Flow of power in an A.C system:

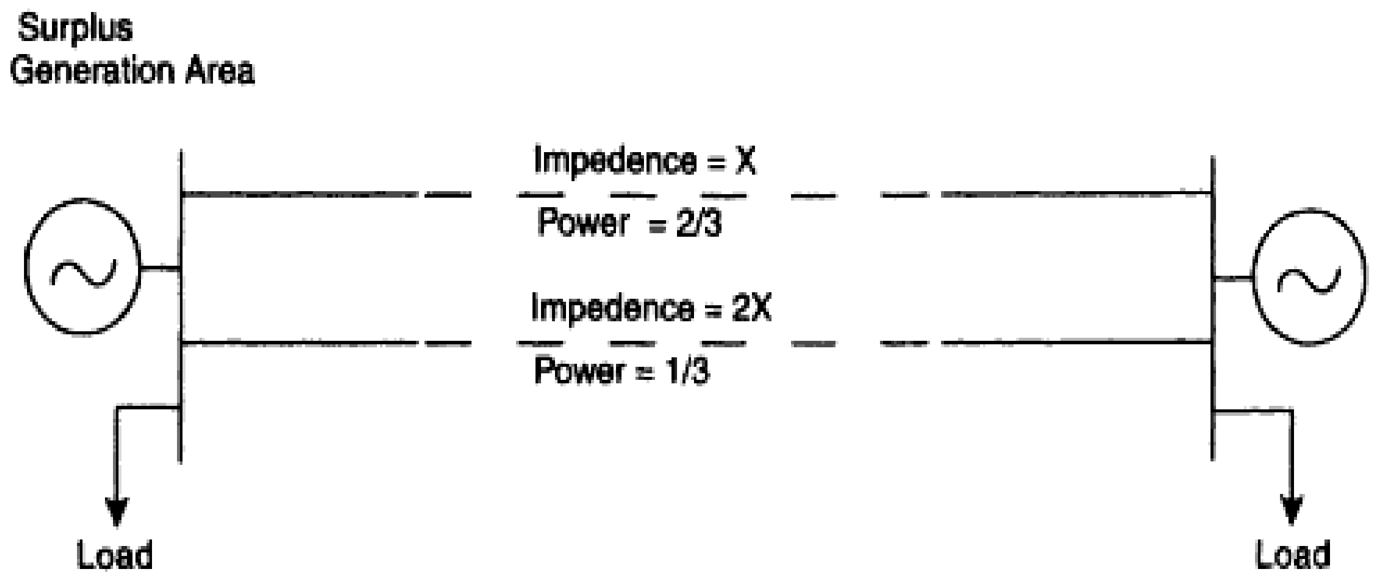
In A.C power systems, storage of electrical power is not so important, the electrical generation and load must balance at all times.

If generation is less than load, the voltage and frequency drop, and there by the load, goes down to equal the generation minus the transmission losses.

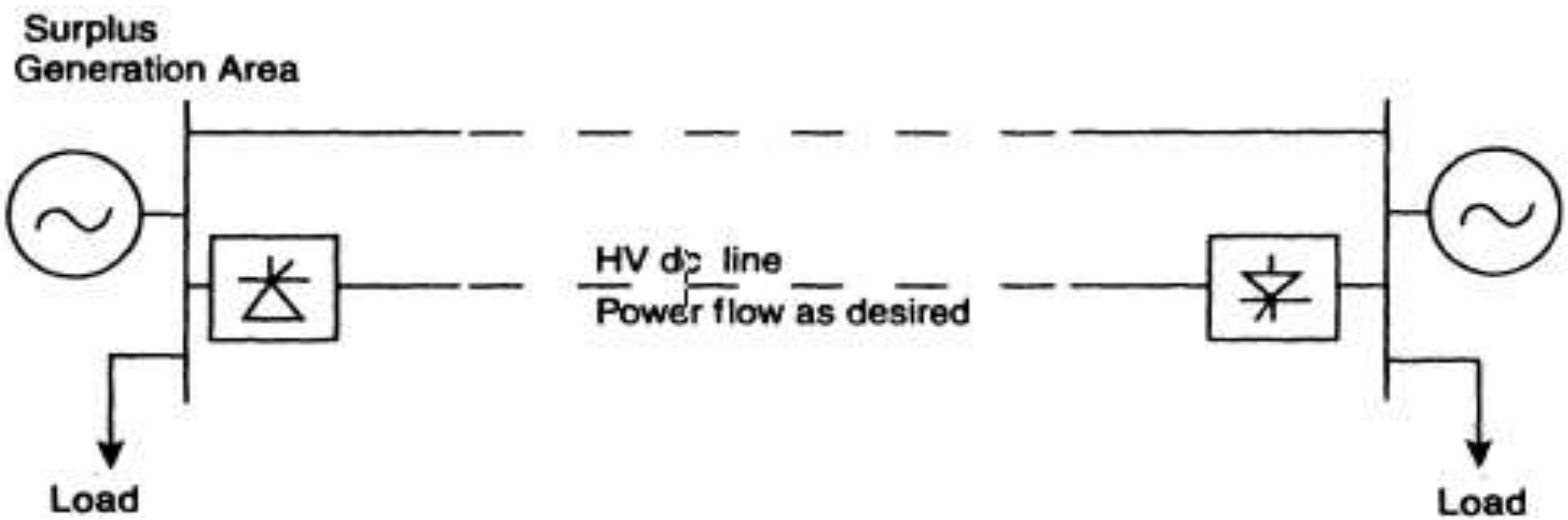
If there is inadequate reactive power, the system can have voltage collapse.

