**Flexible AC Transmission Systems (FACTS) Devices**
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**Lecture – 18**
**External Control Design of Static VAR Compensator**

Welcome to our Flexibility AC Transmission Systems video lecture series. Today we are going to discuss, we have already discussed the actually the comparison between SVC and the STATCOM. We shall see detail today what are the controlled features of the STATCOM that is the title of this topic will be the External Control Design of the Static VAR compensator or SVC.

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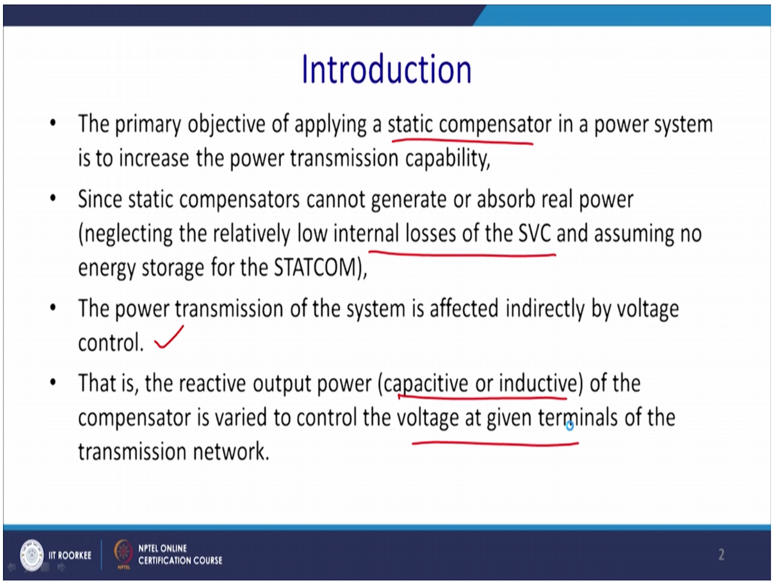


Now, as we know that primary objective of applying the static compensator in a power system is to increase the power transmission capability. This is the basic principle of putting a FACTS devices. Since static compensator cannot generate or absorb real power we have to neglect the switching losses of the SVC, and we should now presently eliminate the idea of putting active component or the storage component with in a STATCOM.

Neglecting the relatively low internal losses of the SVC and assuming that no energy storage for the STATCOM; The power transmission of the system is affected indirectly by the voltage control, that is the reactive power the capacitive or inductive of the compensator is varied to control the voltage at the given terminal of the transmission network.

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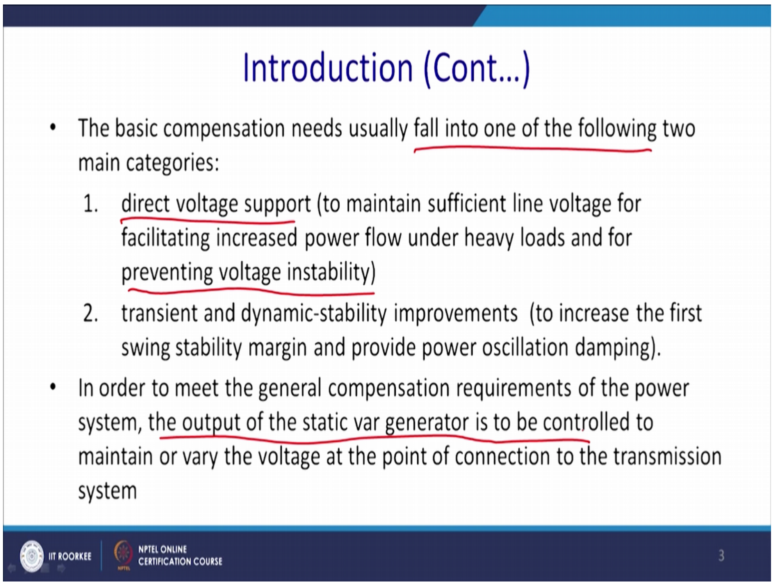


So, the basic compensation needs usually into the following two categories, one the voltage support, direct voltage support to maintain sufficient line voltage facilitating the increase in the power flow under heavy load and for preventing voltage instability. This is may be the purpose another is the transient stability the transient and dynamic stability improvement to increase the first swing stability margin and provide damping to the power oscillation.

So, in order to meet this two demand general compensation requirement of that of the power system, the output of the static var generator is to be is required to be controlled to maintain or vary the voltage at the point of the connections of the transmission line.

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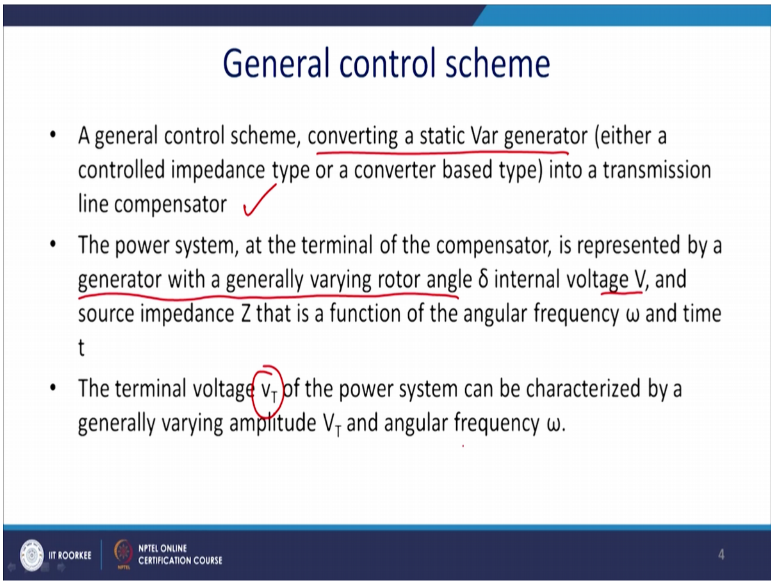


So, this is the one of the desired feature of SVC in general the control scheme converting static var compensator, either to a controlled impedance or a converter type into a transmission line compensator. The power system at the terminal of the compensator is represented by the generator with a generally a varying angle varying rotor angle with the internal voltage V.

So, we know that actually P is given by V 1 V 2 by x sign delta. So, where delta is a rotor angle and the source impedance Z is the function of regular frequency and a time t. The terminal voltage that is V T of the power system, can be characterized by generally varying the amplitude V T with an angular frequency V this is a way we model it.

