

HVDC AND FACTS

(20A02604a)

PPT

III-B.TECH & II-SEM

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HVDC TRANSMISSION



INTRODUCTION

110V DC Central electric station- by EDISON in New York in 1885.

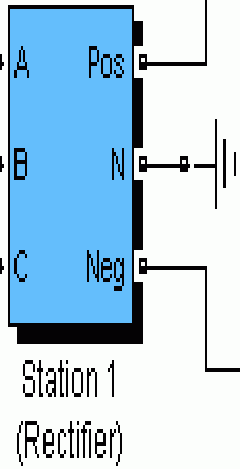
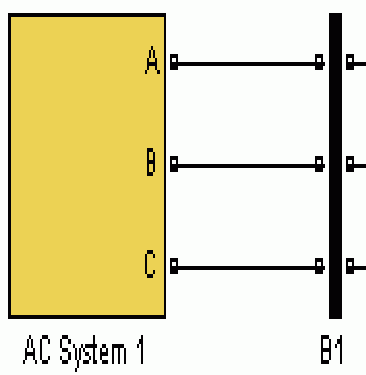
- Introduction of transformers and 3-phase ac system changed the situation.
- Due to advantages of dc transmission extensive research has been carried out by Dr. Uno Iamm in 1929.
- The successful development of high power thyristors HVDC transmission came into existence.
- It became technically and commercially alternative to EHV/UHV-Ac transmission.
- Due to bulk power transmission, cable transmission HVDC have distinct superiority

ADOPTS OF HVDC

- The first dc link was setup in 1954 between Swedish & Gotland which was a monopolar cable system.
- The England-France cross channel dc link was commissioned in 1961 which was a bipolar system.
- The first HVDC transmission has been introduced in India between Rihand & Delhi.
- Another system at Vindhyachal -back to back system.
- At present the world has over 50 HVDC schemes in operation.

LINE DIAGRAM OF HVDC

230 kV, 50 Hz
2 000 MVA equivalent
P, Q
----->



75-km cable

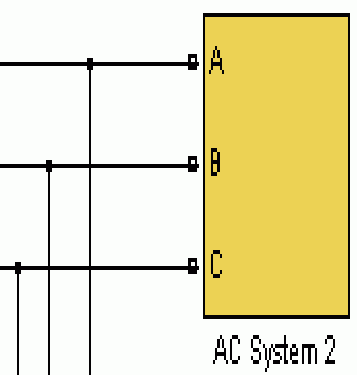
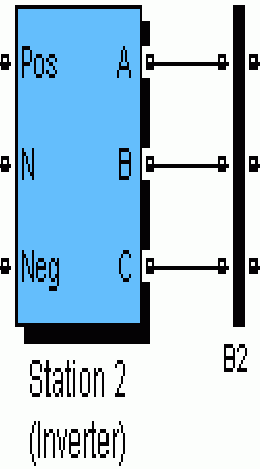


75-km cable



Cable

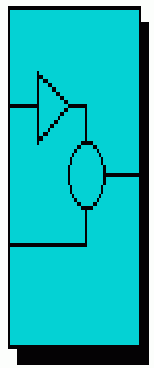
P, Q
-----<
230 kV, 50 Hz,
2 000 MVA equivalent



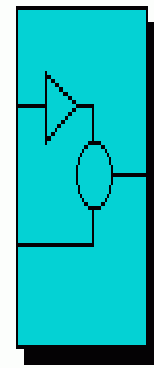
Three-Phase Fault

Open this block
to visualize
recorded signals

Data Acquisition
Station 1



VSC Controller
(Station 1)



VSC Controller
(Station 2)

Open this block
to visualize
recorded signals

Data Acquisition
Station 2

Converters

- It is necessary to have two converter stations one at each end to provide asynchronous link between two ac systems.
- However, these two converters are identical whether they work as rectifier or inverter.
- The main equipments in a converter station are transformers and thyristor valves.
- Chokes and filters are provided for smooth dc and to suppress harmonics.
- The thyristor valves act as rectifier at sending end.
- At the receiving end the thyristor valves act as inverters.

Transmission line

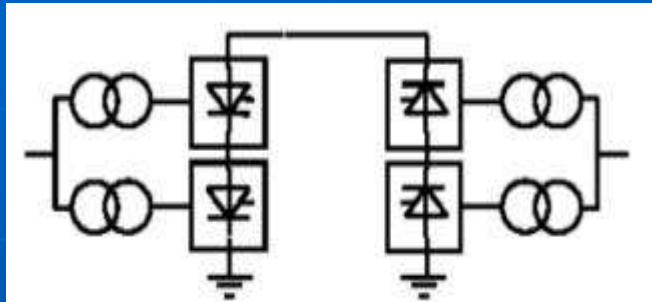
- The rectified current from the converter flows along the transmission line.
- At the start, transmission line will have high voltage direct current.
- This current is converted in to 3-phase ac current by the converter at receiving end.
- There are less losses in the transmission line of HVDC compared to EHV.

There are three different categories of HVDC transmissions:

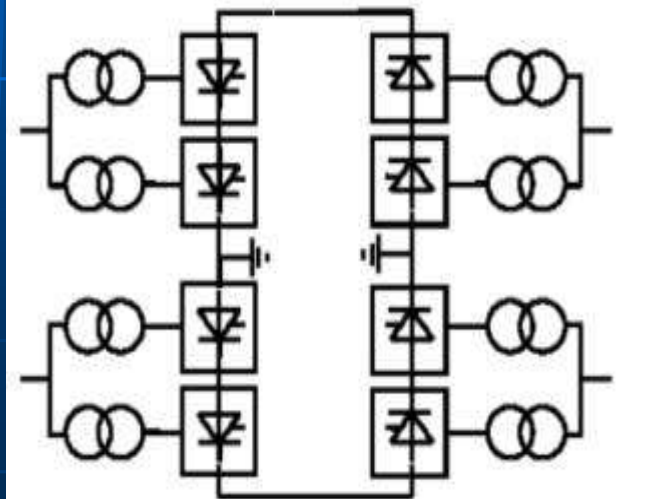
1. Point to point transmissions
2. Back-to-back stations
3. Multi-terminal systems

Types of dc links

- There are 3 types of dc links:
- 1. Monopolar link
- 2. Bipolar link
- 3. Homopolar link.



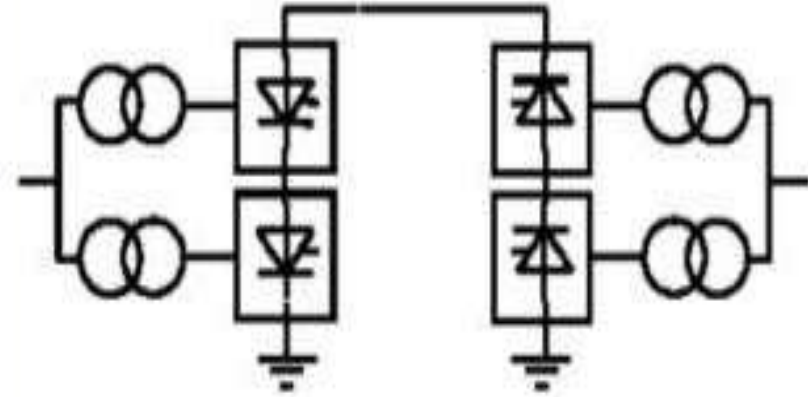
(a) Monopolar configuration



(b) Bipolar configuration

Monopolar dc link

- It has only one conductor and return path is provided by permanent earth or sea.
- These are operated with negative polarity with respect to ground.



