Tutorial on Static Var Compensators

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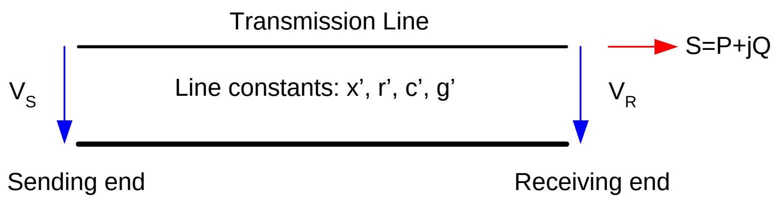
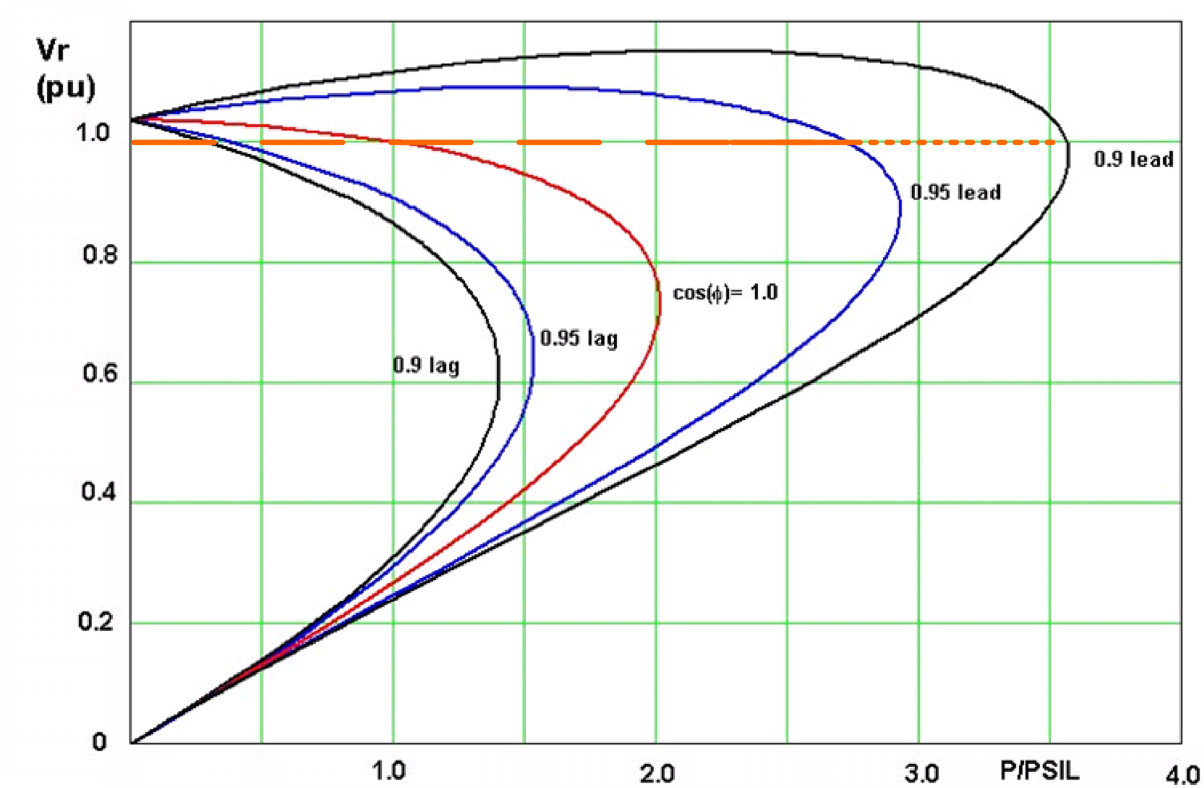
OUTLINE

- Module 1 - Reasons for reactive power compensation
- Module 2 - Basic characteristics of SVC
- Module 3 - SVC configurations and implications
- Module 4 - Main components in existing installations
- Module 5 - Thyristor valves
- Module 6 - Regulation, Control and Protection system
- Module 7 - Commissioning
- Module 8 - Standards
- Module 9 - References

Transmission Line Characteristics
Receiving End Voltage during Power Transfer



P_{SIL} = Surge impedance loading
Example: 200 km line with no losses
Effect of capacitive and inductive loading



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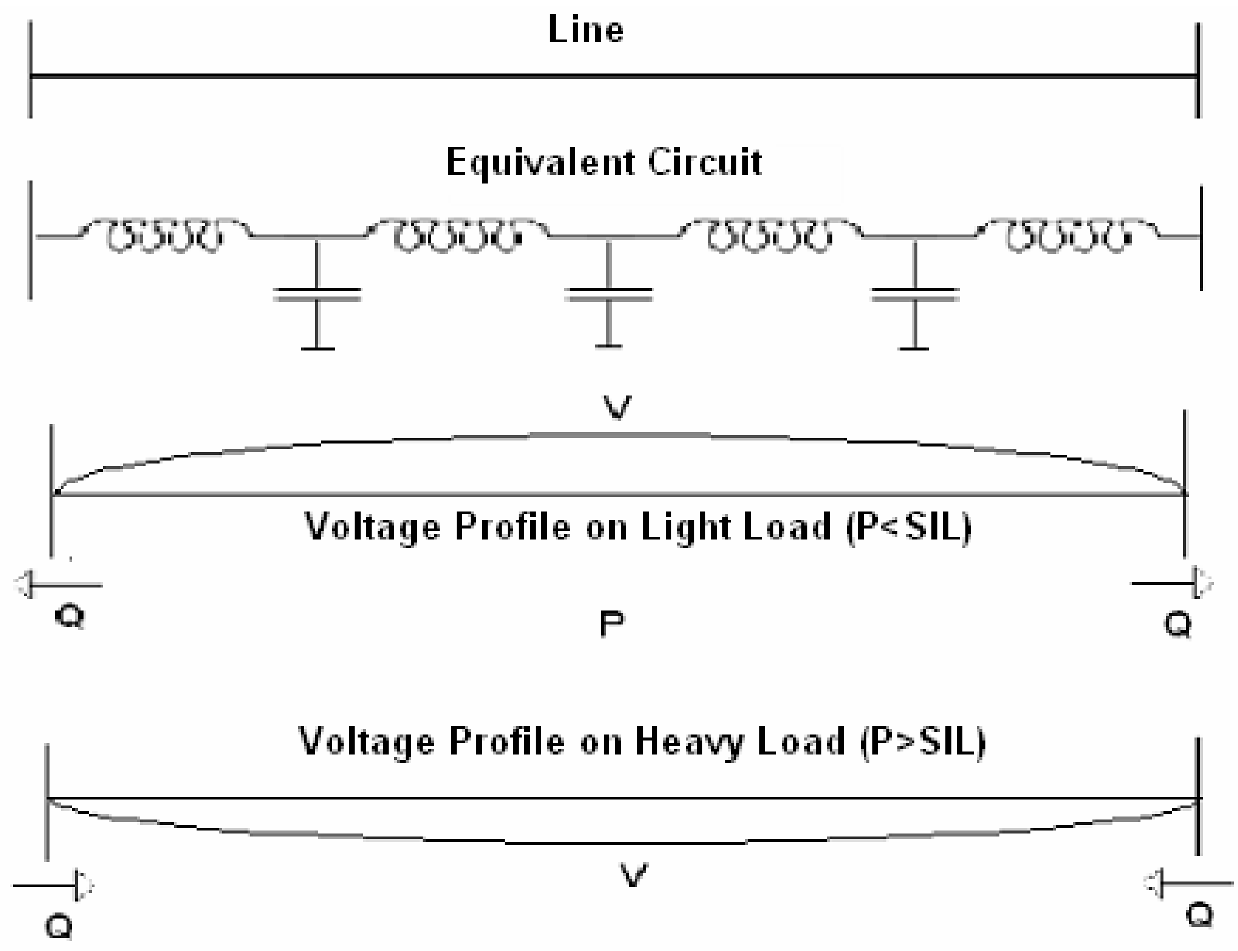
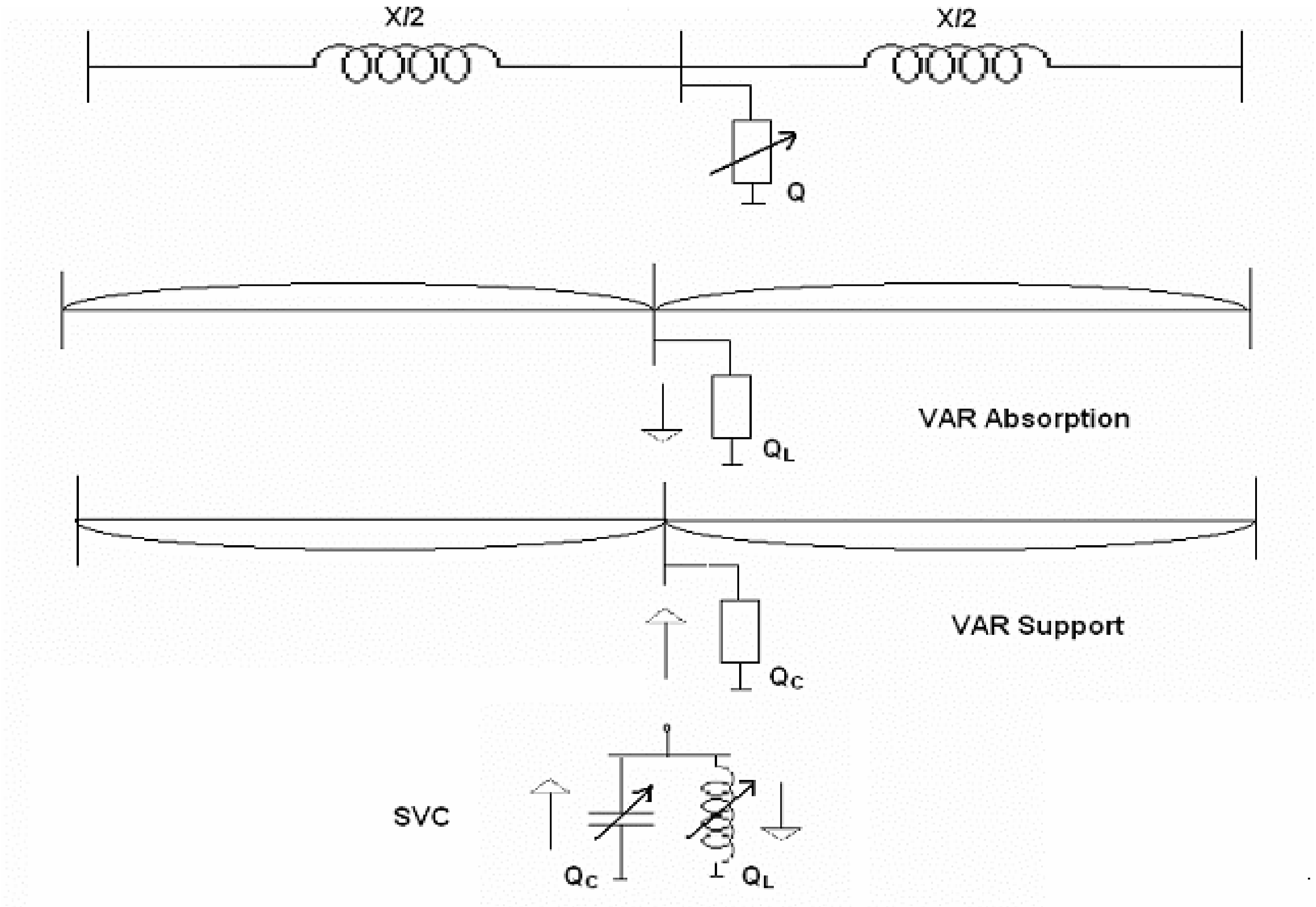
Voltage Profile along a Long Transmission Line



Voltage Profile along a Long Transmission Line with Midpoint Reactive Power Compensation



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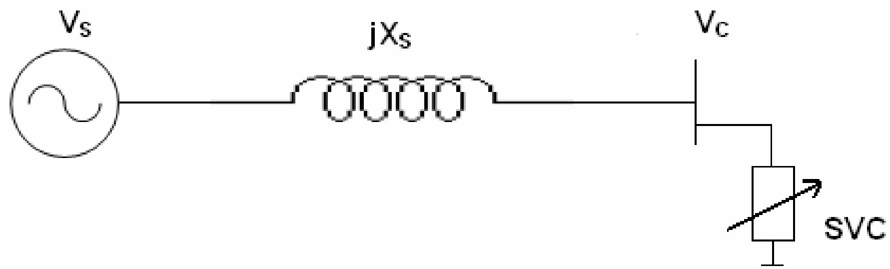
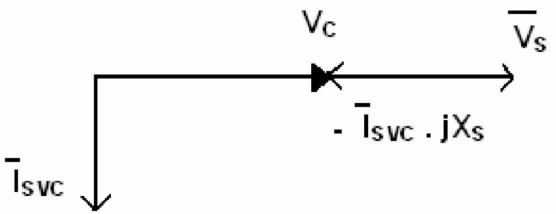
Power System Improvements with Var Control: Influence of a Reactive Power Compensator



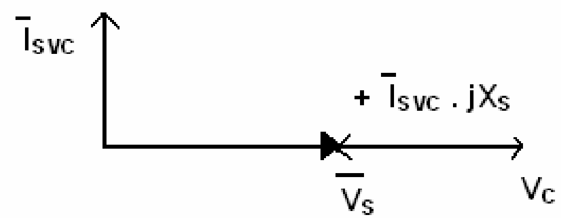
$$\overline{V}_C = \overline{V}_S - \overline{I}_{SVC} \, . \, jX_S$$

1. SVC Inductive



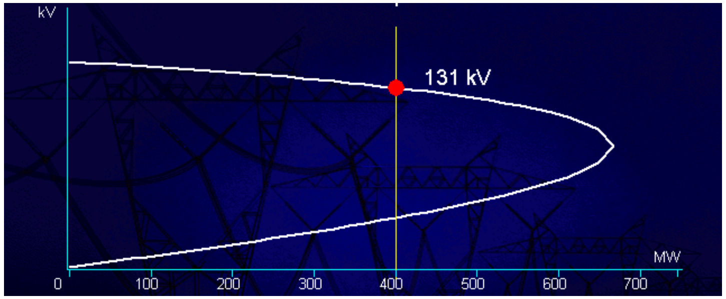
$V_C < V_S$ Reactive Power (VAR) Absorption reduces Compensator Bus Voltage