When adequate generation is available, active power flows from the surplus generation areas to the deficit areas, and it flows through all parallel paths available which frequently involves extra high-voltage and medium-voltage lines.

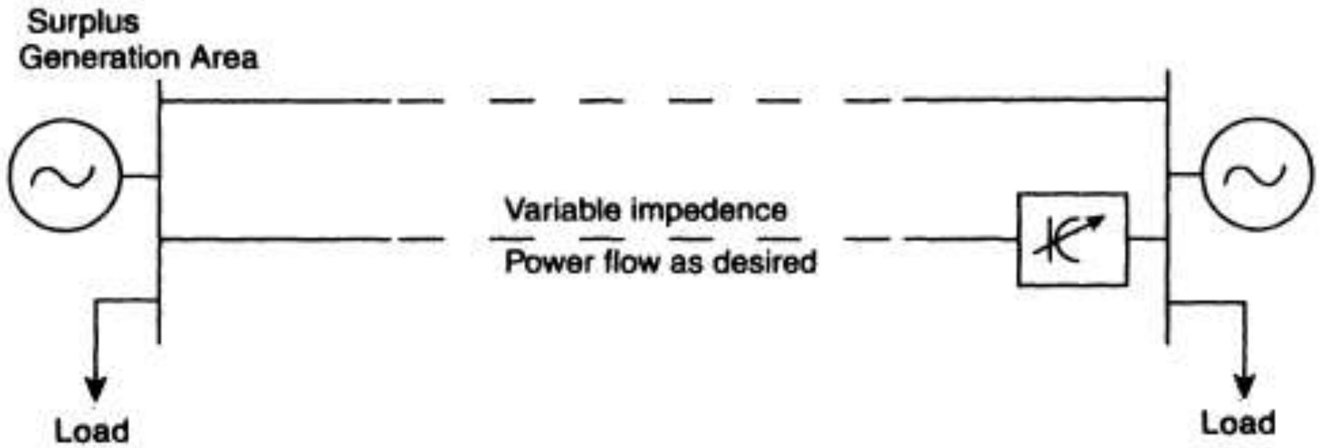
- **Power Flow in Parallel Paths**



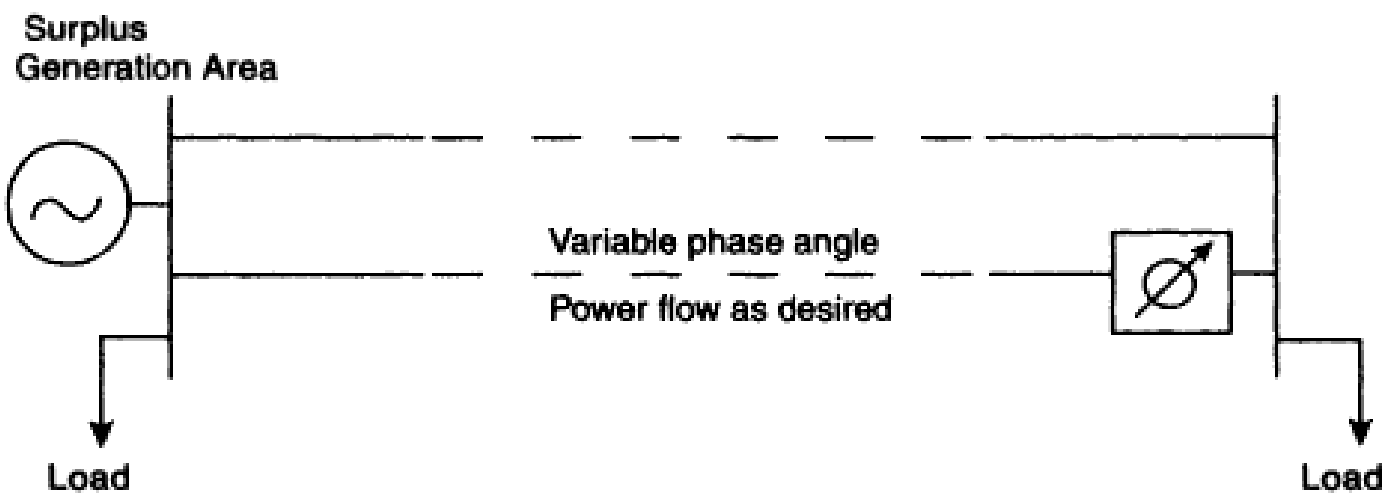
Consider a simple case of power flow through two parallel paths from a surplus generation area with an equivalent generation area on the left as shown to a deficit generation area on the right. Without any power control, power flow is based on various transmission line impedances



