Module 4 : Voltage and Power Flow Control

Lecture 19 : Power Flow Control

Objectives

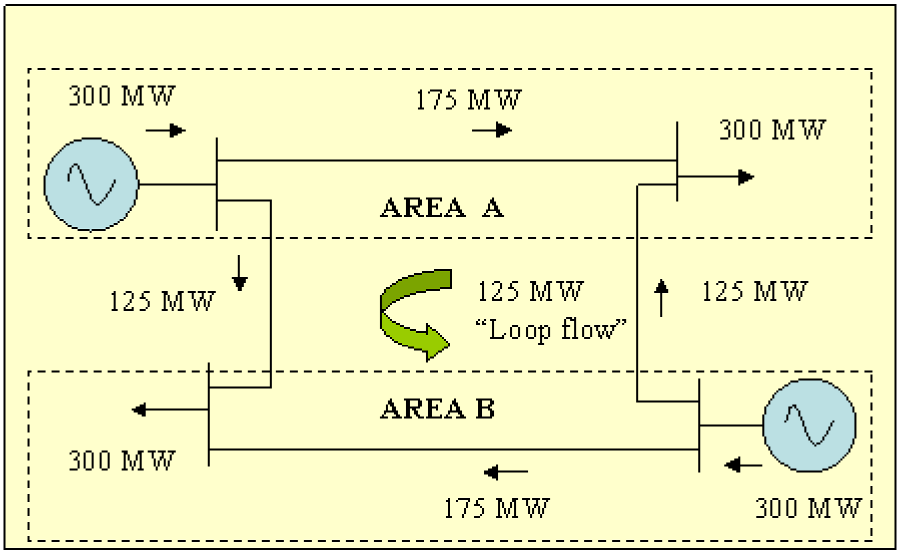
In this lecture you will learn the following

- Power transfer capability of a network may be limited due inability to control power flow in transmission paths.
- What are the ways by which one may control real power flows?

An important feature of interconnected AC systems is that power flow control through specific control paths is often quite difficult. This is because power flows in these paths as per Kirchhoff laws: the line parameters, topology of the network, generation and load location determine the value of flows. The power flows are not directly dependent on transmission line ownership, contracts, thermal limits or losses!

Inability to control power flows may result in situations wherein, some paths may be lightly loaded and some overloaded (to understand what one means by loadability see the discussion on line loadability in module 2).

The figure given on the right demonstrates a possible scenario wherein there is power flow in interconnecting tie lines of the two areas although each of them are individually self-sufficient. Thus the tie lines are unnecessarily loaded. This may be a problem if the capacity of the tie lines is limited and one actually wishes to transfer power from one area to another. This is because a part of the line capacities are utilized due to the undesired "loop flow".



Tie line power flow control by AGC was discussed in the previous module. While *cumulative* power exchange between the two areas through both tie lines may be controlled by adjusting the generated power in areas A and B, independent power flow control in each *individual* line connecting the 2 areas is not possible by generation control alone. In the above figure, cumulative power flow in the two tie lines is zero. It can be changed by reducing generated power in one area and increasing in another. However, the individual power in each line cannot be controlled in this fashion and depends on line parameters and Kirchoff's laws.

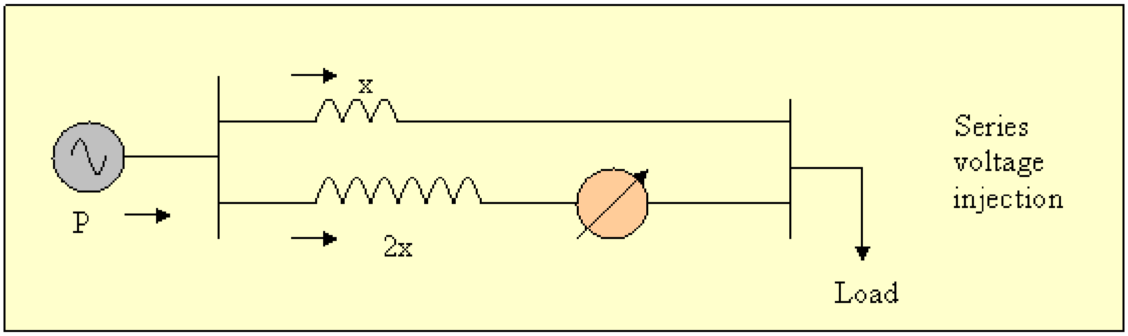
Therefore, special measures have to be taken in order to control power flow through individual transmission paths. Some of these are considered in the following lectures.

