FACTS For Dynamic Compensation In Power Transmission

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Need for Voltage & reactive power support

- Static & Dynamic reactive power support needed to:
- Supply reactive power requirements of customer demand
- Supply reactive power losses in T&D systems
- Provide adequate system voltage control

Why Dynamic Voltage & reactive power support ?

Necessary to avoid voltage instability & widespread system collapse in the event of certain contingencies

Essential during power system disturbances like faults

Voltage & reactive power support

Transmission line charging, series & shunt capacitors are sources of reactive power support, but are static sources

Synchronous generators, synchronous condensers, HVDC, static Var compensators (SVC & STATCOM) and TCSC can provide dynamic support

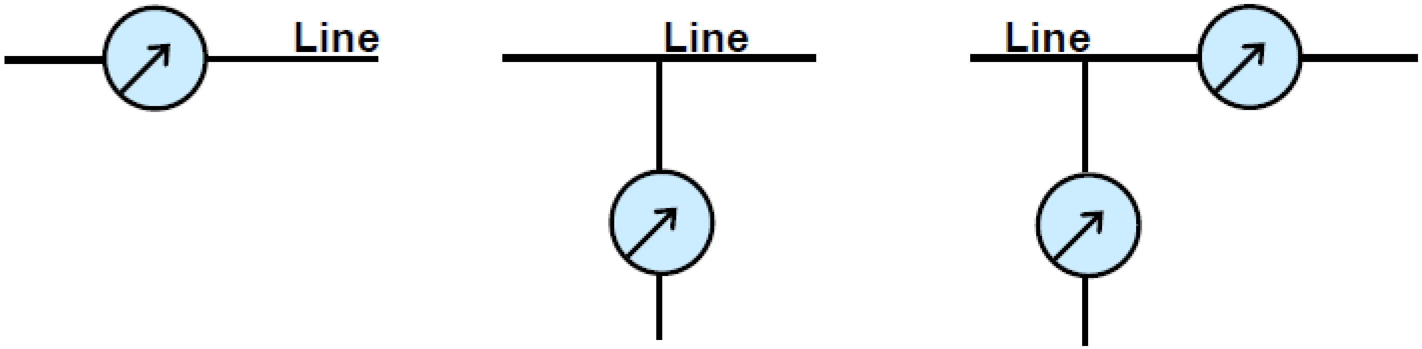
Reactive power control – FACTS devices

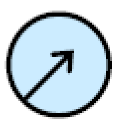
Flexible AC Transmission Systems (FACTS) are the name given to the application of power electronics devices to control the power flows and other quantities in power systems.

As per IEEE definition

FACTS Controllers: A power electronic based system & other static equipment that provide control of one or more AC transmission parameters.

FACTS Concepts





May be active static switch or impedance, converter or a combination thereof Which in effect:

- injects voltage in series.
- or inject current in shunt
- or both

Application of FACTS Technology

- To increase the power transfer capability of transmission networks

- To provide direct control of power flow over designated transmission routes.

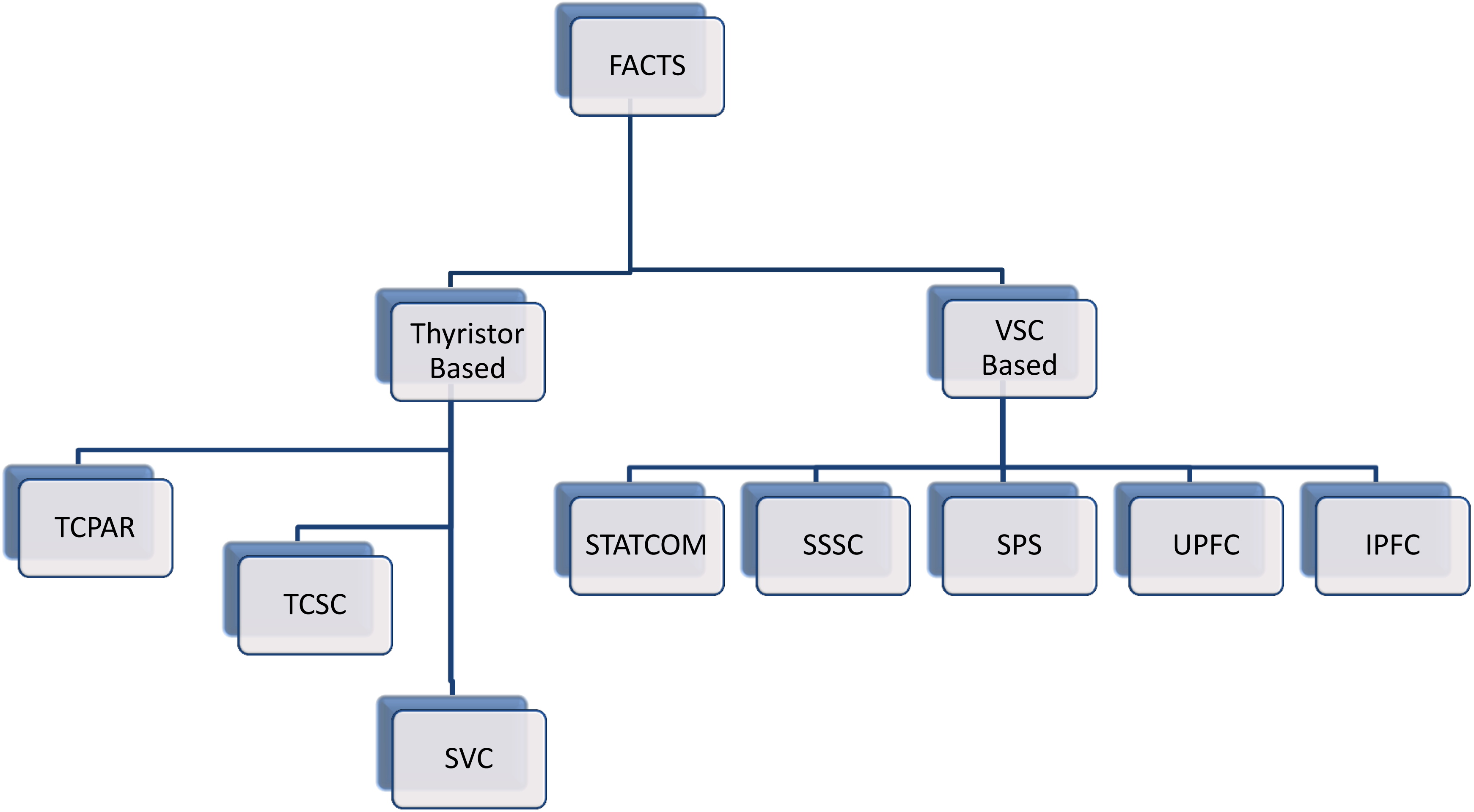
- Dynamic voltage control to:

  - Limit over-voltages over long, lightly loaded lines
  - Prevent voltage depressions or even collapses in heavily loaded or faulty systems.

FACTS opportunities

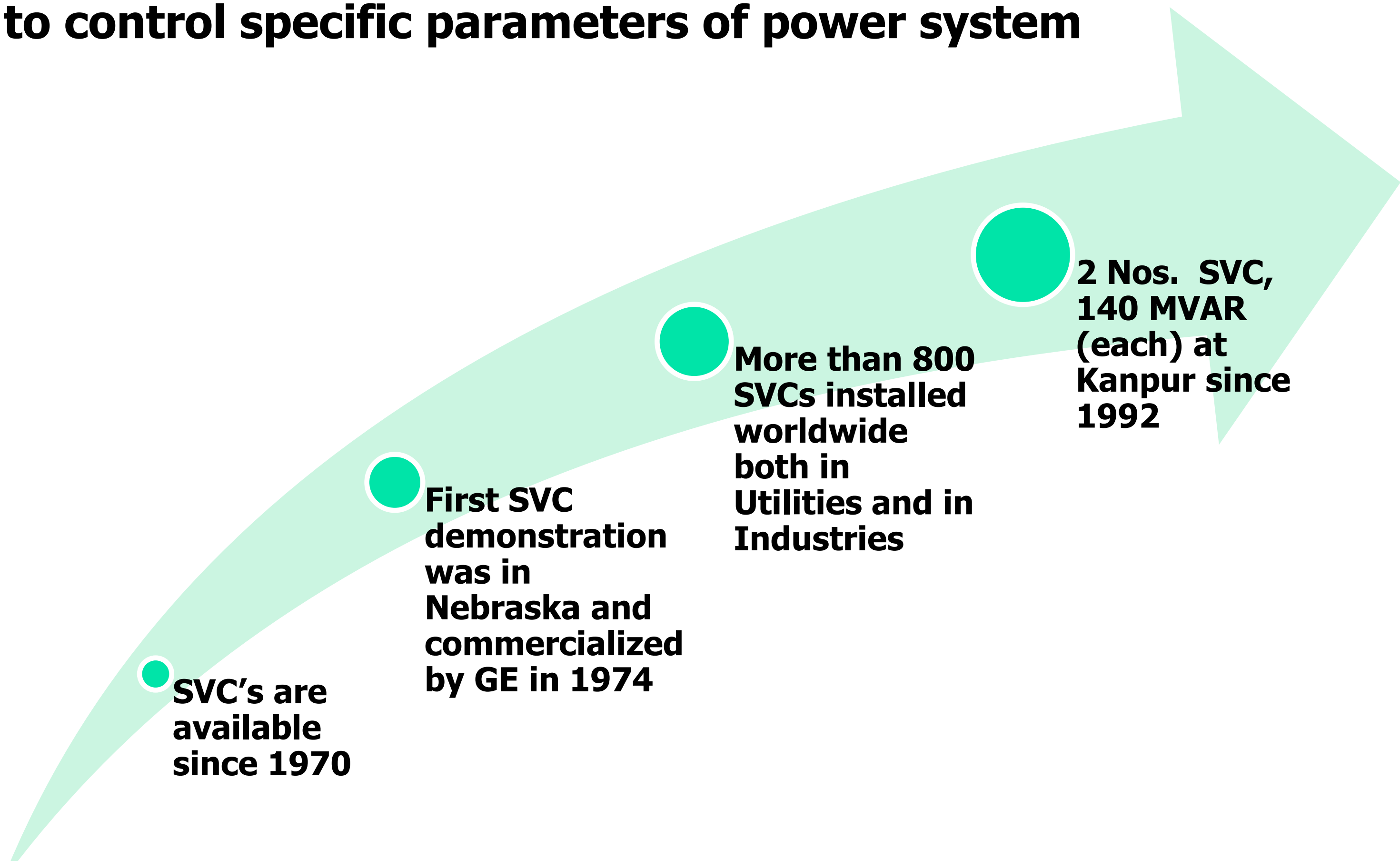
- Increase system security & damping of electromechanical oscillations
- Damping of power oscillations
- Reduce reactive power flows, thus allowing the lines to carry more active power
- Reduce loop flows
- Provide greater flexibility in siting new generation