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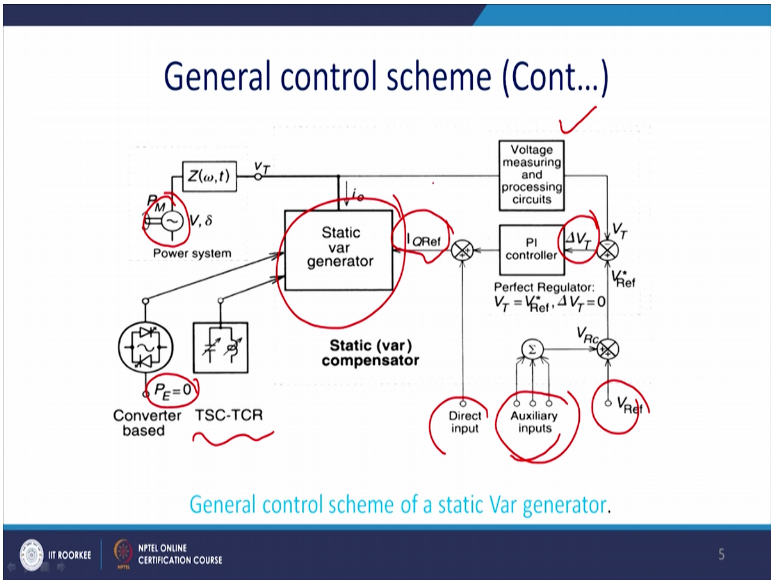


So, this is a general control scheme of SVC what happen you have a prime mover that generates a voltage. So, with an angle V and with voltage V amplitude V and the and the angle delta. So, this is the network and here you put a static var generator, essentially it does not have any power to compensate the real power. So, P is 0 this is the convector converter based and it may be a actually TCSC or TCR. So, what you how you will control it? So, essentially you will measure the voltage.

So, we will check that whether there is a sac in to the system or not. So, accordingly you will actually check the system capability. So, there is a auxiliary input there is a V reference from there will check that, whether there is a sac in input or not and also if it is not so, then you will put this value of the V T as a V reference and thus actually del V becomes 0 and you also have a auxiliary inputs. And from there you know actually you have the direct input and from there you essentially you compute what is your IQ reference.

This IQ reference you may get hybrid stat hybrid STATCOM or you may have a this kind of controlled devices. So, that you required to inject the voltage i proportional to the IQ ref.

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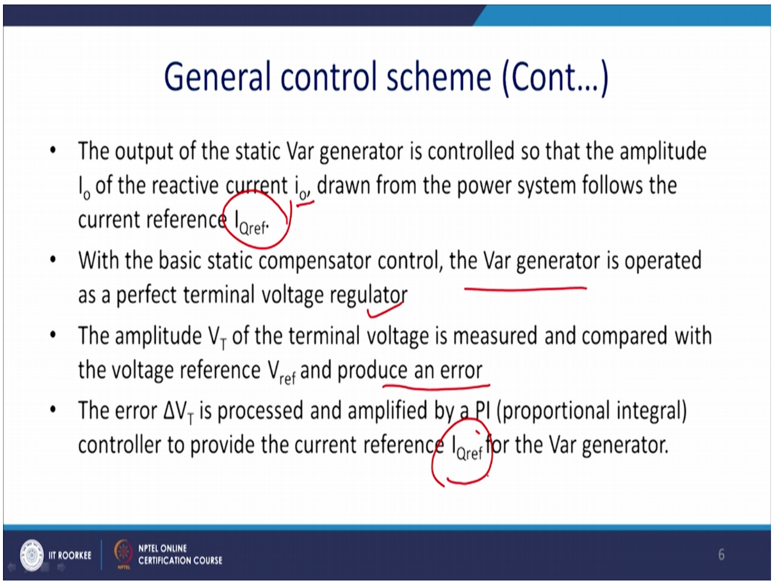


The output of the static Var generator is controlled so, that the amplitude i 0 of reactive current is drawn from the power system and system the reference current IQ ref with the basic compensator control the var generator is operated, at a perfect terminal voltage regulator.

So, that is something we have maintained the amplitude V T of the terminal voltage is measured, and compared with the reference voltage V ref and produce an error this error is fit to the pi controller. This V T is processed and multiplied by a pi controller to provide the current reference IQ ref for the compensation of the var this is the principle operation of this SVC.

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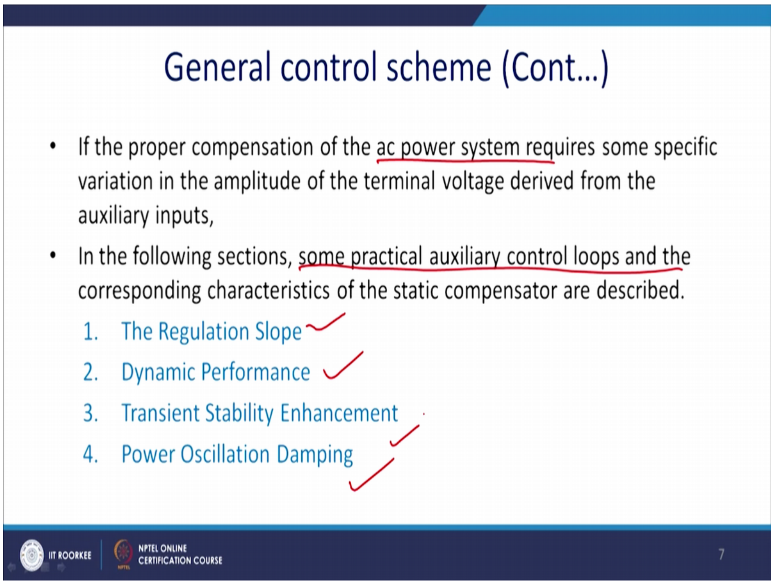


If the proper compensation of the reactive power system require some specific variation of the amplitude of the terminal voltage and that is varied for the auxiliary inputs sometimes it may sac may occur or something. So, there may be the disturbance due to that then we actually work on the auxiliary input.

The following sections some practical auxiliary control loops are corresponding to these following item will be discussed, that is the slope regulation, dynamic performance, transient stability and the power damping. So, these are the four entities mostly will be actually we will see that what are the controlled technique will require to achieve those entities. Now, many applications the static compensation is not used as the perfect terminal voltage regulator.