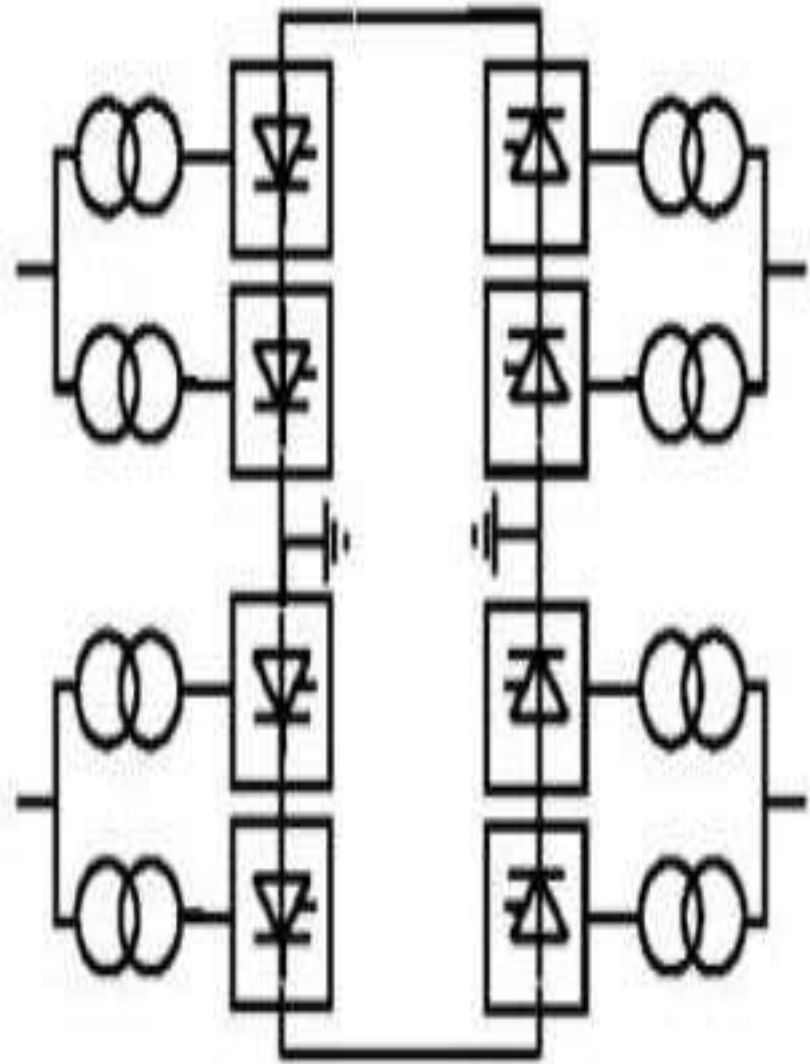
(a) Monopolar configuration

- The ground return path has low resistance.
- More economical than bipolar line.
- Used only for low power rating and mainly for cable transmission.
- By adding additional sub station pole monopolar lines can be converted in to bipolar lines.

Bipolar dc link

- Most widely used dc link for over head long distance HVDC
- This link has two conductors one with positive and other with negative polarities with respect ground.
- Two converters of equal voltage rating in series at each end of line.

- The junction between the converters may be grounded at one end or at both ends.
- If both ends-Each pole operates independently.
- Rated voltage is ± 500 kv .



(b) Bipolar configuration

Homopolar dc link

- It has two or more conductors with same polarity, usually negative.
- Always operates with ground as return conductor.
- In case of fault on any one of the conductors the healthy conductor can supply power.
- It has limited applications.

Advantages

- Cheaper in cost.
- No skin effect.
- Lower transmission losses.
- Better voltage regulation.
- Surge impedance loading.
- Greater reliability.
- Rapid change of energy flow.
- Less corona loss & radio interference.

Disadvantages

- Costly terminal equipment.
- More maintenance of line insulators.
- Voltage transformation.
- Converters need complex cooling systems.

CHARACTERISTICS	EHV	HVDC
Line cost	Higher	Lower
Skin effect	Present	Absent
Ground return	Not possible	Possible
Line losses	High	Low
Power transfer	Limited	No limit
Voltage control	Difficult	Easier
Corona	More	Less
Compensation	Necessary	Not necessary
Reliability	Lesser	More
Stability	Very low	Much higher

CONCLUSION

- Bulk transmission is likely to rely on thyristor-based technology for many years since it is reliable and low in cost, plus losses are low. Increasing the voltage is one way to go here as it would allow much higher powers and very long distances for the links.



A Presentation On....

FACTS DEVICES

FACTS

Flexible AC Transmission System (Facts) is a new integrated concept based on power electronic switching converters and dynamic controllers to enhance the system utilization and power transfer capacity as well as the stability, security, reliability and power quality of AC system interconnections.

INTRODUCTION

- Flexible Alternating Current Transmission System.
- FACTS as they are generally known, are new devices that improve transmission systems.
- FACTS is a static equipment used for the AC transmission of electrical energy.
- It is generally a power electronics based device.
- Meant to enhance controllability and increase power transfer capability.

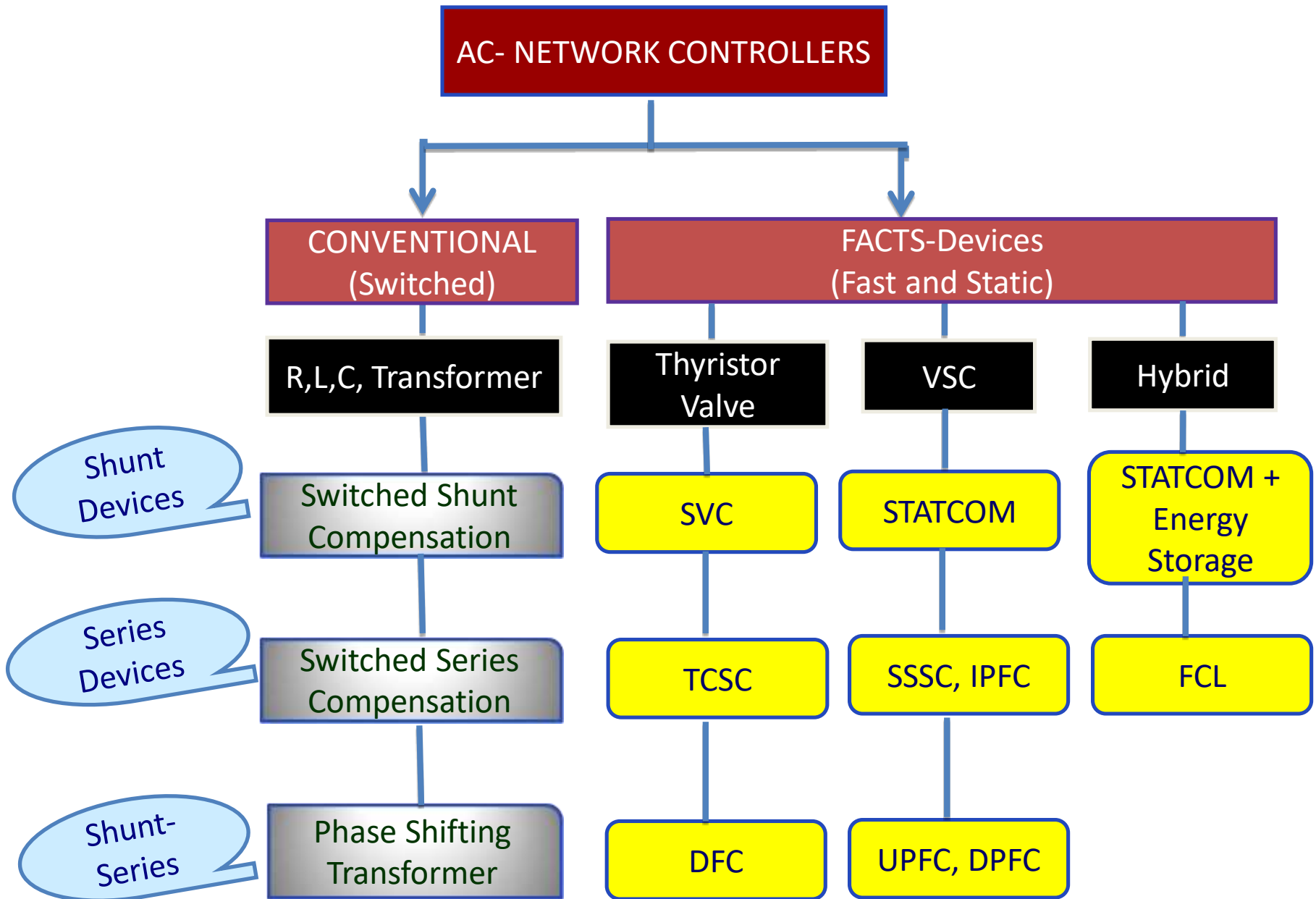
BENEFITS OF FACTS DEVICES

- Regulation of power flows in prescribed transmission routes.
- Reduces the need for construction of new transmission lines, capacitors and reactors.
- Provides greater ability to transfer power between controlled areas.
- These devices help to damp the power oscillations that could damage the equipment.

- Improves the transient stability of the system.
- Controls real and reactive power flow in the line independently.
- Damping of oscillations which can threaten security or limit the usable line capacity.