Power Flow control can be achieved by changing effective line parameters by connection of lumped series capacitors.

Series Compensation of lines

This involves changing the effective series reactance of lines by connecting capacitors in series with a line. Reducing line reactance also improves stability of a system (see module 2 for a discussion of large disturbance stability).

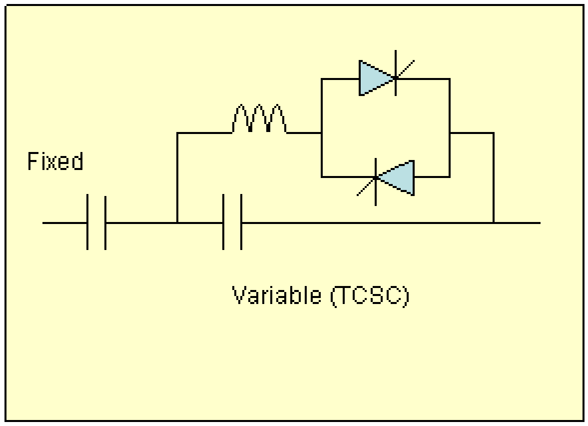
In the figure given below, the power flow in the branch with reactance 2x can be increased by compensating it with a series capacitor.



Since the amount of loading changes with time, the amount of series compensation may be varied by bypassing (shorting out) these capacitors when not necessary.

Normally a capacitor can allow for short duration over-rating for a few seconds. This allows insertion of larger capacitive reactance into a line for a short time in order to improve angular stability.

Alternatively, they may be controlled using power electronic controllers. For example, a TCR (discussed in the section on voltage control), may be connected in parallel to the series capacitor and its effective reactance may be controlled by controlling the firing angle delay. This device is called a **Thyristor Controlled Series Compensator (TCSC).**