As HVDC is expensive, it is usually considered when long distances are involved, With HVDC, power flows as ordered by the operator, because with HVDC power electronics converters power is electronically controlled due to which it can be used to its full thermal capacity if adequate converter capacity is provided.

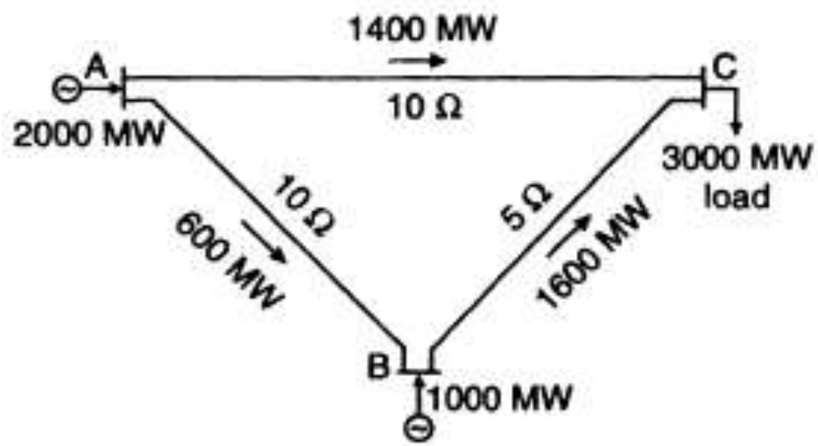


As alternative FACTS controllers, figures show one of the transmission lines with different types of series type FACTS controllers which are used for controlling impedance (or) phase angle (or) series injection of appropriate voltage which can control the power flow as required.

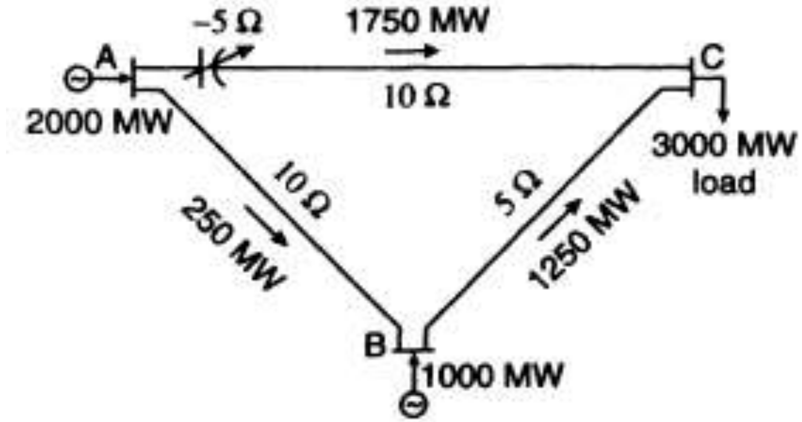


Maximum power flow in fact can be limited to its rated limit under contingency conditions when this line is expected to carry more power due to the loss of a parallel line where contingency can be defined as in an electrical system it might be due to loss (or) outage of any electrical equipment (transformer, transmission line, generator, relay, circuit breaker and so on).

