2007 CMU Electricity Industry Conference

Vision of Future Energy Networks Session

“Reactive Power Technologies – Value Proposition and Policy”

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Introduction

- Reactive Power Issues on the Transmission System
  - Deregulation Era Issues
  - Transmission Reliability and System Issues
- Reactive Power Planning and Implementation
  - Reducing vs. Eliminating System Constraints
  - Fixed vs. Dynamic Compensation Requirements
- Advanced Reactive Power Technologies Overview
  - Evolution of Reactive Power Technologies
  - Mechanically Switched / Thyristor Controlled / Converter
- Value Proposition of Reactive Power Technologies
  - Advantages and Impact of Technology Implementation
  - Policy Incentives and Recommendations

Reactive Power Issues on the Transmission System

Reactive Power Issues on Transmission

- **Deregulation Era Issues**
  - Power contracts are creating system operational issues
  - Reactive power planning & scheduling is more difficult
  - Power systems are becoming more challenging to operate
  - Reactive power financing policies are vague
- **Transmission Reliability & System Issues**
  - Existing system not designed for today's delivery needs
  - Increased utilization and stress of transmission system
  - System capacity has not kept pace with supply & demand
  - Higher levels of power quality required for "digital society"
  - Difficulty in licensing and installing new transmission lines
  - Increasing needs for voltage & transient stability correction and other constraint compensation

Reactive Power Technology Solutions

REQUIREMENTS

Upgrade Transmission System Infrastructure

to provide enhanced system capacity, operation, and control in order to maintain a stable, secure, and reliable electric supply network

REACTIVE POWER SOLUTIONS

Comprehensive approach including fixed and dynamic sources

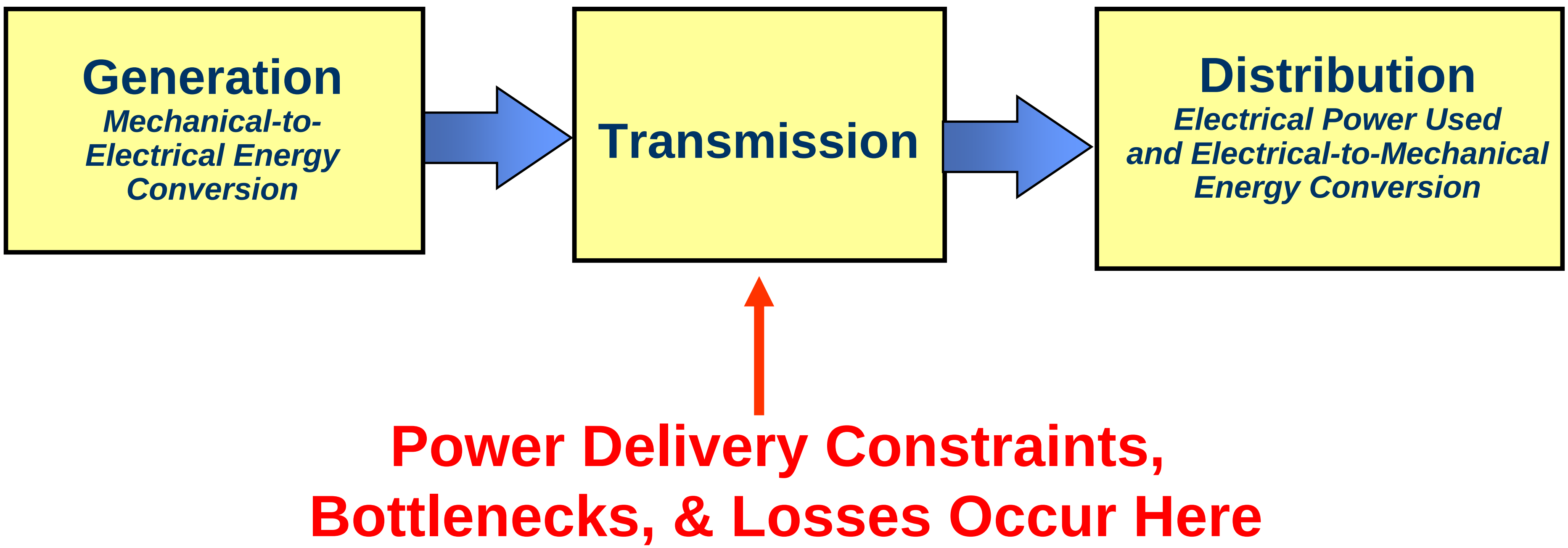
Fixed, Conventional AC Power Equipment

Dynamic, Advanced Power Electronics Technologies

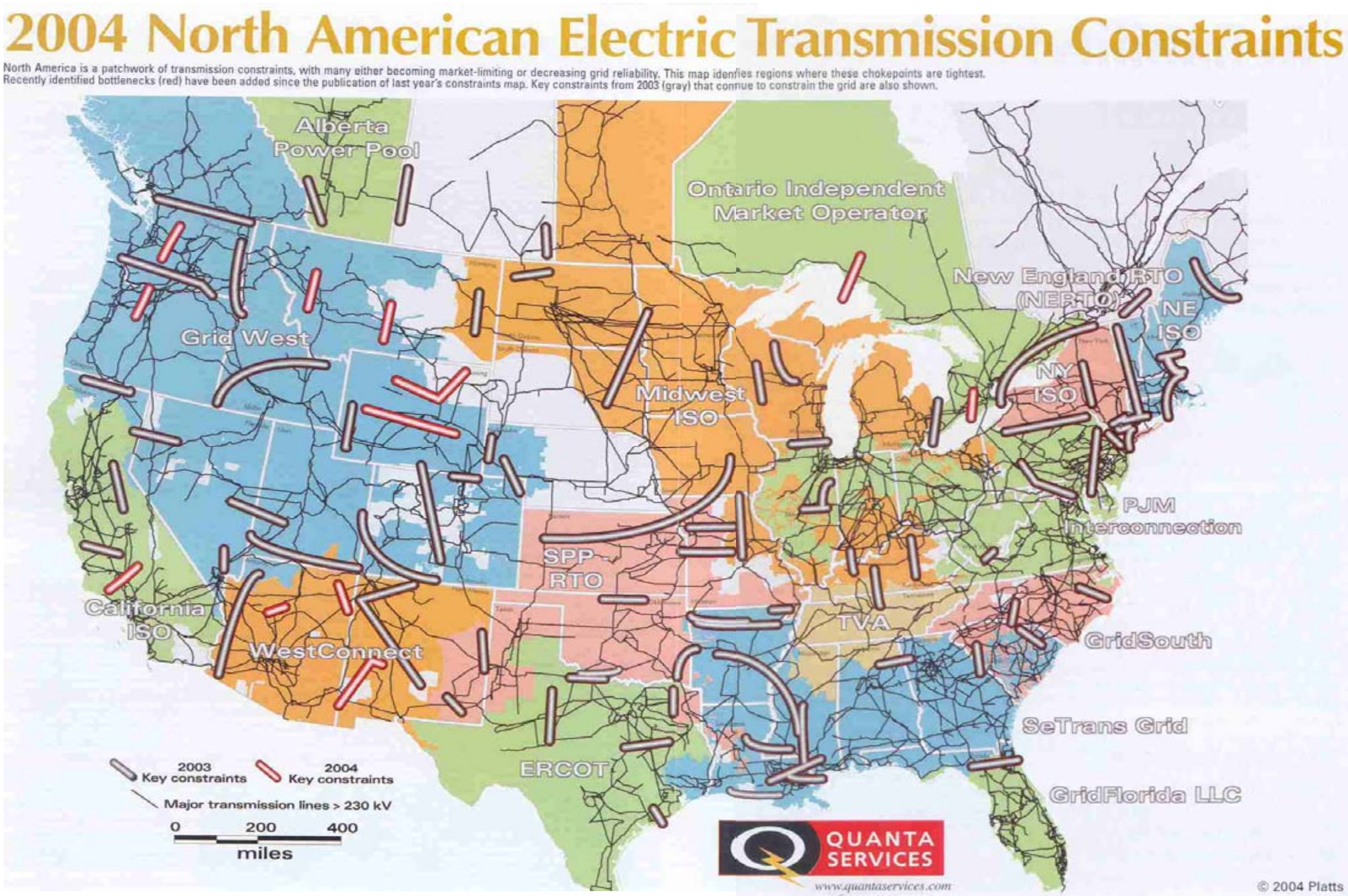
Reactive Power
Planning & Implementation