2. SVC Capacitive

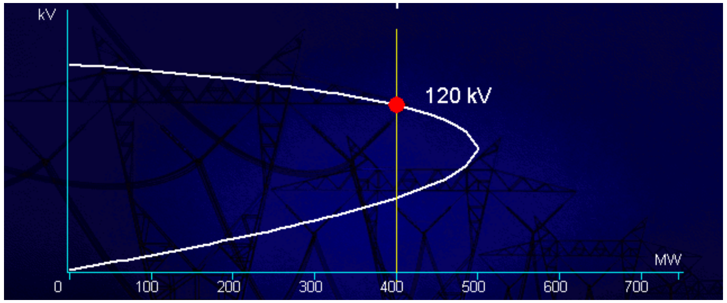


$V_C > V_S$ VAR Supply increases Compensator Bus Voltage

Voltage Stability



Normal System Conditions – 2000 MVA Short Circuit



n-1 Contingency – 1500 MVA Short Circuit Level

- Voltage stability limits power transfer
- Adequate stability margin required for contingencies
- Inadequate reactive power reserve risks voltage collapse
- Dynamic voltage support via SVC permits higher power transfer

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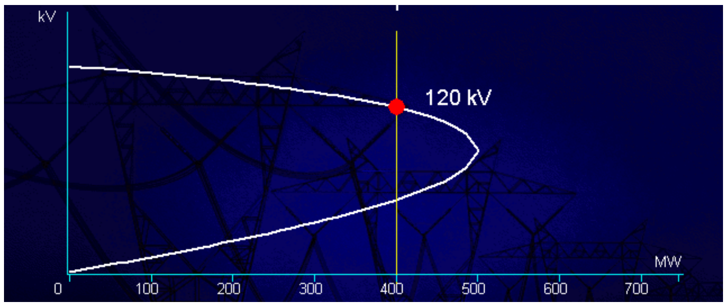
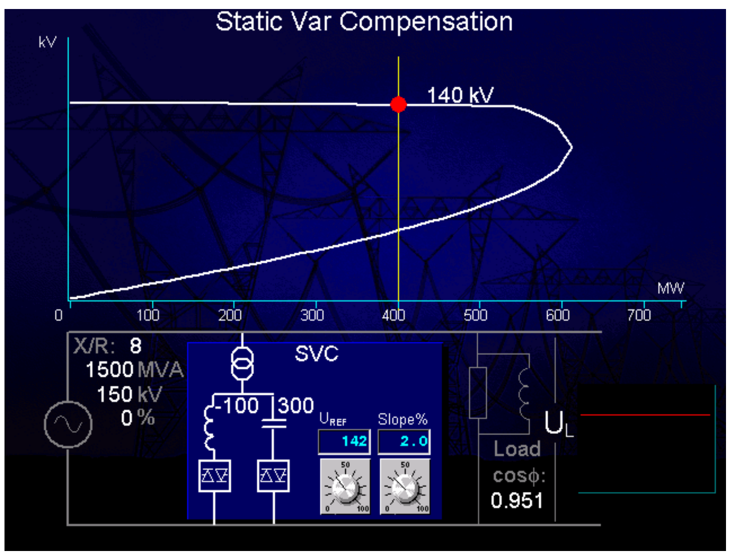
Increased Transfer with Dynamic Voltage Support



n-1 Contingency – 1500 MVA Short Circuit Level



- Maximum power flow depends on network and <u>voltage support</u>
- Steady state voltage via slow devices, e.g., switched capacitors, tap changers
- Dynamic reactive power reserve required for contingencies
- Improved post-contingency voltage profile due to SVC dynamic reactive support

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SVC Applications in LV Transmission Systems

- **Power factor correction**

  Improvement of load voltage

  Decrease of transmission system losses

  - to be added to power plant installations
  - to be added to operating costs

- **Load balancing**

  Symmetrisation of system voltage

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SVC Applications in HV Transmission Systems

- **Voltage control**
  Improvement of system voltage regulation under varying load conditions
- **Increase in steady state power transfer capacity**
- **Enhancement in transient stability**
- **Prevention of voltage instability**
- **Augmentation of system damping**
- **Improvement of HVDC link performance**

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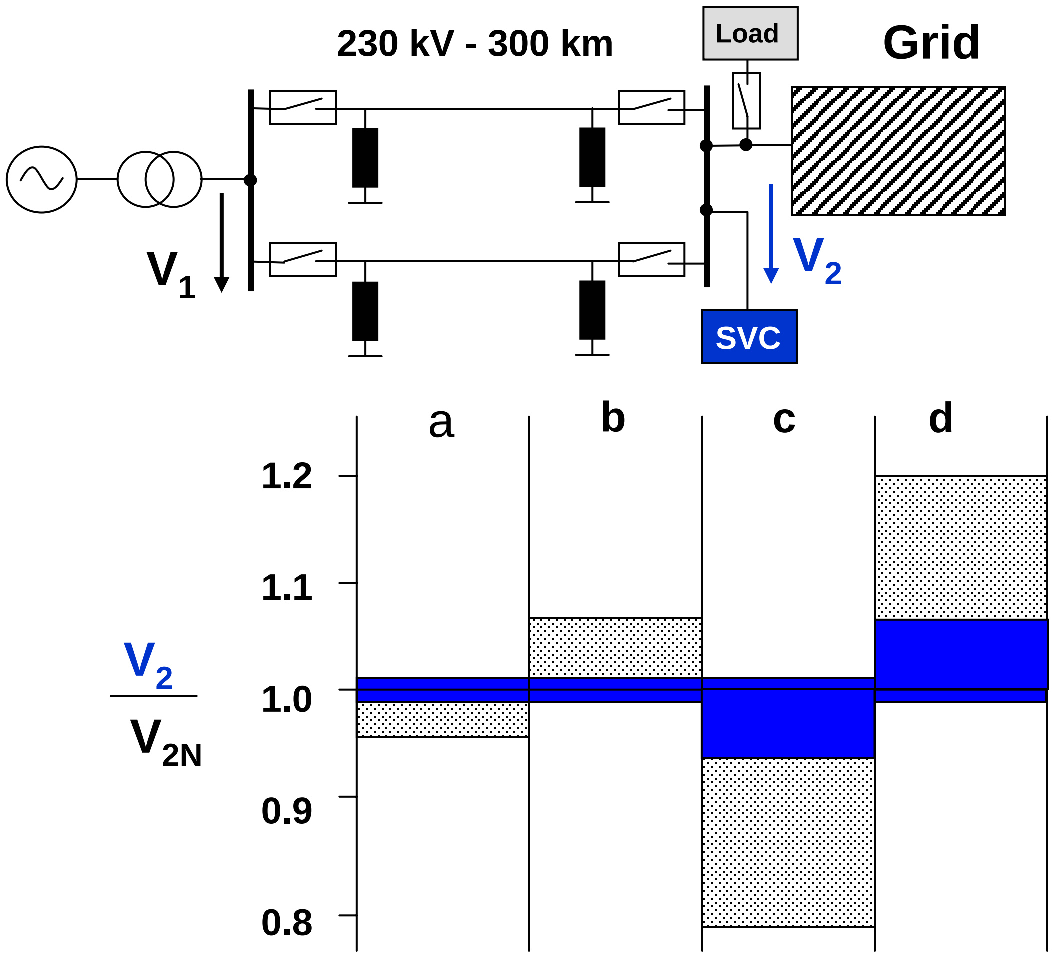
Voltage Control: Voltage in the System for Various Operating Conditions



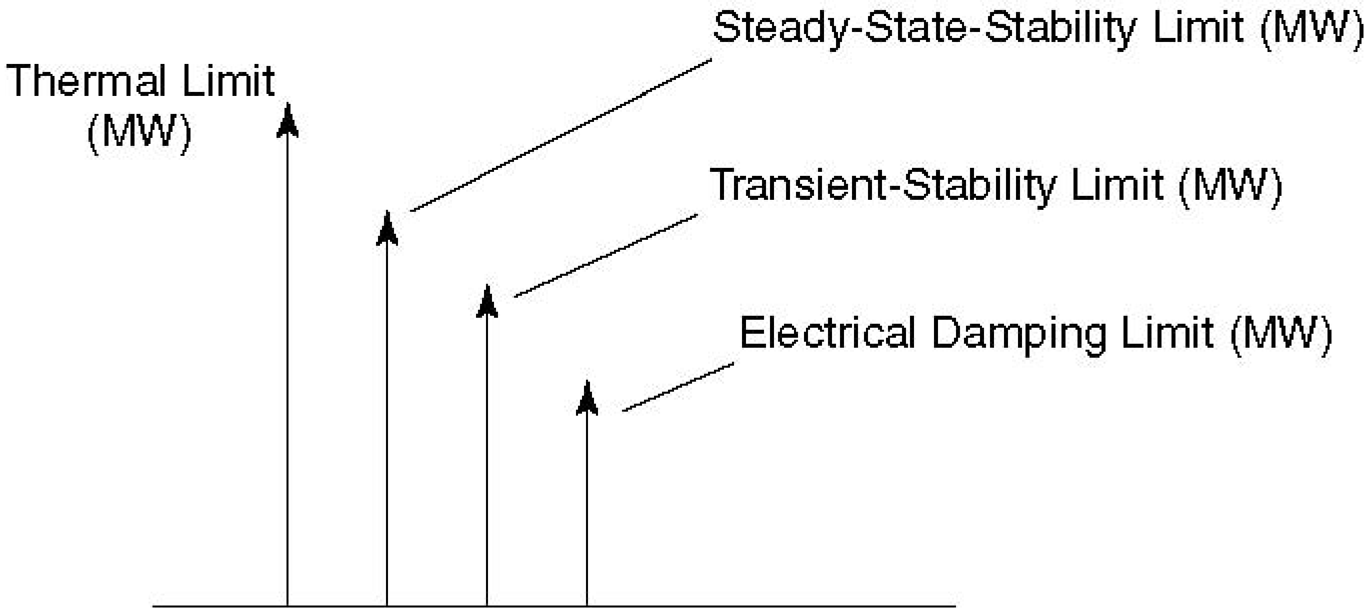
System Conditions:

- **a** Heavy load
- **b** Light load
- **c** Outage of 1 line (at full load)
- **d** Load rejection at bus 2

without SVC

with SVC

Increase in Steady State Power Transfer Capacity: Comparison of different limits of power flow



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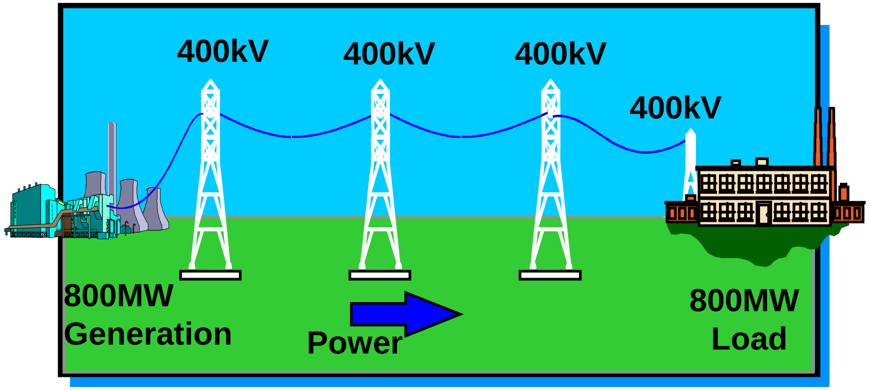
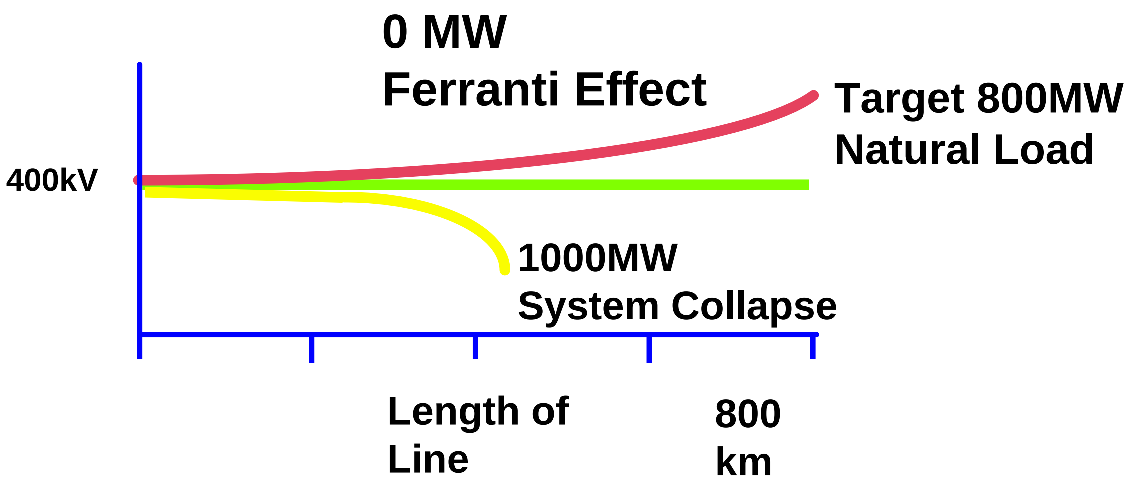
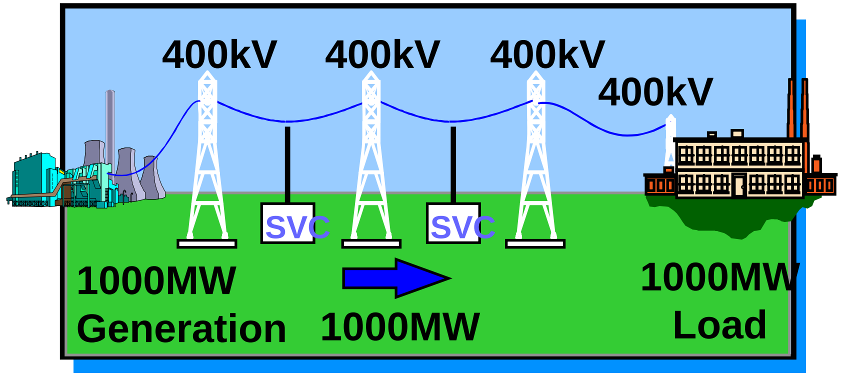
The problems of distance & variable load