Classification of FACTS devices

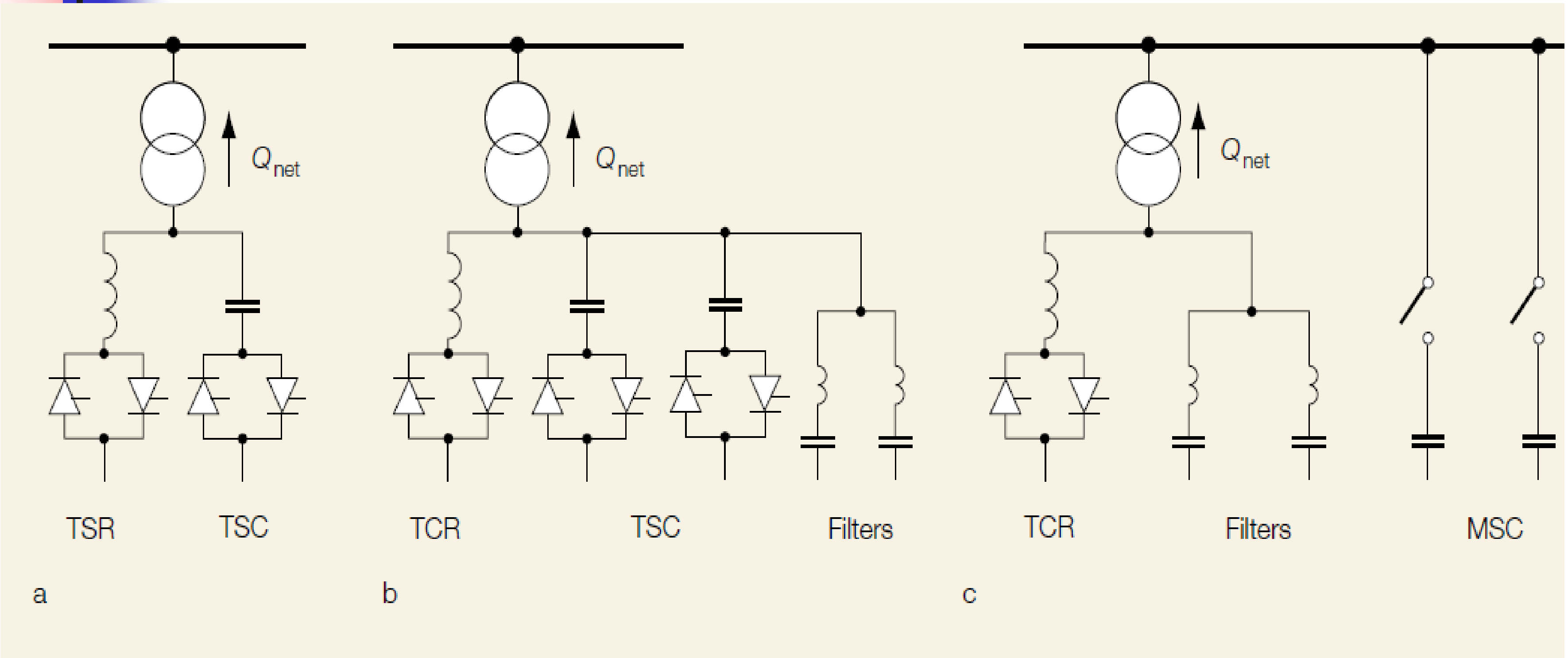


Static Var Compensator (SVC)

SVC: A thyristor controlled, variable reactance, shunt FACTS device which can generate /absorb reactive power at a bus to control specific parameters of power system



SVC Configurations

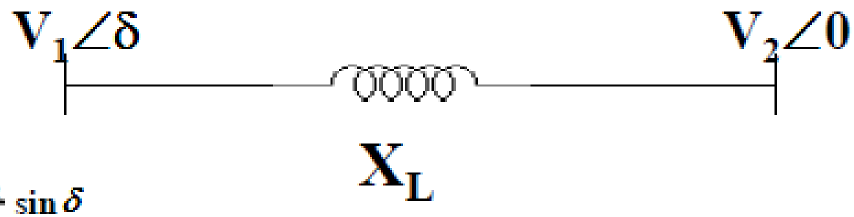


SVC configurations used to control reactive power compensation in electric power systems

a *TSR-TSC configuration*
b *TCR-TSC configuration*
c *TCR-MSC configuration*

Q_{net} *Net reactive power flow to network*

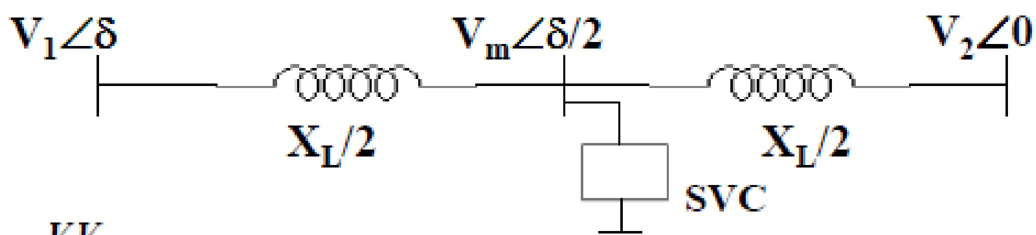
Power Transfer improvement by SVC



$$P_{12} = \frac{V_1 V_2}{X_L} \sin\delta$$

$$If,\ V_1 = V_2 = 1\ pu\ and\ \delta = 90^\circ$$

$$P_{12\,\max} = \frac{1}{X_L}$$



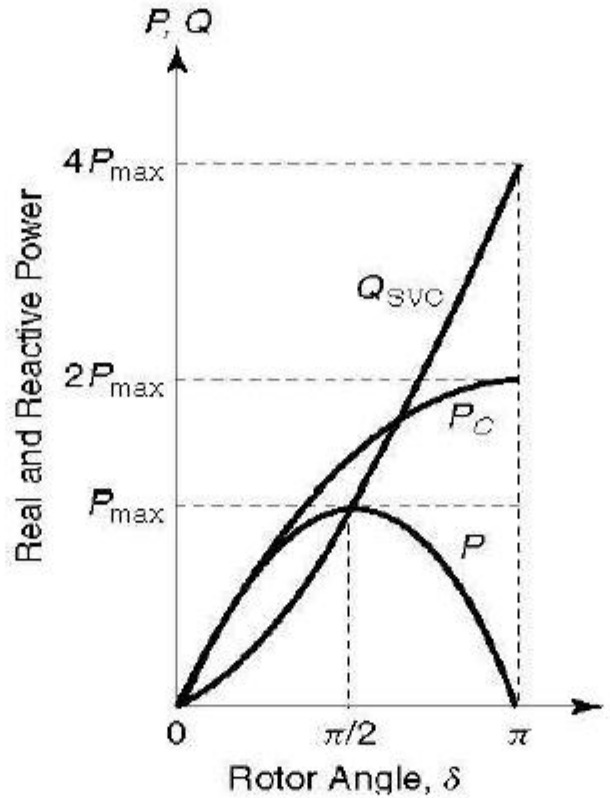
$$P_{12} = \frac{V_1 V_m}{X_L/2} \sin\delta/2$$

$$If,\ V_1 = V_2 = V_m = 1\ pu\ and\ \delta = 180^\circ$$

$$P_{12\,\max} = \frac{2}{X_L};$$

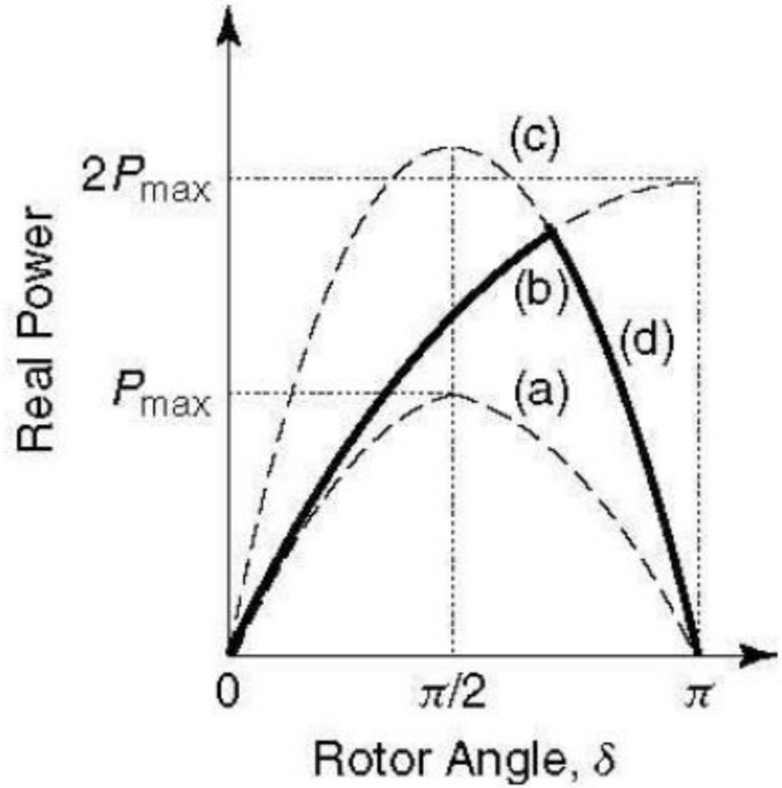
Power transfer has doubled - with large SVC
Power transfer increases substantially – with realistic SVC

Power Transfer improvement by SVC



Variation in real and reactive power in SMIB system

Power Transfer improvement by SVC



Real power of the SMIB system with varying compensation

Transient stability enhancement by SVC

The object is to achieve one or more of the following effects:

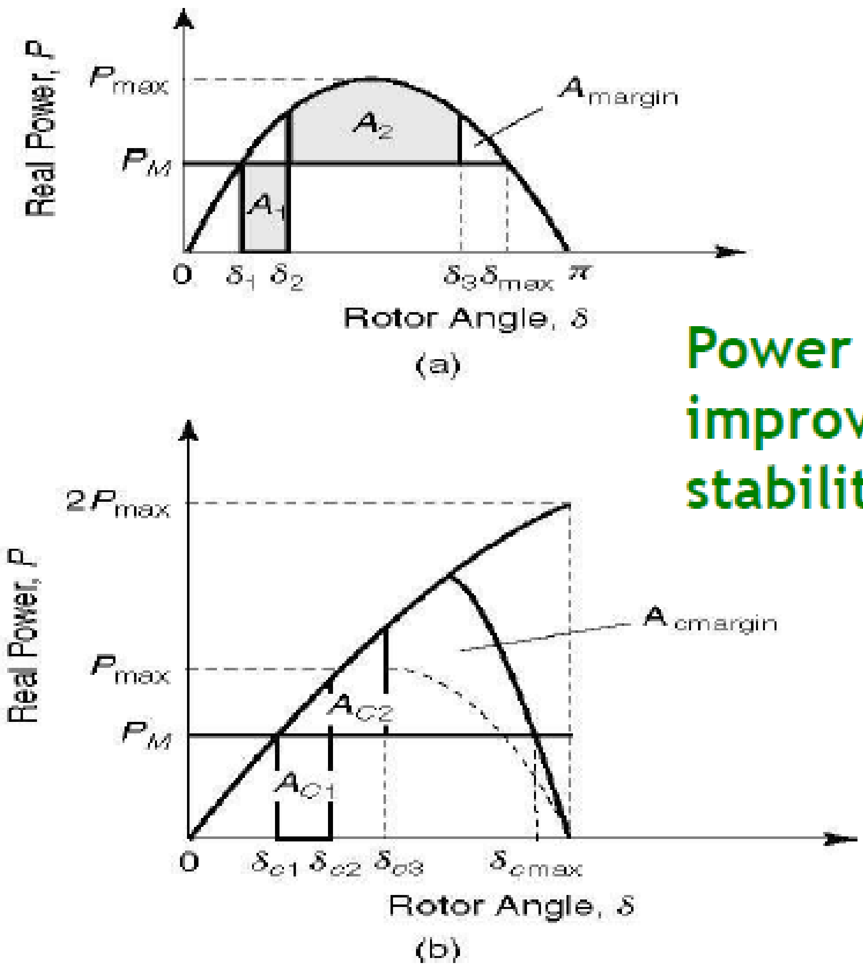
Reduction in the disturbing influence by minimizing the fault severity and duration.

Increase of synchronizing forces.

Reduction of accelerating torque through control of prime-mover mechanical power.

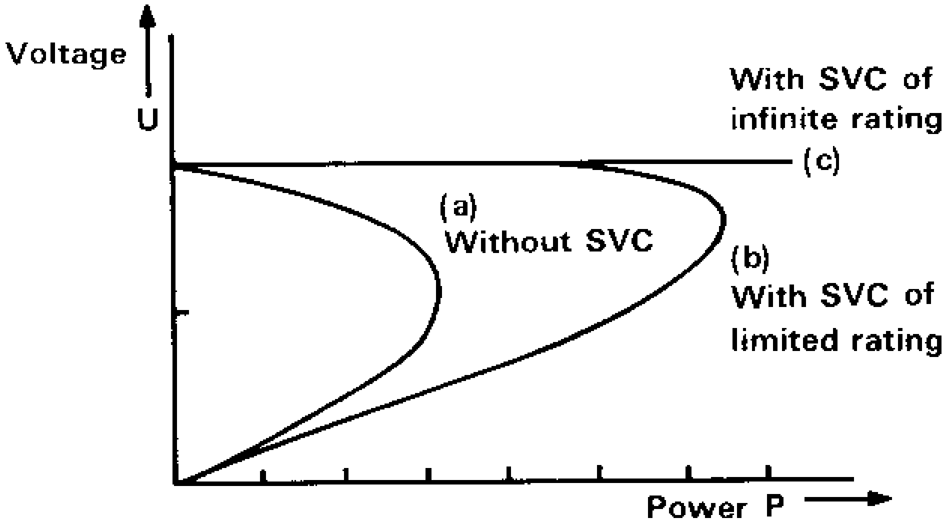
Reduction of accelerating torque by applying artificial load.

Transient stability enhancement by SVC



Power angle curve for improving transient stability margin

Bus Voltage Regulation by SVC



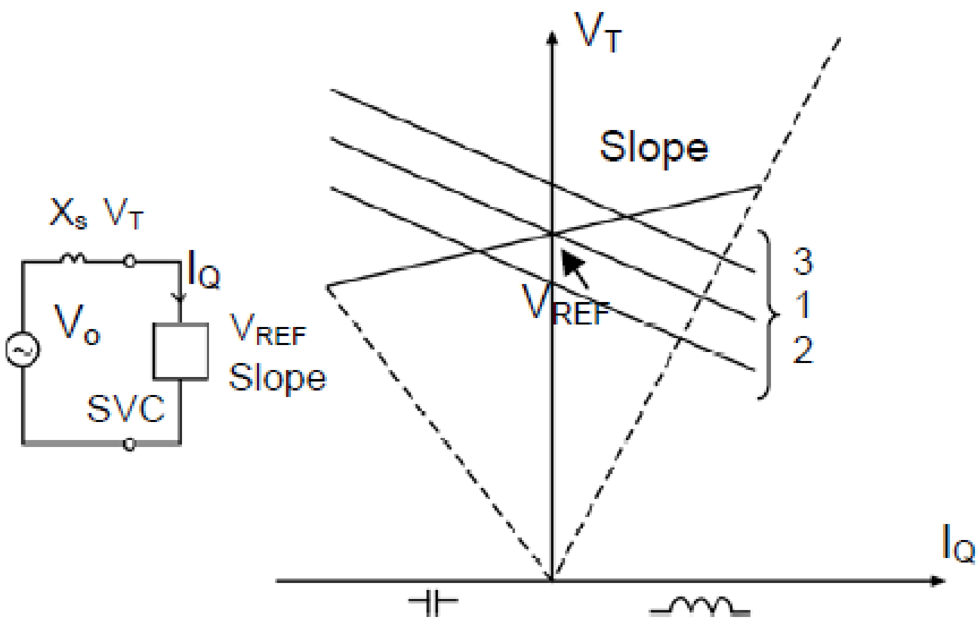
- **Power systems with low SC fault MVA levels / long transmission lines (weak systems)**
- **Buses where voltage variations are significantly effected under light and peak load conditions**

Voltage improving effect of SVC

1: Nominal voltage & load

2: Undervoltage, e.g. due to generator outage

3: Overvoltage, e.g. due to load rejection.

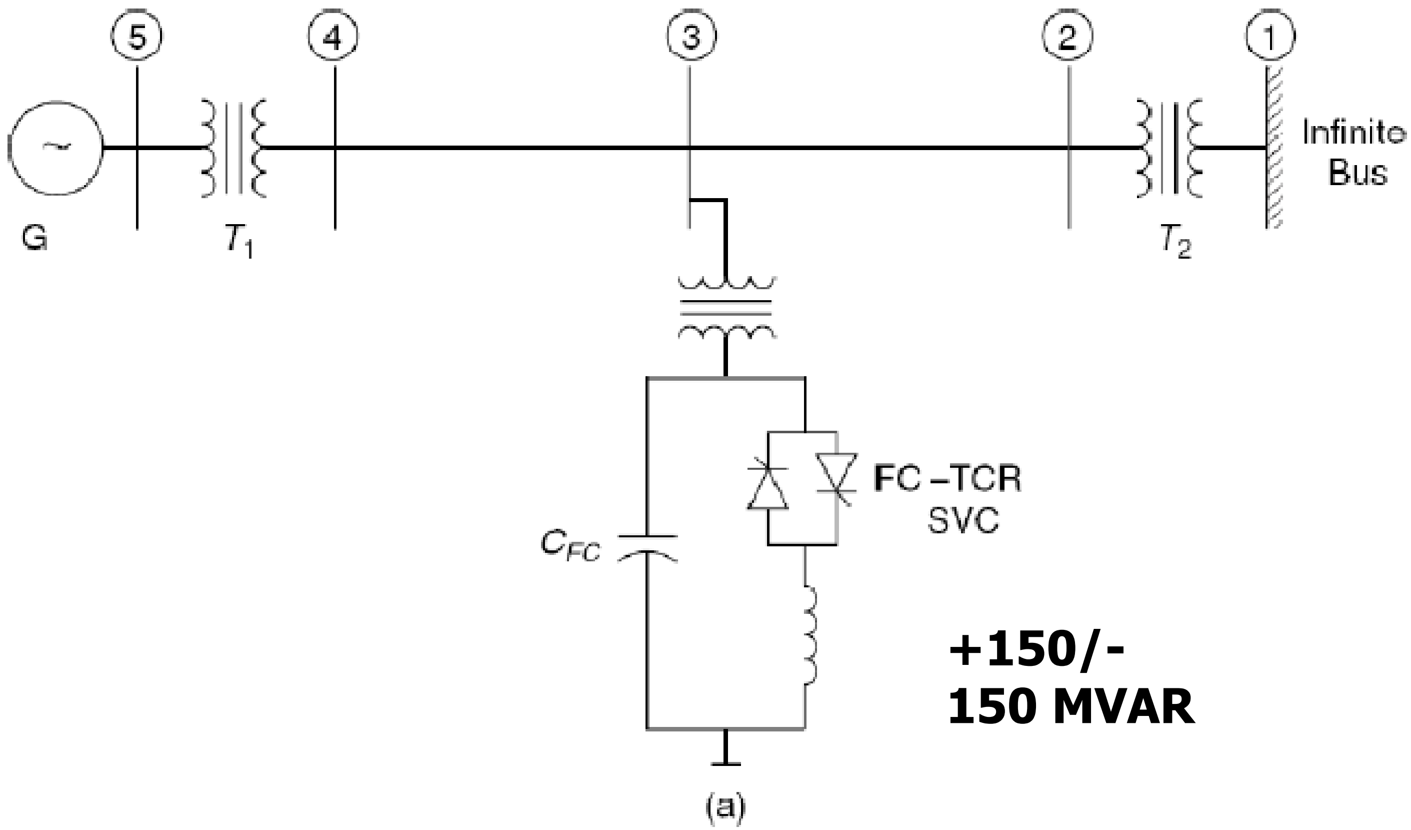


System voltage correction by means of SVC.