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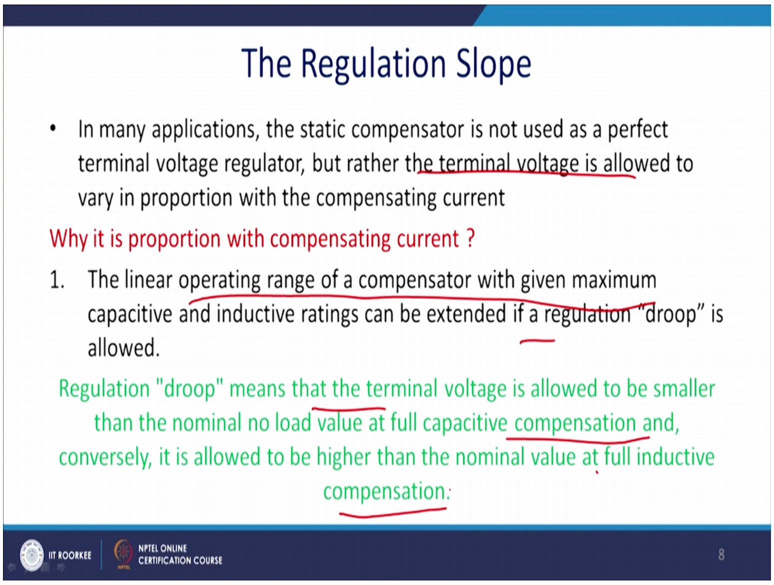


But whether terminal voltage is allowed to vary proportional to the compensating current most of the cases why it is proportional to the compensating current? We know that actually reactive power handling capability varies with the qs in case of the SVC. The linear operating in range of the compensator with the given maximum capacitor and the inducting current can be extended if the regulation droop is allowed.

So, then it will be linear otherwise it is quadratic. Regulation droop means the terminal voltage allowed to be smaller then the nominal no load value, at full capacitive compensation and conversely it is allowed to be the higher than the nominal value at full inductive compensation this is the droop regulation. So, thus what happen? The perfect regulation that mean the 0 droop or slope could results in poorly defined operating point and has a tendency to oscillate.

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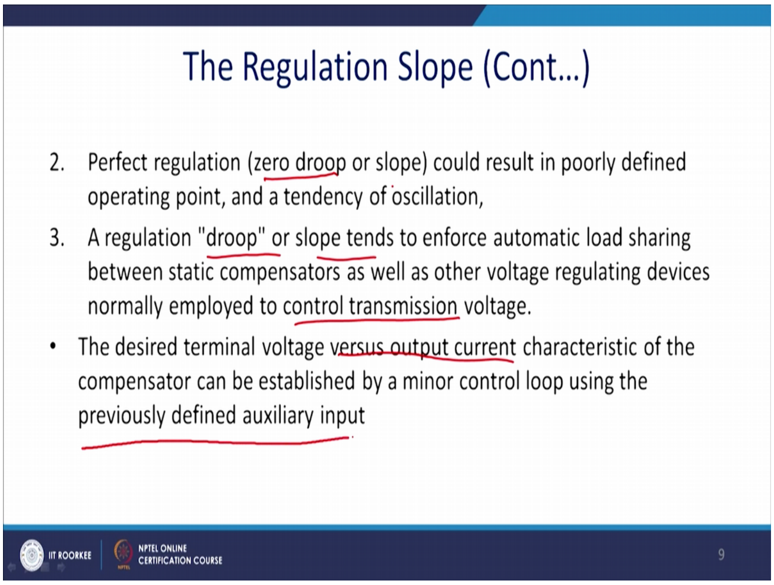


So, that is something we require to prevent the regulation droop or the slope tend to ensure. Automatic load shading between static var compensator as well as the voltage regulating device normally employed to employed to control the transmission voltage. The desired terminal voltage verses the output current characteristics of the compensator can be established by a minor control loop using actually as you have shown a previously defined auxiliary input.

So, that will be used for loop control; loop control is very important feature, while the multiple entities working and how they will share the load ultimately let us assume that power system all of a sudden you have del V comes in to the picture.

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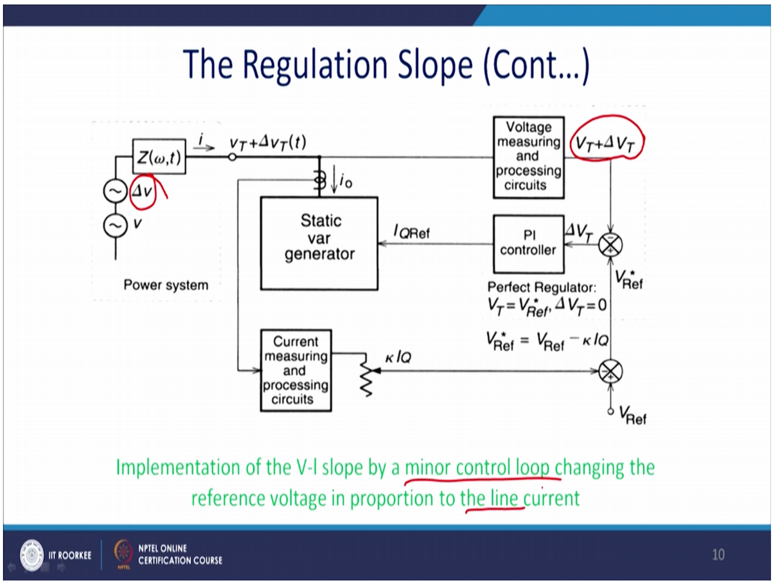


So, you have a soil in voltage and thus what happen this? V T will be added up and this current will be sensed, current sensing and processing circuit and the measuring voltage also measured and will add up plus del V T. So, the error del V T will come and will give you the reference and perfect regulator, when V T equal to V ref and del V T equal to 0 and V ref equal to generally it is V ref minus k into k is the gain of this proportional controller into IQ. Thus it will ensure the sharing of this reactive power between all the element implementation of the V-I slope by minor control loop, changing the reference voltage is proportional to the line current.

So, how this line current changes you actually inject some extra voltage and that is called the droop control feature. So, how you will calculate k that is also a challenge we have written that i into k into i.

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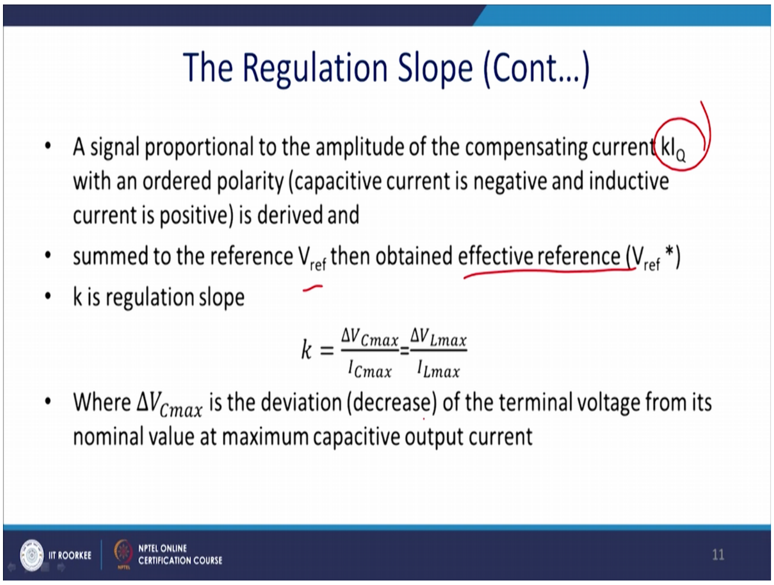


The proportional a signal proportional to the amplitude of the compensating current kIQ with an order of the polarity; capacitive current is negative and the inductive current is positive is derived. Summed to the reference V ref then obtained effective V reference then the V reference will change dynamically as it will be required by the I.