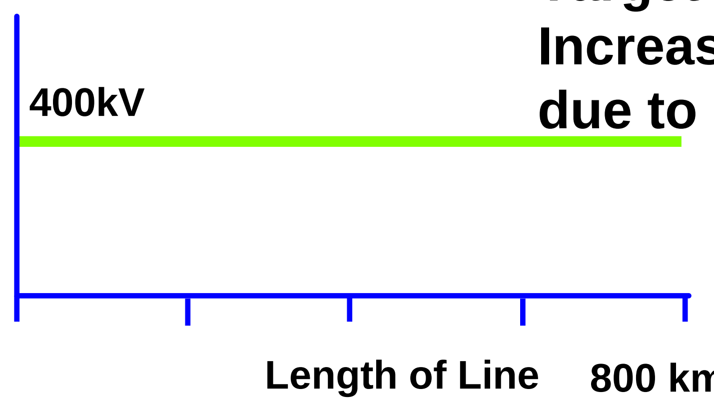
400kV Transmission Line
(uncompensated)



The problems of distance & variable load



Shunt Compensated Line



Target 1000MW
Increased capacity due to SVC

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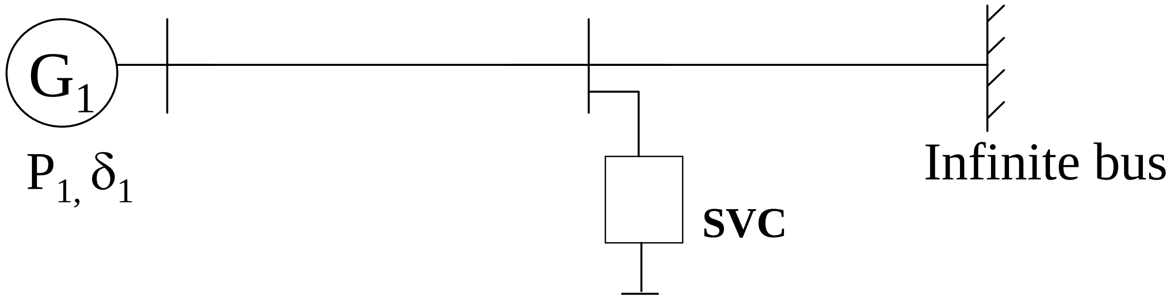
Power Oscillation Damping (POD) with SVC



- If $d(\Delta\delta)/dt$ or Δf is positive, i.e. rotor is accelerating due to built up kinetic energy, the FACTS device is controlled to increase generator electrical power output
- If $d(\Delta\delta)/dt$ or Δf is negative, i.e. rotor is decelerating due to loss of kinetic energy, the FACTS device is controlled to decrease generator electrical power output
- Modulation of SVC bus voltage required through auxiliary signals

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Two - Area study system (cont'd)

Three-phase fault is introduced in one of the transmission lines between bus 8 and bus 9

Oscillations caused:

- **Local rotor mode oscillations**
- **Inter- machine rotor mode oscillations**
- **Inter- area oscillations are associated with swinging of two machines in area 1 against the other two machines in area 2.**

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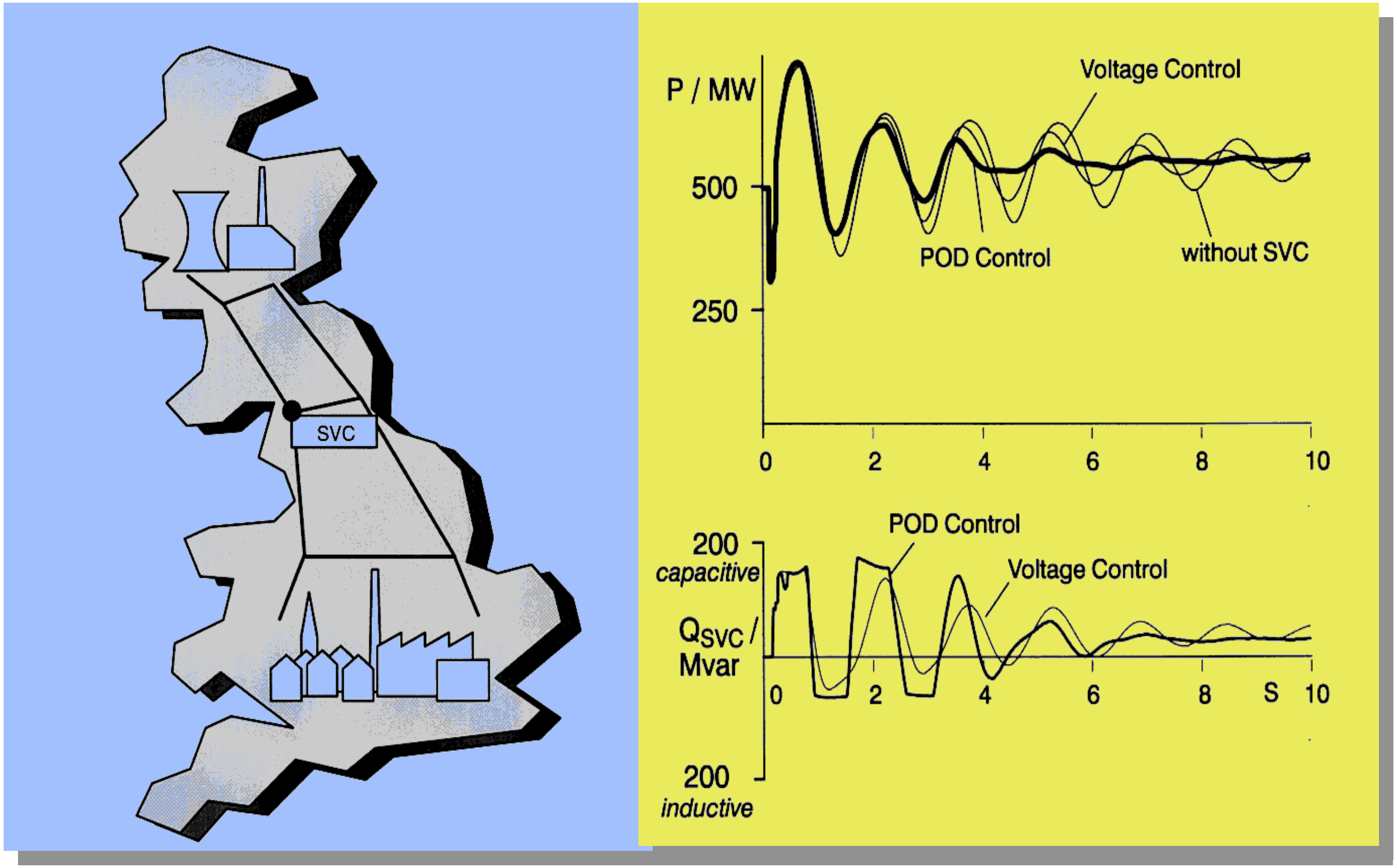
Static Var Compensator (SVC)
Damping of Power Oscillations (POD)



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Improvement of HVDC Link Performance with SVC

- **Voltage regulation**
- **Support during recovery from large disturbances**
- **Suppression of temporary over voltages**

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Static Var Compensator (SVC)
Typical SVC Configuration

① Step-down transformer

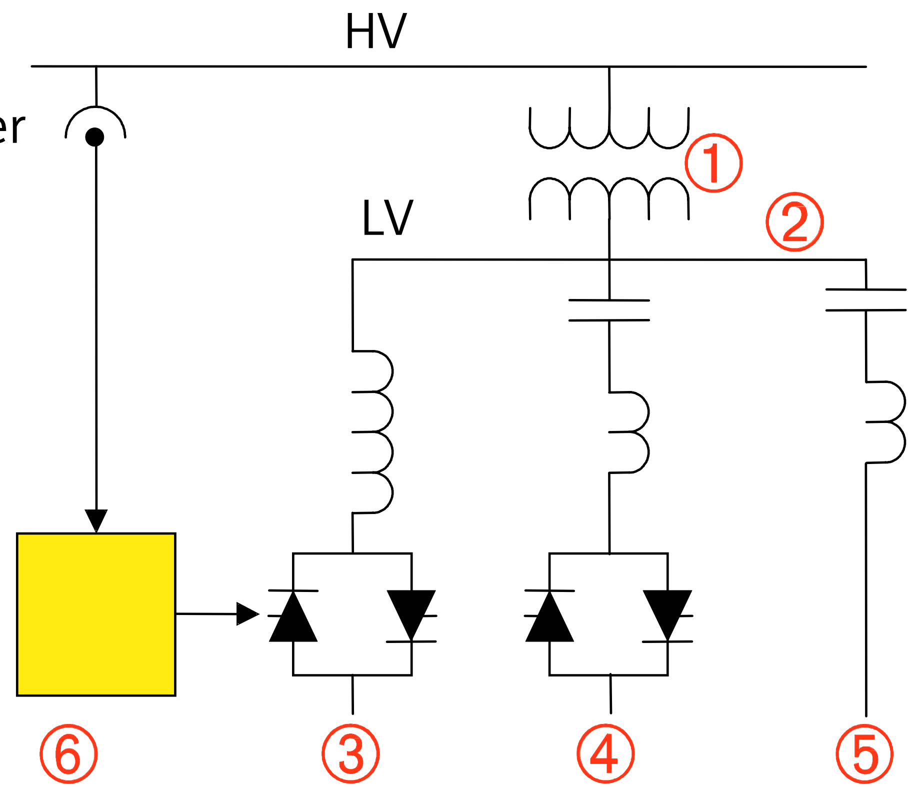
② LV bus bar

③ Thyristor controlled reactor

④ Thyristor switched capacitor

⑤ Fixed filter circuit

⑥ Control



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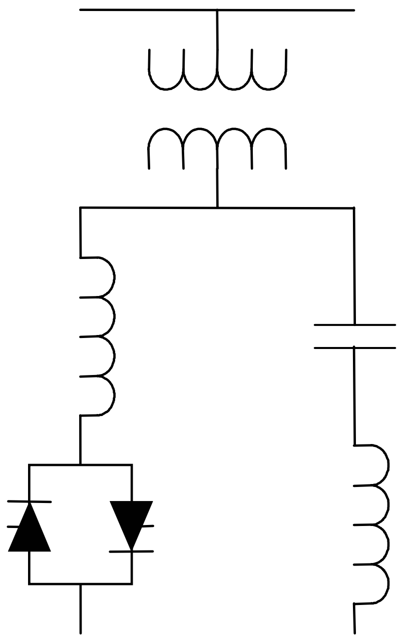
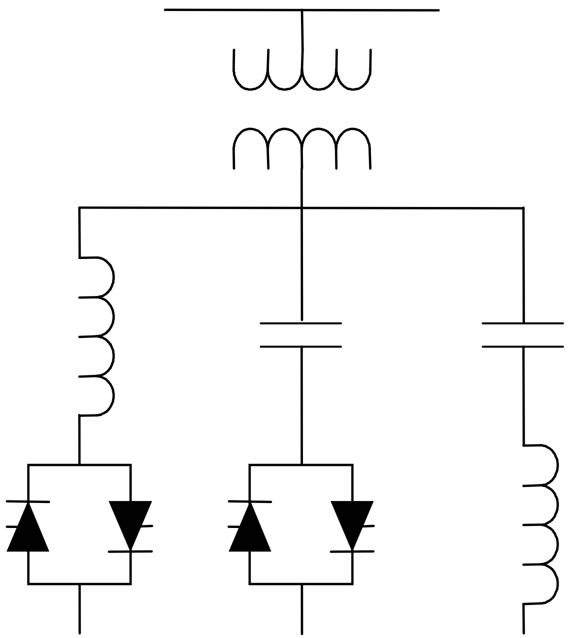
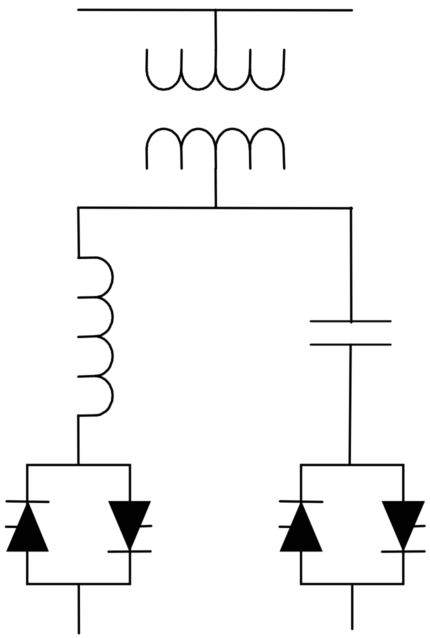
Static Var Compensator (SVC)
Common Configurations (1)