- ✓ Better utilization of existing transmission system assets
- ✓ Increased transmission system reliability and availability (lower vulnerability to load changes, line faults)
- ✓ Increased dynamic and transient grid
- ✓ Stability and reduction of loop flows
- ✓ Increased quality of supply for sensitive industries
(through mitigation of flicker, frequency variations)
- ✓ Environmental benefits

OVER VIEW OF FACTS

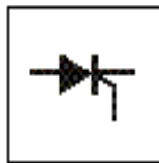


Basic Types of FACTS Controllers

Basic Types of FACTS Controllers

FACTS controllers are classified as

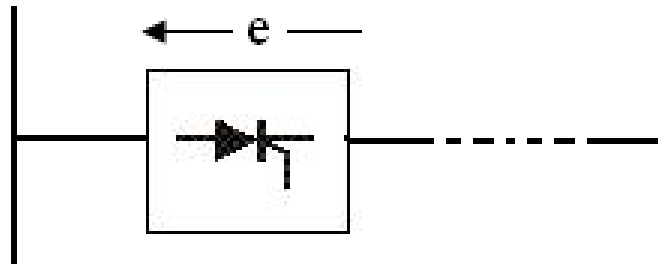
- Series Controllers
- Shunt Controllers
- Combined Series-Series Controllers
- Combined Series-Shunt Controllers



Basic Types of FACTS Controllers

Series Controllers:

- It could be a variable impedance (capacitor, reactor, etc) or a power electronic based variable source of main frequency, subsynchronous and harmonic frequencies to serve the desired need.



Basic Types of FACTS Controllers

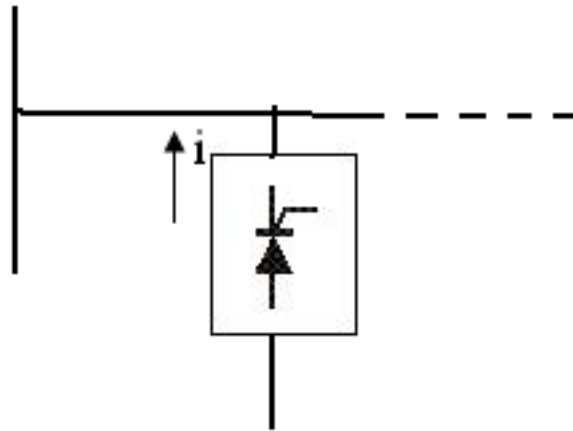
Series Controllers:

- Inject a voltage in series with the line.
- If the voltage is in phase quadrature with the current, controller supplies or consumes reactive power.
- Any other phase, involves control of both active and reactive power.

Basic Types of FACTS Controllers

Shunt Controllers:

- It could be a variable impedance (capacitor, reactor, etc) or a power electronic based variable source or combination of both.



Basic Types of FACTS Controllers

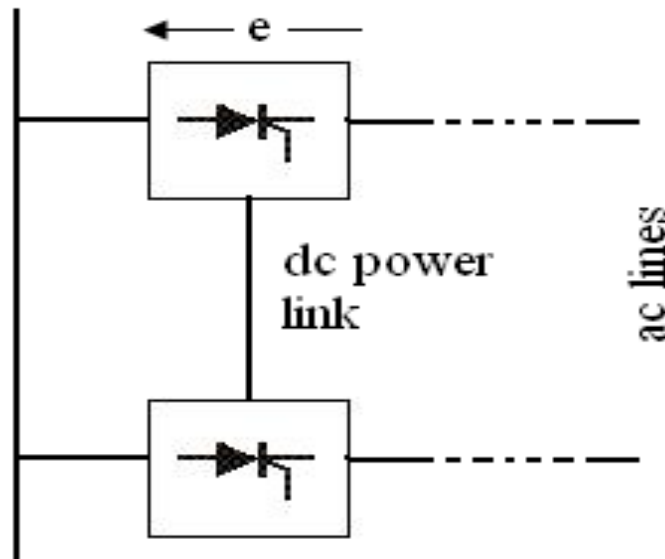
Shunt Controllers:

- Inject a current in the system.
- If the current is in phase quadrature with the voltage, controller supplies or consumes reactive power.
- Any other phase, involves control of both active and reactive power.

Basic Types of FACTS Controllers

Combined Series-Series Controllers:

- It could be a combination of separate series controllers or unified controller.



Basic Types of FACTS Controllers

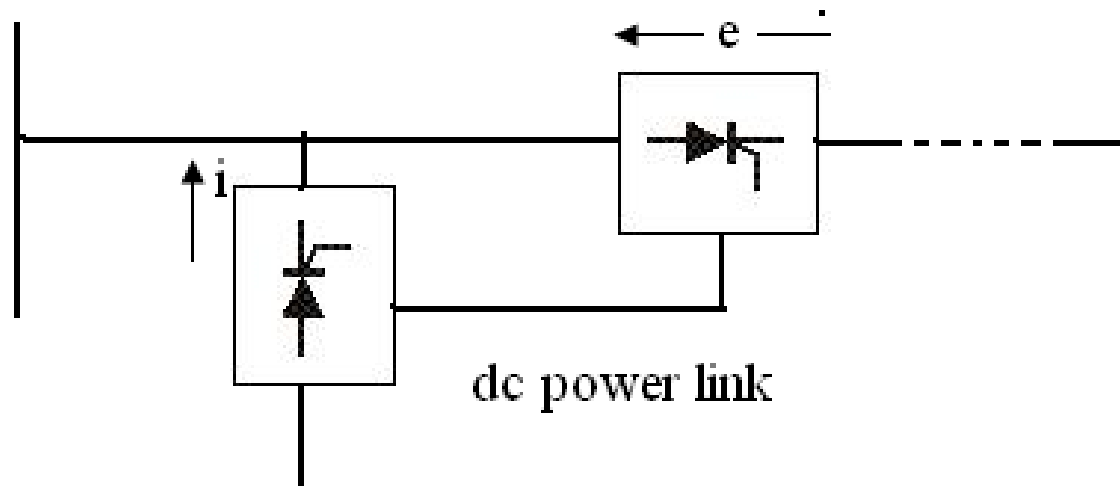
Combined Series-Series Controllers:

- Series controllers supply reactive power for each line and real power among lines via **power link**.
- **Interline power flow controller** balance real and reactive power flow in the lines.

Basic Types of FACTS Controllers

Combined Series-Shunt Controllers:

- It could be a combination of separate series & shunt controllers or **unified power flow controller**.



Basic Types of FACTS Controllers

Combined Series-Shunt Controllers:

- Inject current into the system with the shunt controller and voltage in series with the line with series controller.
- When the controllers are unified, exchange real power between series and shunt controllers via power link.

Basic Types of FACTS Controllers

Choice of the controller:

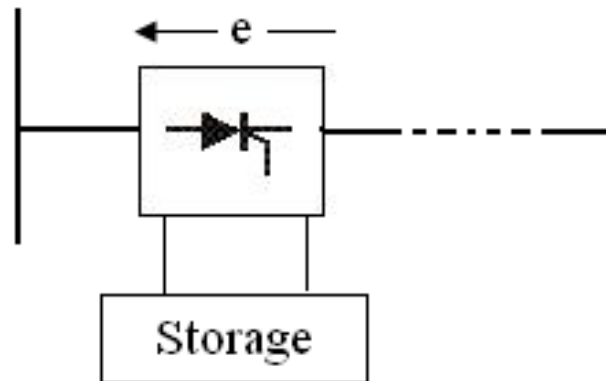
- Series controller controls the current/power flow by controlling the driving voltage.
- To control current/power flow and damp oscillations, series controller is several times more powerful than shunt controller.
- Shunt controller injects current in the line
- Thus it is used for more effective voltage control & damp voltage oscillations.

Basic Types of FACTS Controllers

- Injecting the voltage in series with the line can improve the voltage profile.
- But shunt controller is more effective to improve the voltage profile at substation bus.
- For a given MVA, size of series controller is small compared to shunt controller.
- Shunt controllers cannot control the power flow in the lines.
- Series controllers should bypass short circuit currents and handle dynamic overloads.

Basic Types of FACTS Controllers

- Controllers with gate turn off devices are based on dc to ac converters and exchange active/reactive power with ac lines.
- This requires energy storage device.