•**Power flow in a meshed system**



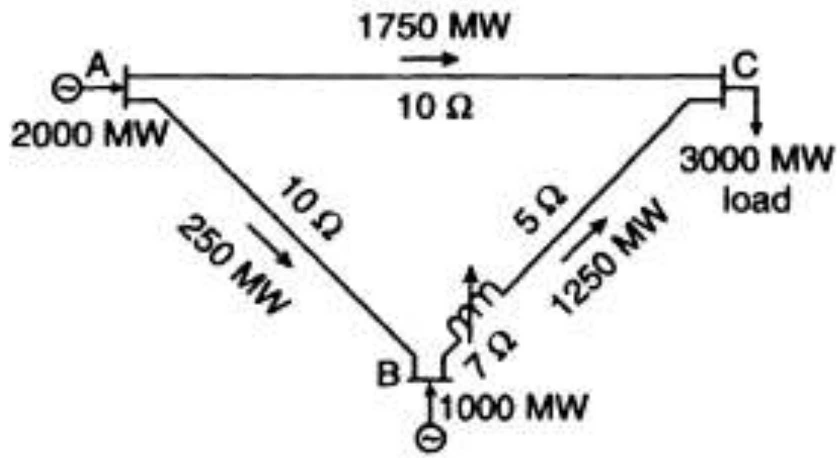
Consider a power system where generation is 2000MW and 1000MW at two different generating stations to meet the load of 3000MW. Here transmission lines AB, BC and AC are rated at 1000, 1250 and 2000MW respectively. As the transmission line BC is overloaded generation at B is to be decreased and generation at A is to be increased.



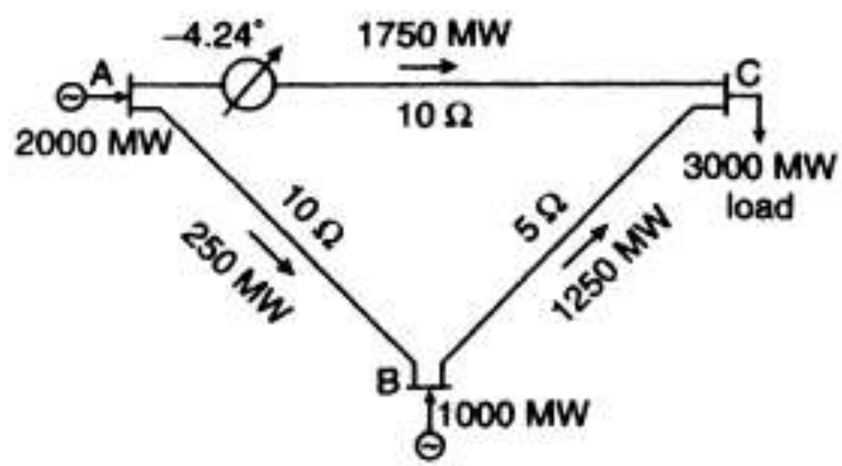
A capacitance whose reactance is -5Ω is inserted in series to one of the transmission line which reduced the line impedance from 10Ω to 5Ω so, that the power flow to the lines AB, BC and AC will be 250, 1250 and 1750MW respectively.

If series capacitor is adjustable then the power flow level can be easily adjusted.

A series capacitor in a line may lead to sub-synchronous resonance (for 60Hz system) which occurs when one of the mechanical resonance frequencies of the shaft of multiple-turbine generator unit coincides with 60Hz.



By increasing the impedance of one of the lines by inserting a 7Ω reactor inductor) in series with the line which helps to adjust the power-flow as well as unwanted oscillations



Loading Capability:

Basically, there are three kinds of limitations;

- Thermal
- Dielectric and
- Stability

➢ **Thermal**

Thermal capability of an overhead line is a function of ambient temperature, wind conditions of the conductor, and ground clearance.

During planning / design stages, normal loading of the lines is frequently decided on a loss evaluation basis under assumptions which may have changed for a variety of reasons; however losses can be taken into account on the real-time value basis of extra loading capability.

There is possibility of upgrading a line by changing the conductor to that of a higher current rating, which may in turn require structural upgrading of converting a single-circuit to double-circuit line.

- **Dielectric**

From insulation point of view, also nominal voltage rating, it is possible to increase normal operation by +10% of the nominal voltage rating where care is needed to ensure transient and dynamic over voltages within the limits. The FACTS technology could be used to ensure acceptable over-voltage and power flow conditions.

- **Stability**

There are number of stability issues that limit the transmission capability which includes;

•Transient Stability

•Dynamic Stability

•Steady-State Stability

•Voltage Collapse

•Frequency Collapse

•Sub-synchronous Resonance

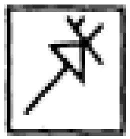
The FACTS technology certainly be used to overcome any of the stability limits.

Basic Types of FACTS Controllers

In general, FACTS Controllers can be divided into four categories which are

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

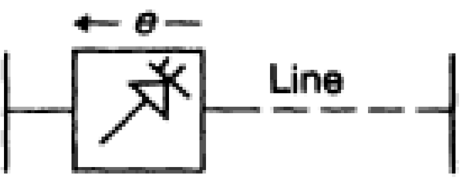
In general, a FACTS controller is represented by a thyristor arrow inside a box.