TCR, FC



TCR, TSC, FC



TSR, TSC

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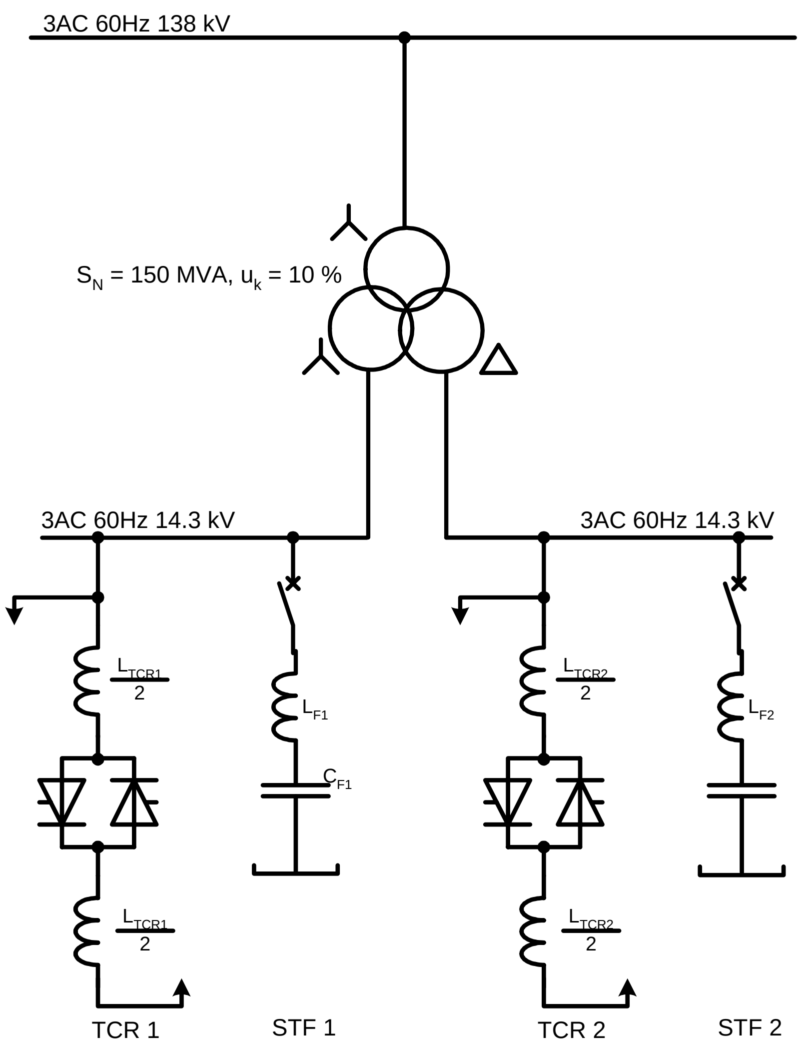
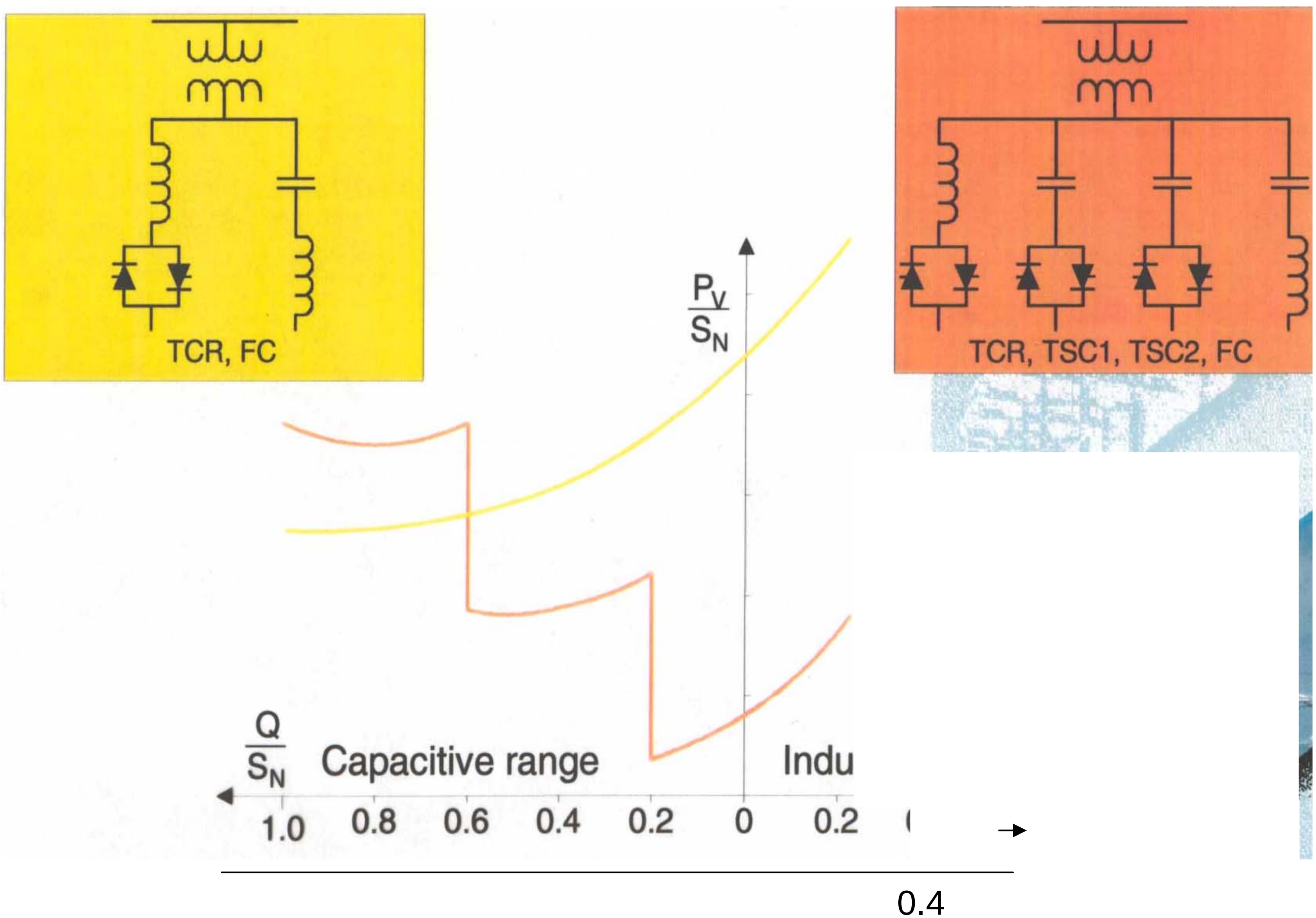
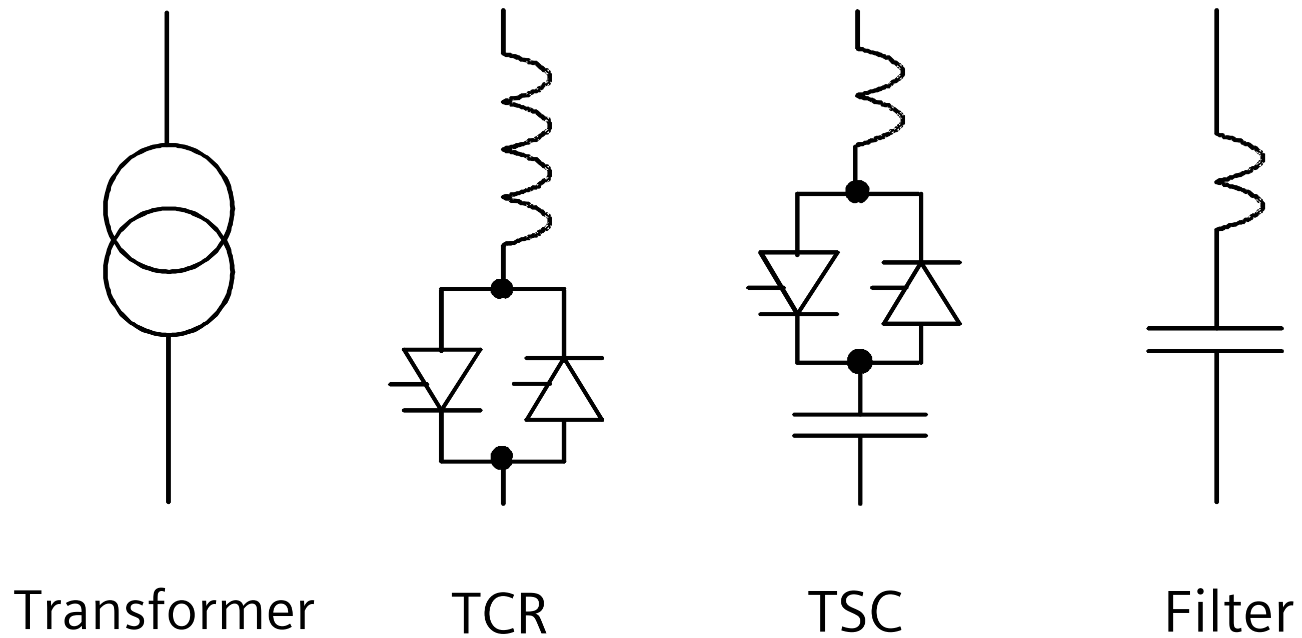
Static Var Compensator (SVC)
Common Configurations (2)



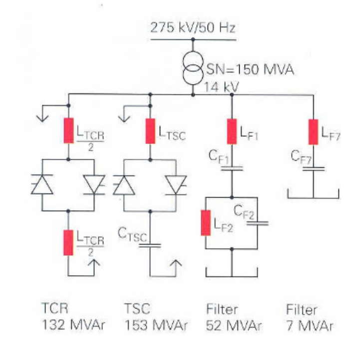
Static Var Compensator (SVC)
Loss Comparison



Main Components of an SVC



SVCs Centrals, NGC, UK 275 kV, 150 c / 75 i MVar



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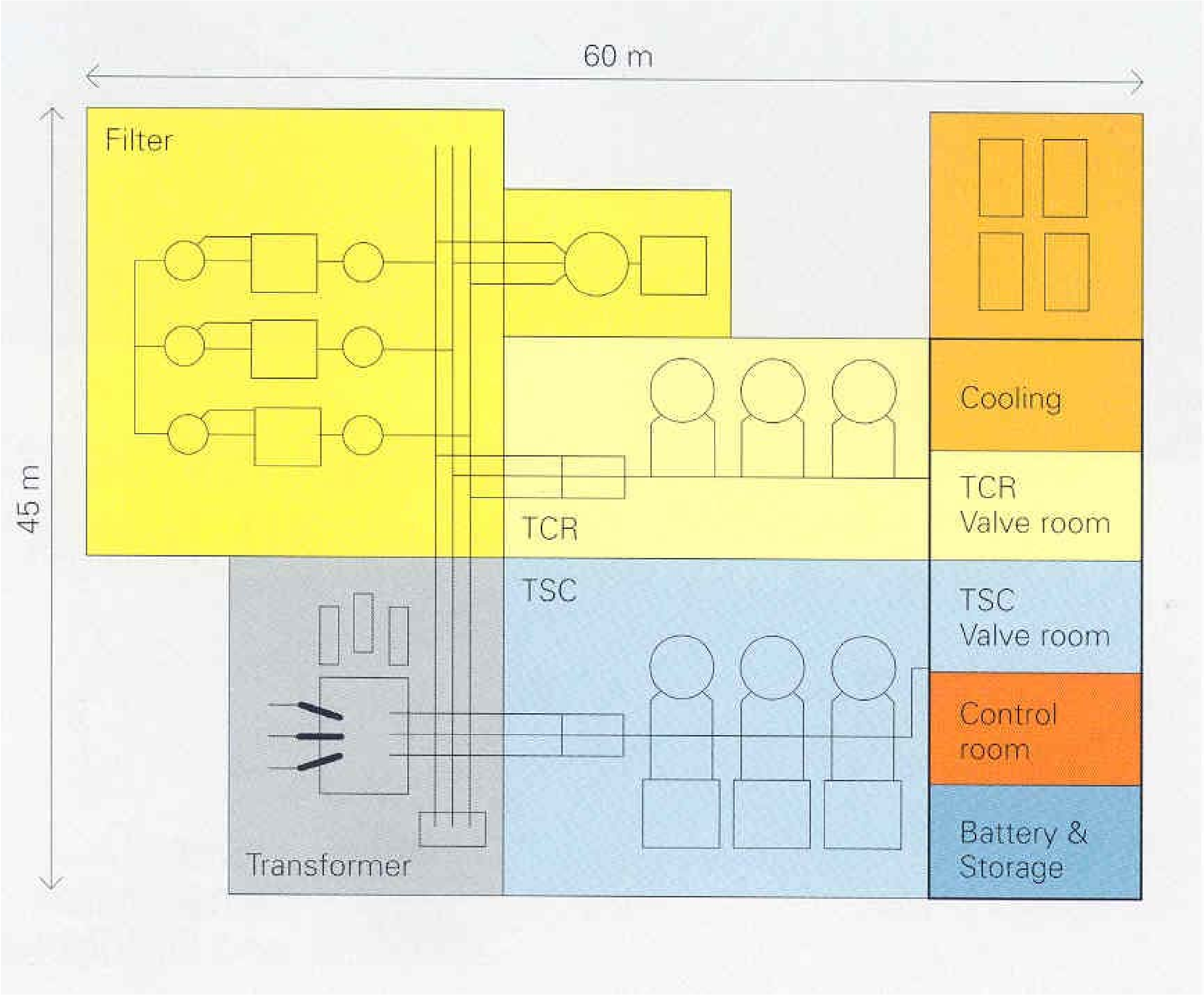

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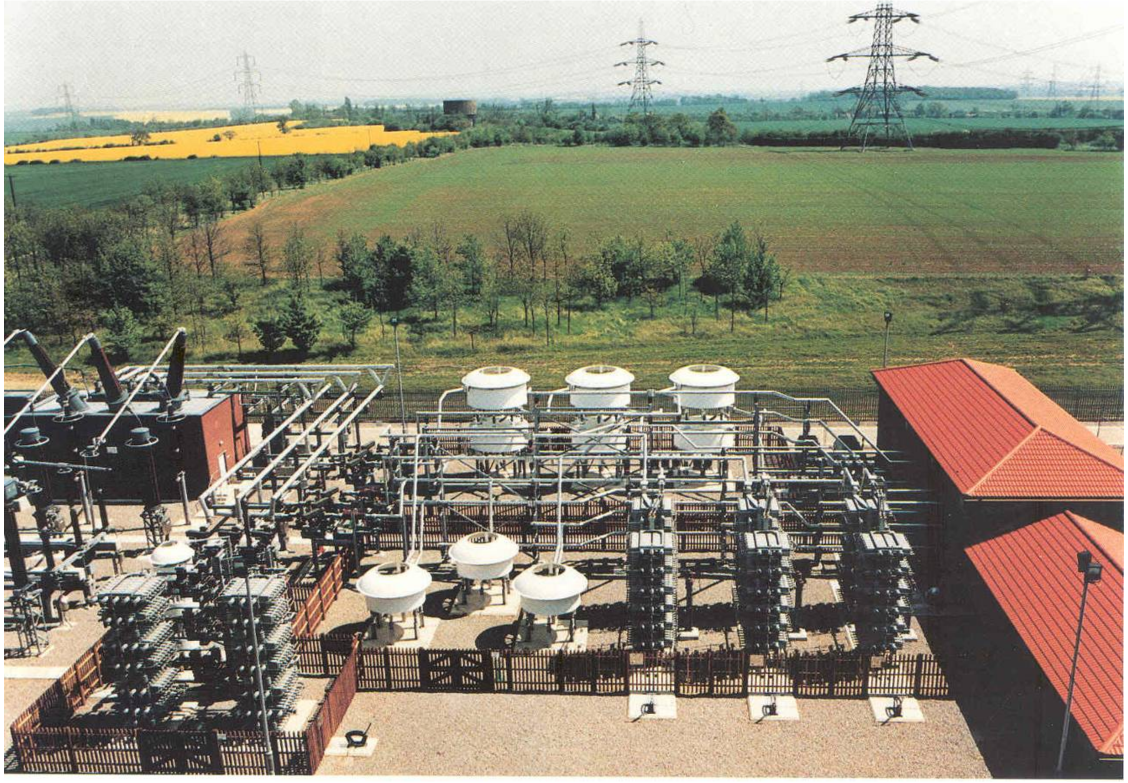
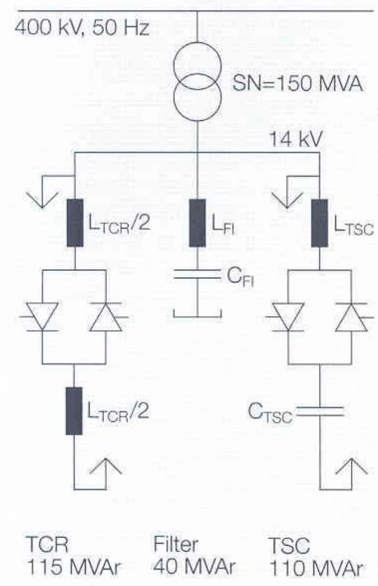
SVC Pelham, NGC, UK 400 kV, 150 c / 75 i MVar