CASE STUDY:

POWER TRANSFER STUDIES USING SVC

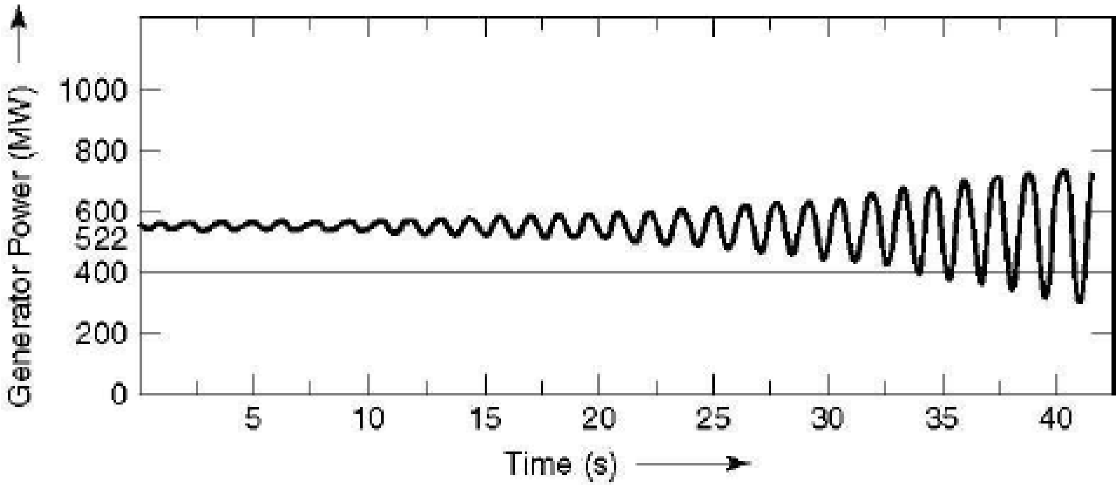
SINGLE MACHINE INFINITE BUS SYSTEM



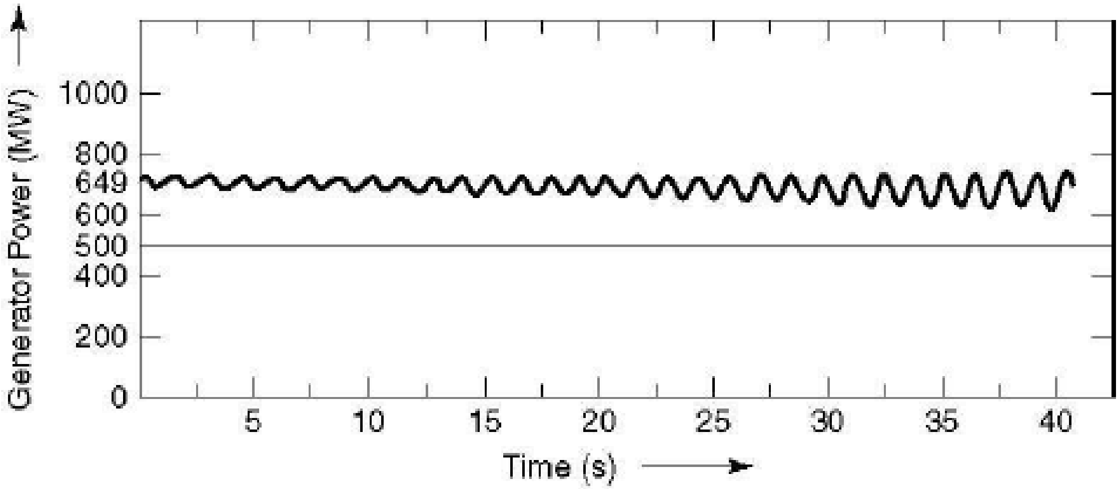
+150/-150 MVAR

RTDS simulation of SMIB system

Power transfer limits – with damping control



(a)

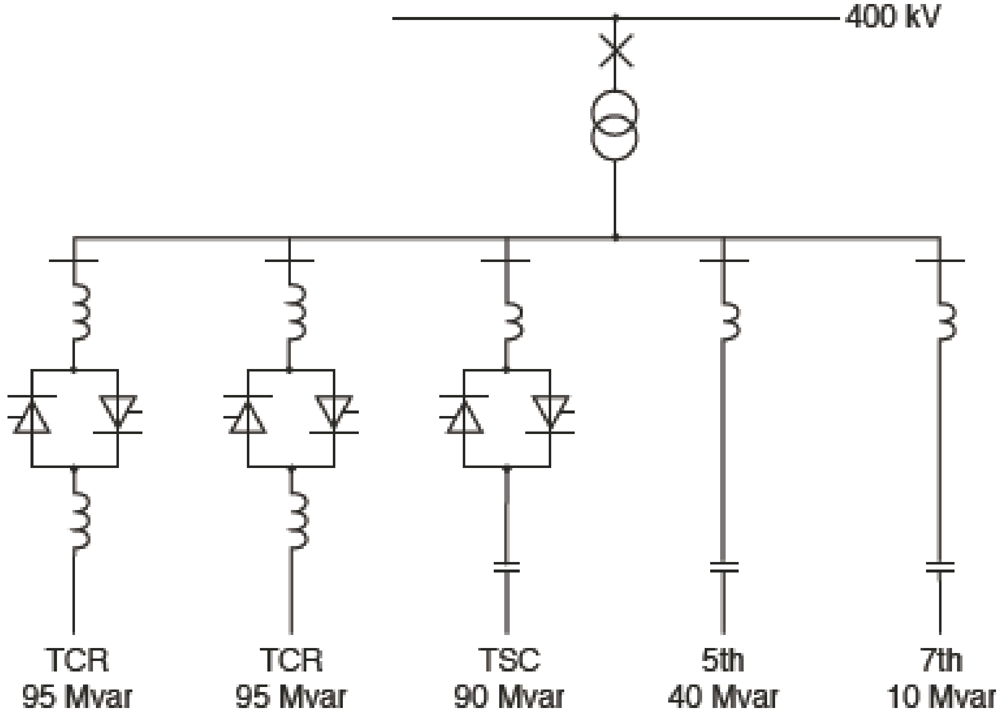


(b)

(a) Without SVC

(b) With SVC

Single-line diagram, for one SVC

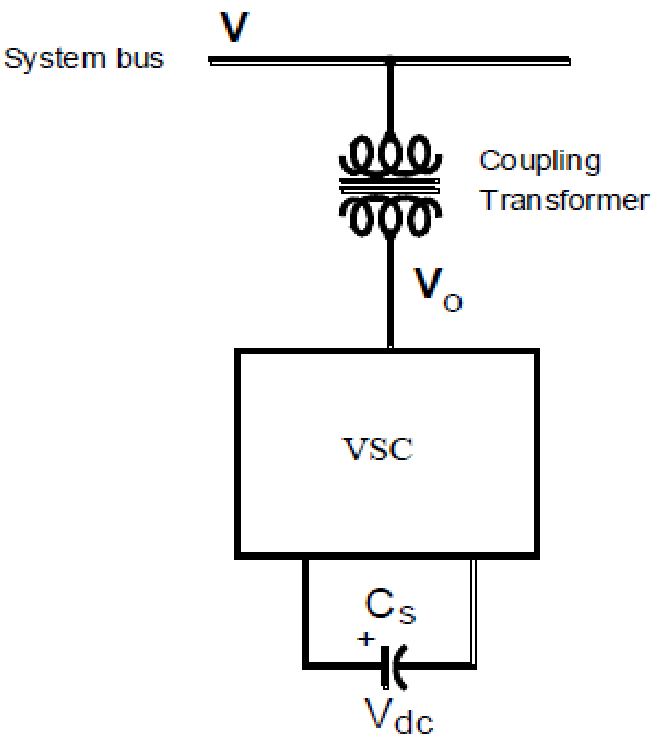


Technical data	
Controlled voltage	400 kV
SVC rating (per compensator)	140 Mvar inductive to 140 Mvar capacitive
Control system	Three-phase voltage control by means of a voltage regulator. Regulator functions include strategy selection and gain supervision/optimization.
Thyristor valves	Water cooled three-phase valves with magnetic firing.

SVC at Kanpur; 2Nos., 140 MVAR each

Shunt FACTS controllers - STATCOM

Shunt Compensation (STATCOM)



It is superior than SVC

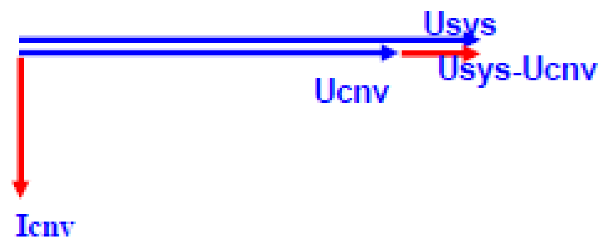
Reduction in outdoor area requirement as it reduces voluminous capacitor/ Reactors.

Improvesd performance at low voltage

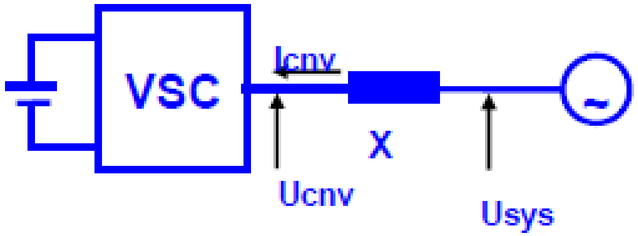
Reduces need of filters.

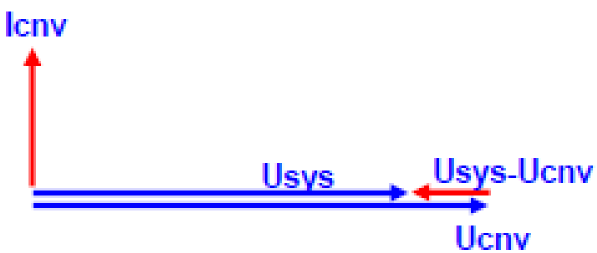
Active & Reactive Power control in STATCOM