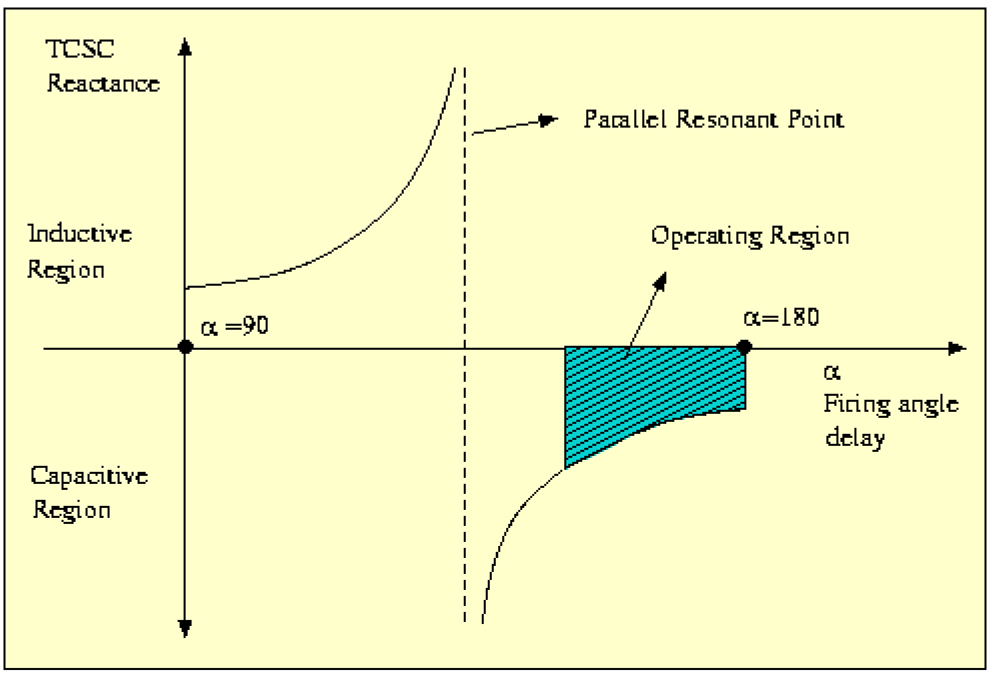


Thyristor Controlled Series Compensator

The effective reactance is the parallel combination of a fixed capacitor and variable reactance.

Parallel resonance may occur at certain values of firing angle. The characteristics of a TCSC are given on the right.

Why cannot we increase the effective reactance of the parallel combination to much larger values say upto the parallel resonance point?



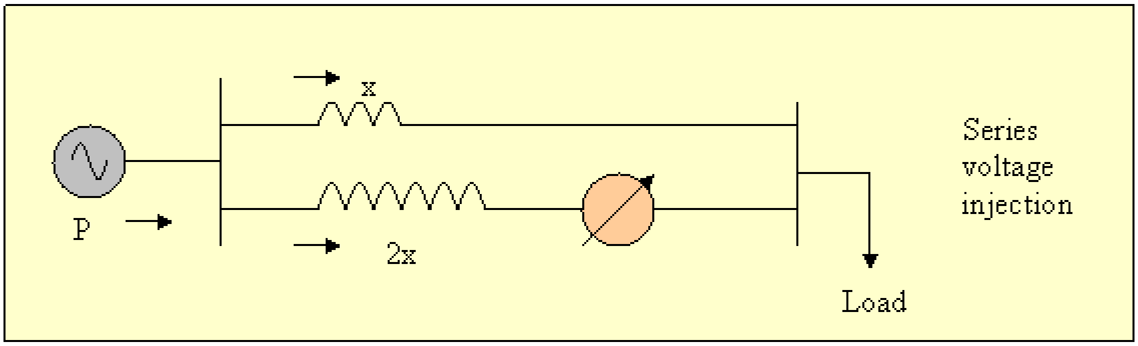
One of the major consideration of any series connected device is the need to bypass the device when *faults* occur nearby. Faults cause large overcurrent in a line, which in turn results in overvoltage across a capacitor. Therefore, Metal Oxide Varistors (which are nonlinear devices which have very low resistance when voltage magnitude is greater than a particular value) and circuit breakers are generally connected across series connected devices. Note that during faults, a series connected device is bypassed. However, immediately after the fault is cleared, it is necessary to insert maximum capacitive reactance in order to improve the stability of the rotor angular deviations which occur due to the fault.

Examples of controlled series compensation installations in India are the Raipur - Rourkela TCSC and the Kanpur Ballabhgarh TCSC. Details of the Kanpur-Ballabhgarh installation are given in the next module.

You may simulate the working of a TCSC using the MATLAB/SIMULINK file (TCSC3.mdl).

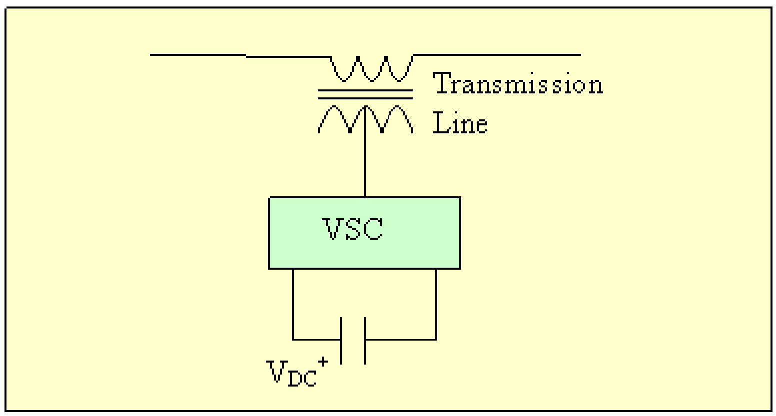
Series Compensation of lines

It is also possible to change power flows by injecting variable voltage in series with a line through a transformer as shown below.