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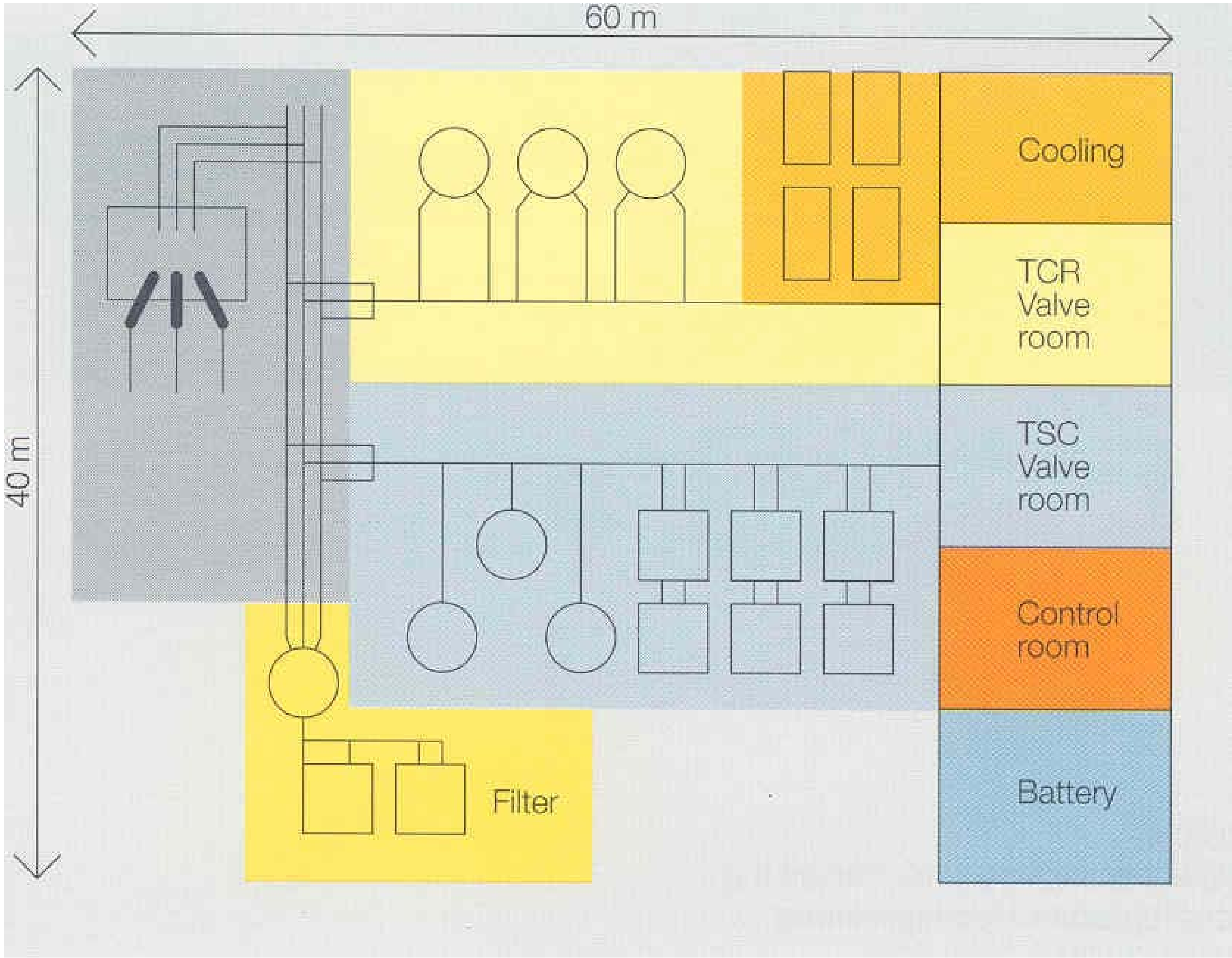

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Natal SVCs, Eskom, South Africa
Double stacked air core reactor

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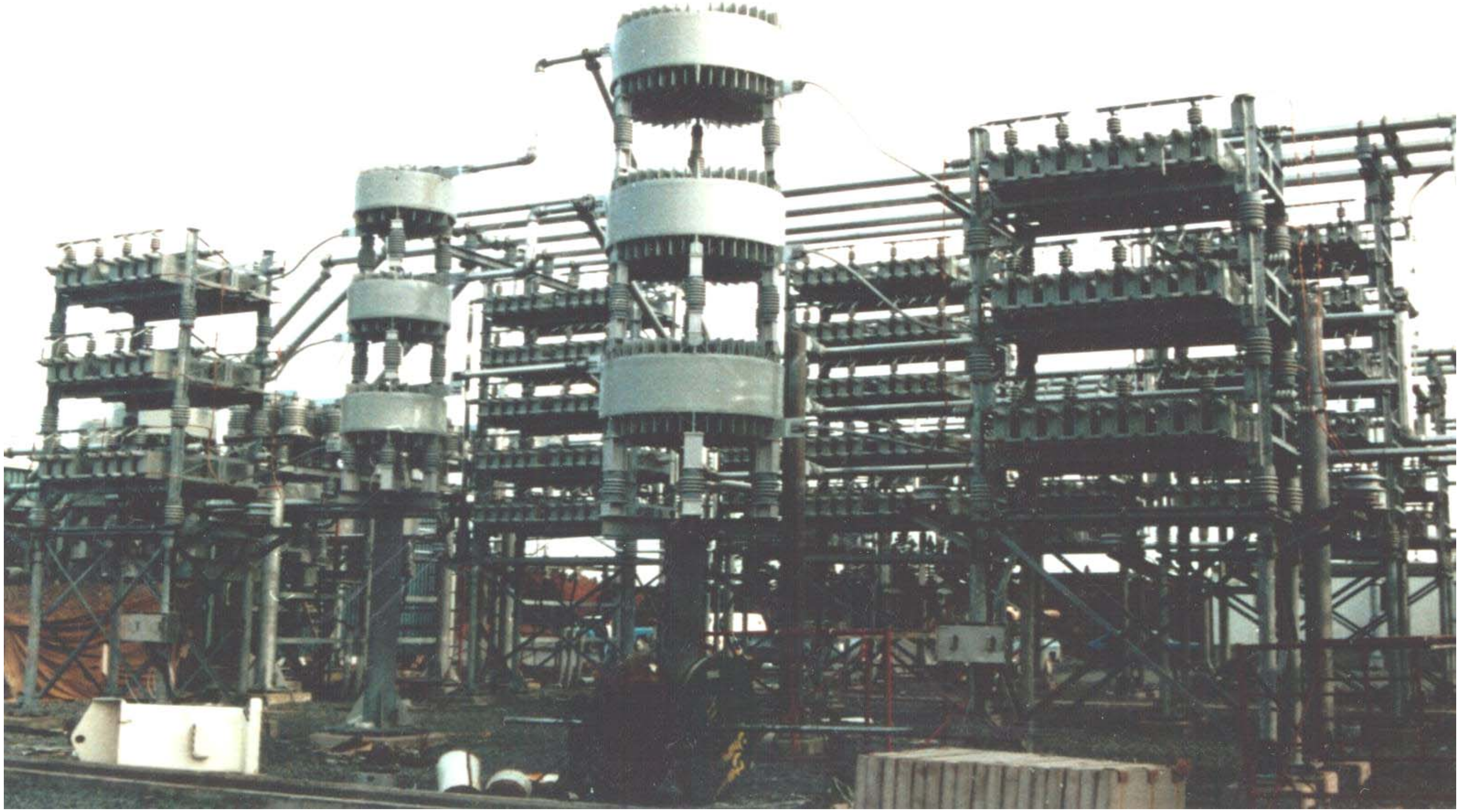
SVC Brushy Hill, NSPC, Canada
Filter Branches



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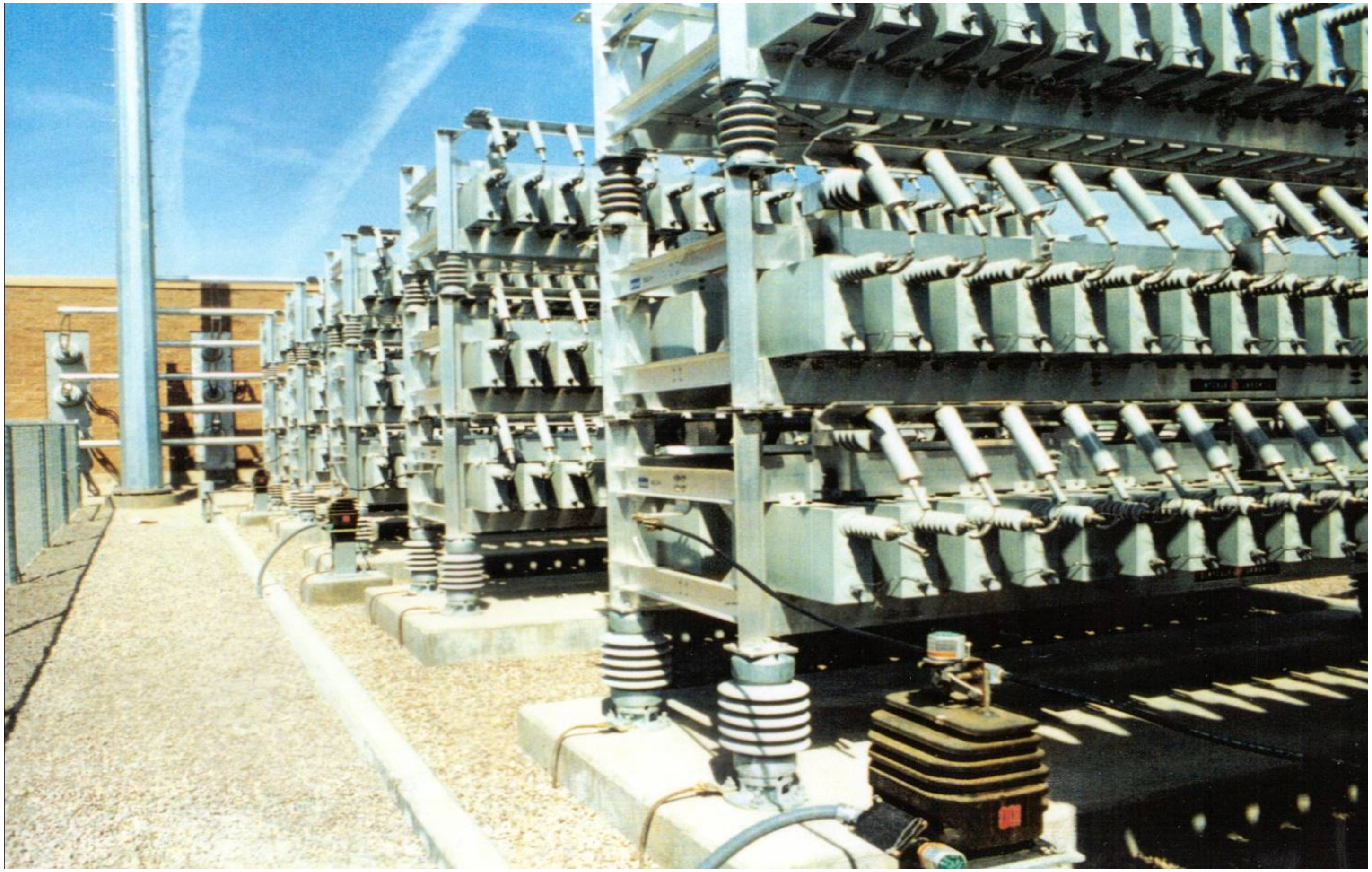
SVC Mead Adelanto, LADWP, USA
Capacitor banks (externally fused)