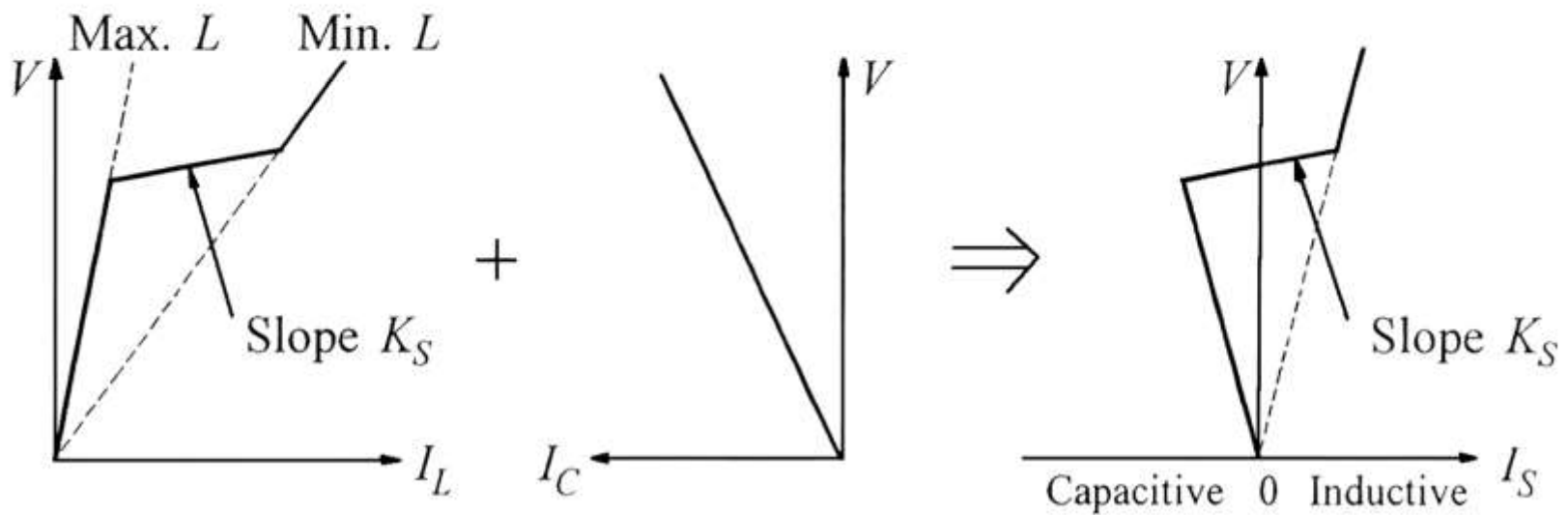
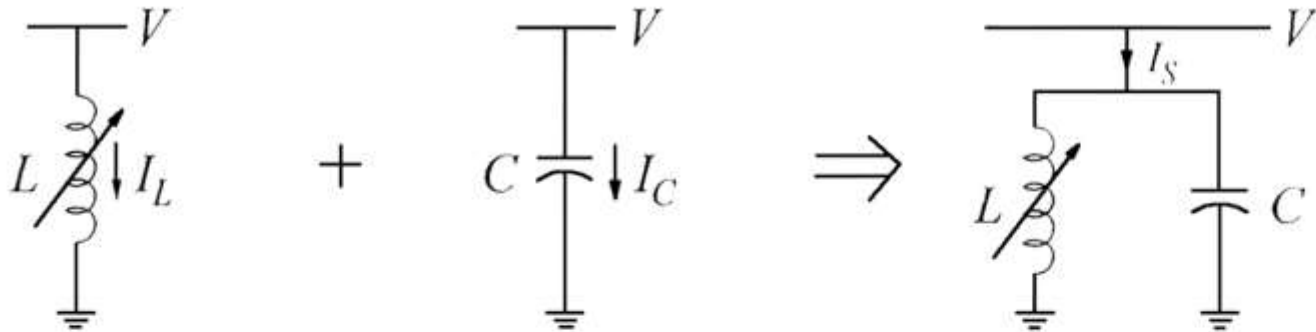
Basic Types of FACTS Controllers

- Energy storage systems are needed when active power is involved in the power flow.
- A controller with storage is more effective for controlling the system dynamics.
- A converter-based controller can be designed with high pulse order or pulse width modulation to reduce the low order harmonic generation to a very low level.
- A converter can be designed to generate the correct waveform in order to act as an active filter.

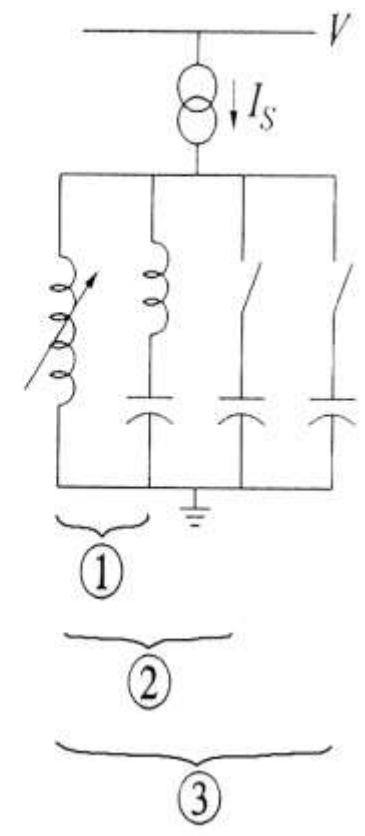
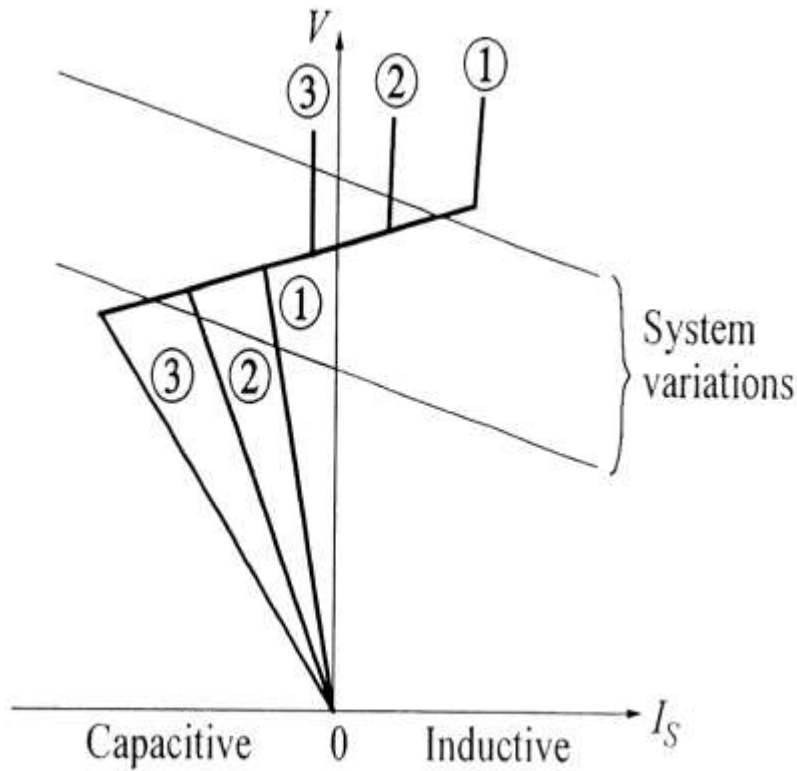
Static VAR Compensators (SVC)

- Shunt connected static var generators and/or absorbers whose outputs are varied so as to control specific power system quantities
- The term static is used to denote that there are no moving or rotating components
- Basic types of SVCs:
 - Thyristor-controlled reactor (TCR)
 - Thyristor-switched capacitor (TSC)
 - Saturated reactor

- A static var system (SVS) is an aggregation of SVCs and mechanically switched capacitors or reactors whose outputs are coordinated
- When operating at its capacitive limit, an SVC behaves like a simple capacitor

