

## Module 4 : Voltage and Power Flow Control

### Lecture 19a : Use of Controllable Devices : An example

#### Objectives

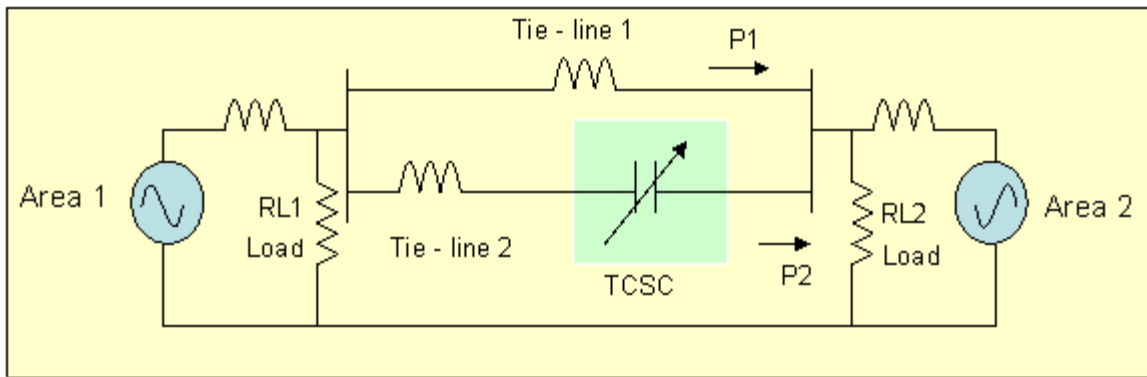
In this lecture you will learn the following

- The use of controllable devices with the help of an example

#### An example

In the previous lectures we have seen that power electronic based controllers like generator excitation systems, SVC, TCSC and DC links allow real and reactive power flow control. In this lecture, we try to understand how this can be achieved in practice, by considering a simple example. Most of the concepts in this lecture have been introduced previously. However, it is hoped that this lecture will not be a mere reiteration, but will bring clarity to most points.

Consider a two area system shown below, connected by two tie lines. A series controlled device (TCSC) is placed in one of the parallel lines. The lines have unequal impedance. Therefore steady state power flow through them is not equal.



We can utilize the power flow control ability of a TCSC to assist the system in the following tasks:

- a) Regulate power or current in the parallel AC tie line in case it is thermally overloaded by diverting power to the line in which TCSC is connected.

**Note:** This function is "given up" in case the TCSC compensated line reaches its thermal limit or the TCSC itself reaches some limit (voltage, current or firing angle limit). In case *both paths* are thermally overloaded, a TCSC cannot help, and efforts will have to be made to reduce the cumulative power flow between the two areas by adjusting the generation (AGC) and/or loads.

- b) Increase the "stiffness" of the tie-lines connecting the two areas by increasing series capacitive compensation for a short while after large disturbances. This will aid in improving angular stability -- keeping the two areas in synchronism.

- c) Modulate the series capacitive reactance so as to make the relative angular motions (swings) settle down quickly.

The first function can be achieved "slowly", since thermal time constants are large. However, the last two functions require quick response capability which is possible since TCSC is power electronically controlled.

We now consider control systems which will help us achieve these strategies.

#### Control Strategy for Power Flow Control

To divert power flow through the TCSC compensated line when a parallel path is overloaded, one would need to first sense that such a condition exists. Therefore the current in the parallel tie line is measured.

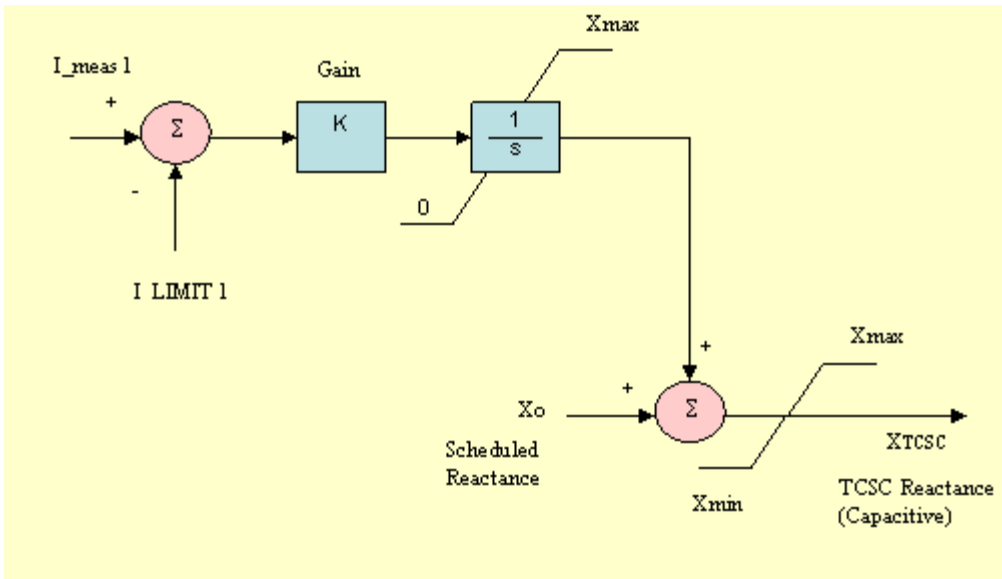
(One can also synthesize the current in the parallel path using only *local measurements* of current and voltage