So, avoid k is the regulating slope, but k is given by del V C max by I C max or del VCL max by IL max depending on the capacitive or the inductive compensation. Where the del VC max is the deviation or decrease in the terminal voltage from its nominal value at the maximum capacitive current, but by using this reference the amplitude of the terminal voltage V T is regulated at a linear slope over the control range of the compensator.

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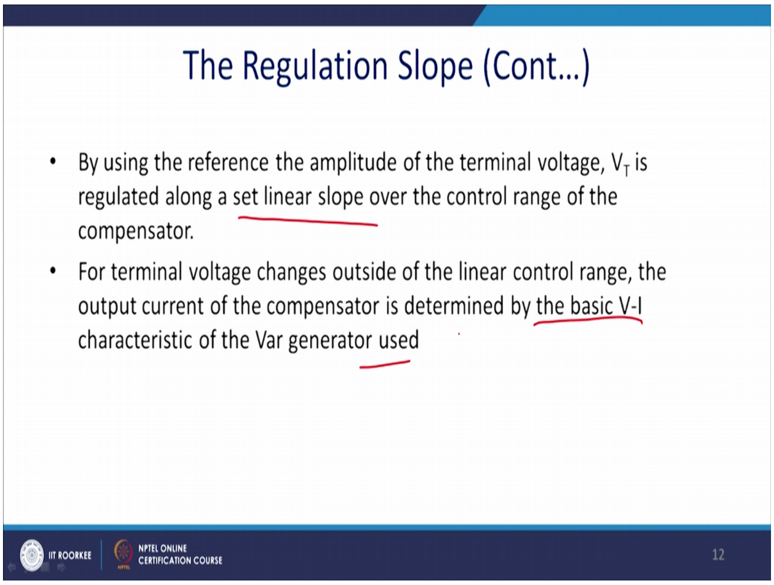


For terminal voltage range outside the linear control range the output current of the compensator is defined by the basic V I characteristic of the Var generator let us see this curve and that will explain the case.

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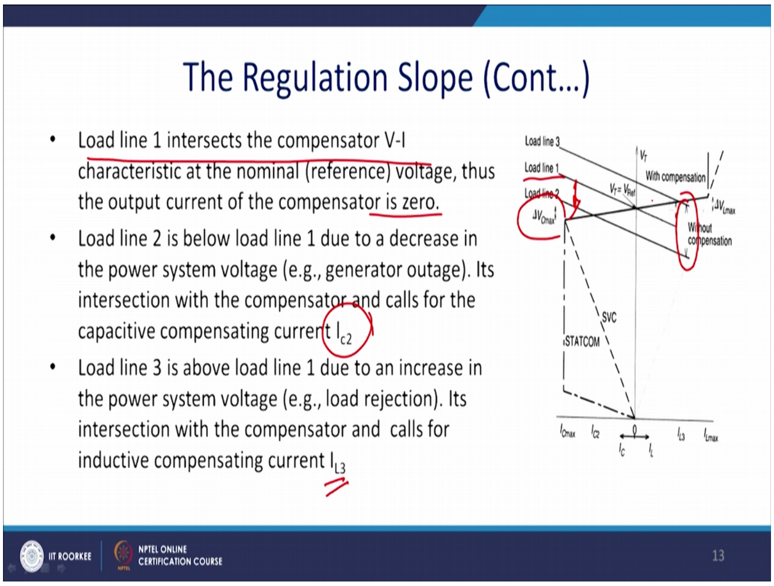


Let us consider that the load line 1 intersects the V I curve. So, this is the load line 1 and this is the load line 1 and the characteristics of the nominal reference voltage and thus what happen? The output current of the compensator is 0 and this is the actually the load line 2. Load line 2 is a below the load line 1 due to decrease in the power system voltage that mean the generator out h or something like that or sac it interacts interaction with the compensator and calls for the capacitive compensation of current I c 2.

So, there will be some current it will be difference. Same way if there is voltages (Refer Time: 13:50) and the load line three is above the load line 1 due to the increase in the power system voltage, may be due to the load rejections. The intersection with the compensator and calls for the inducting compensation of current L 3; so, there will be a some amount of extra current will come. So, you know if it is STATCOM then it will have a this kind of characteristics and if it is SVC you have linear characteristics and this is the actually without compensation.

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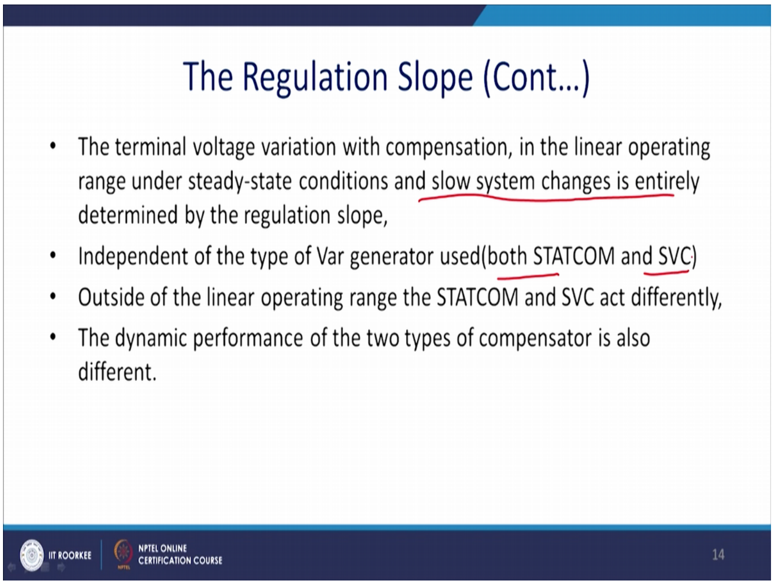


Now, the terminal voltage variation with the compensation in the linear operating range under steady state condition and slow system change is entirely determined by the regulation loop that is called loop control. Independent of the type of the var generator used both it can be SVC or STATCOM. Outside the linear operating range STATCOM and SVC act differently. So, that is the challenge; the ironic performance of the two types of compensator also will be different please note that. So, let us see that dynamic performance.