- **Series Controllers**

Series Controllers can be of variable impedance such as capacitance, reactance (or) any power electronic device based variable source.

Series Controllers inject voltage in series to the transmission line and as long as the voltage is in phase with line current the series controllers supplies (or) consumes reactive power.



Examples

•SSSC (Static Synchronous Series Compensators)

•IPFC (Interline Power Flow Controller)

•TCSC (Thyristor Controlled Series Capacitor)

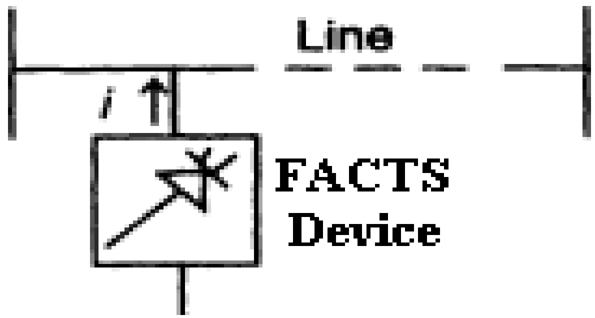
•TSSC (Thyristor Switched Series Capacitor)

•TCSR (Thyristor Controlled Series Reactor)

•TSSR (Thyristor Switched Series Reactor)

- **Shunt Controllers**

Shunt Controllers can be of variable impedance (or) variable source (or) a combination of these



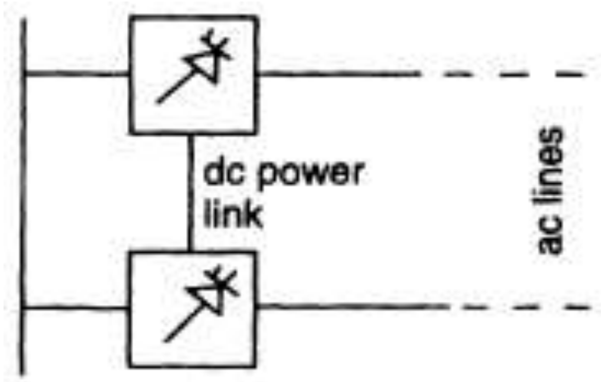
Shunt Controllers inject current into the system and as long as current is in phase with line voltage the shunt controllers supplies (or) consumes reactive power.

Examples

•STATCOM (Static Synchronous Compensator)
•SSG (Static Synchronous Generator)
•BESS (Battery Energy Storage System)
•SMES (Super-conducting Magnetic Energy Storage)
•SVC (Static VAR Compensator)
•TCR (Thyristor Controlled Reactor)
•TSR (Thyristor Switched Reactor)
•TSC (Thyristor Switched Capacitor)
•SVG (Static VAR Generator (or) Absorber)
•SVS (Static VAR Source)
•TCBR (Thyristor Controlled Braking Resistor

- **Combined Series-Series Controllers**

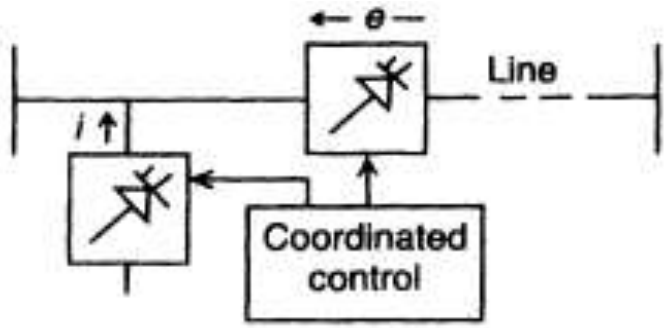
It is a combination of two series controllers which are controlled in a coordinated manner in a multi-line transmission system which compensates reactive power and also transfers real power through the D.C link



The D.C terminals of controller converters are connected together through a D.C link for real power transfer

- **Combined Series-Shunt Controllers**

It is a combination of separate series and shunt controllers where voltage is injected in series to the line with the help of series controller and current is injected with the help of shunt part of the controller



When the two controllers are connected, there can be more amount of real power exchange between the controllers via D.C link.

Examples for combined controllers

•UPFC (Unified Power Flow Controller)

•IPC (Interphase Power Controller)

•TCPST (Thyristor Controlled Phase Shifting Transformer)

(or)

•TCPAR (Thyristor Controlled Phase Angle Regulator)

Basic Description and Definitions of FACTS Controllers:

The converter-based controllers are of two types with gate turn-off devices which are voltage-sourced converters and current-sourced converters.