Control of Power Systems

Power Generation, Transmission and Distribution



National Transmission System Constraints



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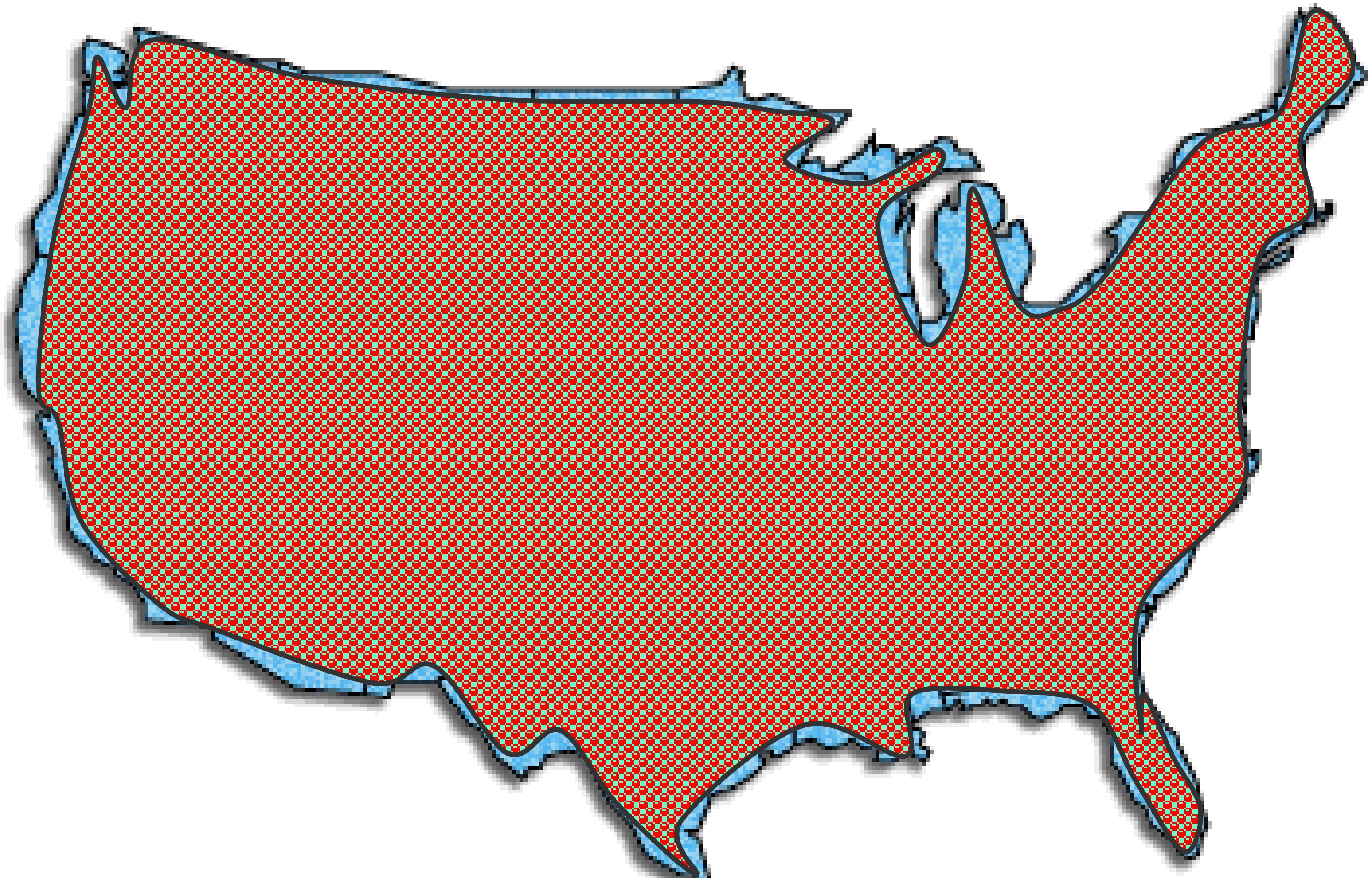
Regional Transmission System Constraints

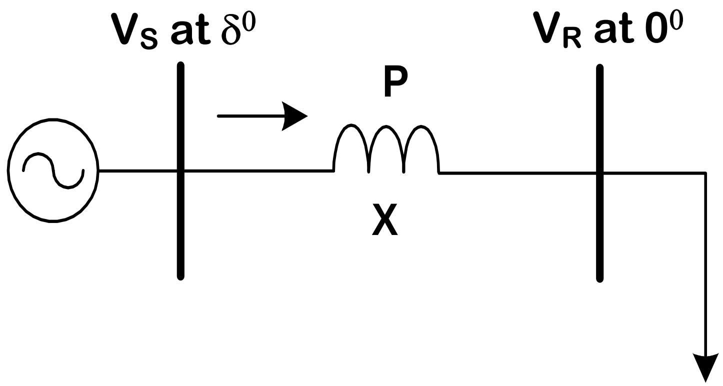


Indicates a possibility for a regional constraint

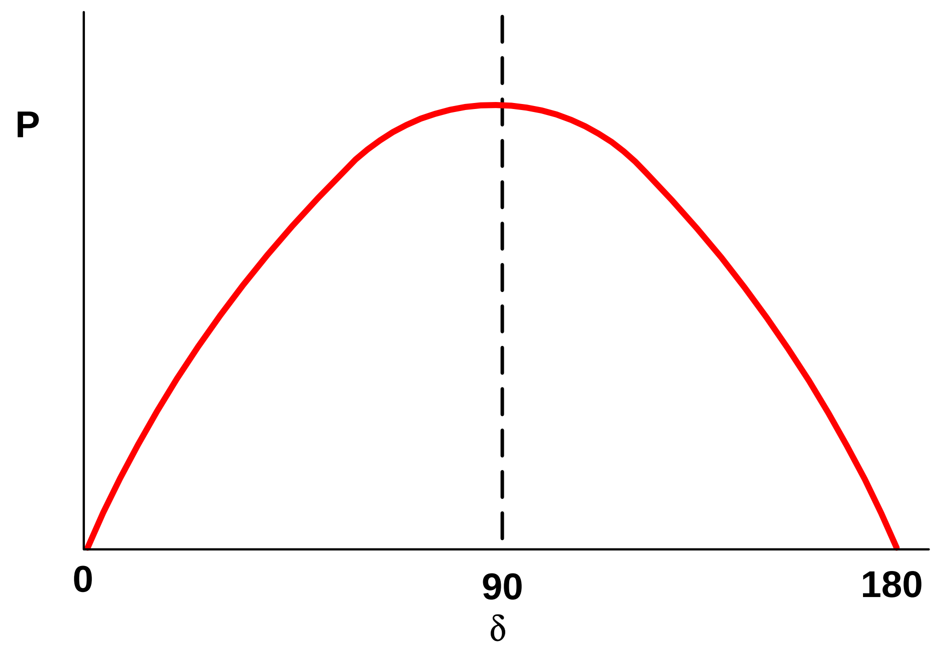
Transmission System Constraints

- **Types of System Constraints and Bottlenecks**
  - **Steady-State Power Transfer Limit**
  - **Transient Stability Limit**
  - **Voltage Stability Limit**
  - **Power System Oscillation Limit**
  - **Short-Circuit Current Limit**
  - **Loop Flow Limit**
  - **Thermal Limit**