phasors at the TCSC location, provided all line parameters are known. How can one do it ?)

In case the current magnitude in the parallel tie - line is greater than the permissible value due to thermal limit, increase the power (or current) flow in the TCSC compensated line by increasing the TCSC capacitive reactance. Since the effective impedance of the TCSC compensated line is reduced, it will take on a larger share of the total power flow between the 2 areas.

A feedback control system which can achieve this is shown below.  $I\_LIMIT1$  denotes the current limit of the tie line which is parallel to the TCSC compensated line.  $X_{max}$  and  $X_{min}$  denote the minimum and maximum controllable reactance of a TCSC in the capacitive region. The integrator has minimum and maximum limits of 0 and  $X_{max}$ . This means that as soon as the output of the integrator crosses these limits, then the integration is halted and resumes **only if** the sign of the input to the integrator is such that further integration will get the output back into the the range 0 to  $X_{max}$ .

For example if the input to the integrator at a particular instant is -0.5 and the output is 0, then integration is stopped (the output of the integrator remains frozen at 0). It resumes only after the input becomes positive. Similarly if the input is +0.8 and output is  $X_{max}$ , then integration is stopped, and it resumes only when input becomes negative.



It can be inferred that if current exceeds the limit  $I\_LIMIT1$ , then the output of the controller increases the value of TCSC reactance above its scheduled (or set point) value. On the other hand, if the limit is not exceeded, the integrator output will settle to the integrator lower limit, i.e., zero.

## Auxiliary Control for improving angular stability

One could use the quick response capability of a TCSC to limit transient relative angular deviations between the two areas following disturbances, and make the transient angular oscillations "die" out.

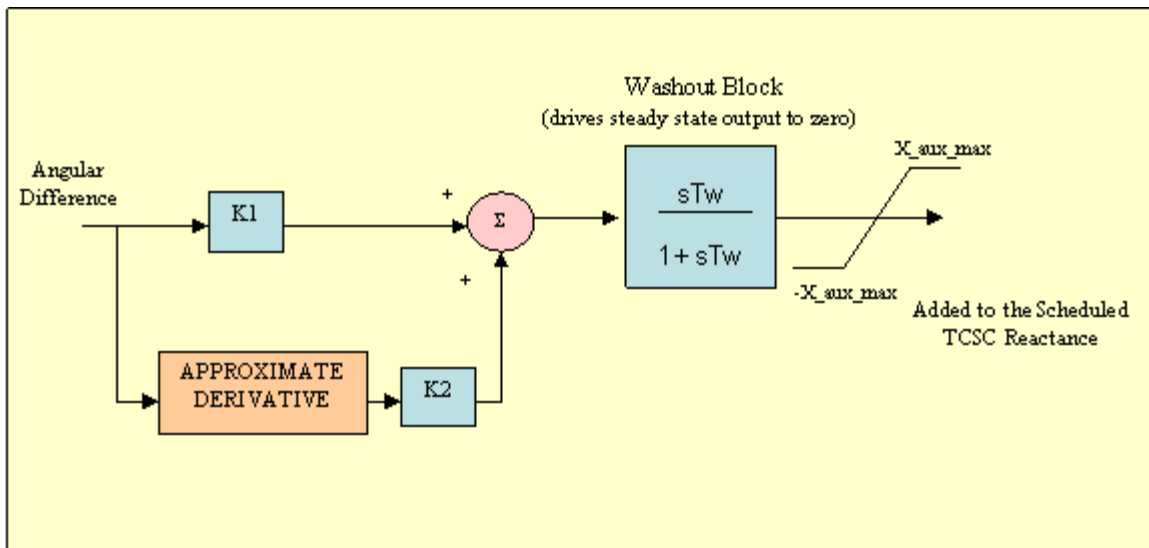
In other words, we wish to prevent potential loss of synchronism and also make the system settle down to a steady state as soon as possible.