This can be achieved by using power electronics based voltage source converters - VSC - (dc/ac converters). The schematic of this device is shown on the right.

When this device injects three phase reactive power in series with the line (no active power interchange), what is the nature of current on the dc side if the VSC is lossless? Does that explain why one can work with a capacitor (as shown) instead of a battery on the DC side?



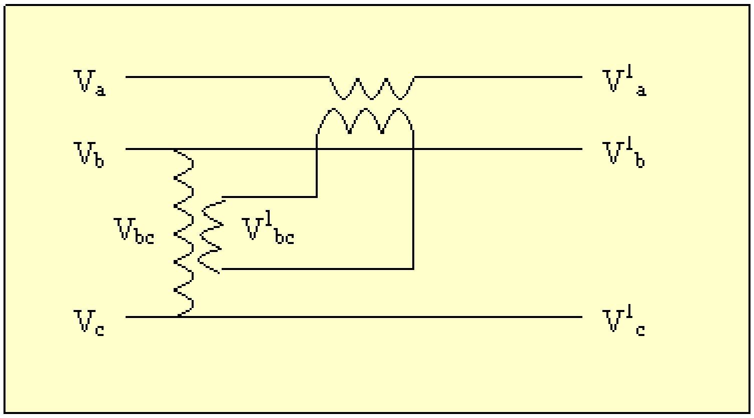
Devices like a TCSC or the device shown above are often called "Flexible AC Transmission Systems" controllers, because they increase the flexibility of AC system operation by allowing additional control.

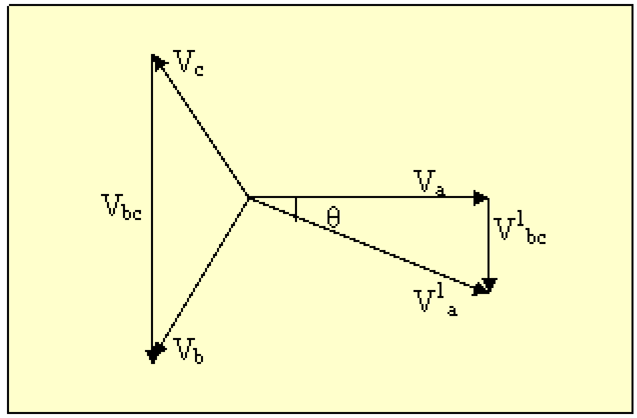
Series connected inductors can be connected to thermally limited lines to reduce power flow through them.