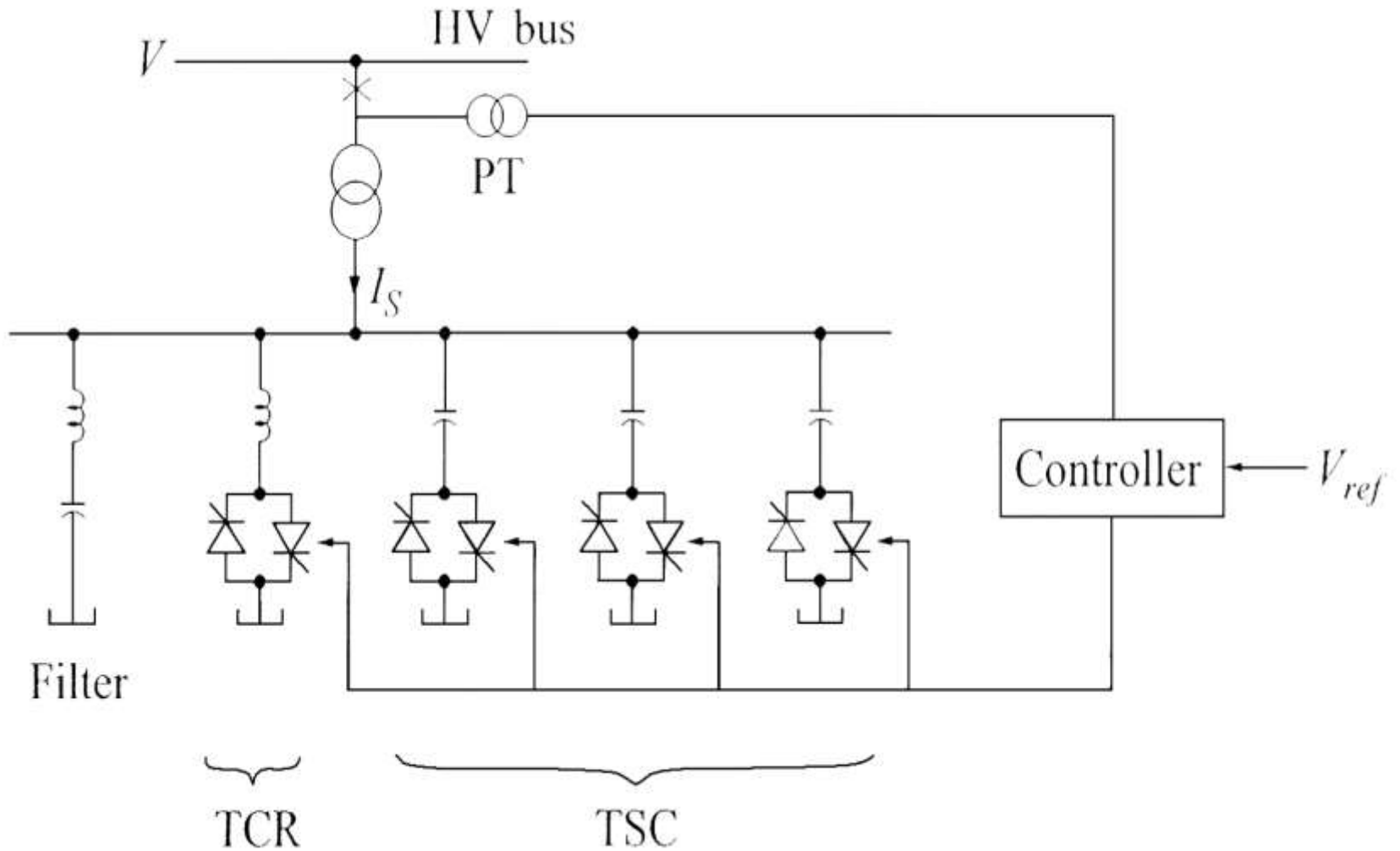


Composite characteristics of an SVS

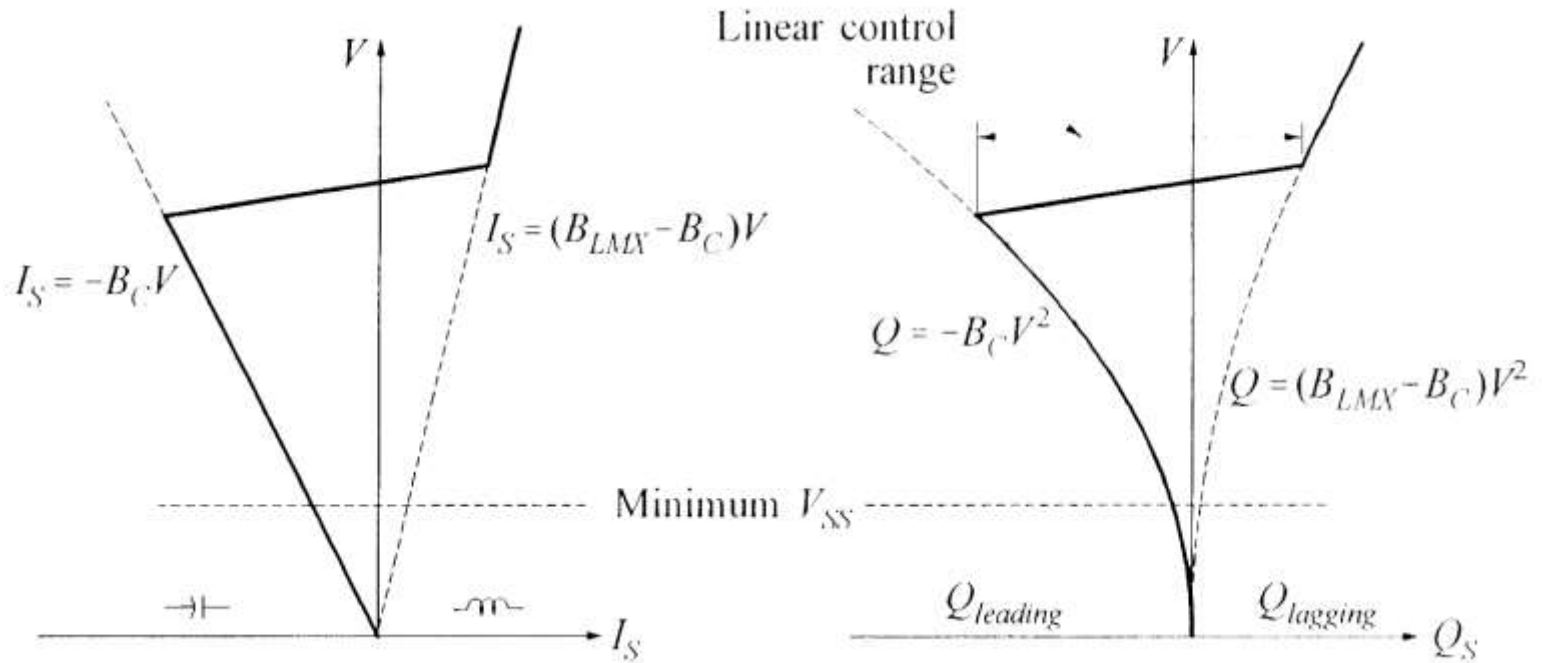


Use of switched capacitors to extend continuous control range

A typical static var system



SVS steady-state characteristics



(a) Voltage-current characteristic

(b) Voltage-reactive power characteristic

Static Synchronous Compensator (STATCOM)

❖ This shunt connected static compensator was developed as an advanced static VAR compensator where a voltage source convertor (VSC) is used instead of the controllable reactors and switched capacitors.

❖ Although VSCs require self-commutated power semiconductor devices such as GTO, IGBT, IGCT, MCT, etc (with higher costs and losses) unlike in the case of variable impedance type SVC which use thyristor devices.

A STATCOM is comparable to a Synchronous Condenser (or Compensator) which can supply variable reactive power and regulate the voltage of the bus where it is connected. The equivalent circuit of a Synchronous Condenser (SC) is shown in Fig.1.

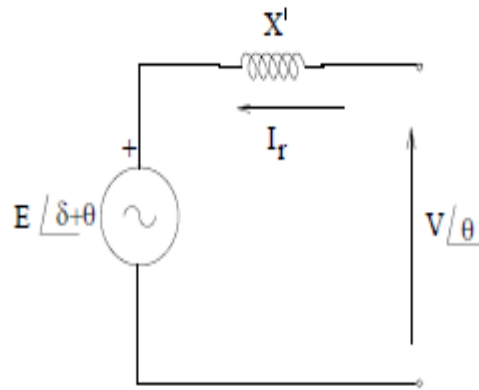


Fig.1. Synchronous condenser

A STATCOM (previously called as static condenser (STATCON)) has a similar equivalent circuit as that of a SC. The AC voltage is directly proportional to the DC voltage (V_{dc}) across the capacitor (see Fig.2. which shows the circuit for a single phase STATCOM)

There are many technical advantages of a STATCOM over a SVC. These are primarily:

(a) Faster response

(b) Requires less space as bulky passive components (such as reactors) are eliminated

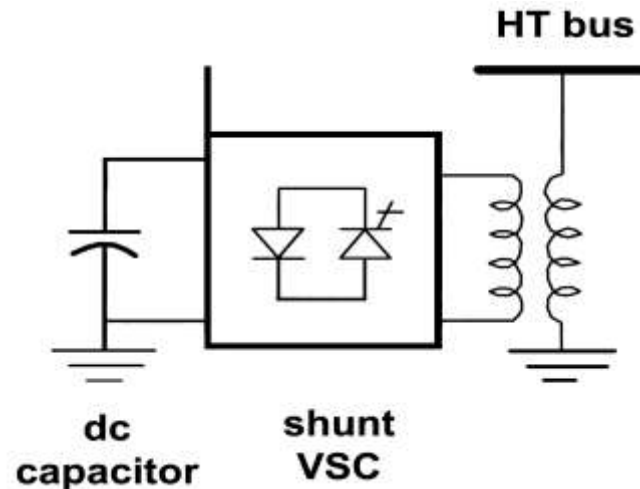
(c) Inherently modular and relocatable

(d) It can be interfaced with real power sources such as battery, fuel cell or SMES (superconducting magnetic energy storage)

(e) A STATCOM has superior performance during low voltage condition as the reactive current can be maintained constant (In a SVC, the capacitive reactive current drops linearly with the voltage at the limit (of capacitive susceptance). It is even possible to increase the reactive current in a STATCOM under transient conditions if the devices are rated for the transient overload. In a SVC, the maximum reactive current is determined by the rating of the passive components – reactors and capacitors.