Controllability of Power Systems



$$P = \frac{V_S V_R}{X} \sin\delta$$



- Voltage (V_S, V_R)
- Impedance (X)
- Angle (δ)

“Reducing” Transmission Constraints

- **Conventional Solutions “Reduce” Constraints**
  - **Switched Shunt Capacitors and Reactors (V)**
  - **Series Capacitors (X)**
  - **Transformer LTC’s (V)**
  - **Phase Shifting Transformers (δ)**
  - **Synchronous Condensers (V)**
  - **Special Stability Controls (V, P, or X)**
  - **Others (When Thermal Limits are Involved)**

“Reducing” Transmission Constraints

- **Benefits of Conventional Solutions Applied to “Reduce” System Constraints**
  - **Increased Loading**
  - **More Effective Use of Transmission Corridors**
  - **Added Power Flow Control**
  - **Increased System Security**
  - **Increased System Reliability**
  - **Added Flexibility in Siting New Generation**
  - **Elimination / Deferral of Need for New Transmission Lines**

“Eliminating” Transmission Constraints

- **Advanced Power Electronics Solutions**
  - **Advanced Control Technologies Developed and Applied to “Eliminate” System Constraints**
  - **FACTS**
    - ➔ **Shunt: SVC, STATCOM**
    - ➔ **Series: TCSC, SSSC**
    - ➔ **Combined: UPFC**
  - **HVDC**
    - ➔ **Back-to-Back DC Links**

“Eliminating” Transmission Constraints

- **Benefits of Power Electronics Solutions Applied to “Eliminate” System Constraints**
  - Increased Loading
  - More Effective Use of Transmission Corridors
  - Added Power Flow Control
  - Increased System Security
  - Increased System Reliability
  - Added Flexibility in Siting New Generation
  - Elimination/Deferral of Need for New Transmission Lines

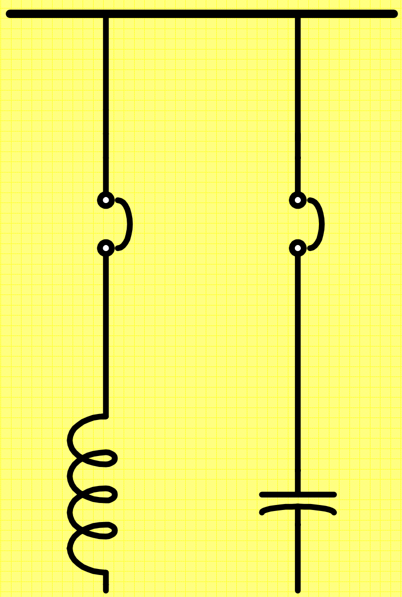
Reactive Power Planning & Implementation

- **Reactive Power Planning Considerations**
  - **Determine System Performance Issues and Constraints**
  - **Identify Needs for “Shunt vs. Series” Compensation**
  - **Identify Needs for “Fast vs. Slow” Switching Speeds**
  - **Evaluate the performance, economics, and value criteria of the various solutions available on the market**
  - **Perform detailed systems analyses and develop well-defined technical specifications**
  - **Establish detailed project management scheme for successful implementation**

Advanced Reactive Power Technologies Overview (Shunt Devices)