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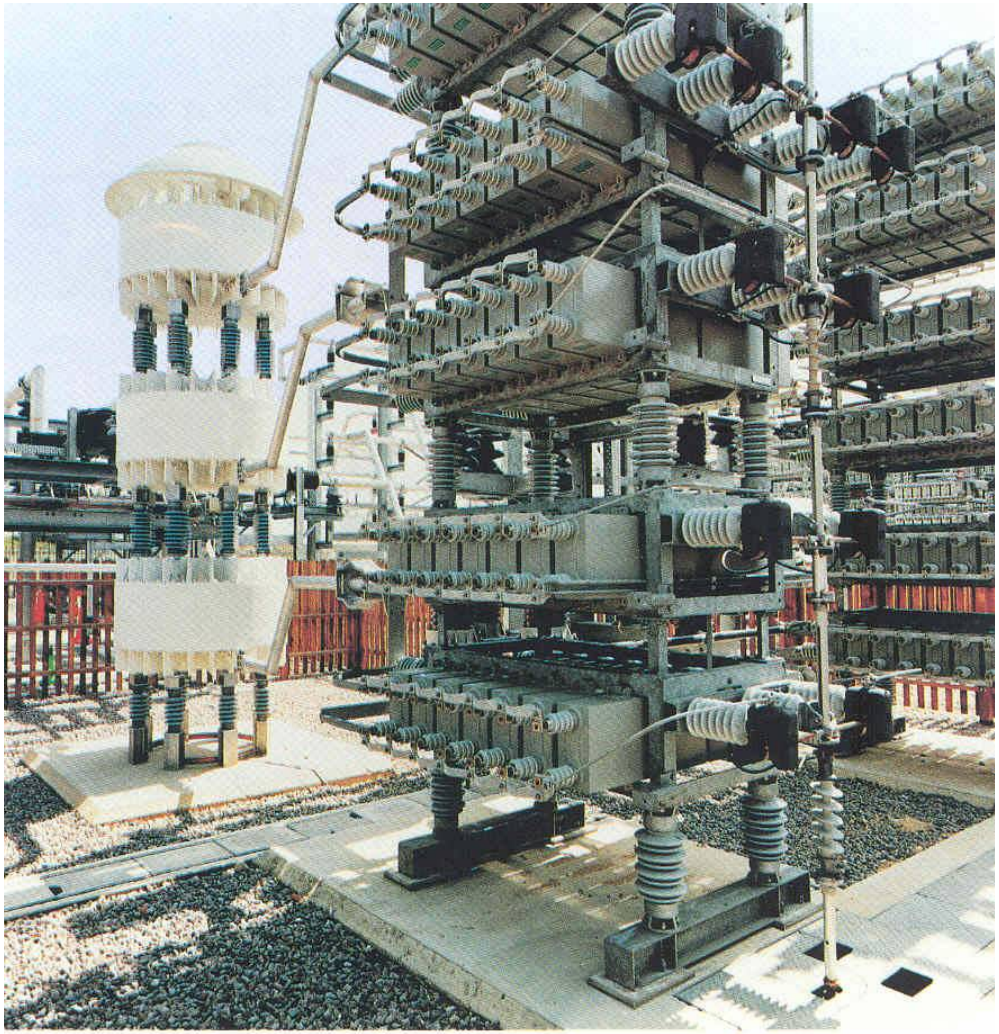
Static Var Compensators (SVC)
Filter Capacitor Bank (internally fused)



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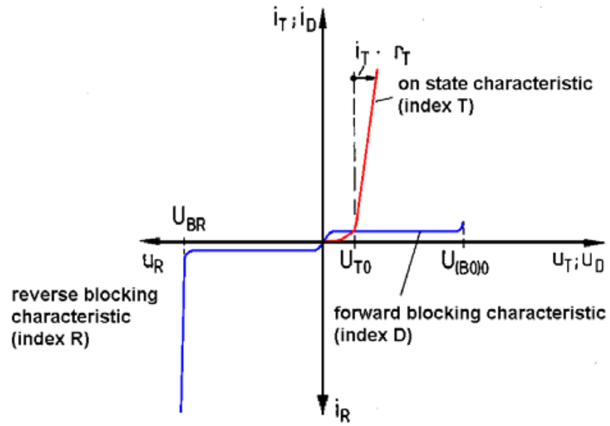
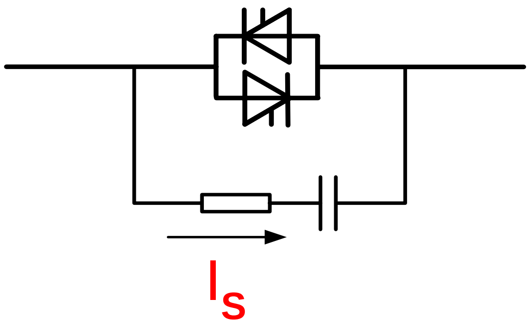
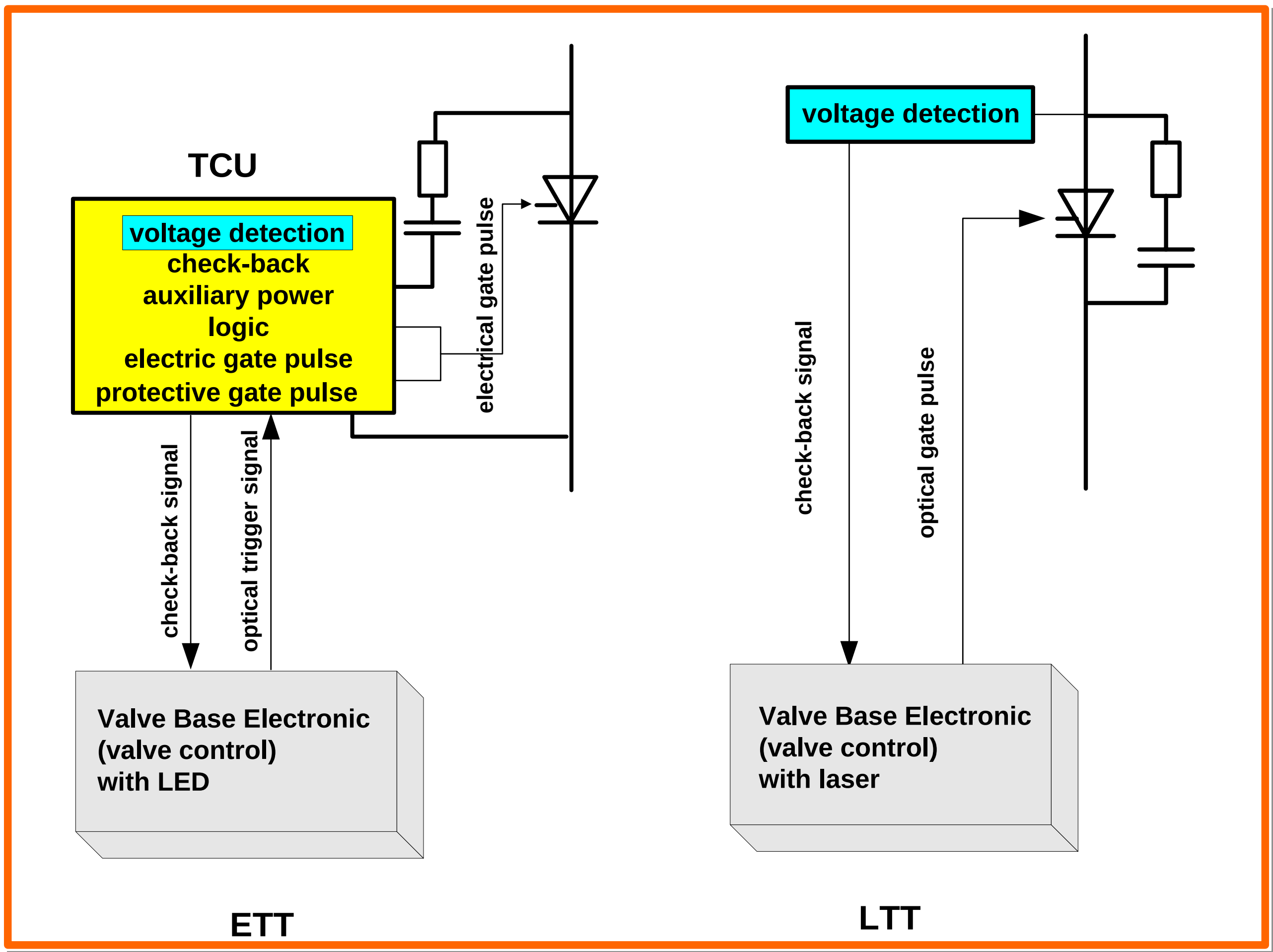
Thyristor Valve Cooling





- Major producers of heat losses are thyristors and snubber resistors
- Thyristor losses are determined by the forward voltage in the on state and the switching losses during turn on and turn off
- Snubber losses result from the charging current of the snubber capacitors

Thyristor Triggering & Monitoring Approaches



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Auxiliary Power for Triggering (Gating) of Thyristors

Typical gate pulse for ETT has

- duration of 10 µs
- peak power of 50 W

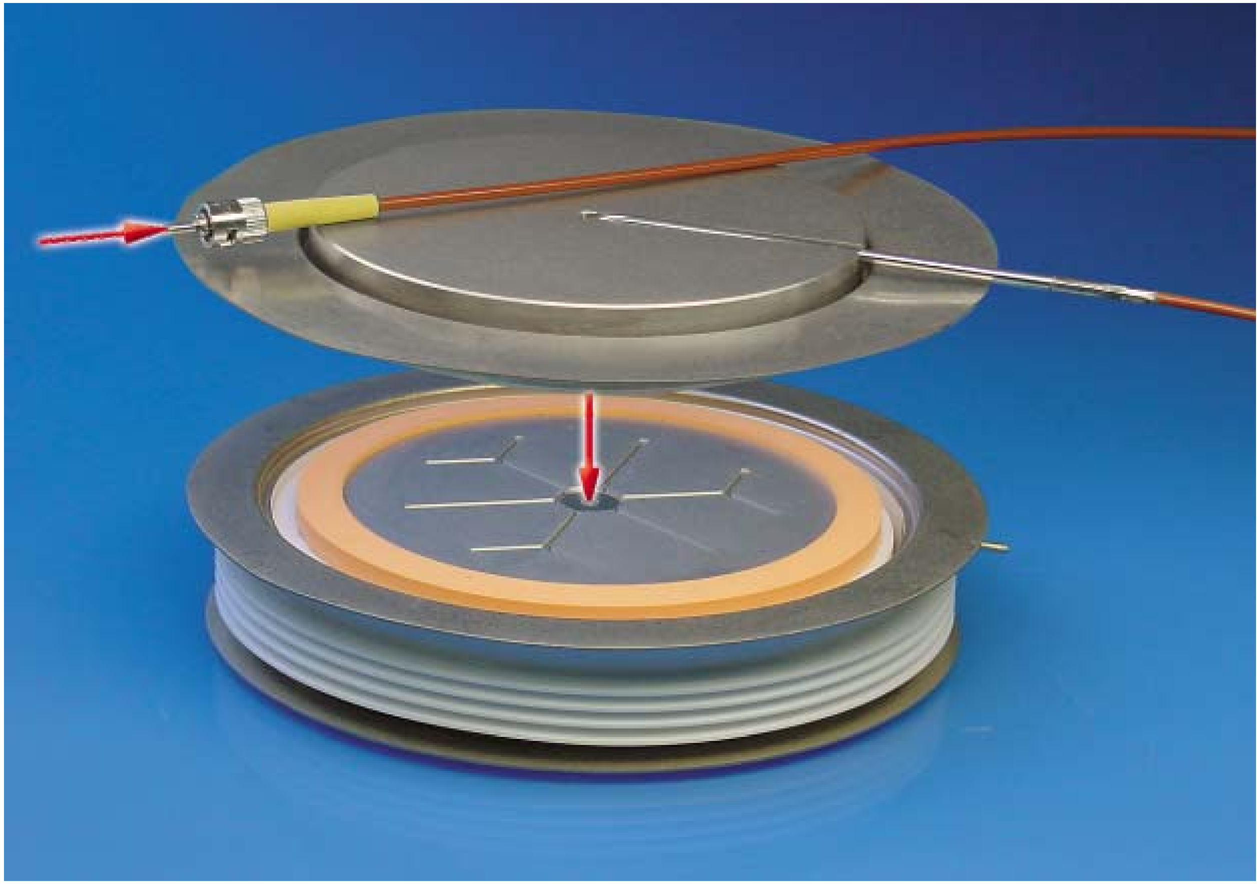
Energy is extracted from power circuit at each level

Typical gate pulse for LTT has

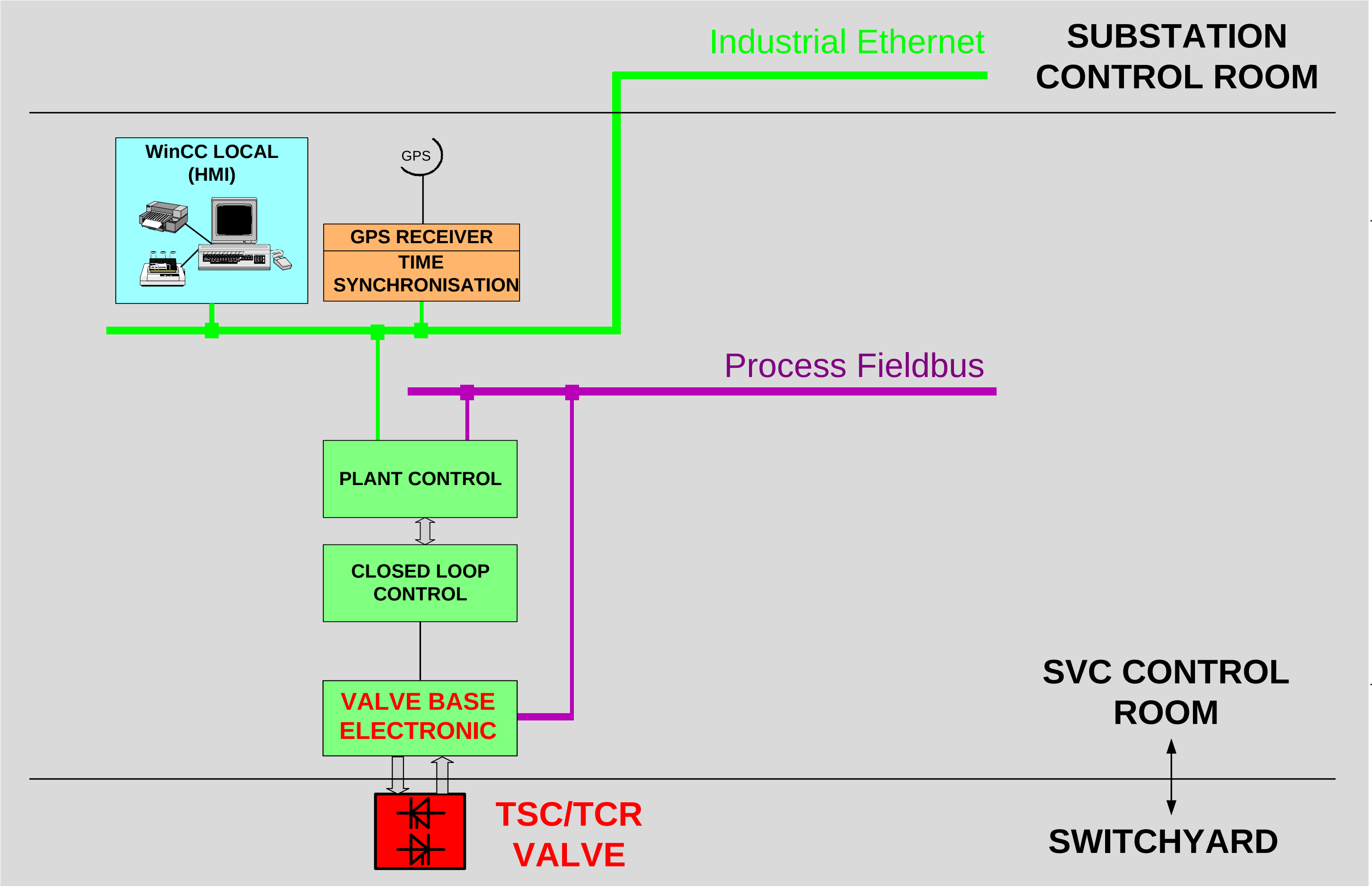
- duration of 10 µs
- peak power of 40 mW