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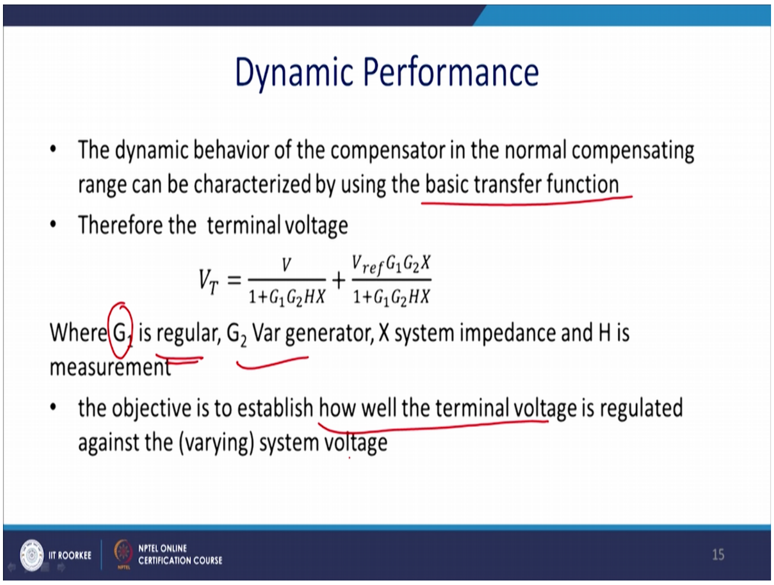


The dynamic behavior of the compensator in a normal compensating range can be characterized by using a basic transfer function and therefore, the terminal voltage V T is V 1 plus G 1 G 2 HX plus V ref G 1 G 2 X 1 plus G 1 G 2 HX am coming to it. So, where G 1 is a regulator, G 2 is a var generator and X is a system impedance and H is the actually the transfer function of the measuring devices. The object is to establish how well terminal voltage is regulated against the varying system voltage.

So, that is something we require to put it let us assume that V ref equal to 0 and consider the small variation only.

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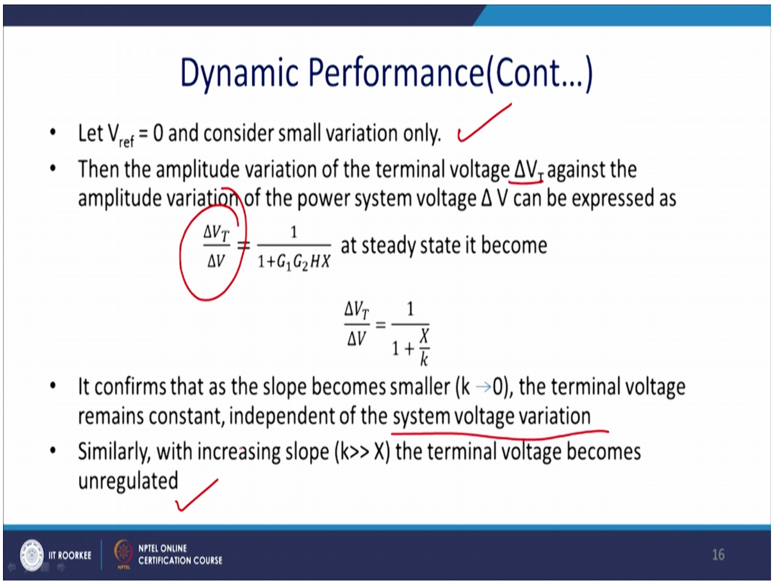


So, then amplitude of the variation of the terminal voltage V T against the amplitude variation of the power system del V can be expressed in this term. At the steady state this becomes just 1 by 1 plus X by k. This confirms that the slope becomes smaller if k becomes large; the terminal voltage remains constant independent of the system variation. Similar with the increasing case slope the terminal voltage; becomes unregulated. So, we require to keep this terminal performance in to the mind the equation shows that a dynamic behavior of the compensator is the function of the power system impedance.

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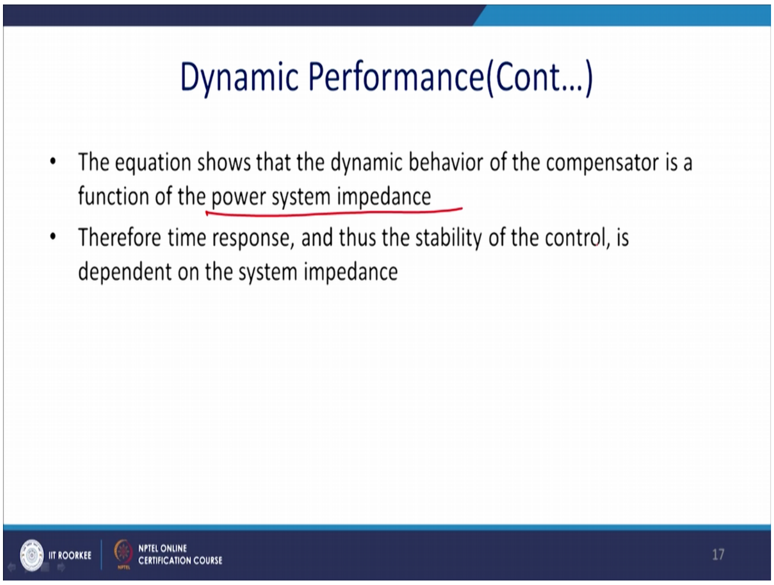

So, SVC basically changes the power system impedance, therefore time response and thus the stability of the control is depend on the system impedance. So, this is something we require to keep in mind. Now transient stability with this SVC; this transient stability indicates the capability of the power system to recover from the major disturbance.

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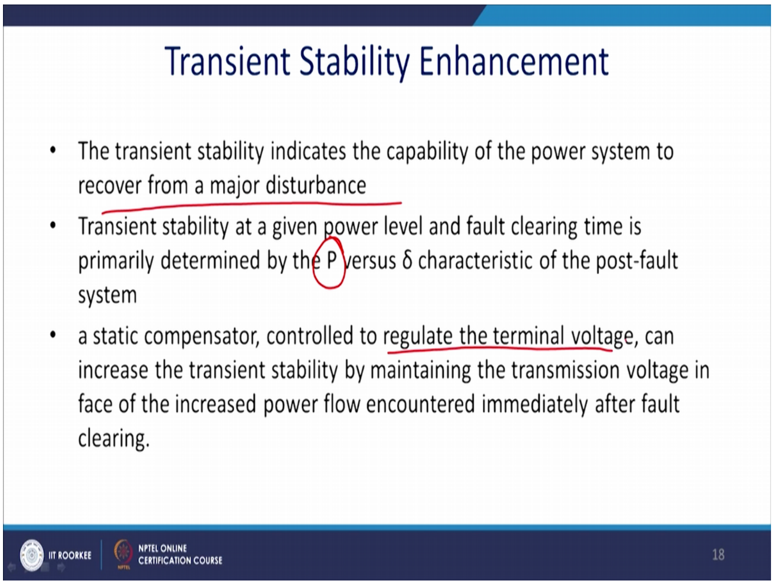


Transient stability at a given power level or the fault clearing time is primarily determined by the power it is actually handling at the moment and the torque angle delta and the post fault system condition. The static compensator controlled to regulate the terminal voltage we have seen that can increase the transient stability by maintaining the transmission line voltage, in the phase of the increased power flow countered immediately after the faults shearing.