Shunt Compensation Evolution

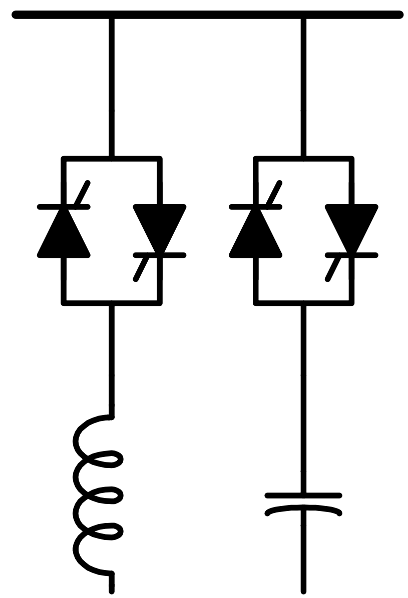
Conventional



Mechanically Switched

Slow VARs

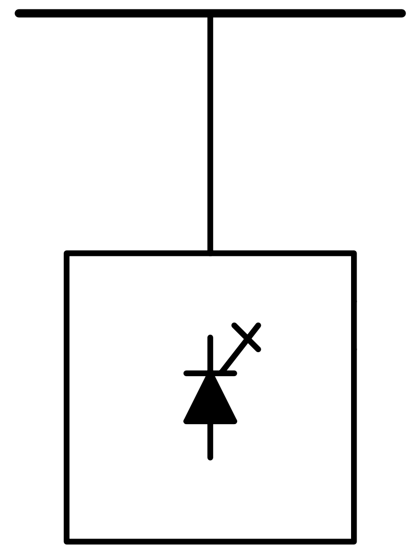
SVC



Thyristor Controlled

Fast VARs

STATCOM



Converter

Fast VARs

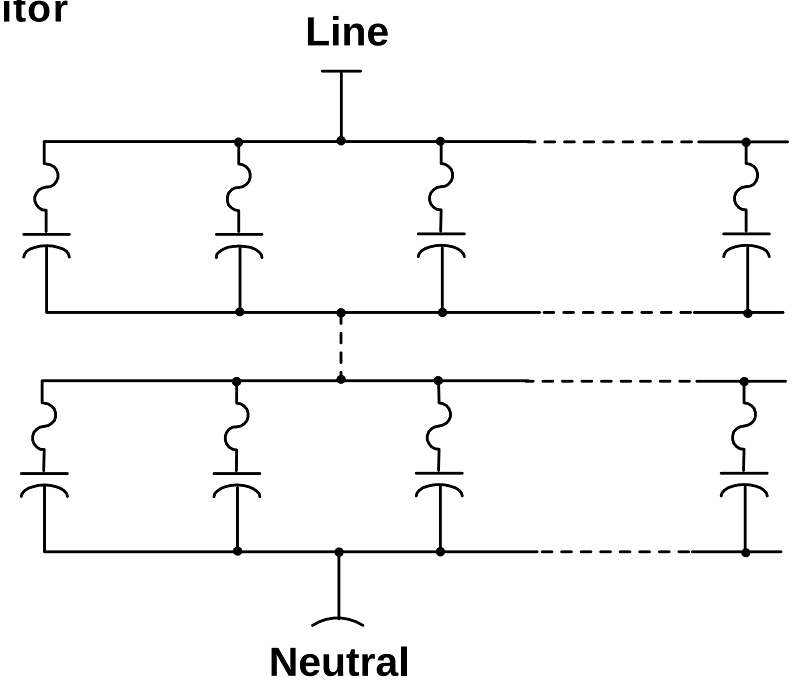
Shunt Capacitor Bank

Cap Bank ΔV Issue

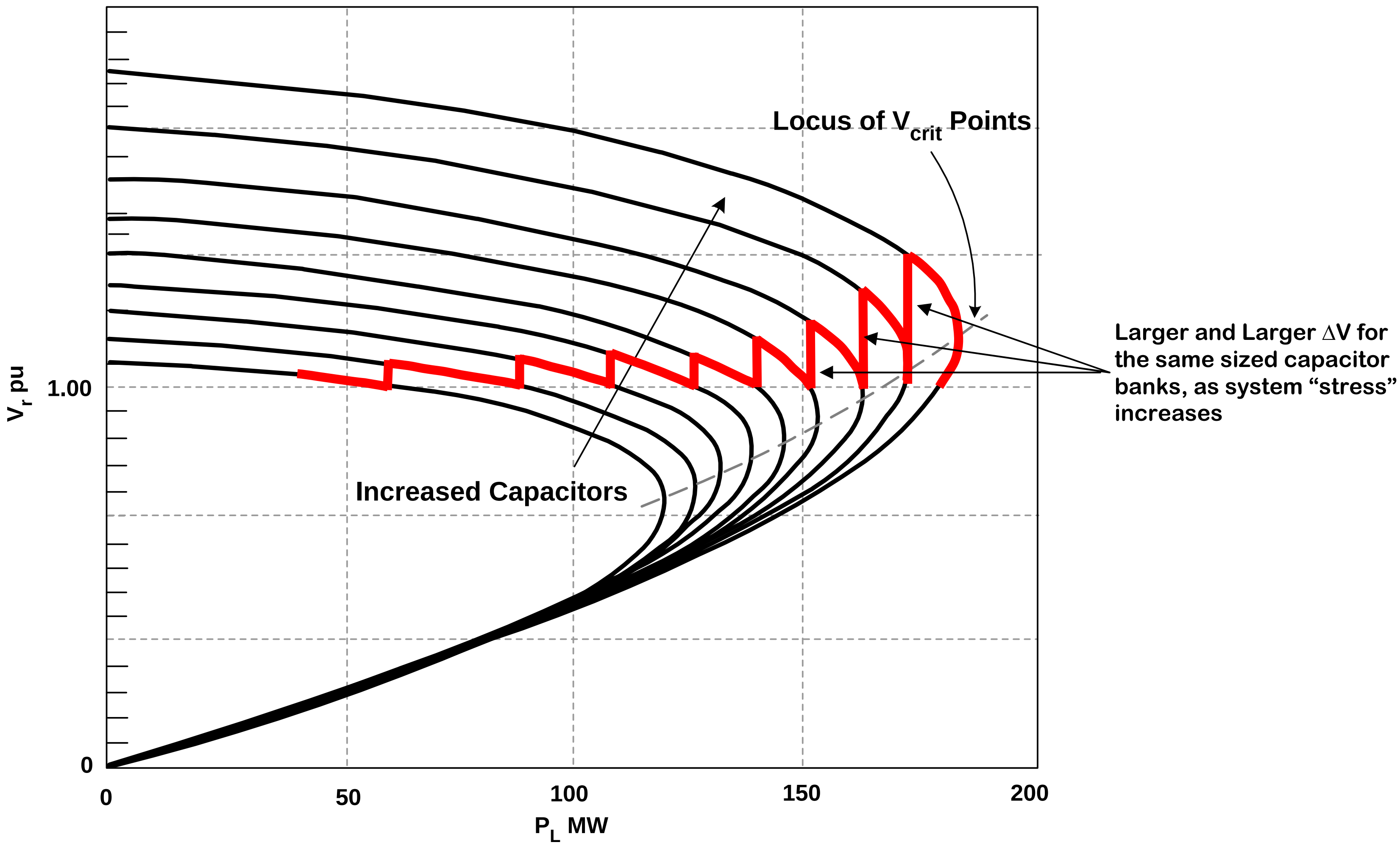
- “First-response” is to apply shunt capacitor banks
- Limit ΔV to 2%-to-3% When Switching

$$\Delta V \cong \frac{\text{Mvar}_{\text{capacitor}}}{\text{MVA}_{\text{short circuit}} - \text{Mvar}_{\text{capacitor}}} \left(\text{for strong systems}\right)$$

- Larger Banks, Multiple Steps
- Configuration
  - Series groups/parallel units
  - Imbalance considerations