The voltage-sourced converters are suitable for high power applications with a unidirectional DC voltage with a DC capacitor presented to the AC side as AC voltage through sequential switching of devices.

For the current-sourced converters, the DC current is presented to AC side through the sequential switching of devices as AC current is variable in amplitude and also in phase relationship.

From overall cost point of view, the voltage-sourced converters are mostly preferred for most converter-based FACTS Controllers.

The ability to accommodate changes in the electric transmission system or operating conditions while maintaining sufficient steady-state and transient margins is called **Flexibility of Electric Power Transmission**

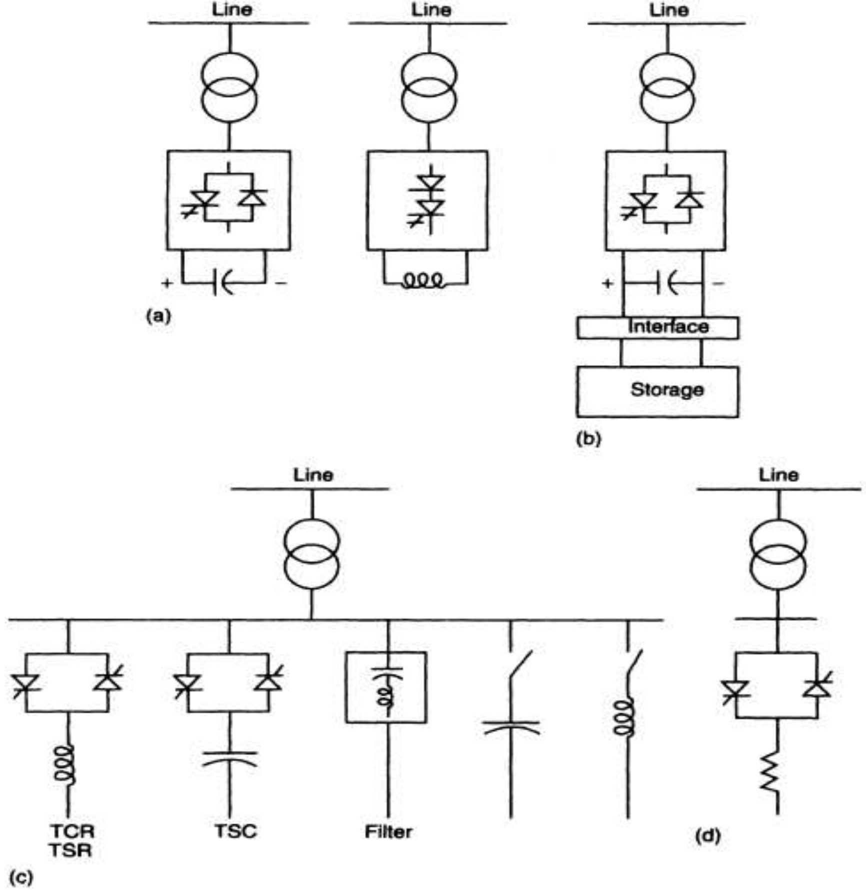
Alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability is called **Flexible AC Transmission System (FACTS)**.

A power electronic-based system and other static equipment that provide control of one or more AC transmission system parameters is called **FACTS Controller**

- **Shunt Controlled Converters**
- **Static Synchronous Compensator (STATCOM)**

A static synchronous generator operated as a shunt-connected static VAR compensator whose capacitive output current can be controlled independent of AC system voltage which is based on voltage-sourced or current-sourced converters.

- **Static Synchronous Generator (SSG)**



Shunt-connected Controllers: (a) Static Synchronous Compensator (STATCOM) based on voltage-sourced and current-sourced converters; (b) STATCOM with storage, i.e., Battery Energy Storage System (BESS) Superconducting Magnet Energy Storage and large dc capacitor; (c) Static VAR Compensator(SVC), Static VAR Generator (SVG), Static VAR System (SVS), Thyristor-Controlled Reactor (TCR), Thyristor-Switched Capacitor (TSC), and Thyristor-Switched Reactor (TSR); (d) Thyristor-Controlled Braking Resistor.

A static self-commutated switching power converter supplied from an appropriate electric energy source and operated to produce a set of adjustable multiphase output voltages, which may be coupled to an AC power system for the purpose of exchanging independently controllable real and reactive power

- **Superconducting Magnetic Energy Storage (SMES)**

A superconducting electromagnetic energy storage device containing electronic converters that rapidly injects and / or absorbs real and / or reactive power or dynamically controls power flow in an AC system.