Icnv=(Usys-Ucnv)/jX



Case 1: Coverter absorbing reactive power

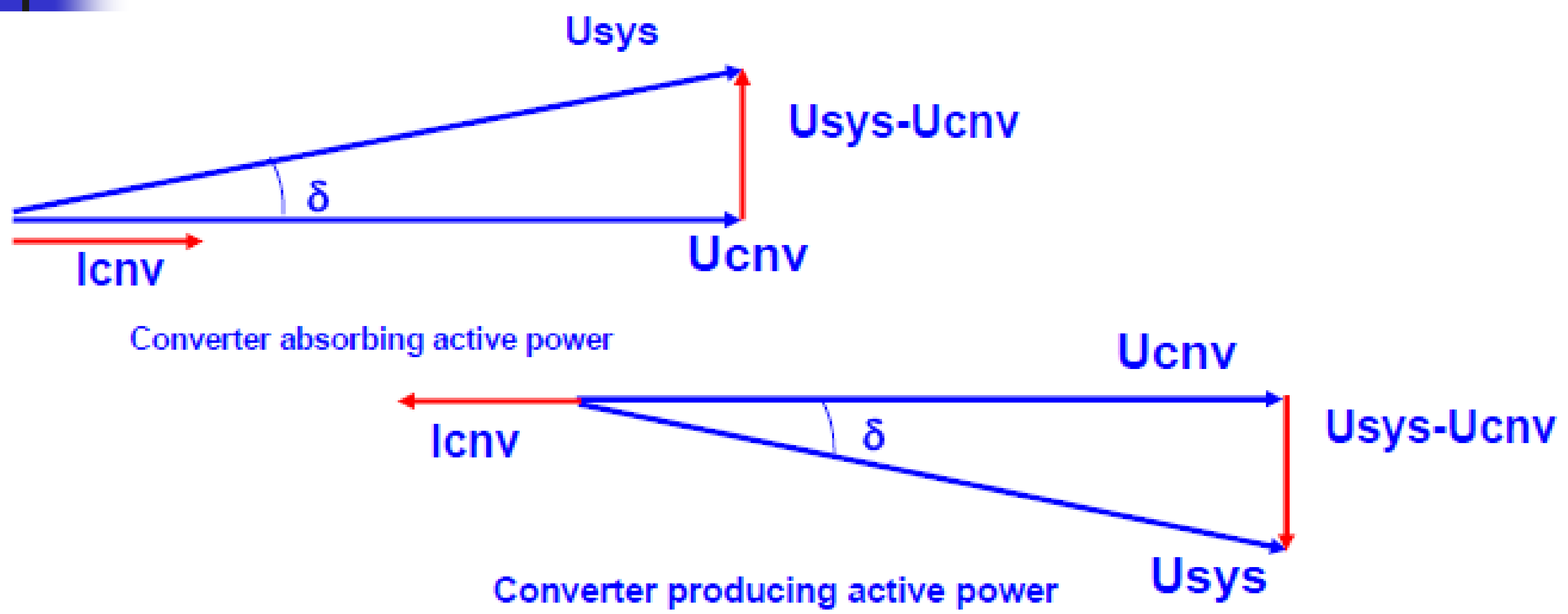




Reactive power is primarily determined by |Ucnv|

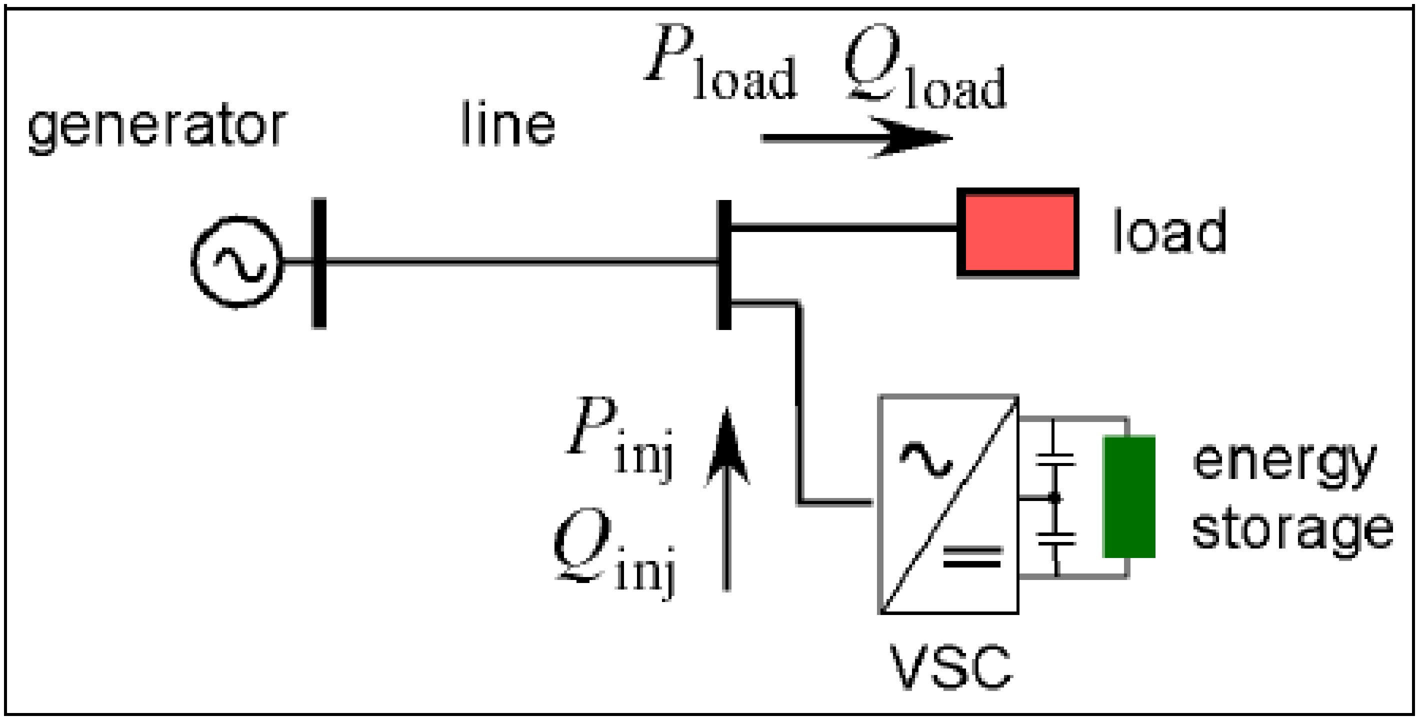
Case 2: Converter producing reactive power

Active & Reactive Power control in STATCOM



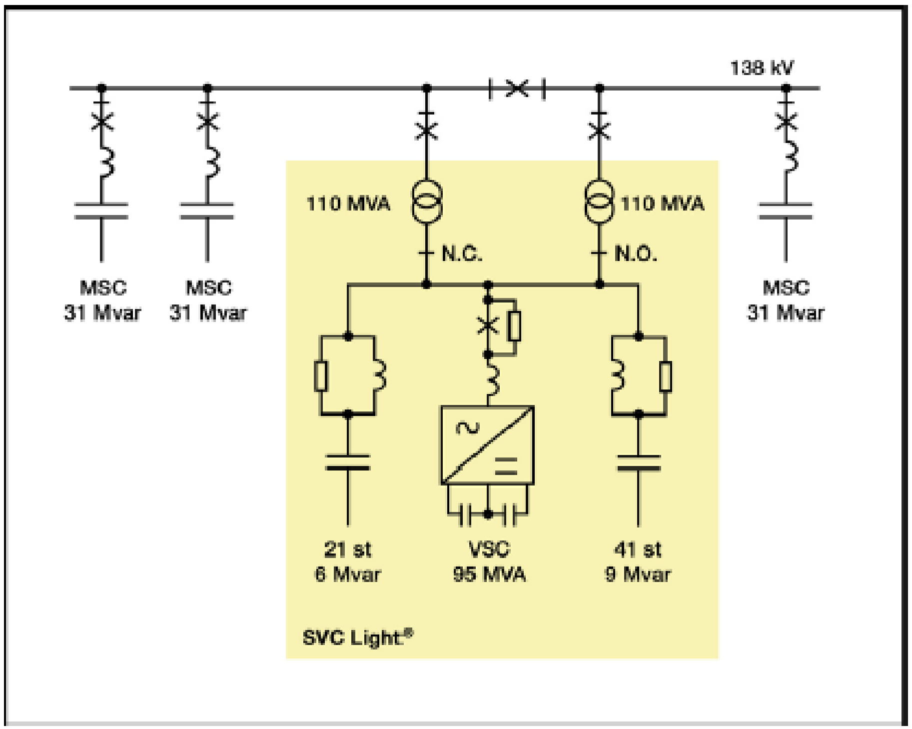
Active power is primarily determined by angle δ

Active Power exchange with STATCOM



Case study

STATCOM for dynamic grid voltage control: Holly / Austin, Texas

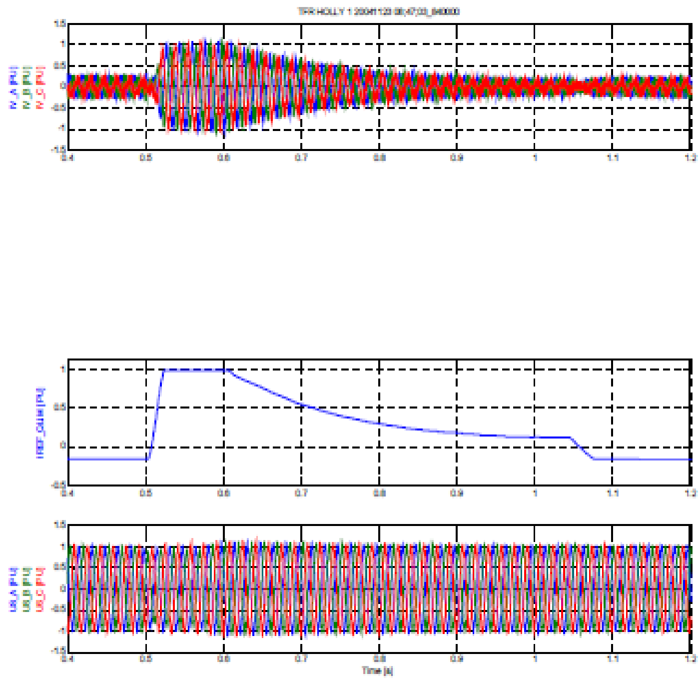


Operating strategy:

- **MSCs to yield the major reactive power support during slow varying conditions in the system.**
- **This leaves STATCOM to rapidly respond to disturbances in the grid requiring fast voltage support**

Courtesy: ABB

Holly STATCOM:
Proven under realistic conditions



Example of STATCOM response during a transmission line fault (top to bottom):

- Three VSC phase currents
- VSC reactive current reference calculated by the control system
- 138 kV system line-to-ground voltages.