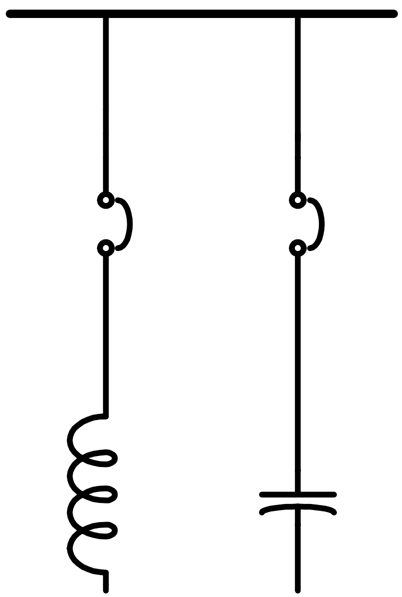
ΔV Limiting for Highly Stressed Systems



SVC Technology

Shunt Compensation Evolution

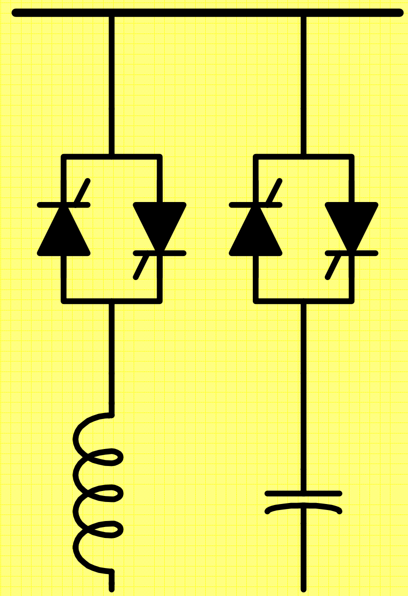
Conventional



Mechanically Switched

Slow VARs

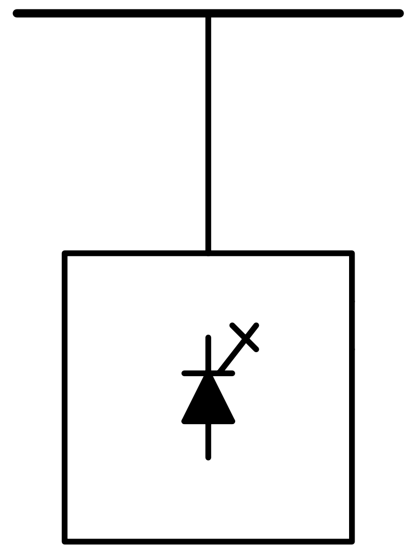
SVC



Thyristor Controlled

Fast VARs

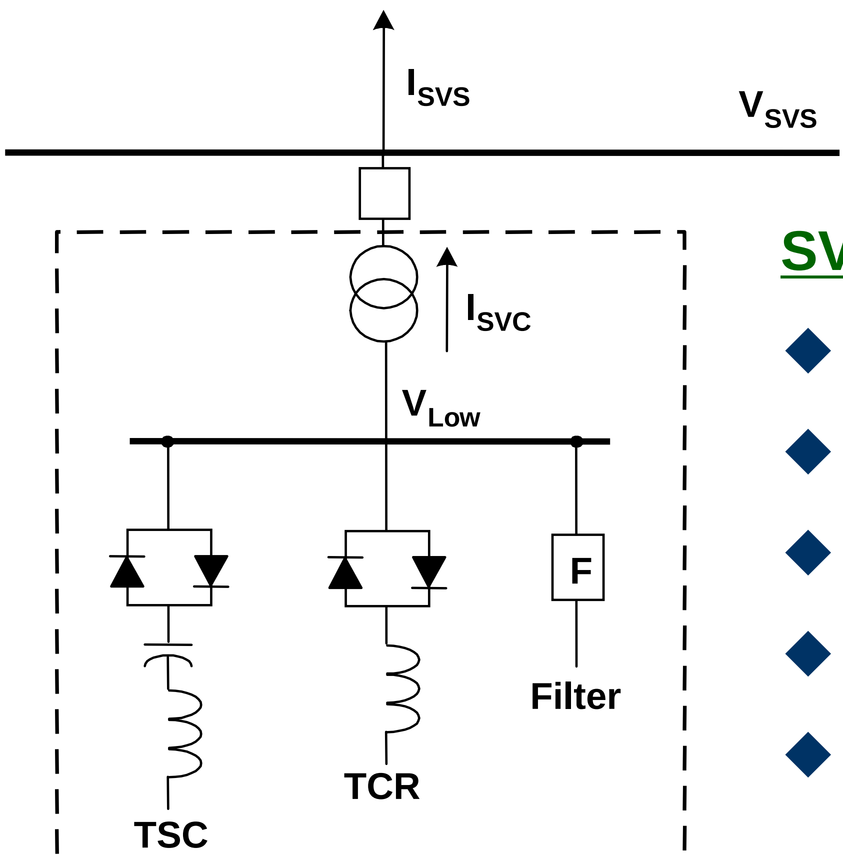
STATCOM



Converter

Fast VARs

SVC – Typical Configuration

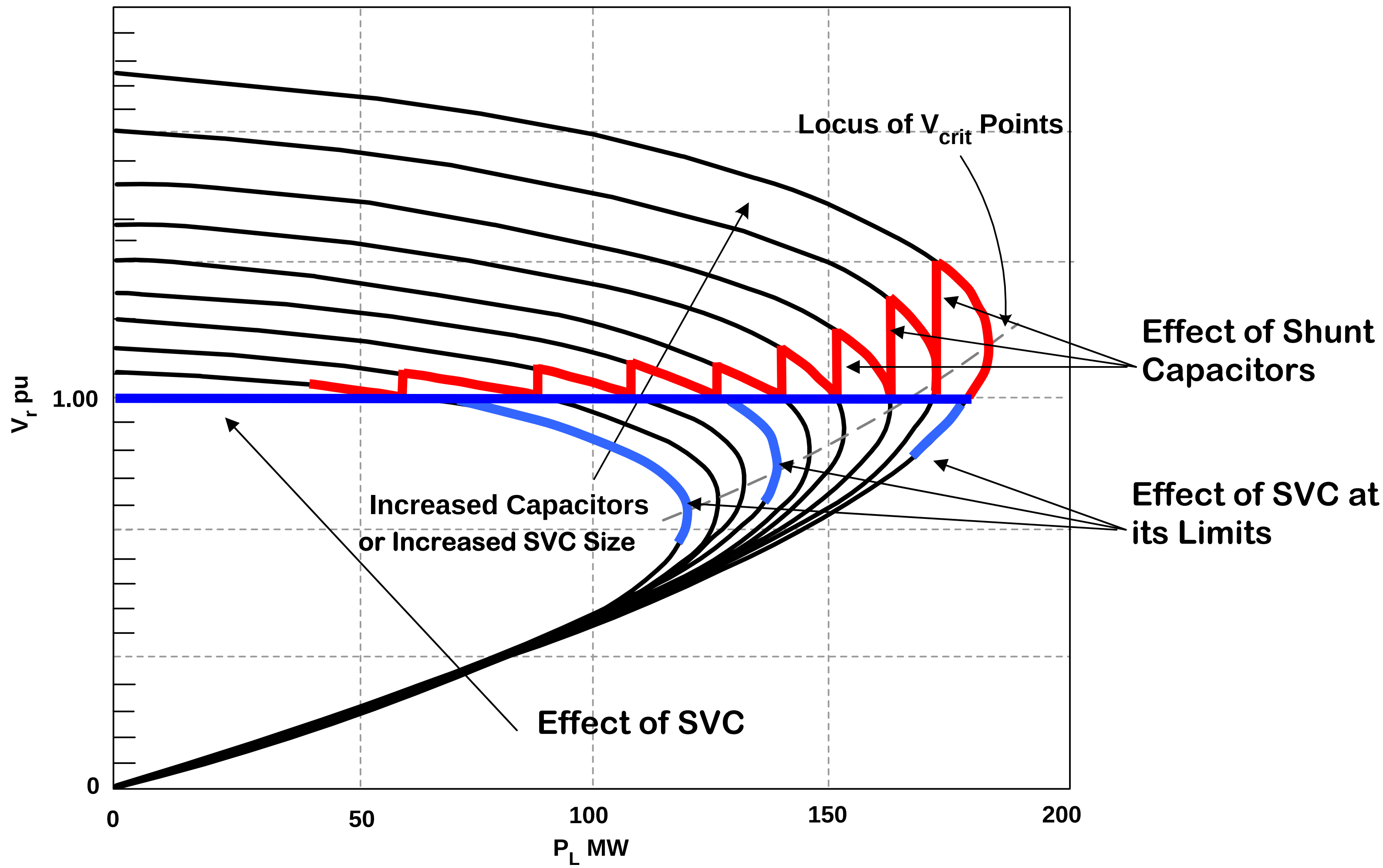


Static Var Compensator
(SVC)