- **Static VAR Compensator (SVC)**

A shunt-connected static VAR generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system.

- **Thyristor Controlled Reactor (TCR)**

A shunt-connected, thyristor-controlled inductor whose effective reactance is varied in a continuous manner by partial-conduction control of the thyristor valve.

- **Thyristor Switched Reactor (TSR)**

A shunt-connected, thyristor-switched inductor whose effective reactance is varied in a stepwise manner by full or zero-conduction operation of the thyristor valve.

- **Thyristor Switched Capacitor (TSC)**

A shunt-connected, thyristor-switched capacitor whose effective reactance is varied in a stepwise manner by full- or zero-conduction operation of the thyristor valve.

- **Static VAR System (SVS)**

A combination of different static and mechanically-switched VAR compensators whose outputs are coordinated.

- **Thyristor Controlled Braking Resistor (TCBR)**

A shunt-connected thyristor-switched resistor, which is controlled to aid stabilization of a power system or to minimize power acceleration of a generating unit during a disturbance

- **Series Controlled Converters**
- **Static Synchronous Series Compensators (SSSC)**

A static synchronous generator operated without an external electric energy source as a series compensator whose output voltage is in quadrature with, and controllable independently of, the line current for the purpose of increasing or decreasing the overall reactive voltage drop across the line and thereby controlling the transmitted electric power. The SSSC may include transiently rated energy storage or energy absorbing devices to enhance the dynamic behavior of the power system by additional temporary real power compensation, to increase or decrease momentarily, the overall real (resistive) voltage drop across the line.

- **Interline Power Flow Controller (IPFC)**

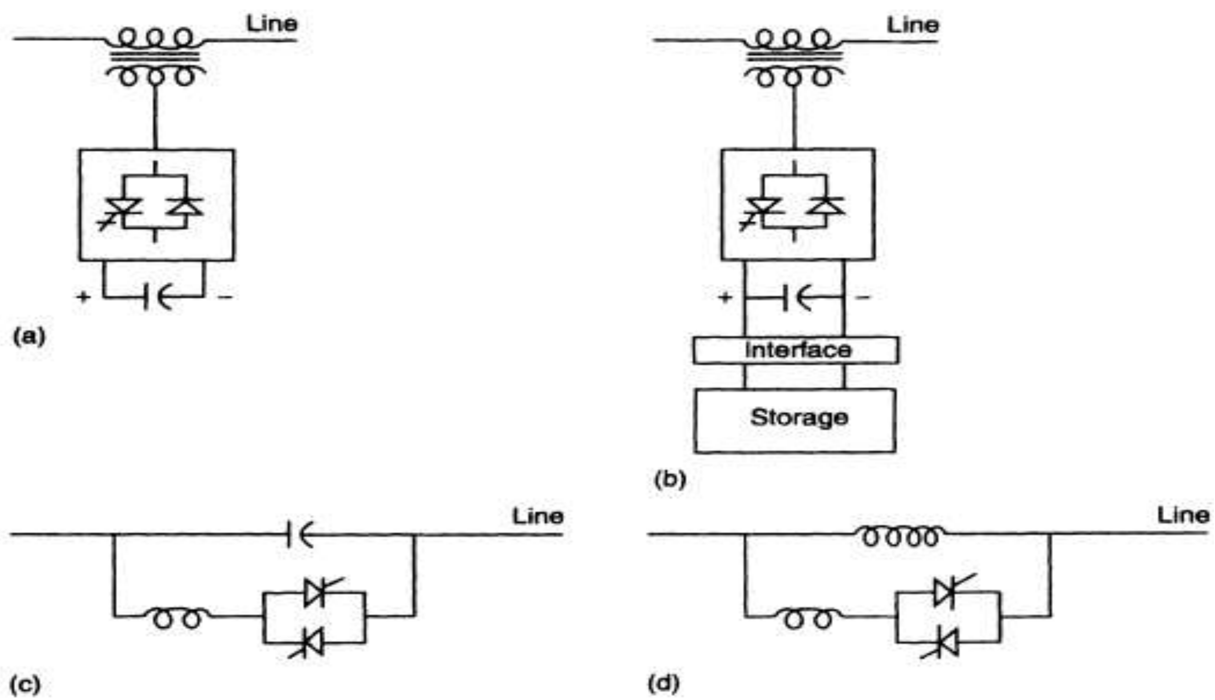
The combination of two or more Static Synchronous Series Compensators which are coupled via a common DC link to facilitate bi-directional flow of real power between the AC terminals of the SSSCs, and are controlled to provide independent reactive compensation for the adjustment of real power flow in each line and maintain the desired distribution of reactive power flow among the lines. The IPFC structure may also include a STATCOM, coupled to the IPFC's common DC link, to provide shunt reactive compensation and supply or absorb the overall real power deficit of the combined SSSCs.