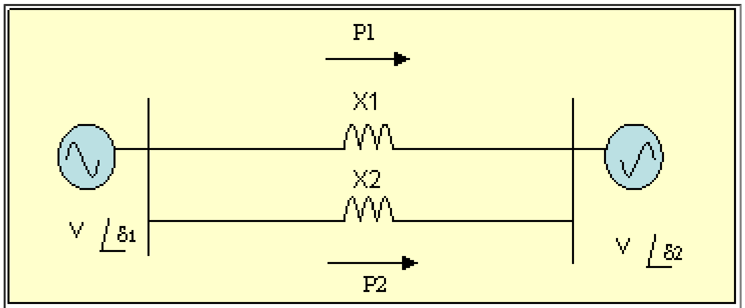
Phase Shifting Transformers

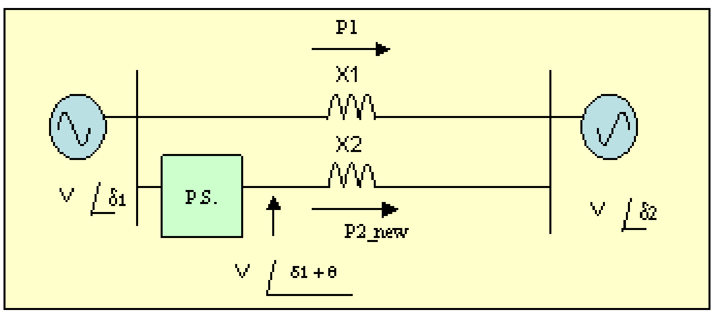
Another method of changing power flow through a transmission line is by use of a phase shifter.

A phase shifter introduces a small phase shift in the voltage at its two terminals by injection of a series voltage. The series injected voltage of one phase is in phase with the line voltage across the other 2 phases. This implies that the voltage injected in one phase is in **quadrature** to the bus voltage at one terminal of that phase. This small quadrature voltage injection mainly affects the bus voltage *angle* at the other terminal (which has superscript 1). The magnitude is not affected much if the series injected voltage is small. This is illustrated in the figures below. In the phasor diagram, the mechanism of obtaining a phase shift of q is shown. Similarly, a phase shift of -q can be obtained by reversing the injected voltage.









A phase shifter can alter the power flows in a transmission system.

In the figures shown on the left, for the given phasor angles at both ends, the power flow in line 2 can be altered. Thus the *sharing* of the total power flow :

$$\frac{P2_{new}}{P2_{new} + P1}$$

between the two lines can be altered. The expression for power flow in line 2 is given by,

$$P2_{new} = \frac{V^2 \sin(\delta_1 + \theta - \delta_2)}{x2}$$

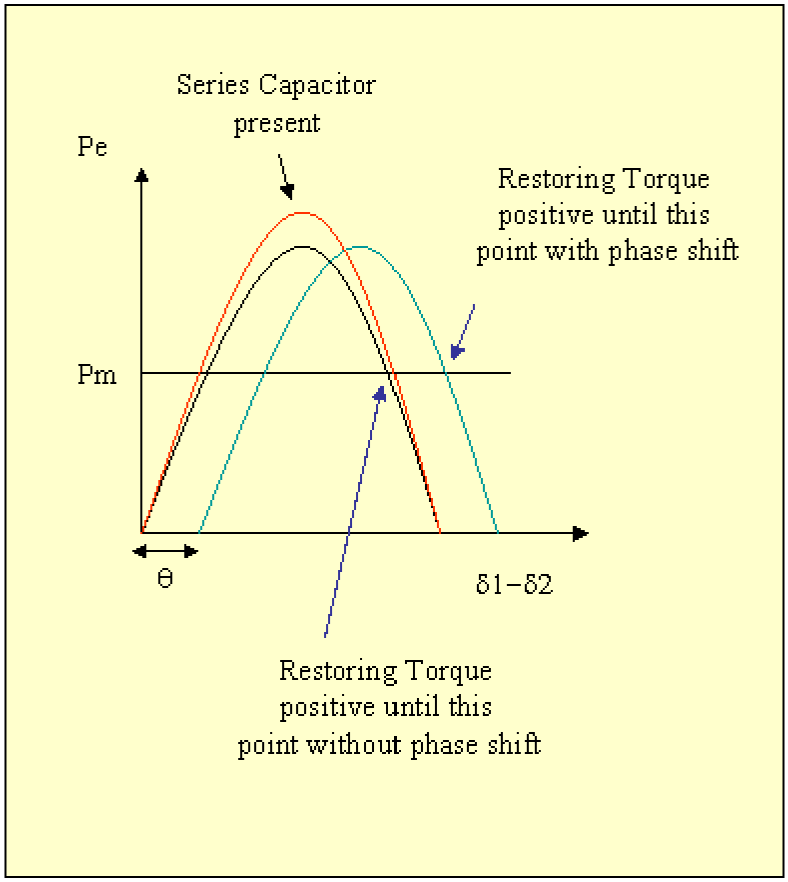
A phase shifter can alter the power versus (d1-d2) curve in a way that benefits stability.