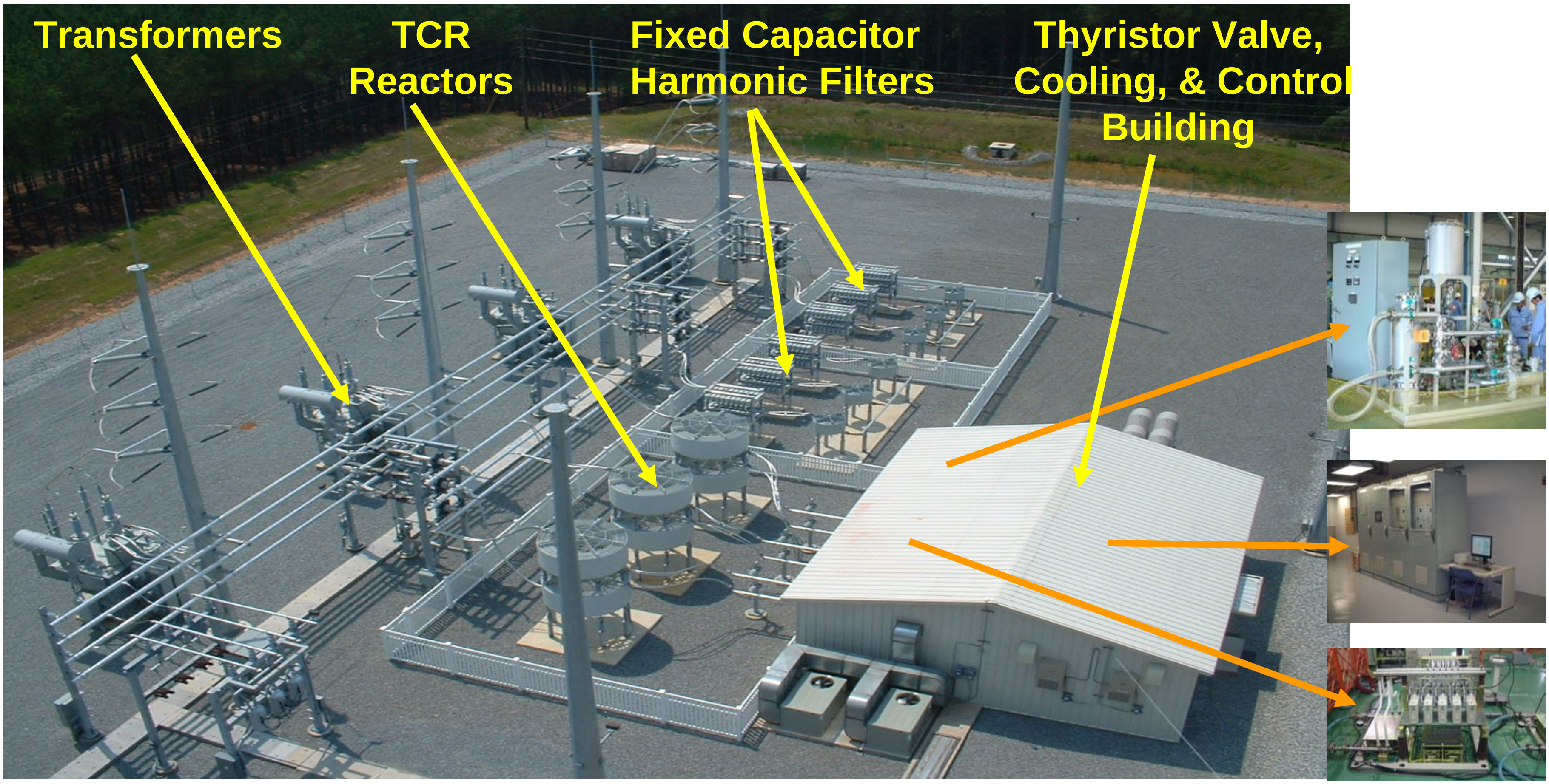
<u>SVC MAIN EQUIPMENT</u>

- Coupling Transformer
- TCR (Thyristor Controlled Reactor)
- TSC (Thyristor Switched Capacitor)
- Filter and/or Fixed Capacitor
- Various configurations of the TSC, TCR, and Filter / Cap branches can be applied for specific ratings and system applications

ΔV Limiting for Highly Stressed Systems



SVC Installation Example

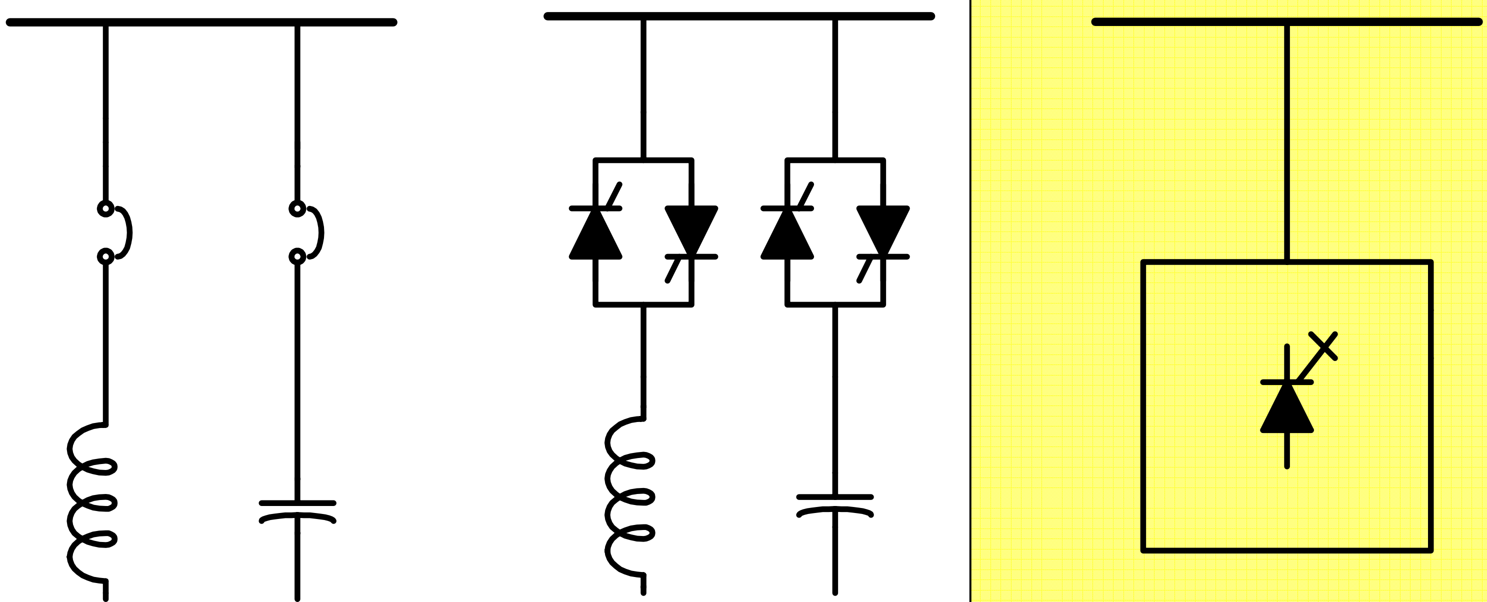


Laurens County 115 kV, +87 MVAr SVC System (LTT-Based)

STATCOM Technology

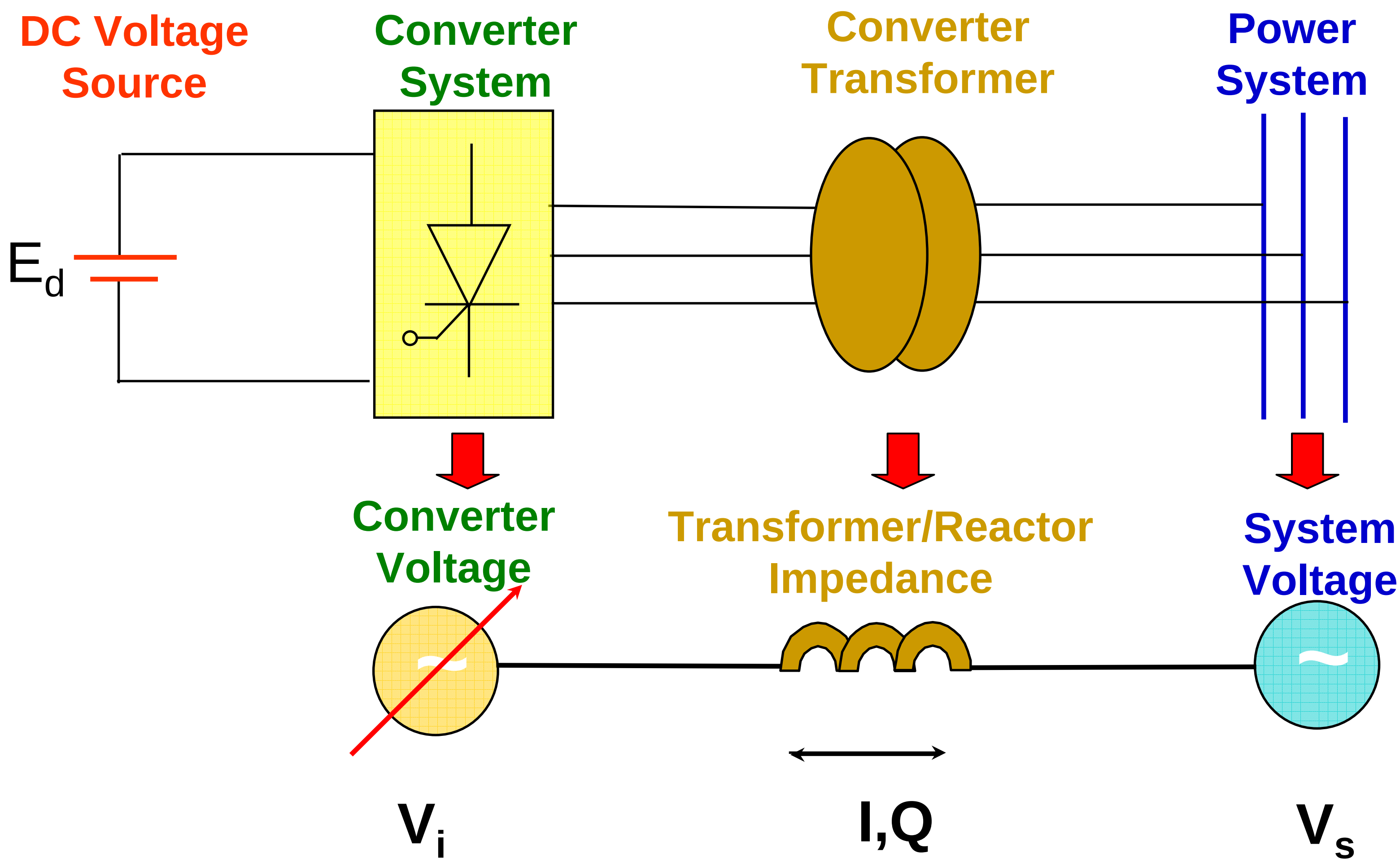
Shunt Compensation Evolution

Conventional	SVC	STATCOM



Mechanically Switched	Thyristor Controlled	Converter
Slow VARs	**Fast VARs**	**Fast VARs**