- **Cascading faults hit the 138 kV grid. One such case of 5 cycle fault with STATCOM response shown below:**
- **STATCOM control system first disables the MSCs following disturbance & drives VSC to its maximum capacitive output.**
- **Maximum capacitive output achieved in about 1 cycle.**
- **After fault clearing, VSC current ramped down to its initial pre-fault value in a controlled manner.**
- **STATCOM ready to support the grid for any other disturbances**

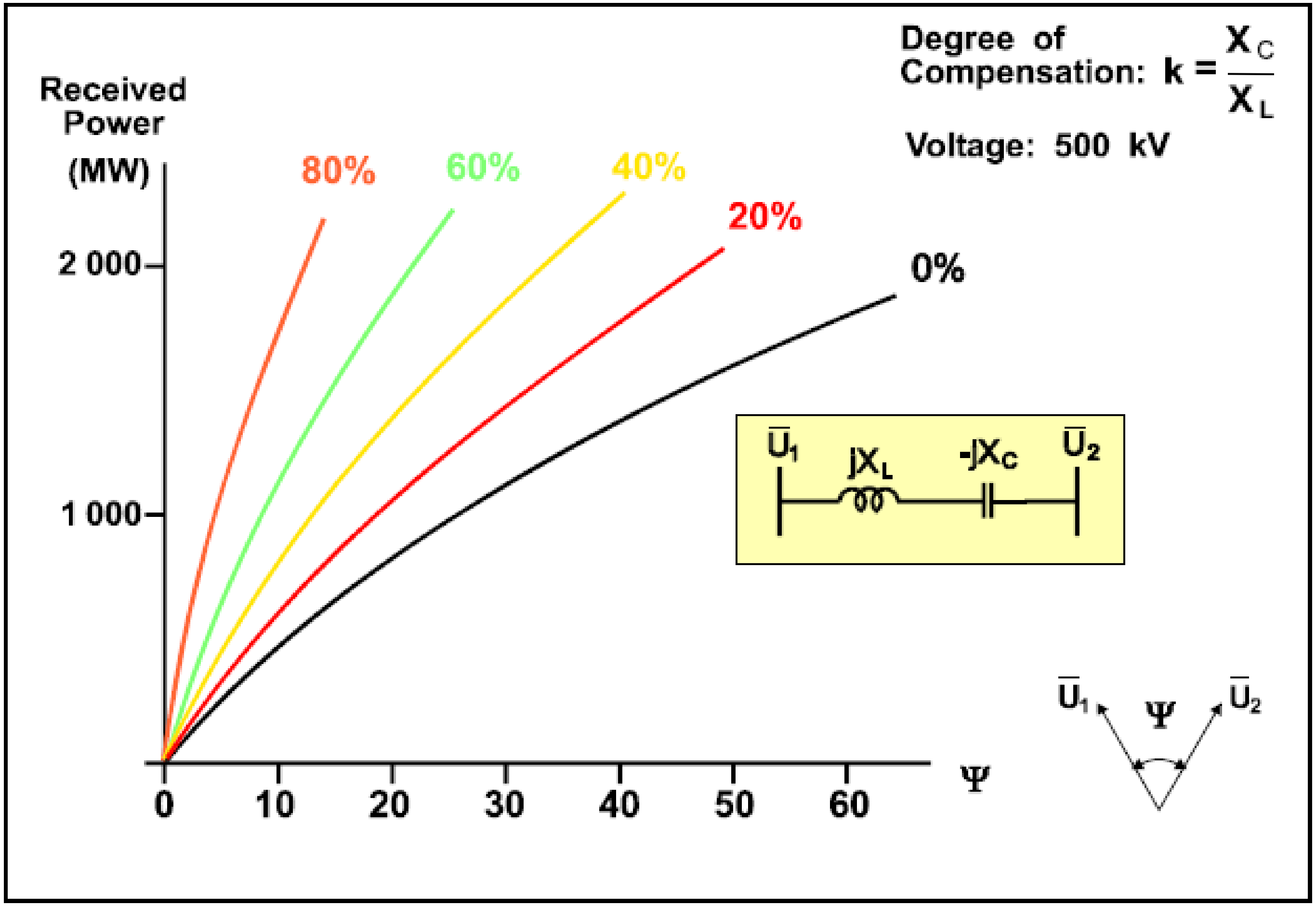
Series FACTS Controllers -TCSC

- **Shunt capacitors must typically be connected at the mid point of line whereas no such requirement exists for series compensation**

- If Q_{se} and Q_{sh} be the ratings of series and shunt capacitor, respectively, to achieve same level of power transfer through a line which has a maximum angular difference of δ_{max} across its two ends, then

$$\frac{Q_{se}}{Q_{sh}} = \tan^2\left(\frac{\delta_{max}}{2}\right)$$

Specifically, for a δ_{max} of 35°, Q_{se} will be approximately 10% of Q_{sh}.

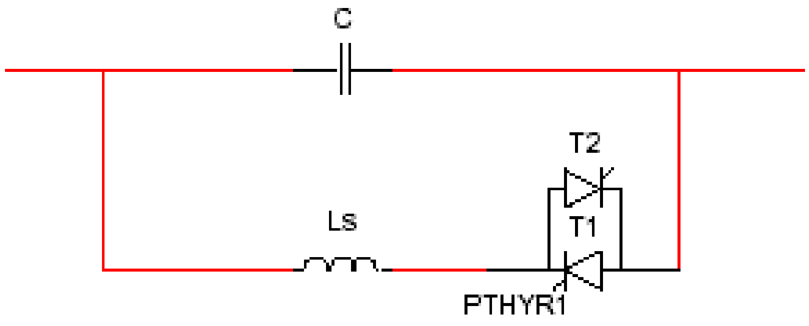


Impact of series compensation on power transmission capability

Applications of variable series compensation -TCSC

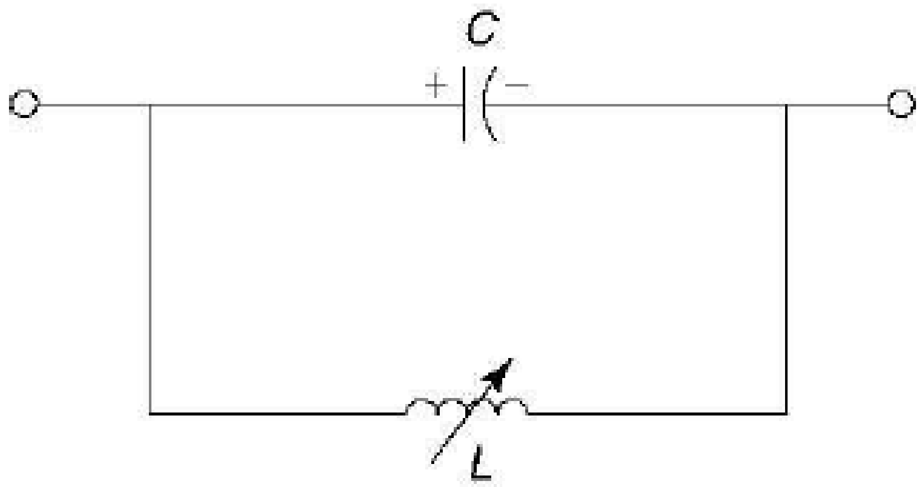
- Power flow control
- Enhancing transient stability
- Damping of power swings
- Sub-synchronous resonance damping

Fixed value of C made controllable by varying inductive reactance through firing angle control



Operation of Thyristor Controlled Series Compensator (TCSC)

A variable inductor connected in shunt with fixed capacitor



$$Z_{eq} = (-j\frac{1}{\omega C}) // (j\omega L) = -j\frac{1}{\omega C - \frac{1}{\omega L}}$$

Damping effects of TCSC

- Damping effect on an intertie unaffected by location of TCSC
- Does not excite local modes of oscillations
- Effectiveness of TCSC for controlling power swings increases with power transfer levels

Case study :1

Power oscillation damping

Raipur – Rourkela 400 kV TCSC (2 nos.)

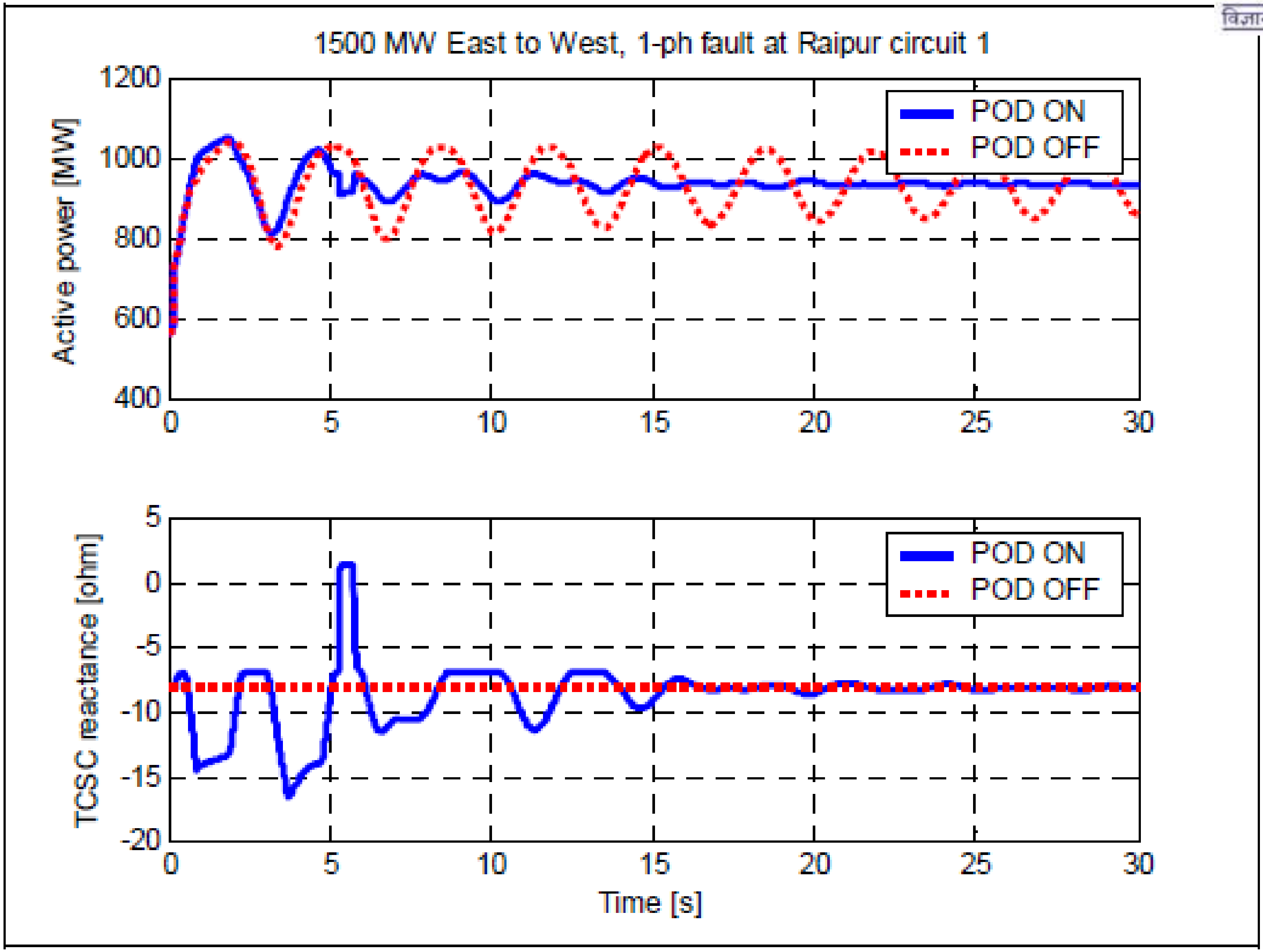
Capacitor reactance: Fixed: 54.7 Ω (40%)
Variable: 6.83 Ω (5%)

Rated capacitive reactive power : Fixed: 394 Mvar
variable: 71 Mvar

Purpose of TCSC at Raipur

Grid stabilization for large power transfers on the 412 Km inter- regional Raipur- Rourkela 400kV D/C tie-line