In particular, by changing q when the rotor angular separation increases due to a disturbance, it can ensure that the "restoring torque" on the machines at the two ends is positive for larger values of (d1-d2).

In the figures shown above, if only line 2 is present, then the electrical power flow P versus (d1-d2) with and without a phase shift is as shown in the figure on the right. Note that a phase shifter does not change the maximum value of electrical power.

A device such as a capacitor connected in series with a line, on the other hand, increases the maximum value of power (and therefore restoring torque) but does not cause much shift in the point until which restoring torques are positive.

Both series connected capacitor and phase shifter, therefore enhance stability (the mechanisms are however different). Therefore they permit increase in actual line loadability.



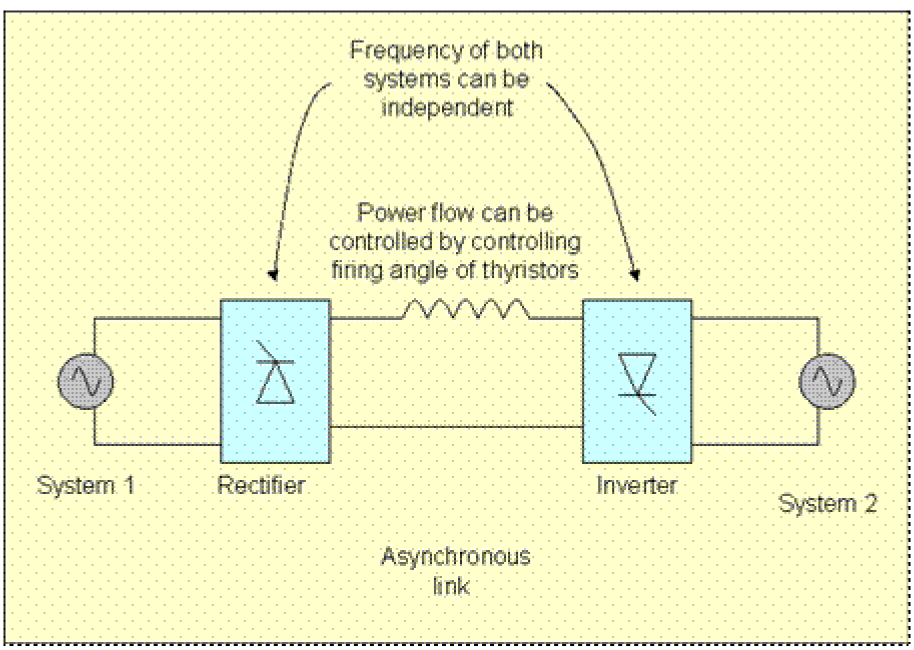
AC-DC-AC conversion

Power Flow can also be controlled by converting AC to DC by thyristor bridges or Voltage Source Converters and reconverting the DC to AC (at another bus) again by the same means. The converters are connected in shunt with the AC transmission system at 2 buses. If a substantial distance between the 2 buses is involved, then *high voltage* DC transmission is done. The power flow is a function of the converter firing angles and is practically independent of the voltage phase angle and frequency at either end.

Normally, DC links *embedded* in an AC system are mainly used to transfer power over long distances which is difficult with AC lines (see problems with long distance AC transmission in module 2).

DC links are also used to allow for controlled power inter-changes between two systems which are *not synchronously* connected is shown in the figure on the right.

You may simulate HVDC link using the MATLAB/SIMULINK file (hvdc.mdl).



Recap

In this course you have learnt the following

- Inability to control power flows on individual lines may restrict the utilization of a transmission network.
- Series compensation of line parameters by capacitors and phase-shifting transformers are conventional ways to control power flow.
- Power electronics based HVDC converters and controlled series compensation may also be used.

Congratulations, you have finished Lecture 19. To view the next lecture select it from the left hand side menu of the page.