A simple "intuitive" control strategy would be as follows:

1. Boost the electrical power flow from area 1 to area 2 if the angular difference between the voltage phasors at area 1 end of the transmission tie lines and the area 2 end increases. The increased electrical power flow between the two regions when angular deviation increases, retards the relative movement between generator rotors in one area with respect to the other. To boost the power flow, the capacitive reactance of the TCSC can be increased in proportion to the angular difference.
2. How does one make the transient angular swings settle down quickly ? Recall that rotor angular swings are analogous to the oscillations in a spring mass system. Oscillations die out in a spring mass system due to a retarding force which is approximately proportional to speed (i.e. viscous friction). We can try to create similar retarding forces in a power system, by making the electrical power flow to be a function of the *rate of change* of angular difference (it is already a function of the angular difference).

Thus, to reduce angular difference as well as to make the system "settle down" quickly, the TCSC reactance can be made

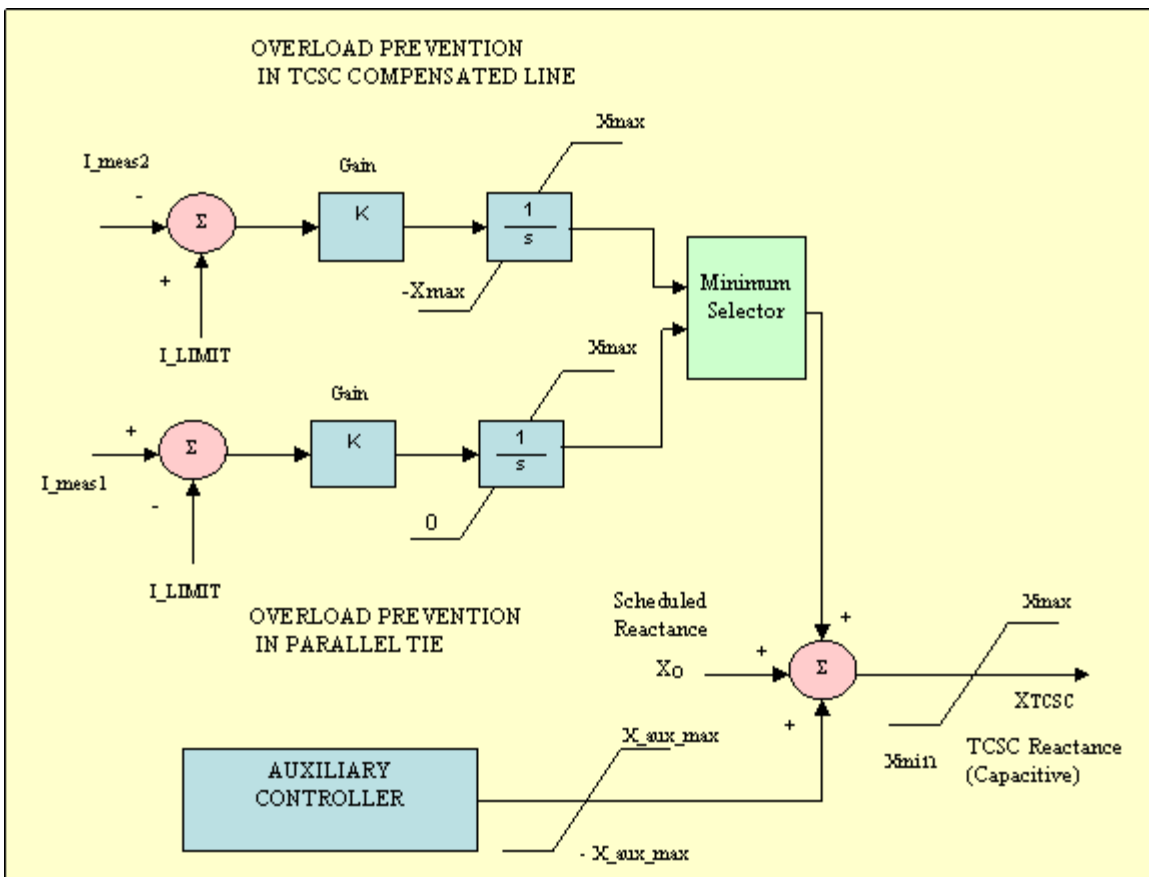
a function of angular difference and rate of change of angular difference. This can be implemented by a controller schematic as shown below:



**Important :** This auxiliary controller is supposed to act only if there are transients corresponding to rotor relative motion (typical oscillation frequencies lie between 0.2-2 Hz). It has no steady state regulation function -- it should not "interfere" with the relatively slow control functions which were described earlier. The output of the controller has to be *gradually* driven to zero in steady state. Therefore a washout transfer function (see lecture 8a, Module 2), which has a steady state gain zero is used in cascade with this controller.

