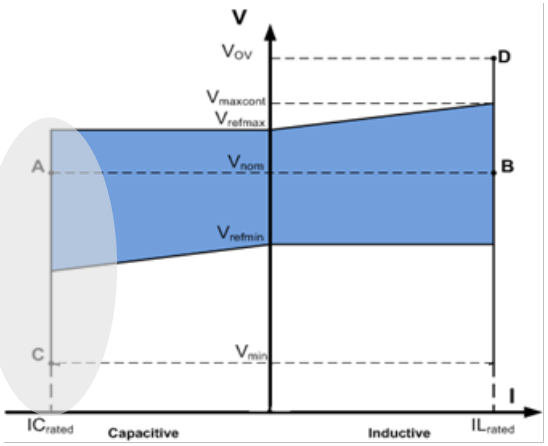
Advances in Transmission Shunt Compensation
STATCOM Harmonic Generation

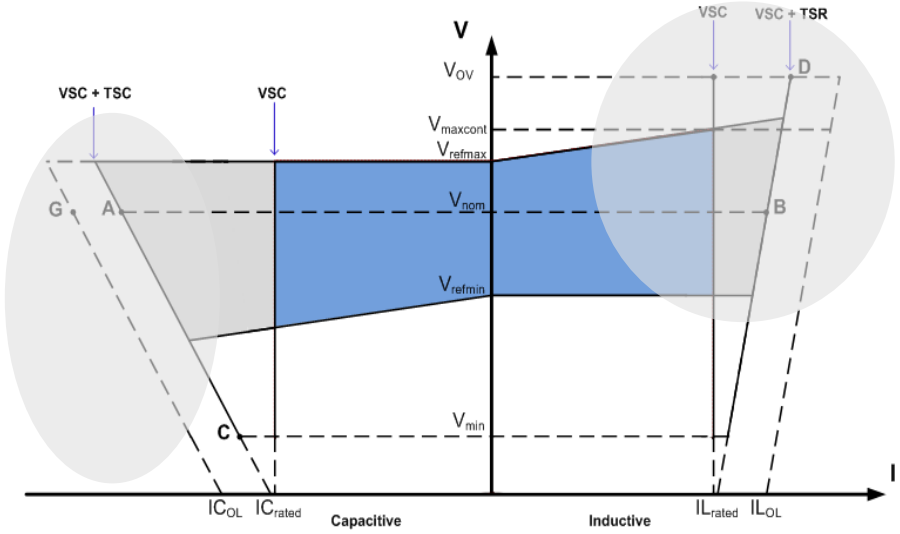




Advances in Transmission Shunt Compensation
VI Characteristics







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