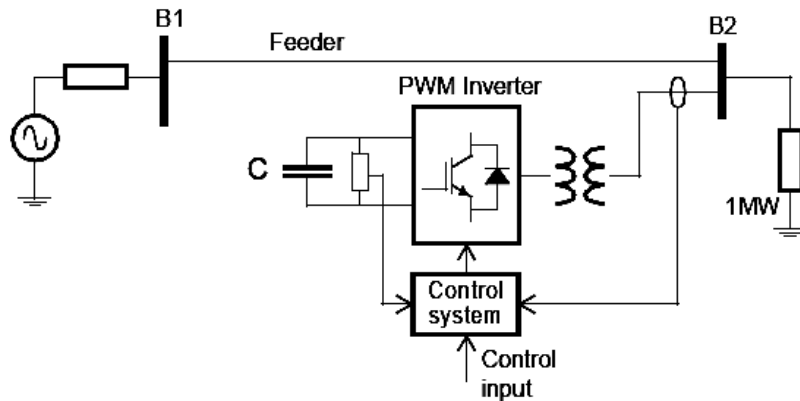
- ❖ STATCOM is a regulating (poor power factor and poor voltage) device.
- ❖ Based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power.
- ❖ If connected to a source of power it can also provide active AC power.
- ❖ STATCOM provides better damping characteristics than the SVC as it is able to transiently exchange active power with the system

- Can be based on a voltage-sourced or current-sourced converter
- Figure below shows one with voltage-sourced converter
 - driven by a dc voltage source: capacitor



- Effectively an alternating voltage source behind a coupling reactance
 - controllable in magnitude
- Can be operated over its full output current range even at very low (typically 0.2 pu) system voltage levels
- Requires fewer harmonic filters and capacitors than an SVC, and no reactors
 - significantly more compact

Structure of STATCOM



- Basically, the STATCOM system is comprised of Power converters, Set of coupling reactors or a step up transformer, Controller

Advantages of STATCOM

- The reactive components used in the STATCOM are much smaller than those in the SVC.
- The characteristics of STATCOM are superior.
- The output current of STATCOM can be controlled up to the rated maximum capacitive or inductive range.
- Reduction of the capacity of semiconductor power converter and capacitor bank to one half of those for the conventional SVC.
- Better transient response of the order of quarter cycle.
- Reduction of harmonic filter capacity.
- Reduction of size of high value air-cored reactor.
- Reduction of equipment volume and foot-print.

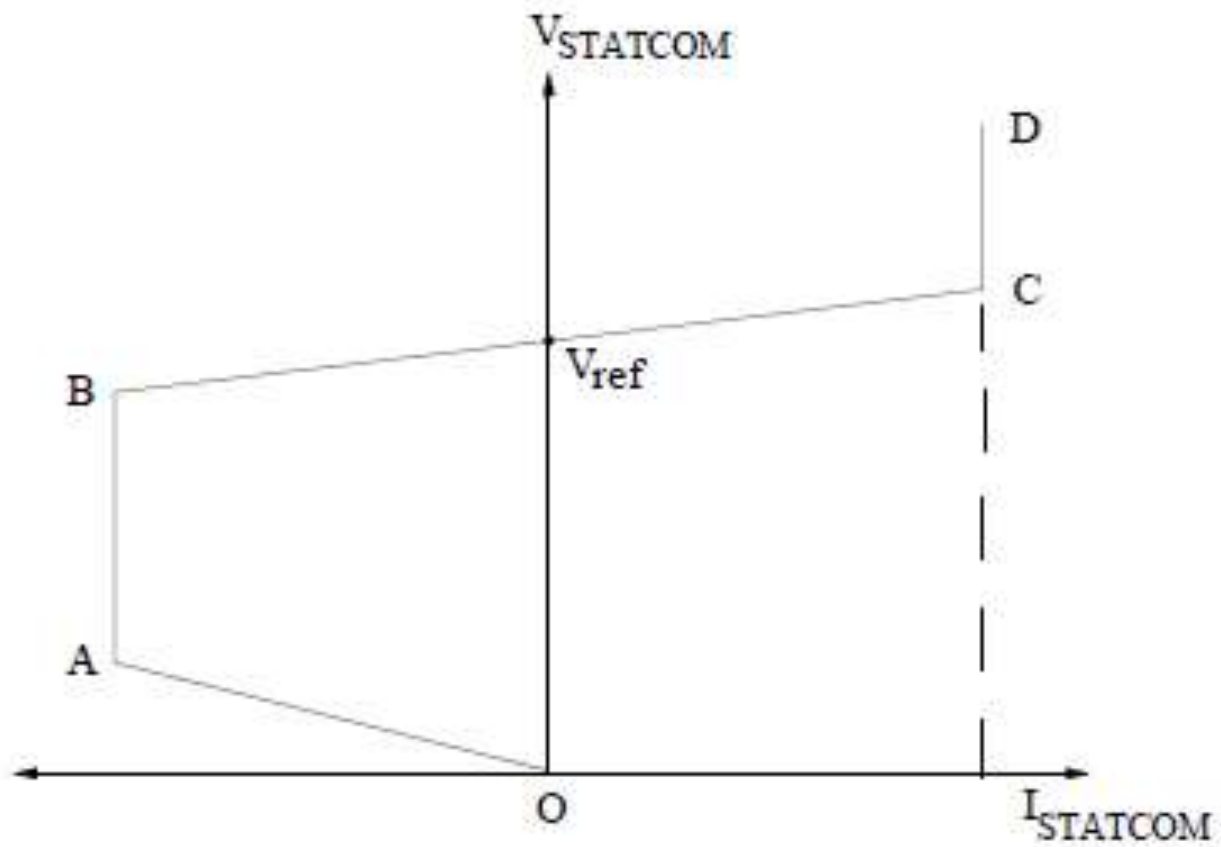
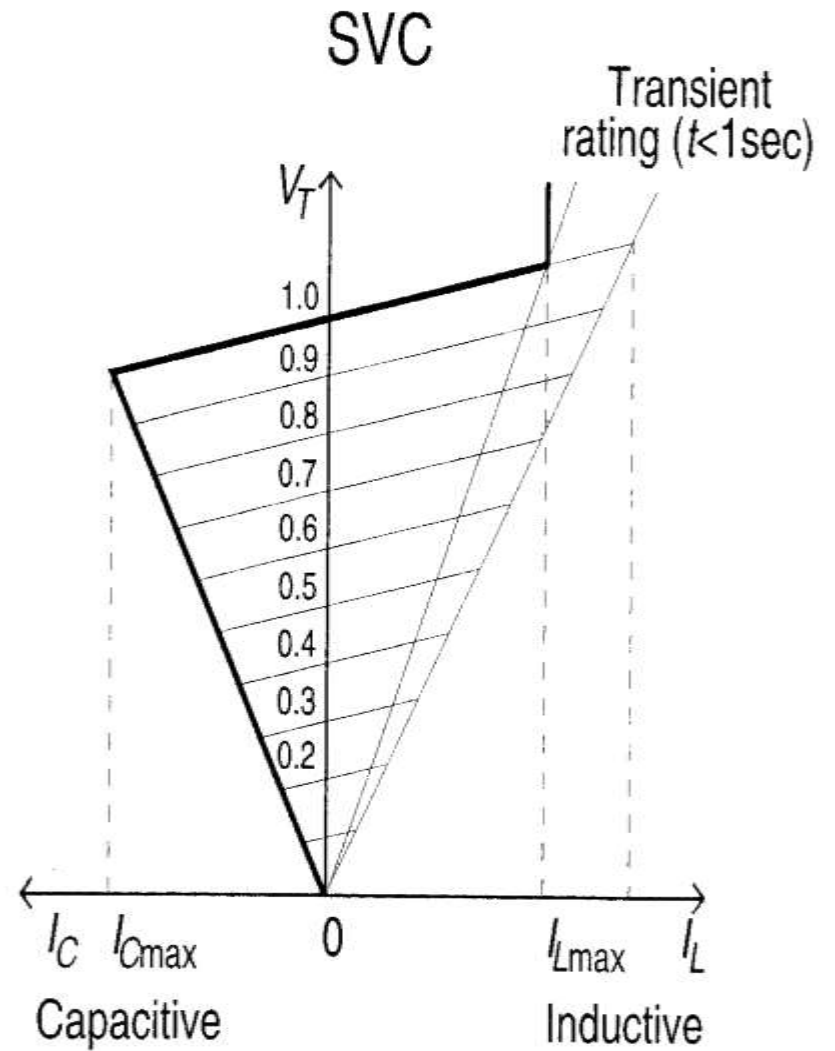
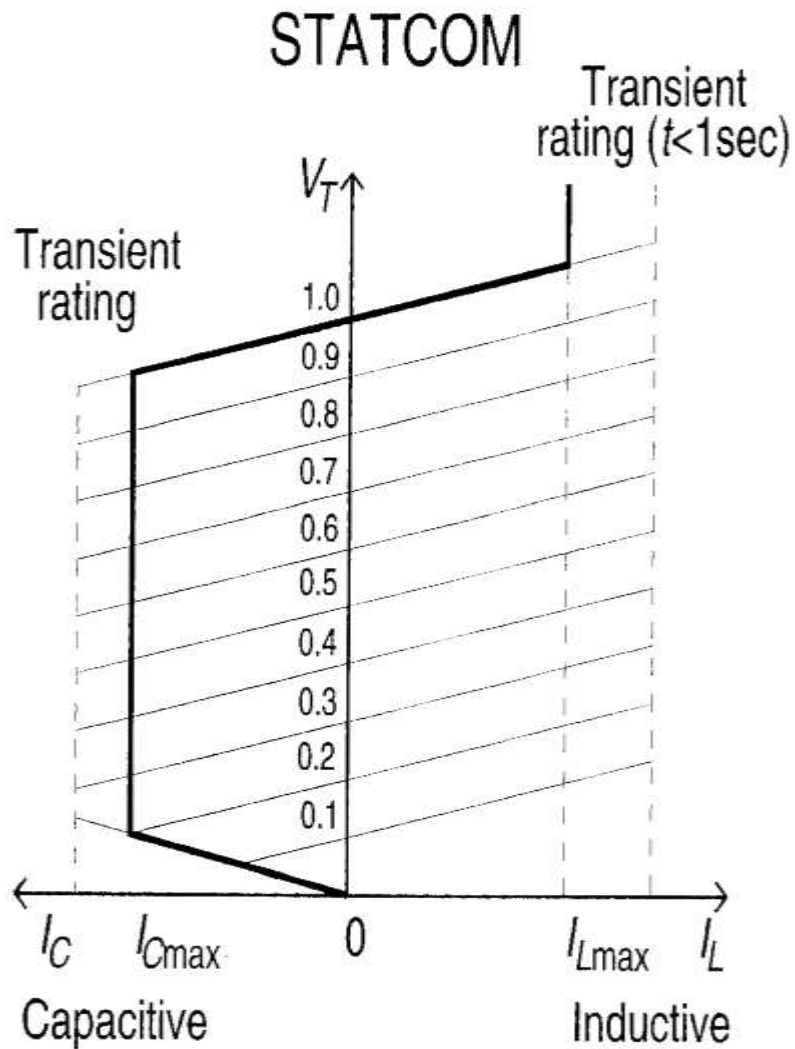