Energy is provided by light pulse from ground level

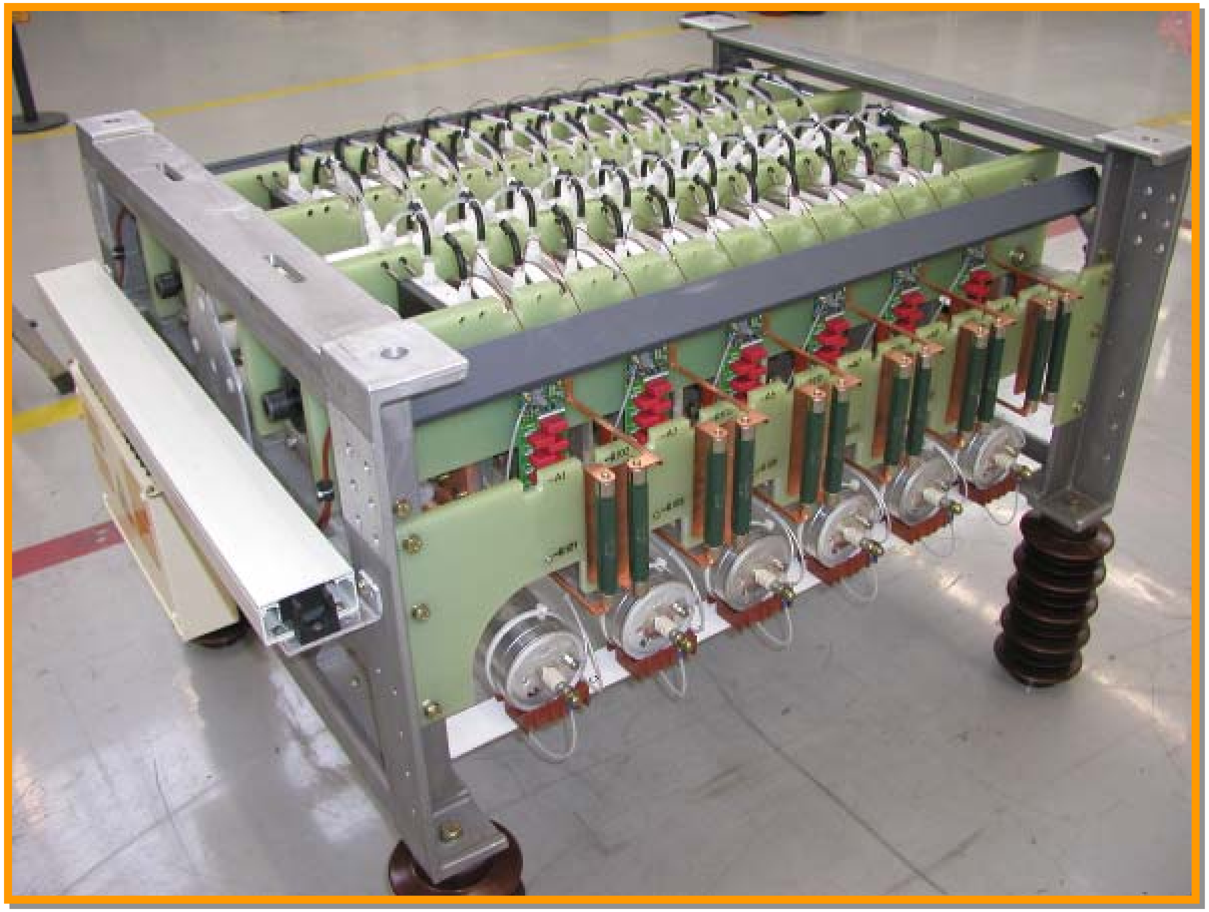
LTT Light Path



Thyristor Valve Control and Monitoring



LTT Thyristor Module for SVC Valve

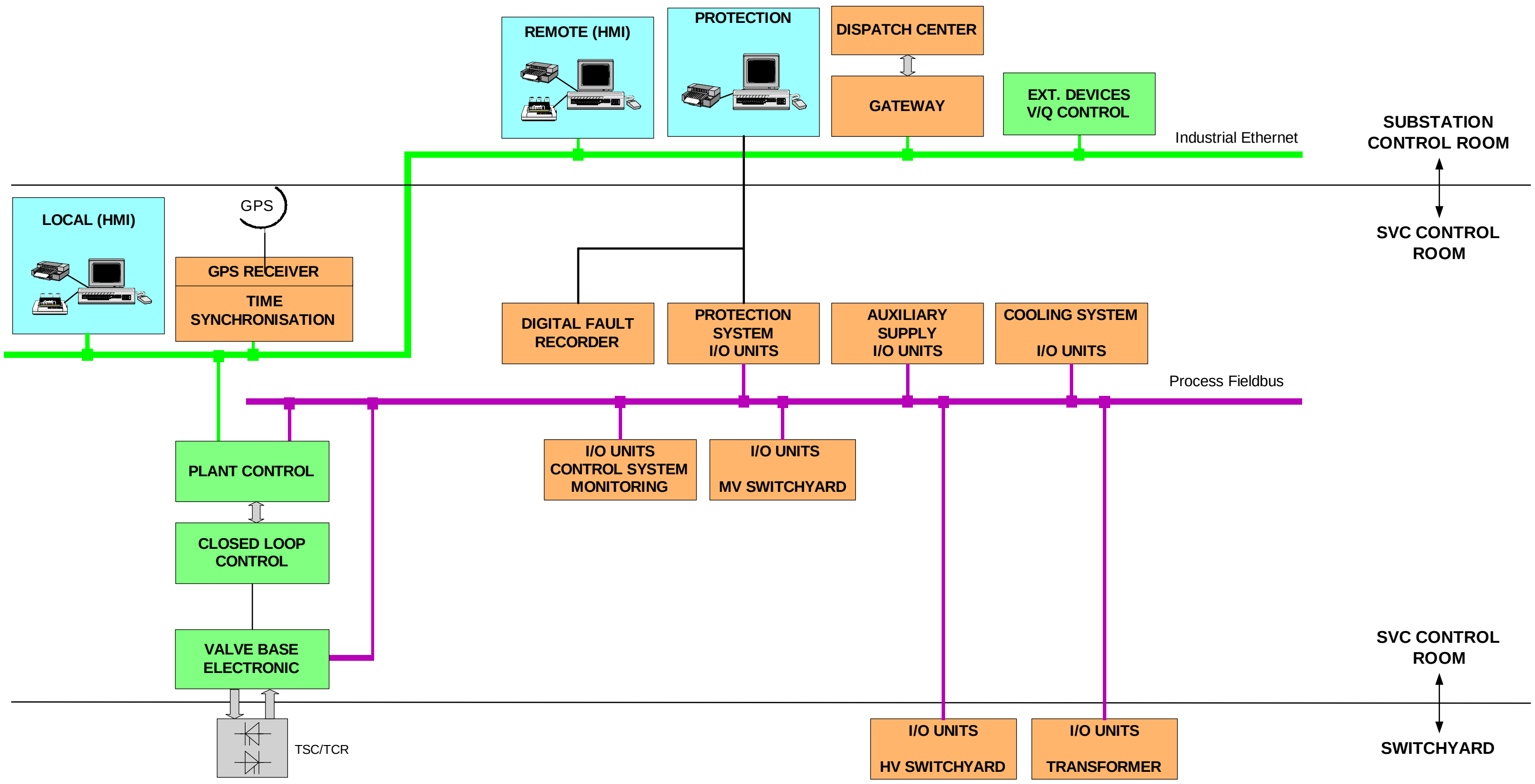


The module is a mechanical building block for the three phase valve setup

Station Control Hierarchies

- *Devices or High-Voltage Equipment in Switchyard*
- *Local control of devices or SVC Control*
- *Substation Control*
- *Dispatch Center Control*

SVC Control, Monitoring and Protection



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SVC Control

- *Plant control and monitoring*
- *Closed-loop control or Regulation*
- *Valve Base Electronic*
- *Protection system*

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Static Var Compensator (SVC) Plant control

SVC Station Control and Monitoring can be divided into:

- Sequence control
- Operator's or Human Machine Interface (HMI))
- Local Area Communication (LAN)
- Time Synchronism and distributions
- Sequence of events and event recording (SER)
- Digital fault recorder
- I/O from switchyard

Typical functions of sequence control

- SVC ON/OFF Sequence
- Auto-Reclosing
- Emergency Shutdown
- Remote Control Function (that may include SCADA interface)
- Manual and automatic switchyard control
- Degraded control modes

Static Var Compensator (SVC) Plant control

The SVC can only be energized if the status of critical systems is confirmed such as:

- Cooling System On-Line and no abnormal flow or temperature conditions
- Interlocks in ready state
- Primary voltage measurement system synchronized and ready
- Switches in closed position
- CLC ready and synchronized
- Valve Firing System ready and valves blocked
- Transformer cooling normal
- Plant Control in proper configuration (local, remote etc.)
- Relay systems set and no lock-out functions detected

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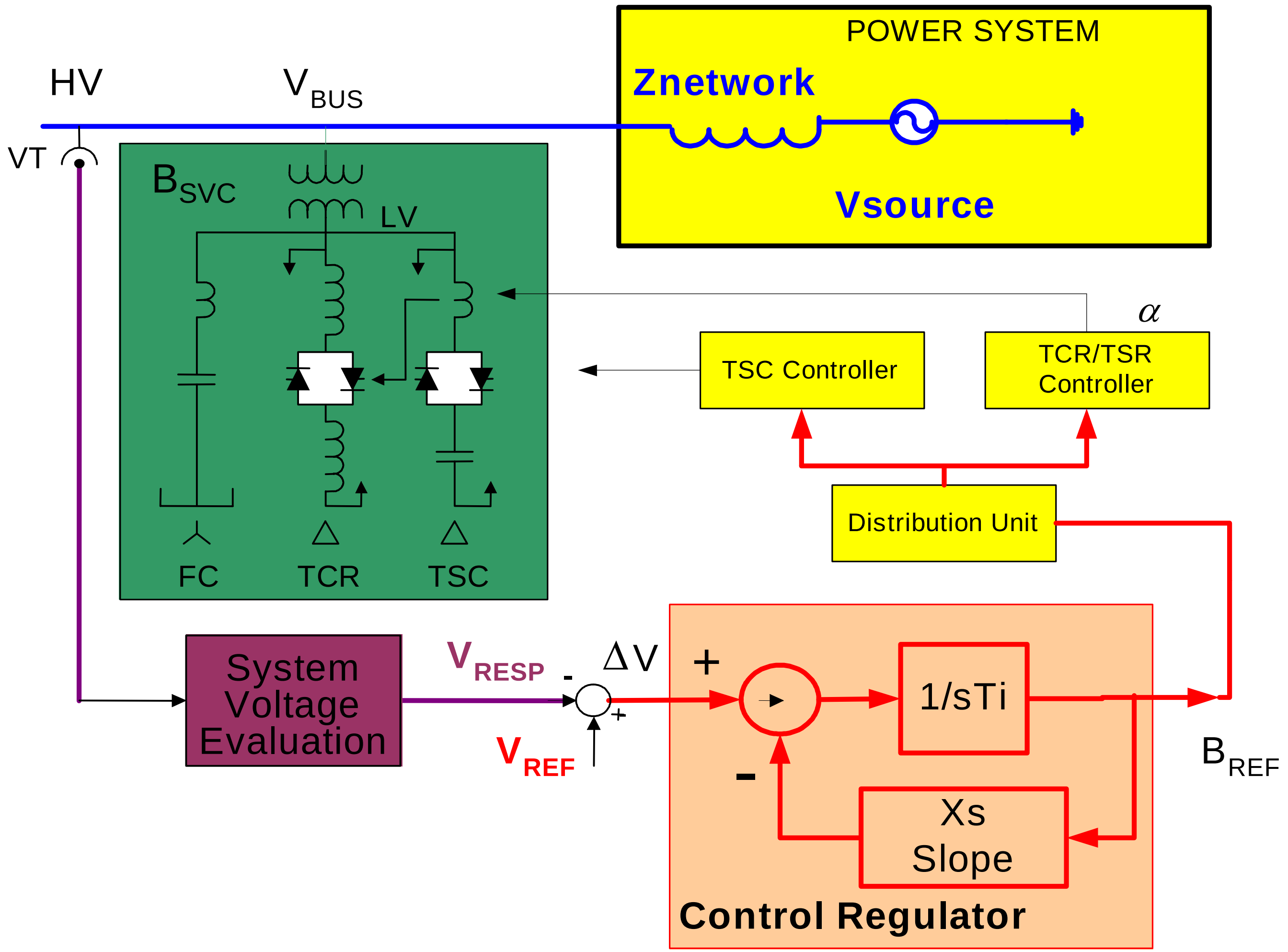
Static VAr Compensator (SVC) Voltage Control



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Static Var Compensator (SVC)
Additional control functions

- POD control
- Q control
- Gain control
- Stability control
- Voltage symmetrisation

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Static Var Compensator (SVC) Further Options