STATCOM – Typical Configuration



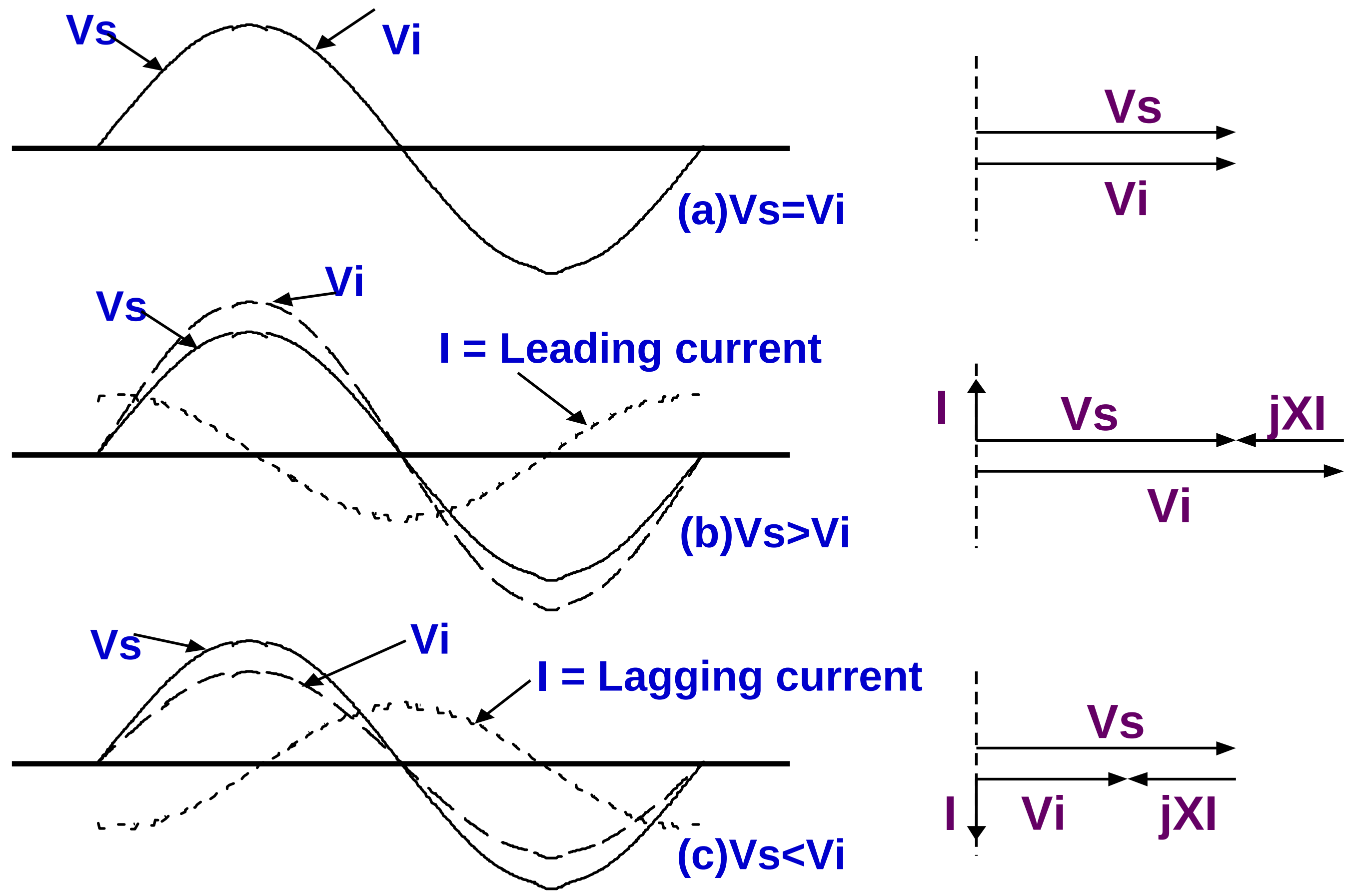
STATCOM - Principal Operation Modes

Mode | **Waveform** | **Phasor**

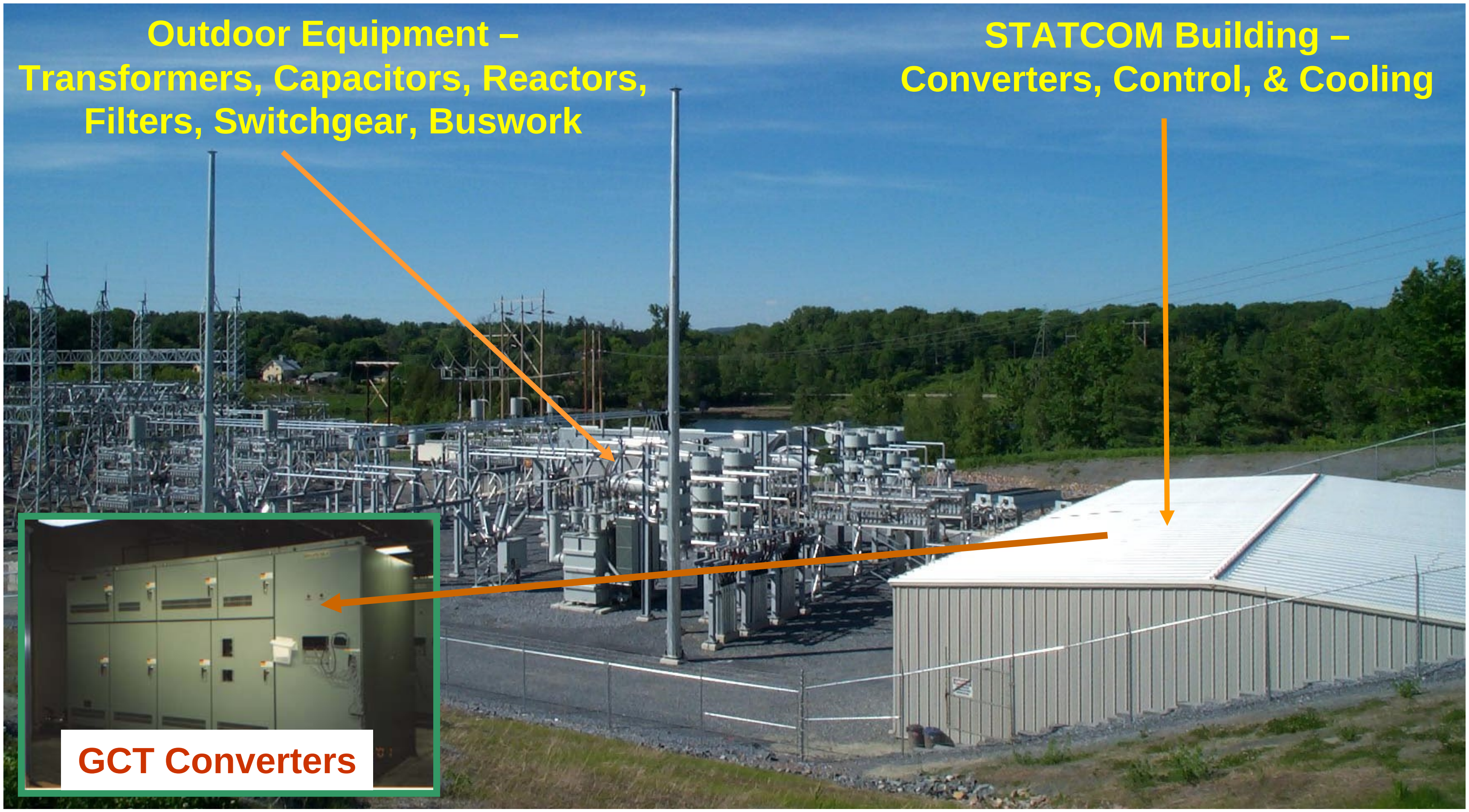
No load mode

Capacitive Operation Mode

Inductive Operation Mode

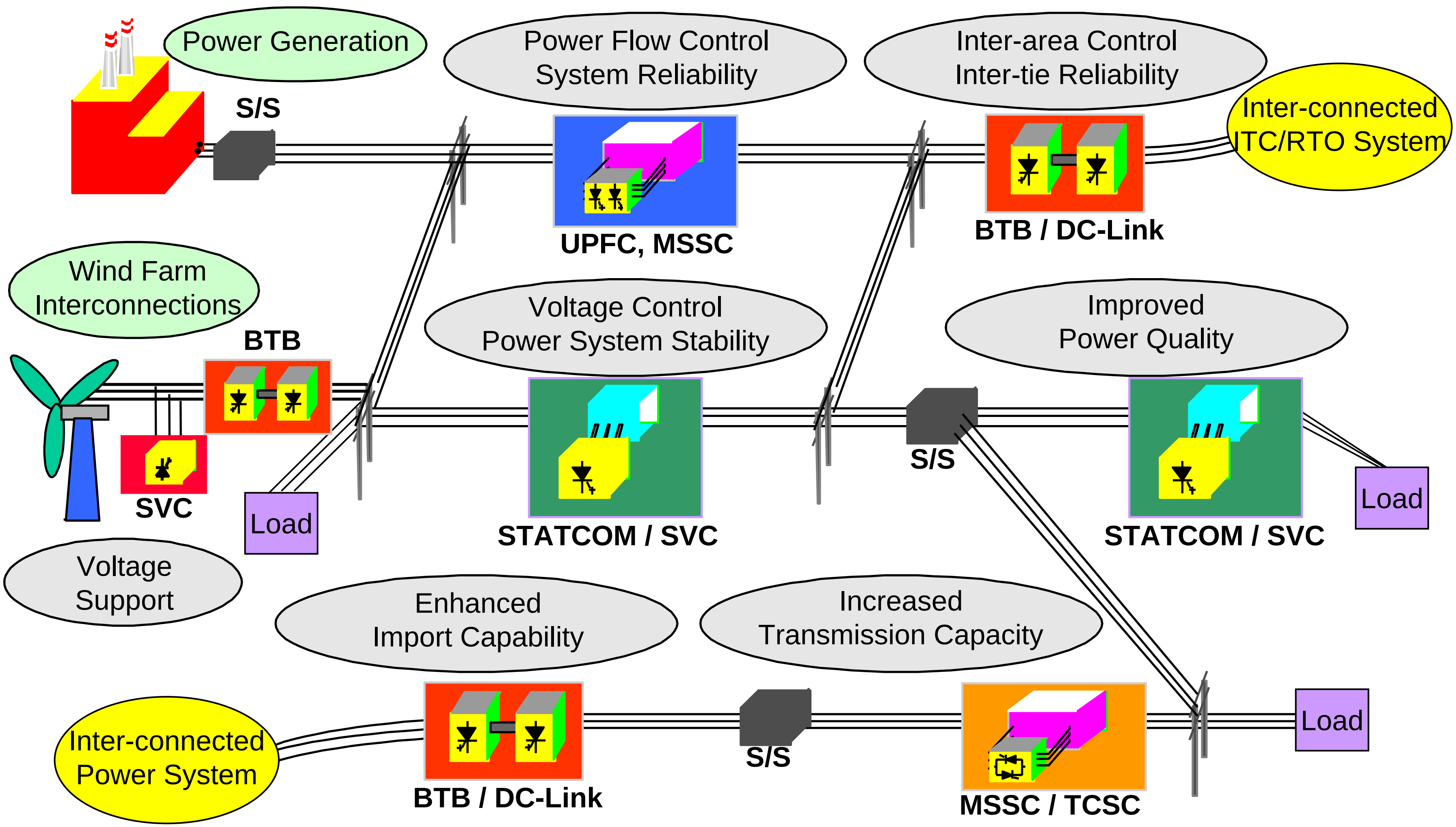


STATCOM Installation Example



Essex +133 / -41 MVA, 115 kV STATCOM System (GCT-based)

Power Electronics Control Technologies



Value Proposition and Policy Aspects of Advanced Reactive Power Technologies

Value Proposition of Advanced Reactive Power Technologies

- **Economic Advantages**
  - Financially sound investments for grid enhancement
  - Transfer more power reliably across existing networks
  - Fraction of expense associated w/ conventional solutions
- **Positive Environmental Impact**
  - Significantly reduces or defers the need for new t-lines
  - Implemented at existing substations w/in property bounds
  - Eliminates right-of-way purchases / eminent domain issues
  - Stabilizes interconnection of renewable energy (e.g., wind)
  - Allows greater flexibility in siting new generation
- **Efficient Implementation**
  - Turnkey projects completed in 12 to 18 months
  - Years less than siting, permitting, & constructing new lines

Value Proposition of Advanced Reactive Power Technologies

- **Proven Reliability**
  - 30+ years of successful worldwide operating experience
  - Reliabilities leading to enhanced quality of power delivery
  - Results in increased power delivery availability
- **More Efficient Utilization/Expansion of Grid Assets**
  - Increases real power capacity of existing systems
  - Integrates intelligence-based control of networks
  - Provides dynamic response to system contingencies
  - Facilitates non-synchronous grid interconnections