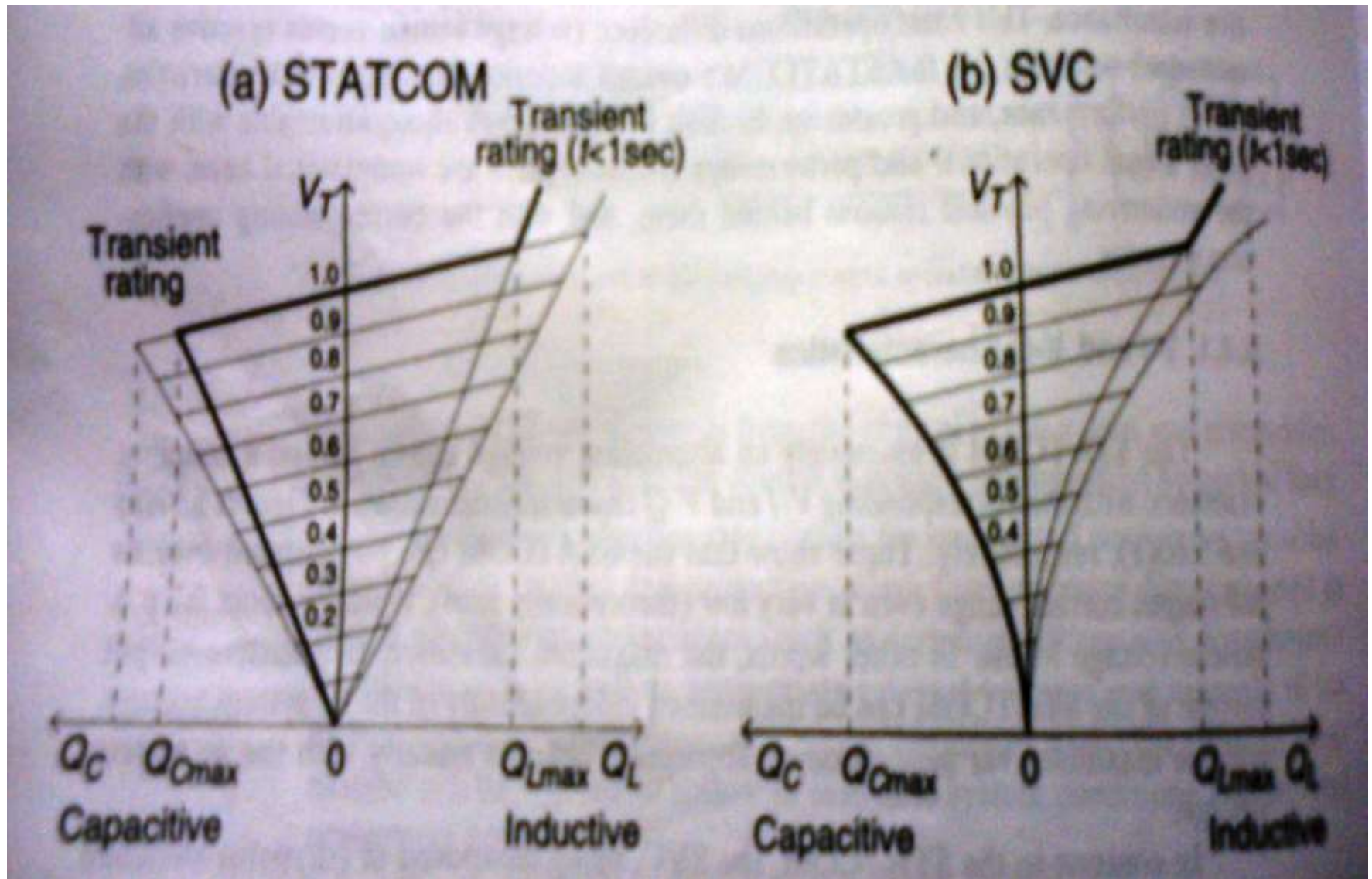
Figure 6.4: Control characteristics of a STATCOM