So, this is something that is specificant and thus increases the transient stability. This transient stability can be increased further by temporally increasing the voltage, above the regulating regulation reference for the duration of the first accelerating (Refer Time: 18:34) what it will do then, what will happen? Then the voltage increase above its nominal voltage value will increase the electric power transmitted.

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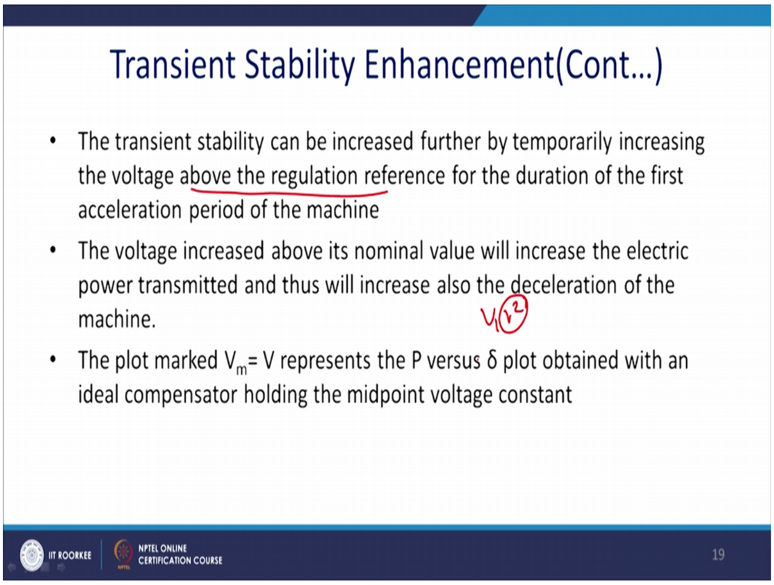


Because you know you have V 1 V 2 if V 2 is increasing. So, power handling capability increases and thus increases also the deceleration of the machine. The plot marked V m equal to V, I shall come now represent the P verses delta power obtained with the ideal compensator holding midpoint voltage constant. So, see that this is the case. So, this is the area and this is the case with the STATCOM and this is the case with the SVC.

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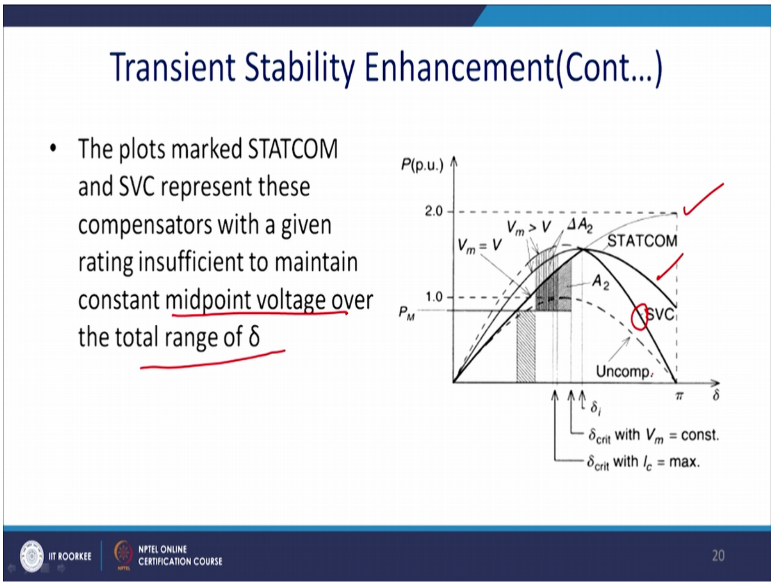


So, this is the SVC and this is basically the STATCOM. So, the plot marks STATCOM and SVC, this compensator with the given rating insufficient to maintain the constant midpoint voltage for the total angle delta because this is basically 0 to pi. So, thus it increases the transient stability.

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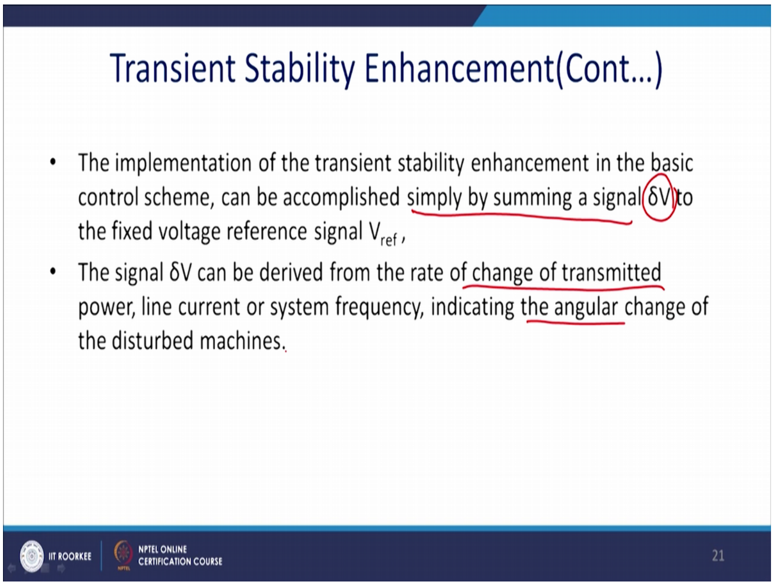


The implementation of the transient stability enhances the basic control scheme and can be accomplished by simply by summing a signal del V to the fixed voltage reference V ref. This signal del V can be derived from the rate of change of the transmitted power if you see that there is a change of transient part it can be changed. The line current or the system frequency indicating that the angular change of the disturbed machine, from there we can calculate what should be the del V change and thus we can incorporate it let us see that how does it work.