- Degraded mode
- Var management
- Test mode
- Redundancy

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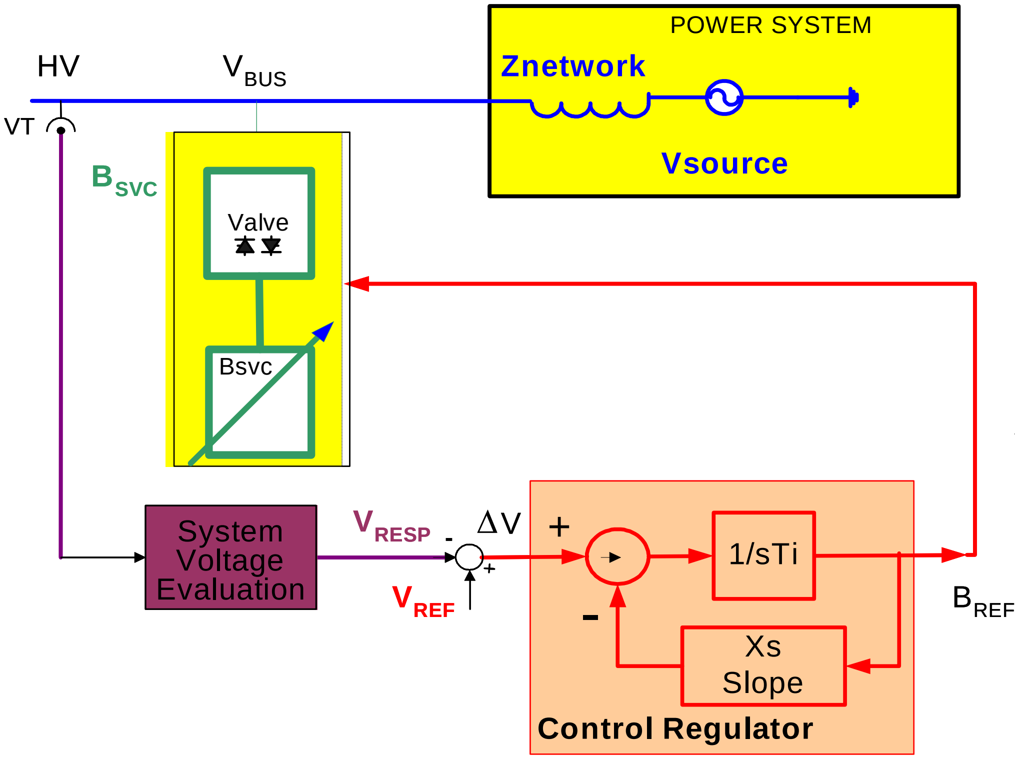
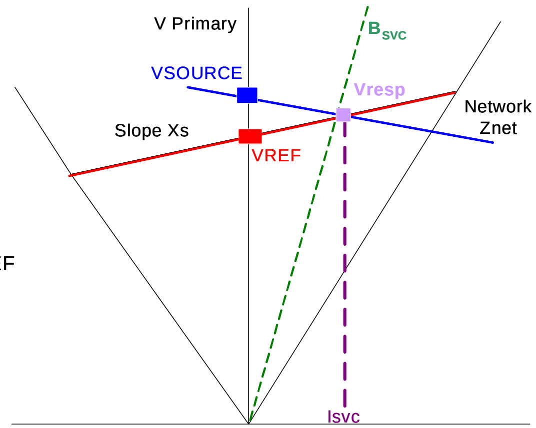
Control and Regulation
Control loop Analysis

The SVC control loop linking the regulator to the power system can be represented as shown

$$V_{BUS} = V_{RESP} = V_{SOURCE} - Z_{NET} \times I_{SVC}$$





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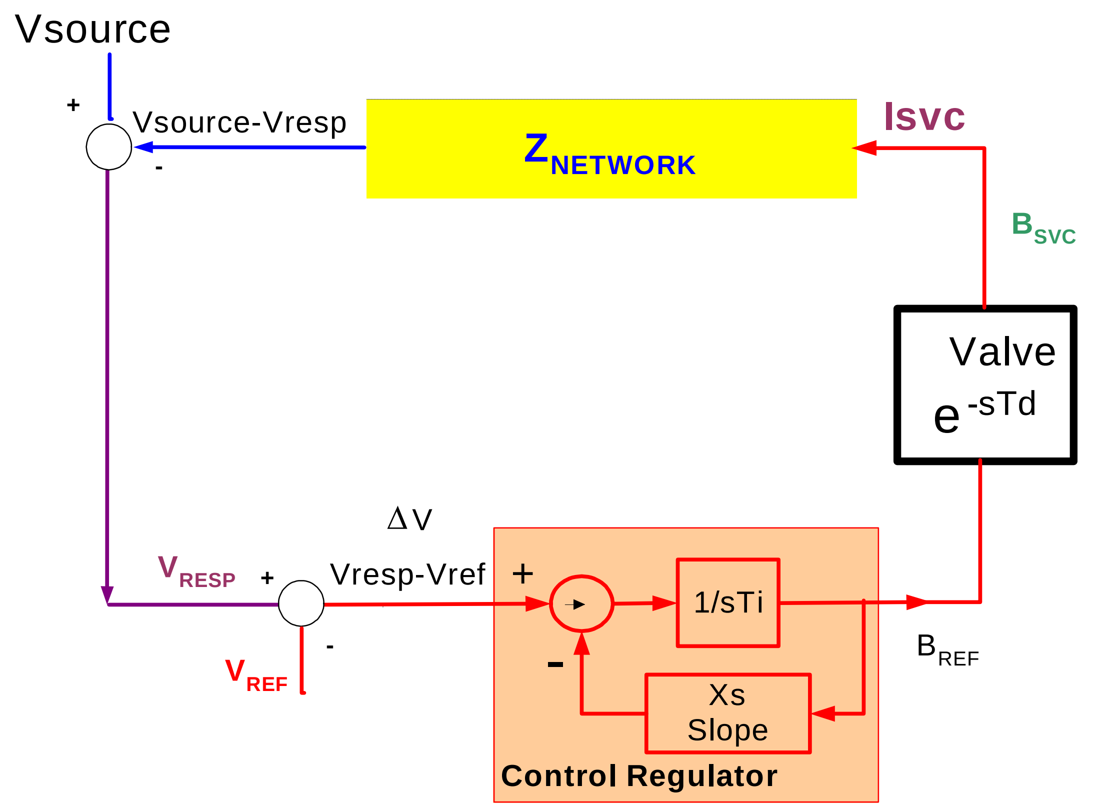

$$Vsource - Vresp = Znet \times Isvc$$

- The commissioning process
- Precommissioning tests
- System and operational considerations
- Commissioning tests
- Standards and guides

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Basic steps in the commissioning process

- Pre-commissioning tests
  - Tests on plant and sub systems
  - Complete before energising SVC at high voltage
- Commissioning tests
  - Correct operation of the SVC design
  - Performance to specification
  - SVC performs correctly on the system
- Acceptance by the purchaser

Precommissioning tests

- Tests on individual items of plant to be done in an agreed way
- InterNational Electrical Testing Association (NETA), www.netaworld.org
  - Produces documentation on test methods and record sheets (Acceptance Testing Specifications)
  - Certifies testing companies and technicians
- Equipment not covered by NETA documentation is tested to manufacturer’s own test sheets by the manufacturer

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Precommissioning tests

- Purpose of pre-commissioning tests
  - Check that equipment is undamaged
  - Electrical tests to confirm rating plate details
  - Checks on installation
    - –Cabling
    - –Connections
    - –Insulation resistance
  - Functional checks
  - Grounding resistance check

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Precommissioning tests

- Tests to be done on the largest possible sub-systems without making equipment alive
- Tests to be witnessed by the purchaser’s representative where possible
- Complete test results accepted by the purchaser
- Test results presented with a master document, listing all test sheets for each equipment

Proceed to the next stage

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Safety

- Safety rules covering live plant
  - OSHA regulations
  - Purchaser’s safety rules
  - Qualification of Vendor’s personnel

Effect on system

- Test program to be agreed in advance
- Program should give details of each test
- Test program should state Mvar output for each test
- Limitations on SVC output during testing
  - Determined from studies by the purchaser
  - Limits may vary with time of day or day of the week
  - Generators may be dispatched during some tests

Operational matters

- Personnel qualified to switch
- Switching jurisdiction
- Liaison with control center
- Test schedule to accompany the test program
    - Control center can plan system reconfiguration

Commissioning tests

- Detailed test program contains
  - Step by Step details for each test
  - Means of recording test results
  - Mvar outputs
- Connect recording equipment
- Stage by stage testing

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Commissioning tests Stage 1

- Tests to confirm that the SVC has been designed correctly
  - Energise all equipment
  - Pass current in manual control
  - Test in automatic control
  - Cooling plant checks
  - Harmonic measurements

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Commissioning tests Stage 2

- Tests to confirm that the SVC has met the performance specification
  - System harmonic measurements
  - Voltage/current characteristics
  - Speed of response
  - RFI measurements
  - Acoustic noise measurements

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Commissioning tests stage 3

- Tests to ensure that the SVC performs correctly
  - Capacitor and reactor switching tests
  - Automatic switchgear control
  - Temperature rise tests
  - Trial operation period
  - Operation during disturbances
  - Service experience

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Service experience

- Extension of commissioning tests
  - Monitoring of service experience may last until the end of the warranty period
- Commissioning test program does not normally include staged faults
- DFR and SER at the SVC installation used to gather performance data

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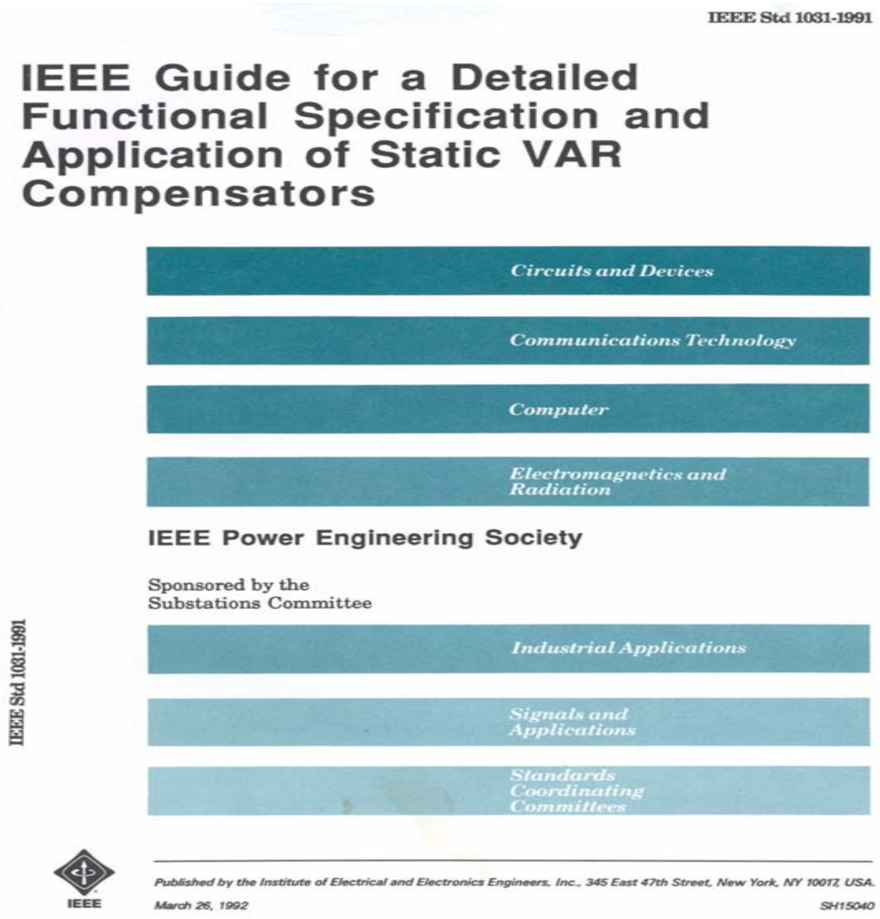
Standards and Guides

- IEEE 1303 : 1994. IEEE Guide for Static Var Compensator Field Tests
- CIGRE Document WG38-01 Task Force 2.   Static Var Compensators, Chapter 6

SVC Design
Functional Specification IEEE 1031



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IEEE Guide for a Detailed Functional Specification and Application of Static VAR Compensators

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Field Tests for Static Var Compensator IEEE 1303

IEEE Guide for Static var Compensator Field Tests

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IEEE Standards Board

Abstract: General guidelines and criteria for the field testing of static var compensators (SVCs), before they are placed in service, for the purpose of verifying their specified performance are described. The major elements of a commissioning program are identified so that the user can formulate a specific plan that is most suited for his or her own SVC.
Keywords: filter, static var compensator, SVC, var

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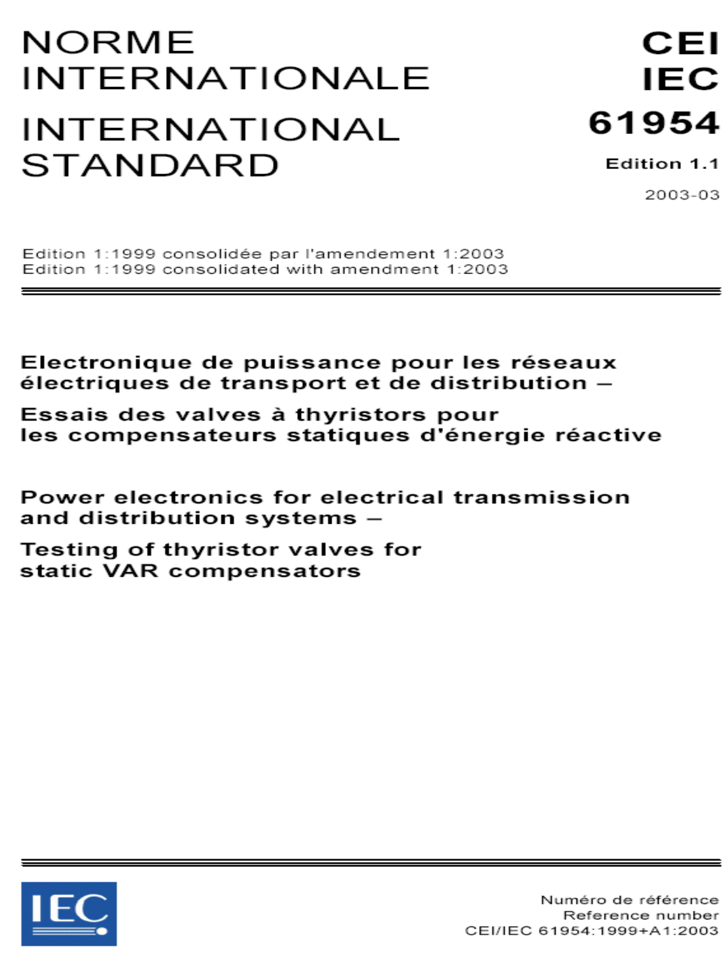
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2003-03

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Essais des valves à thyristors pour les compensateurs statiques d'énergie réactive

Power electronics for electrical transmission and distribution systems –

Testing of thyristor valves for static VAR compensators

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