Damping out low frequency inter-area oscillations (typically in the range below 1Hz) by Power Oscillation (POD) controllers of TCSC

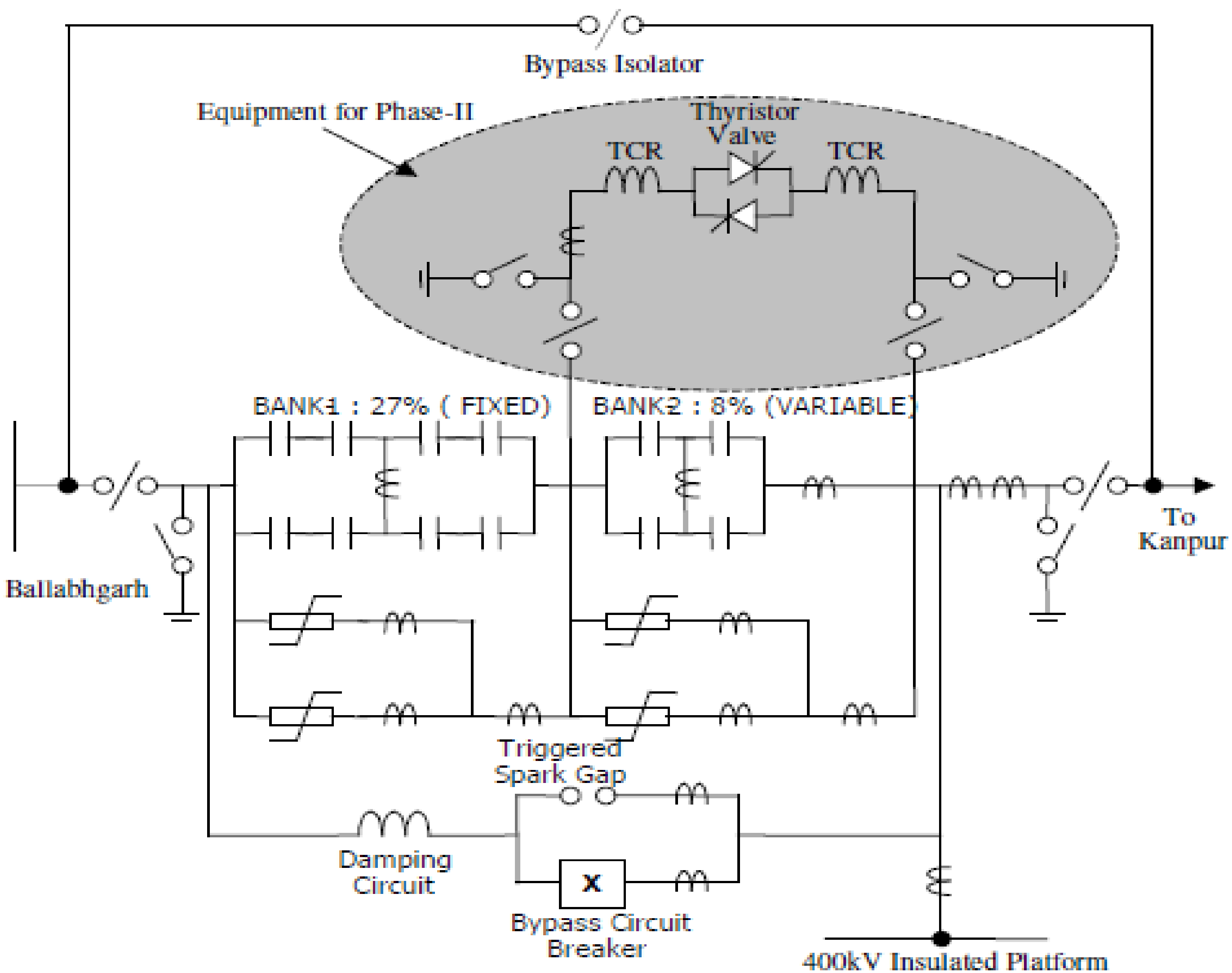


Power oscillation damping with & without POD control in Raipur TCSC

Case study: 2
TCSC OF KANPUR-BALLABHGARH LINE

- Control the power flow over the 400kV Kanpur-Ballabhgarh line
- Providing positive damping support to the Northern Regional Power system.
  - NREB system exhibits two critical low frequency modes of frequency around 0.70Hz - Eastern UP, Rajasthan
  - TCSC controller at Ballabhgarh influences the low frequency mode of eastern-up machines

400 kV TCSC SCHEME FOR KANPUR-BALLABHGARH LINE



COMPENSATION : 35% TO 47%

Major parameters of Kanpur-Ballabhgarh line & TCSC

Positive sequence parameters –

L = 1.044mH/km, C= 16nF/km, R =0.0296Ω/km

Zero sequence parameters –

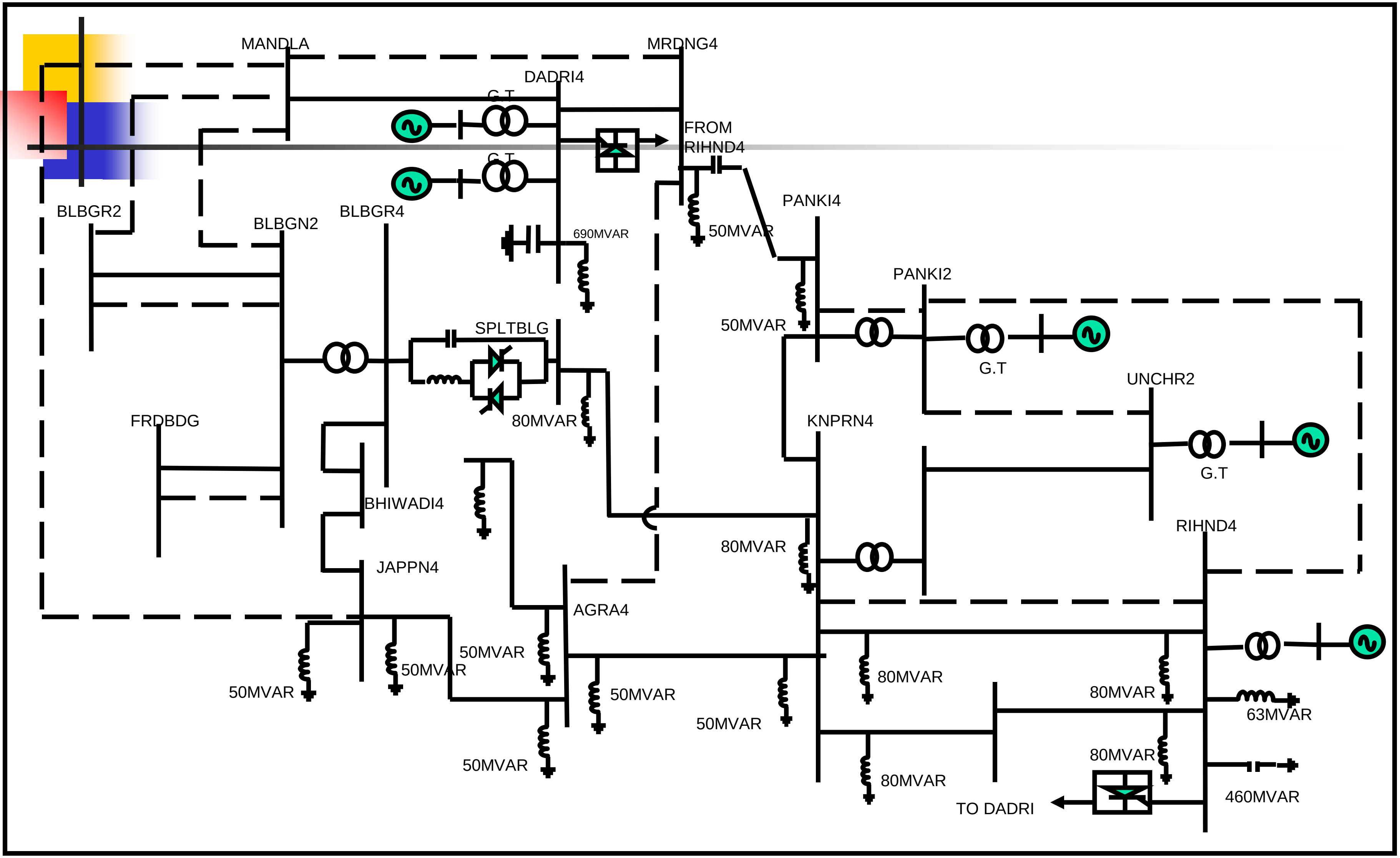
L= 3.259mH/km, C = 9nF/km, R = 0.2986Ω/km