COMPARISON
OF
STATCOM AND SVC CHARACTERISTICS

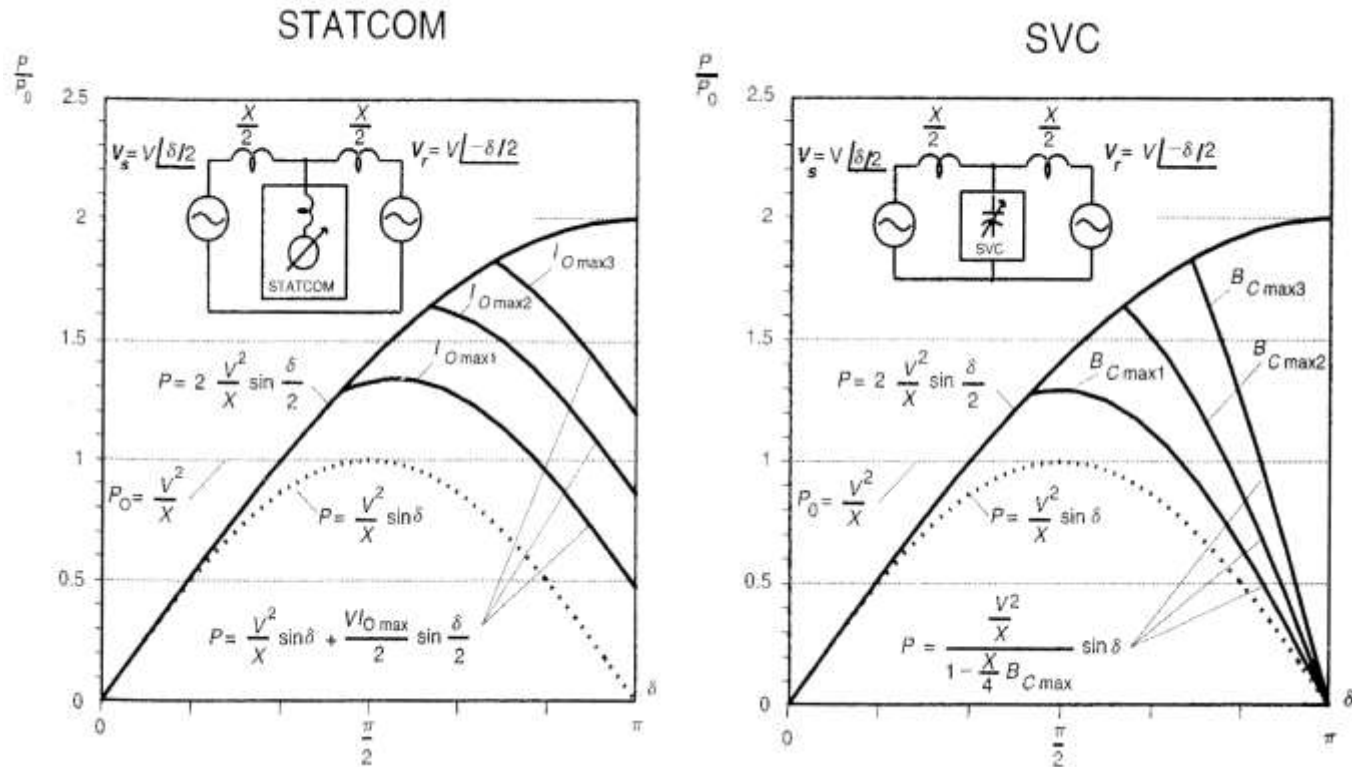
(i) V-I characteristics



(ii) V-Q Characteristics



(iii) Transient stability



P- δ characteristics with mid-point compensation

(iv) Response Time

Transport lag $e^{-T_d s}$

SVC- Between 2.5 ms to 5.0 ms

STATCOM- Between 200 μ s to 300 μ s

(v) Capability to exchange real power

For applications requiring active (real) power compensation it is clear that the STATCOM, in contrast to the SVC, can interface a suitable energy storage with the AC system for real power exchange.

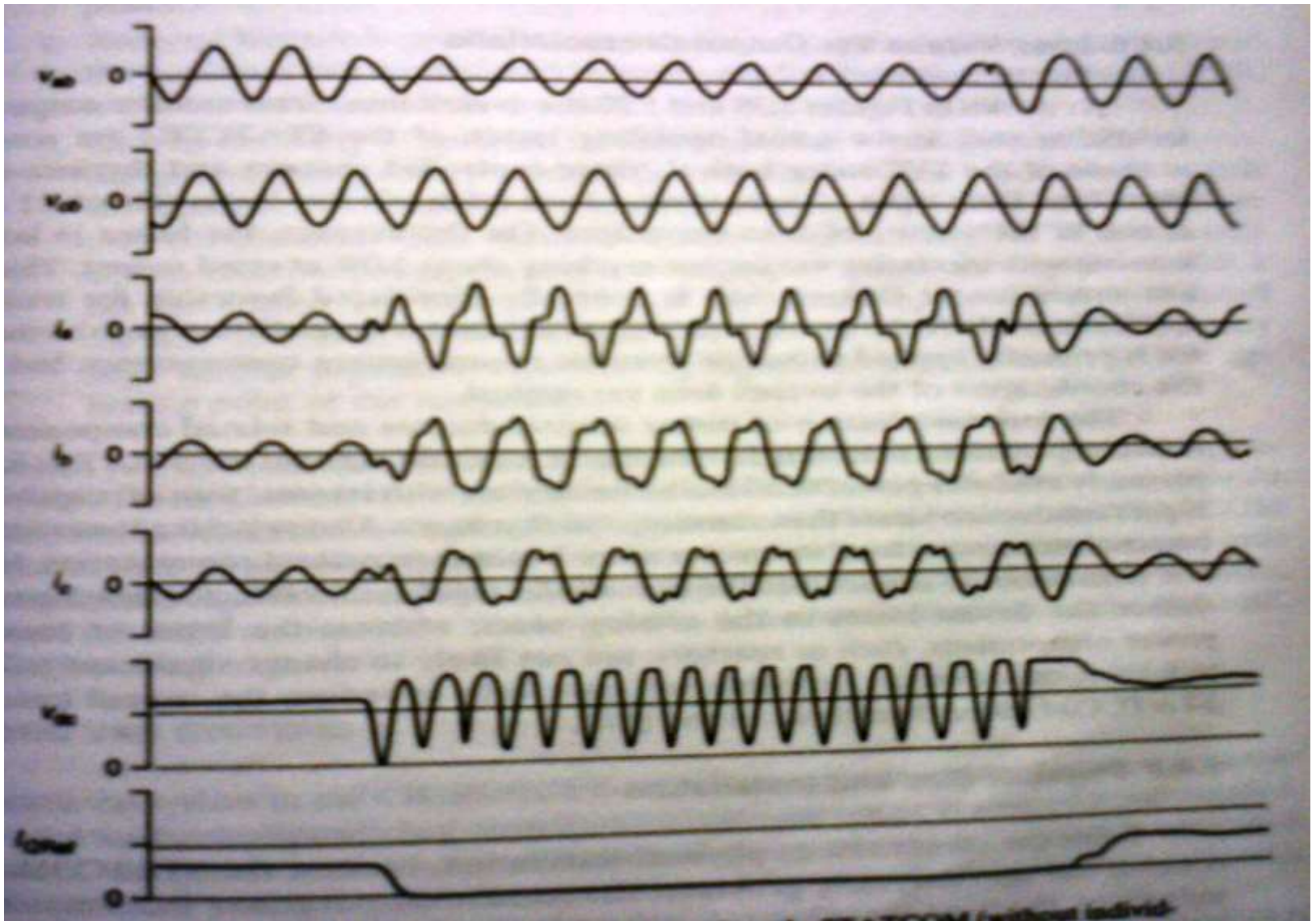
(vi) Operation with unbalanced AC System

❖ **SVC** controls establishes three identical shunt admittances, one for each phase. Consequently, with unbalanced system voltages the compensating currents in each phase would become different . It is possible to control the three compensating admittances individually by adjusting delay angle of the TCRs so as to make the three compensating currents identical.

❖ However in this case triple-n harmonic content would be different in each phase and their normal cancellation through delta connection would not place. This operation mode thus would generally require the installation of the usually unneeded third harmonic filters.

❖ The operation of the **STATCOM** under unbalanced system conditions is different from that of the SVC, but the consequences of the such operation are similar.

❖ The STATCOM operation is governed by fundamental physical law requiring that the net instantaneous power at the ac and dc terminals of the voltage-sourced converters employed must be always be equal. This is because the converter has no internal energy storage and thus energy transfer through it is absolutely direct, and consequently the net instantaneous power at the ac and dc terminals must be equal.



Wave forms illustrating the operation of a STATCOM during LG Fault at the regulated bus

(vii) Loss Versus Var output characteristics

□ The loss contribution of power semiconductors and related components to the total compensator losses is higher for the STATCOM than for the SVC. This is because presently available power semiconductor devices with internal turn-off capability have higher conduction losses than conventional thyristors.

□ Thus the technological advances probably will have help to reduce the overall losses of the STATCOM more than those of the SVC.

(viii) Physical size and installation

➤ From the stand point of physical installation, because the STATCOM not only controls but also internally generates the reactive output power, the large capacitor and reactor banks with their associated switchgear and protection, used in conventional thyristors controlled SVCs, are not needed.

➤ This results in a significant reduction in overall size (about 30 to 40 %) , as well as installation labor and cost.