• **Thyristor Controlled Series Capacitor (TCSC)**

A capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor-controlled reactor in order to provide a smoothly variable series capacitive reactance.

• **Thyristor-Switched Series Capacitor (TSSC)**

A capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor-switched reactor to provide a stepwise control of series capacitive reactance.



(a) Static Synchronous Series Compensator (SSSC); (b) SSSC with storage; (c) Thyristor-Controlled Series Capacitor (TCSC) and Thyristor-Switched Series Capacitor (TSSC); (d) Thyristor-Controlled Series Reactor (TCSR) and Thyristor-Switched Series Reactor (TSSR).

- **Thyristor-Controlled Series Reactor (TCSR)**

An inductive reactance compensator which consists of a series reactor shunted by a thyristor controlled reactor in order to provide a smoothly variable series inductive reactance.

- **Thyristor-Switched Series Reactor (TSSR)**

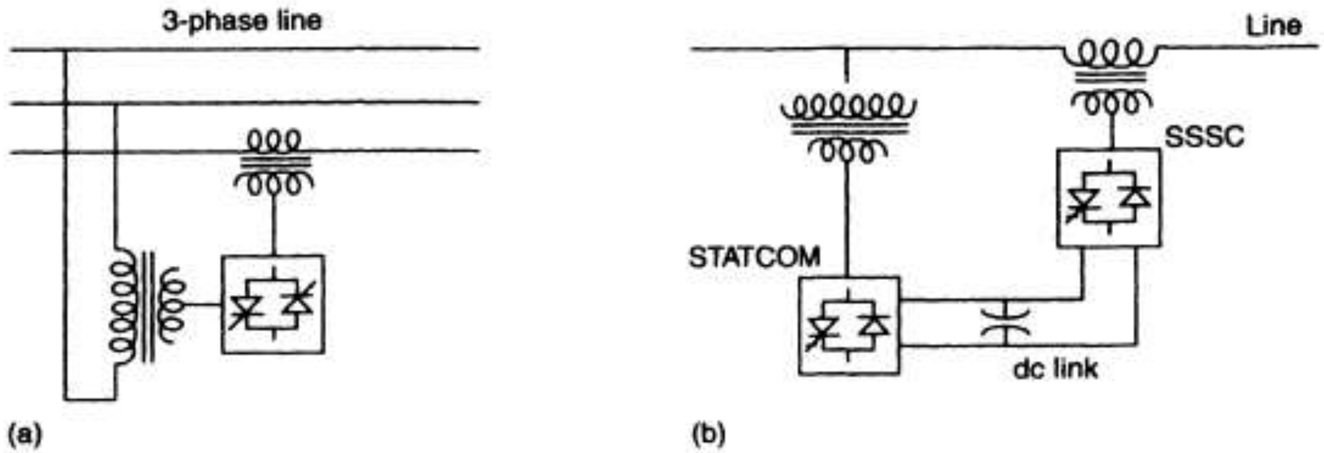
An inductive reactance compensator which consists of a series reactor shunted by a thyristor-controlled switched reactor in order to provide a stepwise control of series inductive reactance.

- **Combined Shunt and Series Connected Controllers**
- **Unified Power Flow Controller (UPFC)**

A combination of static synchronous compensator (STATCOM) and a static series compensator (SSSC) which are coupled via a common DC link, to allow bidirectional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM, and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source. The UPFC, by means of angularly unconstrained series voltage injection, is able to control, concurrently or selectively, the transmission line voltage, impedance, and angle or, alternatively, the real and reactive power flow in the line. The UPFC may also provide independently controllable shunt reactive compensation.

•**Thyristor Controlled Phase Shifting Transformer (TCPST)**

A phase-shifting transformer adjusted by thyristor switches to provide a rapidly variable phase angle



(a) Thyristor-Controlled Phase-Shifting Transformer (TCPST) or Thyristor-Controlled Phase Angle Regulator (TCPR); (b) Unified Power Flow Controller UPFC).

- **Interphase Power Controller (IPC)**

  A series-connected controller of active and reactive power consisting, in each phase, of inductive and capacitive branches subjected to separately phase-shifted voltages. The active and reactive power can be set independently by adjusting the phase shifts and/or the branch impedances, using mechanical or electronic switches. In the particular case where the inductive and capacitive impedance form a conjugate pair, each terminal of the IPC is a passive current source dependent on the voltage at the other terminal.