Fixed portion Series Capacitor: C = 90.7μF

TCSC: Fixed capacitor: C = 306μF,

TCR: L = 4.4mH, Q = 50

REDUCED NREB SYSTEM REPRESENTATION

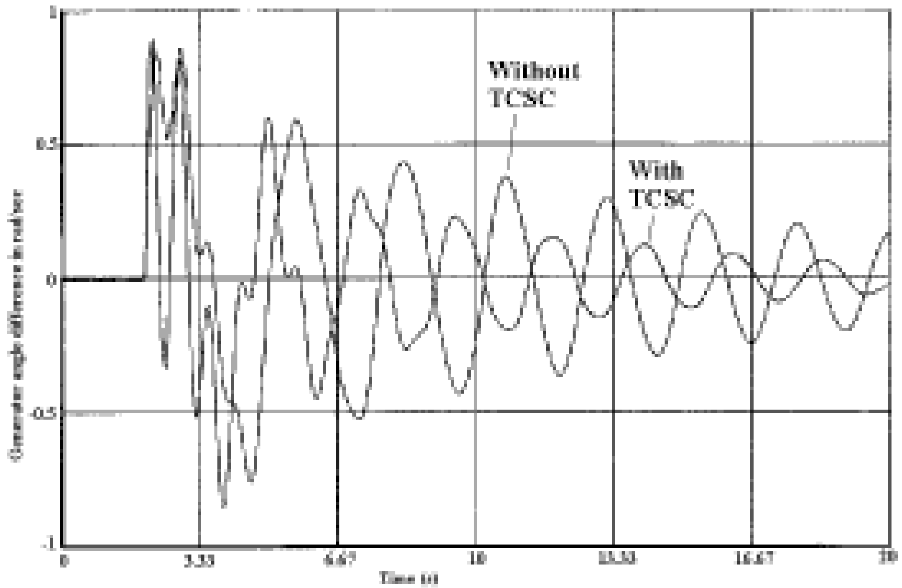


Reduced NREB system representation

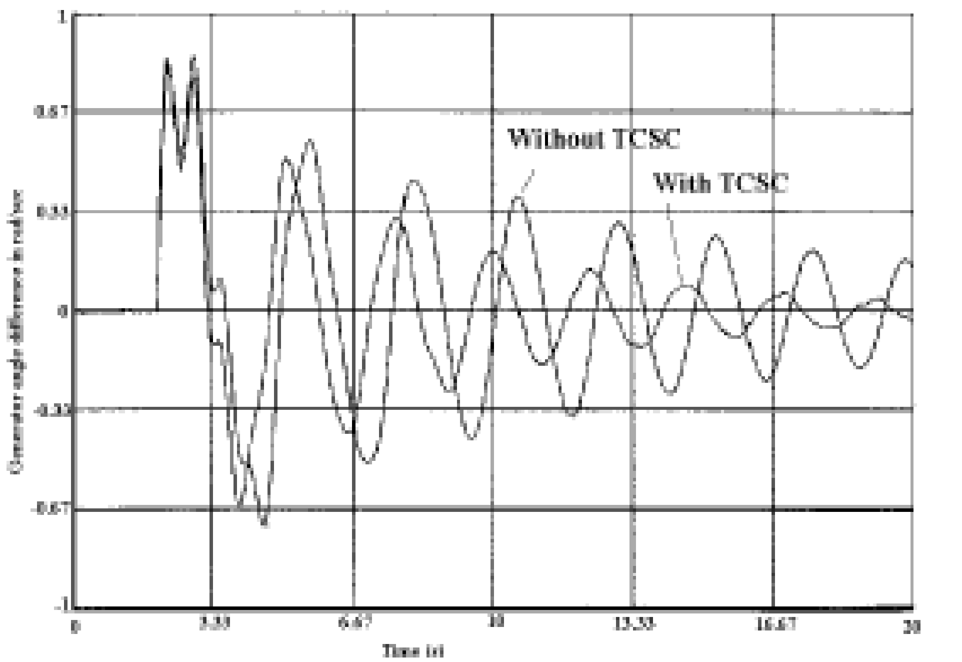
- 14 infinite sources behind a series impedance.
- 22nos of 400kV lines.
- 11nos of 220kV lines.
- 10nos of fictitious line were modeled as series impedance between buses.
- One HVDC bipolar link (Rihand - Dadri) – rated total capacity 1500 MW.
- One SVC at Kanpur rated at 280 MVAR.
- TCSC (27% fixed 8%-20% variable) on the Kanpur Ballabhgarh Line.

Outage of HVDC line with current based controller

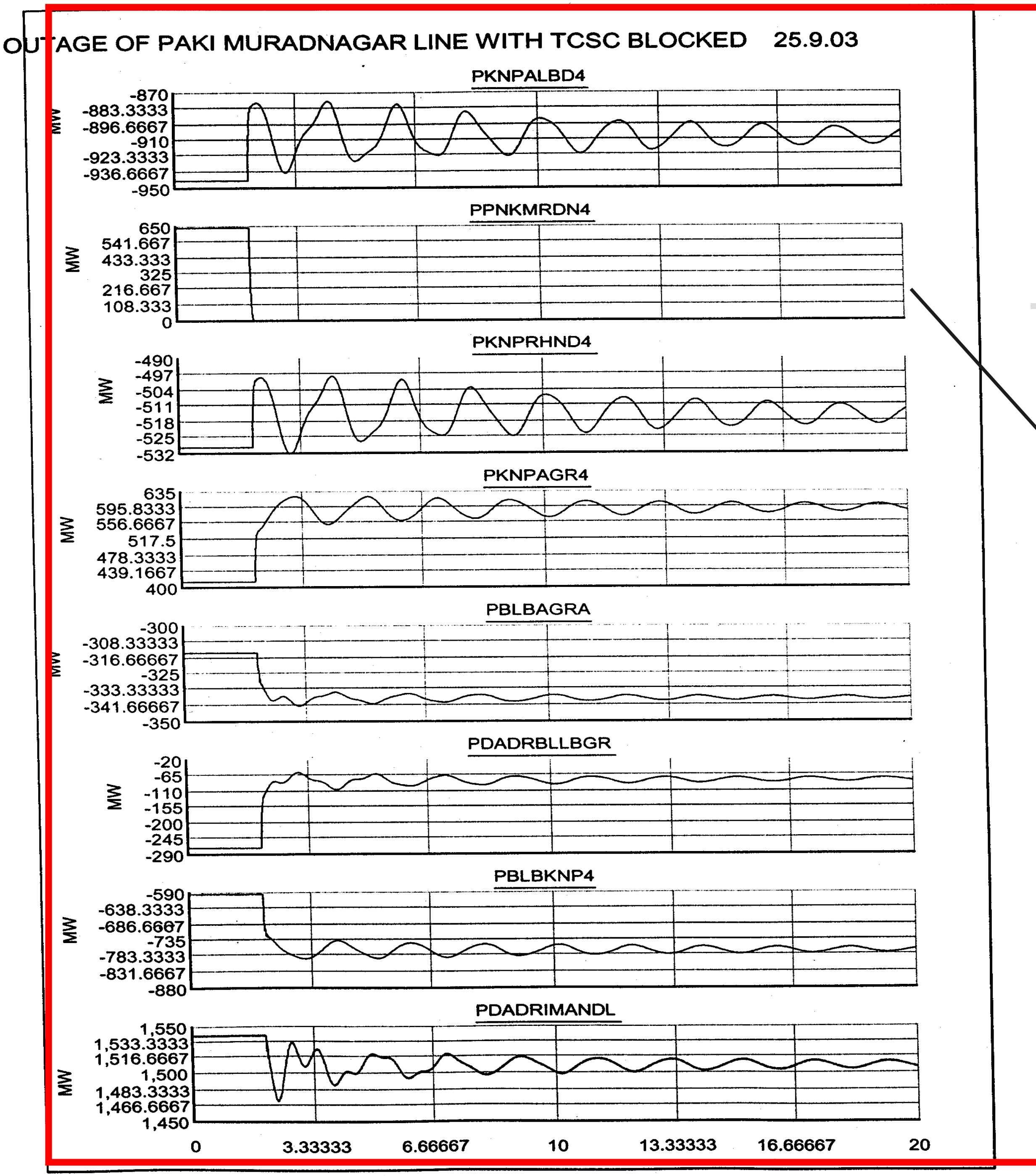
- **Satisfactory Damping**
- **Created disturbance in the Steady state**



Outage of HVDC line with voltage based controller



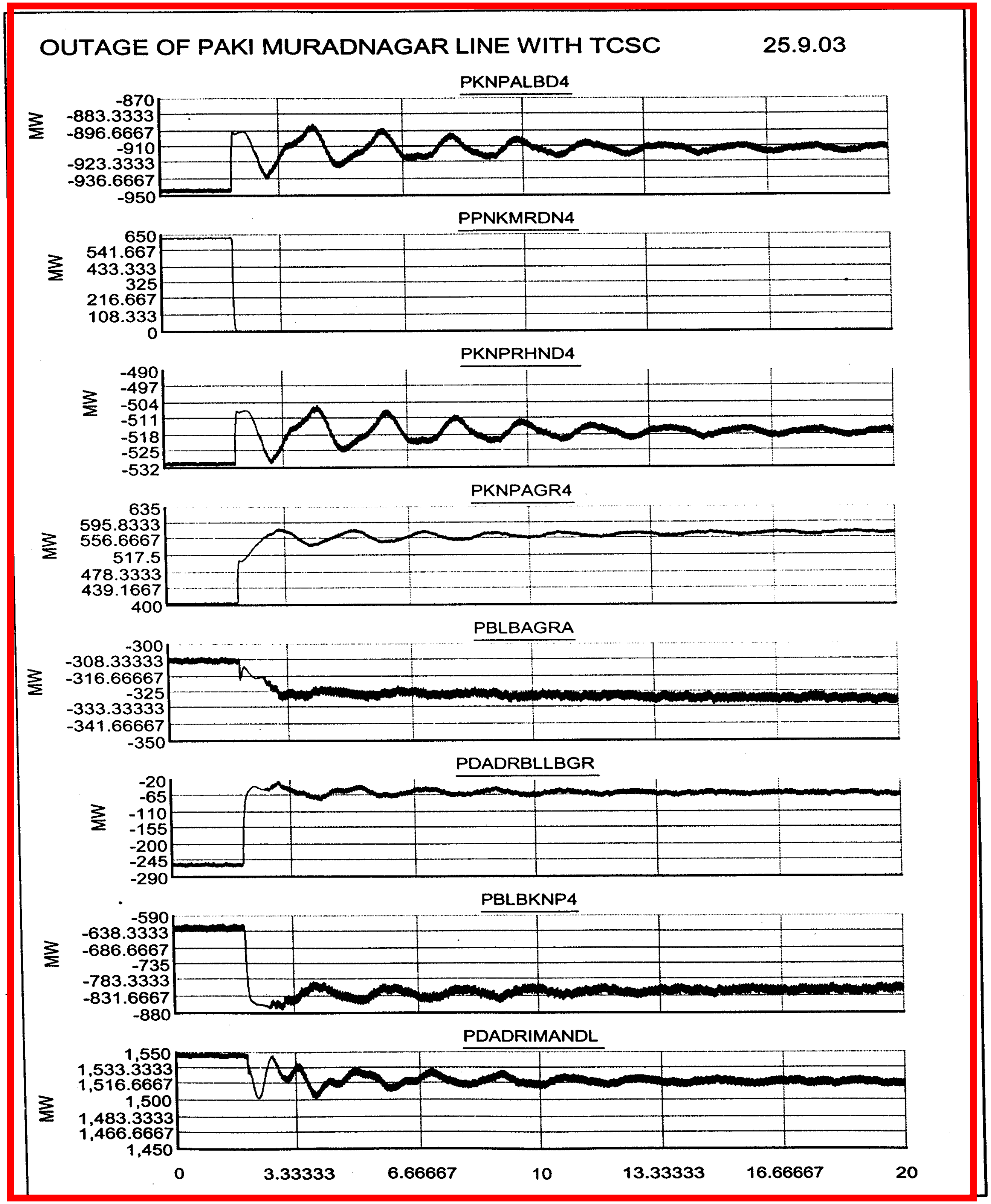
- Better Damping
- Created disturbance in the Steady state



Outage of Panki-Muradnagar Line

Without

Damping Controller



Outage of Panki-Muradnagar Line

With

Damping Controller

Conclusions

- FACTS: a highly useful option from technical, economic and environmental points of view, to increase utilization and stability of transmission systems or inter-ties.
- Vital characteristic: ability to provide dynamic reactive power compensation to maintain, or, in the most difficult cases, restore grids to stable operating conditions.
- Typically done at a cost level and time far less than with traditional means of building new transmission lines.
- With energy storage capability, more efficient implementation of renewable generation such as wind and solar power into grids


THANK
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