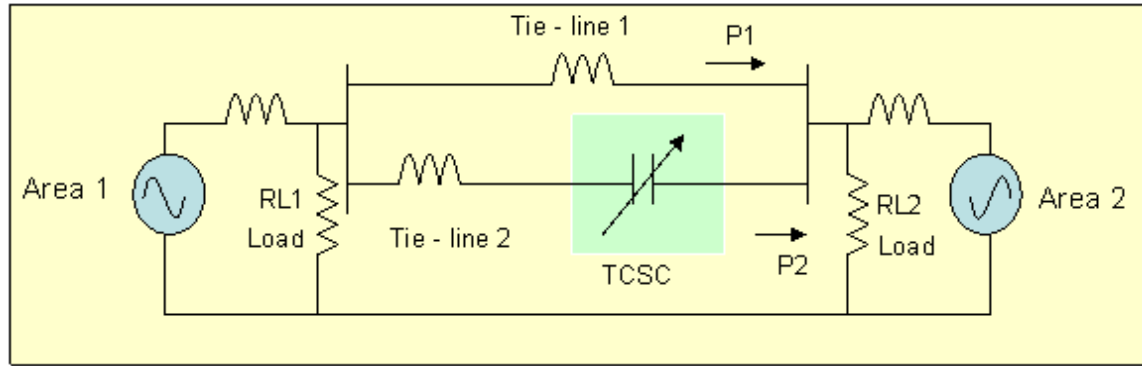
**Caution:** The control strategy given here is simplistic and is chosen to illustrate the concept; in practice, a more rigorous design approach has to be adopted.

The overall controller including the auxiliary controller look as follows:



## Simulation Example

We can simulate using Runge Kutta method, a simple two machine system with local load as shown below:



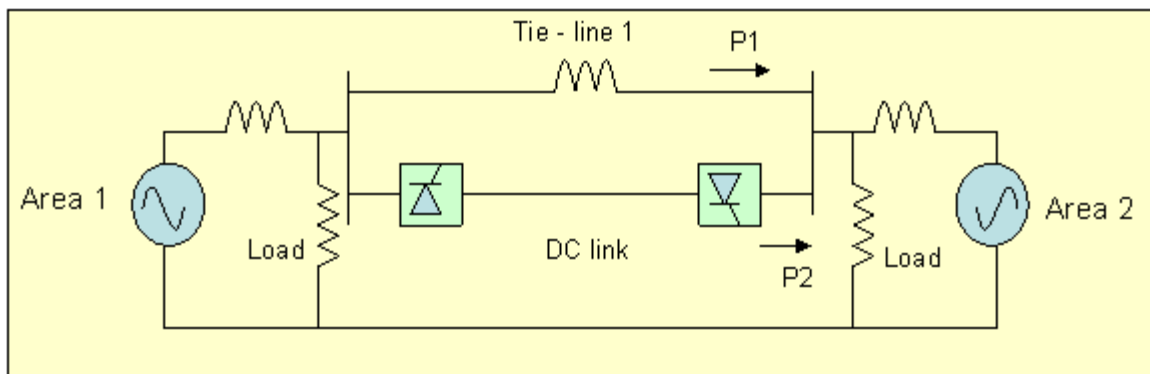
Note that:

1. The two areas are connected by *two* tie lines one of which is compensated with a TCSC.
2. AGC and governor are not considered.
3. The impedance of the first line ( $j \cdot X1 = j \cdot 1.0$ ) and the *compensated* impedance of the second ( $j \cdot X2 - j \cdot X0 = j \cdot 1.2 - j \cdot 0.2$ ) pu are equal.
4. The continuous current (thermal) limits of the tie lines are 0.16 pu and 0.2 pu respectively.
5. Local loads RL1 and RL2 are purely resistive.  $RL1 = 1.579$  and  $RL2 = 0.789$ .
6. Generator Powers (initial values) : 0.95 pu for both generators.
7. Data common to both generators: Inertia Constant  $H = 6$  MJ/MVA, equivalent reactance (between generator internal voltage source and the load in the figure above) is  $Xs = 0.25$ pu
8. Modeling of generator swing equations and network for this simulation is similar to that given in the governor example of Lecture 14 (Module 3). However, governor is not modeled.
9. TCSC is modeled as a variable capacitive whose value is determined by the controller. The dynamics are associated with changing the firing angle and are not modeled explicitly.