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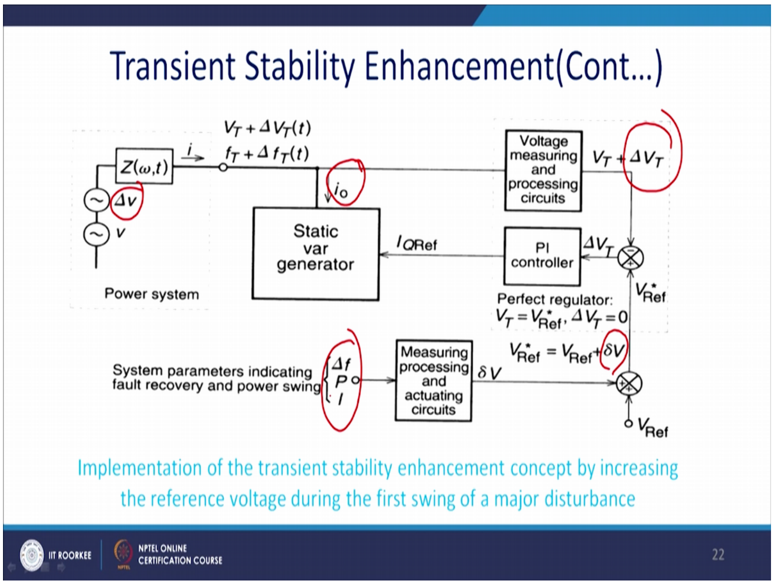


So, power system with fault so, del V has been increased. So, this is basically the change of frequency change of voltage. So, ultimately it will be actually sinking the current i 0 and we have for this reason since it is a del V has been increased.

So, we will increase the actually the terminal voltage by del v. So, ultimately you got a V ref and V ref will be added with the del V and thus you know this k will come and the system parameter indicates that you know if fault has recovered. So, from this parameter we can see that fault has recovered. So, a post fault session it can acts and compensate first.

So, implementing the transient stability enhancement consent by increasing the reference voltage during the first thing or the major disturbance, will try to help us to establish stabilizes the system shown and ends SVC can or can or restore a system faster; Enlargement features of this actually SVC is definitely the power oscillation damping.

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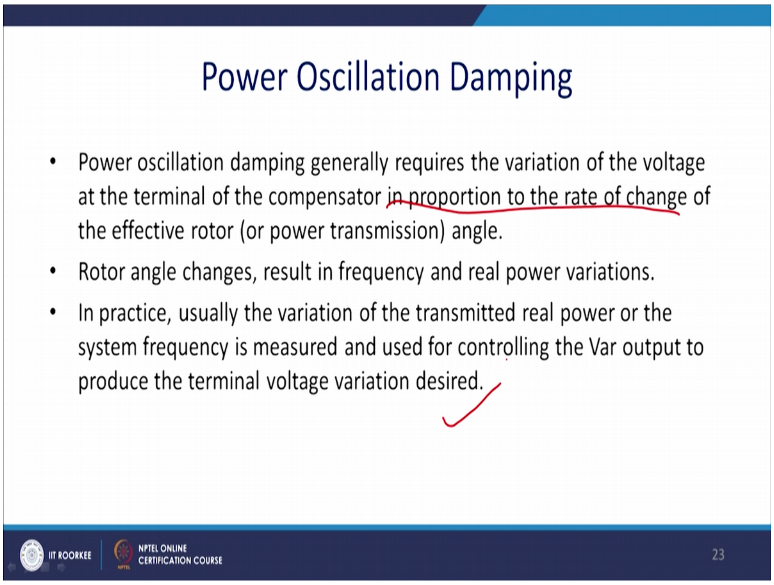


Power oscillation damping we have discussed several time, damping is generally requires the variation of the voltage and the terminal of the compensator in proportional to the rate of change of the effective rotor power angle.

The rotor angle changes and thus what happen results frequency and the real power variations. In practice usually the variation of the transmitted real power or the system frequency is measured and used for controlling the Var output to produce the terminal voltage variation desired.

So, how you will do that?

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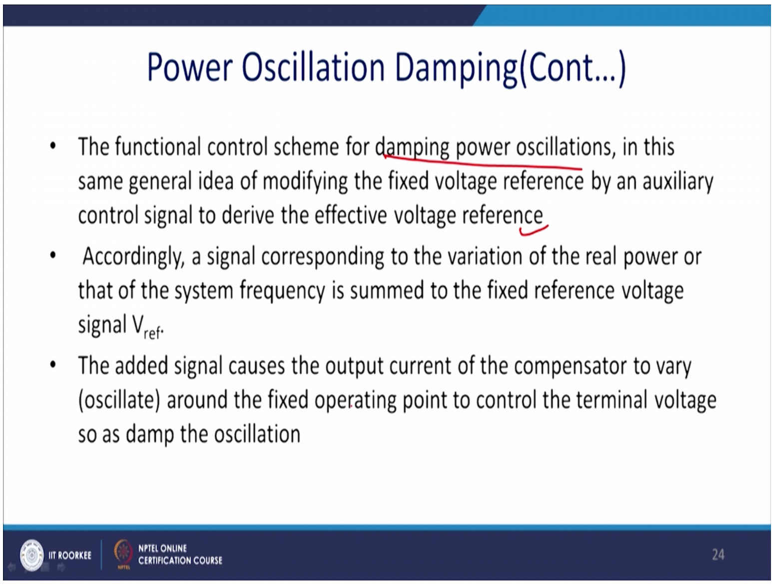


Function of the control scheme definitely is to damping the power oscillation. In this general idea modifying the fixed voltage reference by auxiliary control signal, to derive the effective voltage reference is voltage reference will change accordingly a signal corresponds to the variation of the real power or that of the system frequency, is summed up with the fixed reference signal. The added signal causes the output current and the compensator to vary or change and on the fixed point to control the terminal voltage and thus it will damp out the oscillation. So, this is the case again you have this thing. So, del V.