  - Enhances necessary grid expansion where required
- **Control of Power Flow**
  - Changing the "laws of physics" on the power system
  - Directing power delivery for maximum operating efficiency

Policy and Value Proposition

- **Equivalent Value of Power Electronics Technologies**
  - **FACTS are "generators" of Vars (Reactive Power)**
    - **Vars are needed to maintain system voltage and stability**
  - **DC Links are "controllers" of Mega-Watts (Real Power)**
    - **Controllable Mega-Watts are needed to regulate operation**
- **Policy Must Allow Incentive to Realize this Value**
  - **"Merchant Plant" approach to transmission technologies**
  - **Place value on Generated Vars and Controllable Mega-Watts**
- **Effective Policy will lead to System Improvements**
  - **Wide-scale power electronics will enhance grid reliability**
  - **Necessary grid expansions will be better facilitated**

Policy Recommendations

- **Accelerated Depreciation of Technology Investments**
  - Accelerated depreciation for investments in technologies that are, from a public policy and technical perspective, clear alternatives to the protracted process of transmission line construction.
- **Increased Rate-of-Return on Technology Investments**
  - Increased rate of return on investment in transmission assets should be commensurate with the value to the system of having adequate transmission capacity. Compared to costs of outages, congestion and lack of access to low-cost electricity, the cost of upgrade is minimal.
- **Value of Technology Recognized through Incentives**
  - Consistency between the regulations and incentives that have been established for generator interconnections (merchant plants & IPPs) with respect to generated Vars and controllable Mega-Watt values.