Study the data ([init.m](#)) and the MATLAB/SIMULINK simulation ([tcsc\\_controller.mdl](#)) for a sudden 5% increase in generated power of one area and a 5% reduction in generated power in the other.

Note how the TCSC controller can divert power in the tie lines (provided its own limit is not reached !)

## DC Link vs TCSC controlled AC link

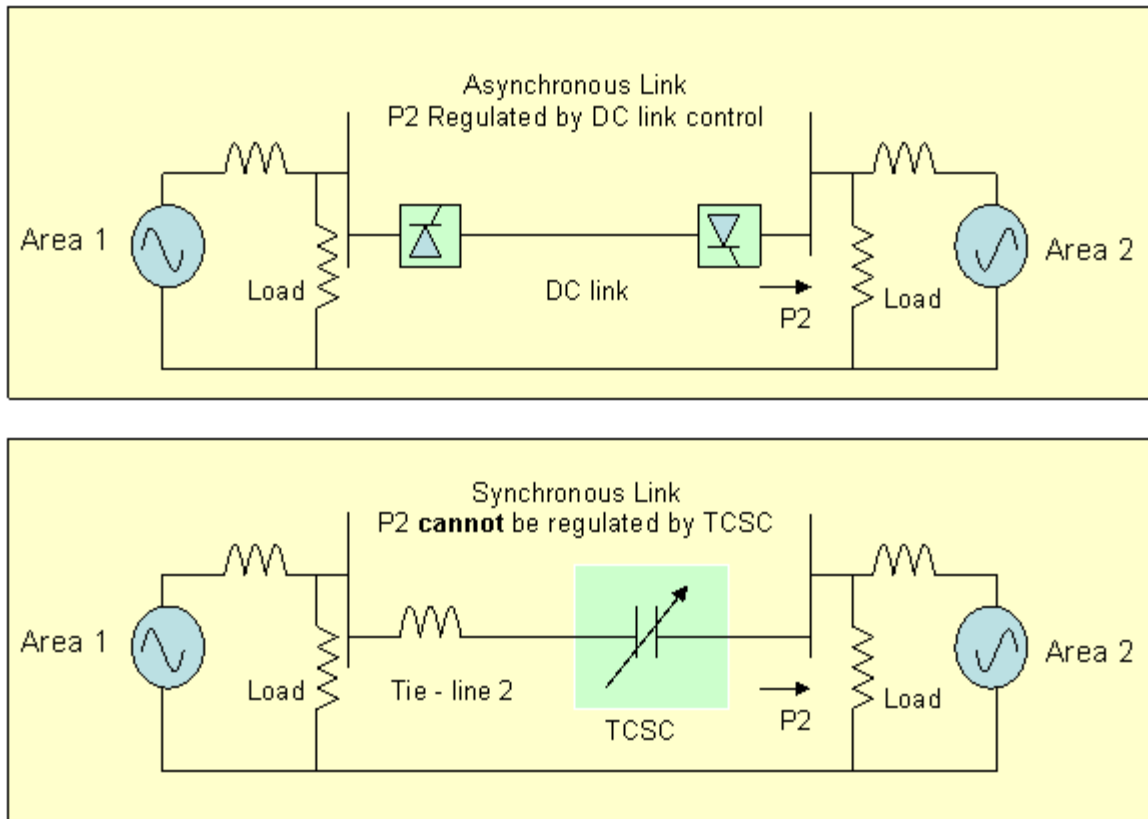


A TCSC controlled AC link and an HVDC link embedded in a synchronous grid can give equivalent functionality.

It must have occurred to an intelligent reader that a DC link should also give us more degrees of freedom in control since we have *two* converters, thereby we have two firing angles which can be

independently controlled. Alas, for thyristor based converters used in most DC links, a degree of freedom in control is lost due to the constraints placed on the reactive power drawal at both ends as well as the need to prevent firing angle at the inverter from straying too close to 180 degrees.

However, an HVDC link is able to provide an asynchronous tie in case other parallel AC paths are lost. Control of power between the two regions is regulated by the HVDC link itself. On the other hand, loss of synchronism is unacceptable for a system with a TCSC connected link. Moreover, a TCSC cannot regulate *cumulative* power flow between the two areas (AGC is required for this).



## Recap

In this module you have learnt the following

- Using an illustrative example, we have seen how one can have more flexibility in system operation and control

Congratulations, you have finished Lecture 19a. Please view the next slide for concluding remarks for this module.