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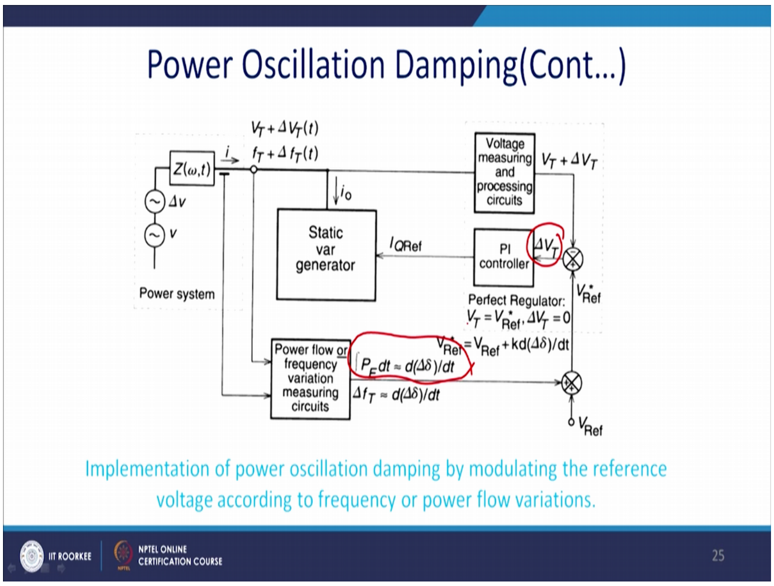

And in this case what will happen? You know actually you will you will add up. So, so basically P dt will increase. So, that ultimately you will add up this. So, that power flow frequency variation circuit it can measure and accordingly. So, you will actually give you will feed the V reference.

So, this will give you a delta change and this delta will be need and varying according to the power oscillation and that value will give you a varying IQ reference, and that will essentially damp out the oscillation. So, var reserve even in the area of the voltage regulation the static compensator is viewed as primarily as a fast source to counter, counteract the rapid or unexpected voltage disturbance due to fault line load switching etcetera.

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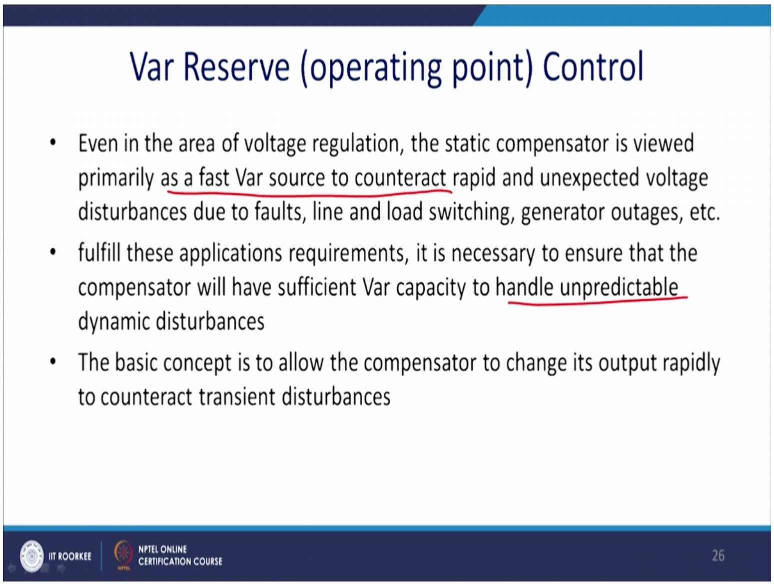


To fulfill this application requirement it is necessary, to ensure that the compensator will have sufficient var capability to handle the unpredictable dynamic disturbances. The basic conserve is to allow the compensator to change this output rapidly to encounter this transient disturbance.

So, we require to have a in built var handling capability. A possible scheme to implement the basic var control the magnitude of output current of the compensator is measured and compared against the reference IQ.

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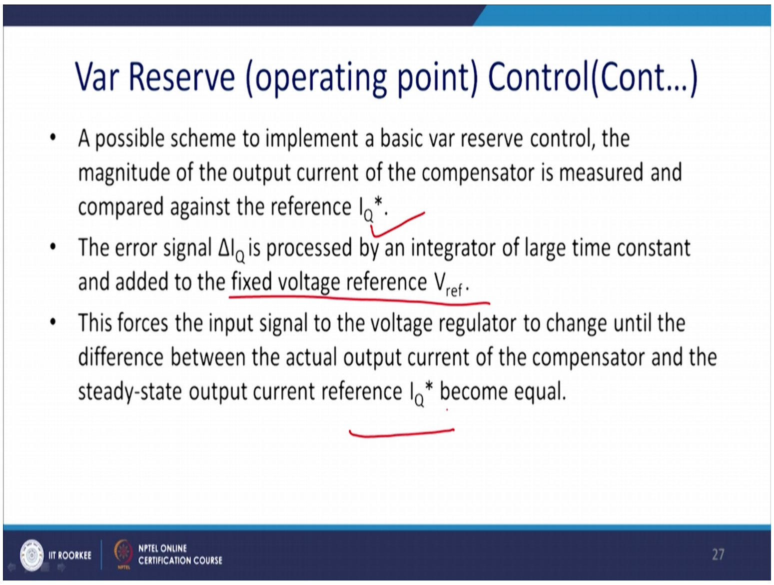


The error signal V Q is then processed by the integrator of the large time constant and added to the fixed value of the voltage reference what happen then? This forces the input signal of the voltage to regulate to change until the difference between the actual output current and the compensator, and the steady state output current reference become equal. So, this is a way to achieve it.

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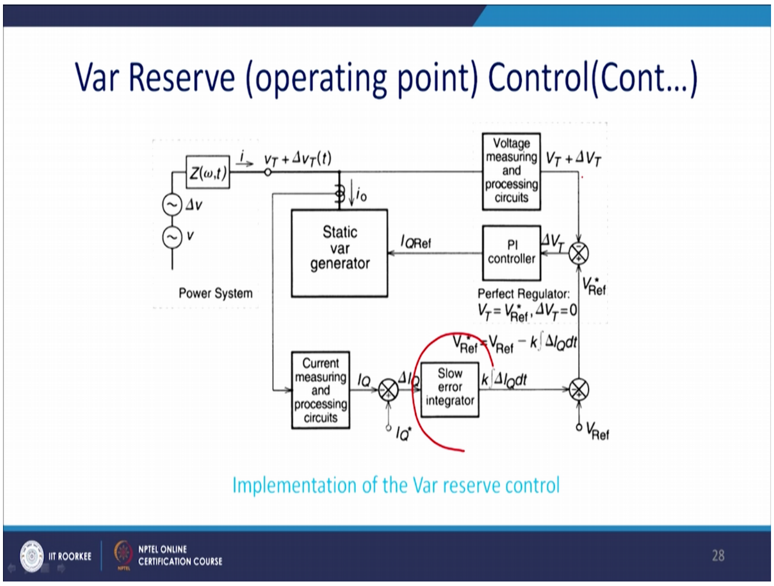


So, this is the Var reserve capability and so, what happens is a slow integrator. So, it measures the current you have a IQ reference. So, it will integrate and the ultimately this will change the terminal voltage and in that way it will control the reference. Thank you for your attention this is the controlled technique of the SVC, we shall continue with the next class with some control technique of the SVC, thereafter we shall discuss about some entities and amplification of the STATCOM then we shall switch over to the series compensation.

Thank you so much for your attention.