Flexible AC Transmission Systems (FACTS) Devices
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Lecture – 25
SSSC III and TSSC

Welcome our lectures on Flexible AC Transmission System. Today, we will continue our discussion with triple S C remaining part of it, thereafter we so, we try to also discuss about T double S C. So, what we are discussing on previous class. So, let us see that the real power compensation capability of the triple S C.

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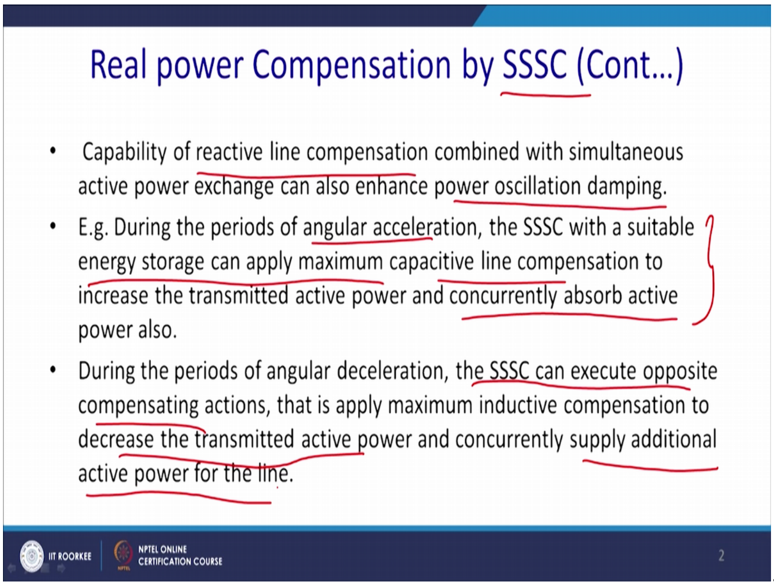

The capability of the reactive line compensations combined with simultaneous the active power exchange can also enhance the power oscillation damping. So, triple S C can provide the active damping. For example, during the period of the angular acceleration the triple S C with a suitable energy storage can supply, the maximum capacitive of the line compensation to increase the transmitted power and concurrently absorb the active powers.

So, this is actually the way it can increase the stability and can damp out the power frequency oscillation. During the period of deceleration, when energy comes down triple S C can execute the opposite operation opposite compensating action, that can apply the maximum inductive compensation to the line to decrease the transmitted active power and concurrently the supply of the additional active power to the line.

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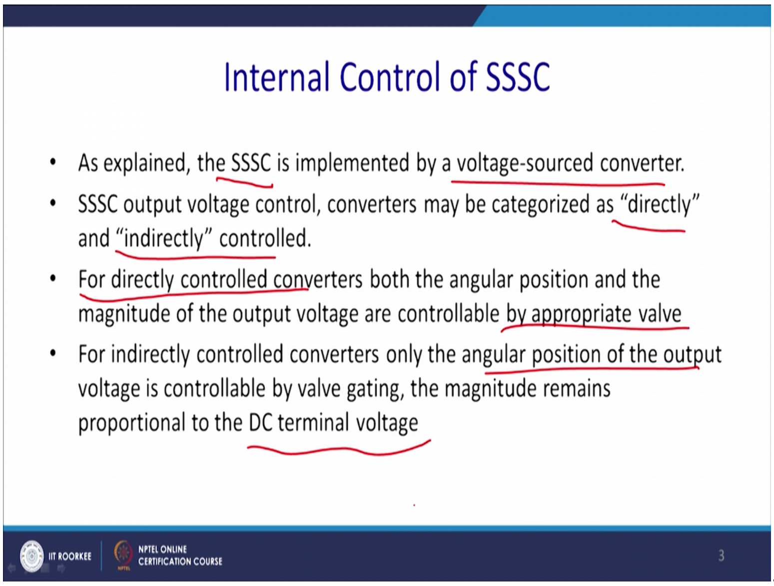

Now, how S S S C can be controlled? Please note that this control technique, which we are discussing, it is more or less combine for all the series type compensator. As explained, triple S C is implemented by a voltage sourced converter.

So, S S S C output voltage control converter may be categorized as "directly" and "indirectly" controlled. Same way we have seen in case of the STATCOM directly and indirectly injection. So, same way we have a same kind of thing in STATCOM in case of the triple S C.

For directly controlled converters both angular position and the magnitude of the output voltage are controlled by appropriate value of this actually with this actually voltage can controlled current source converter. In case of the indirect control converter only the angular position of the output voltage is controlled by the valve and magnitude remain proportional to the D C terminal voltage. So, you allow that D C voltage to factual X.

So, we shall see that pros and cons of this 2 methods.

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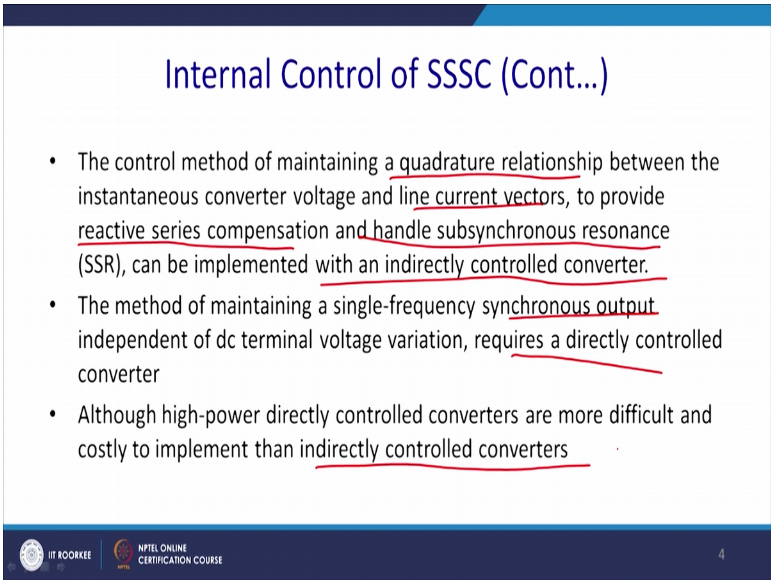

The control method of maintaining a quadrature relationship between the instantaneous converter voltage and a line current vector, to provide the reactive series compensation and handle the sub synchronous resonance or S S R can be implemented with indirectly controlled converter. So, you just control the phase angle rest it will take care of by the deceiver's voltage.

The method of maintaining a single frequency synchronous output independent of the d c terminal voltage variation requires a directly controlled converter. So, if you goes to mitigate the sag then you have a directly controlled converter.

Although, the high power directly controlled converter more difficult we shall see in the control technique and costly to implement than the indirectly control converter. So, indirectly controlled converter is a cost effective solutions in triple S C. So, let us discuss about the internally controlled internal control scheme for the indirectly current controlled triple S C.

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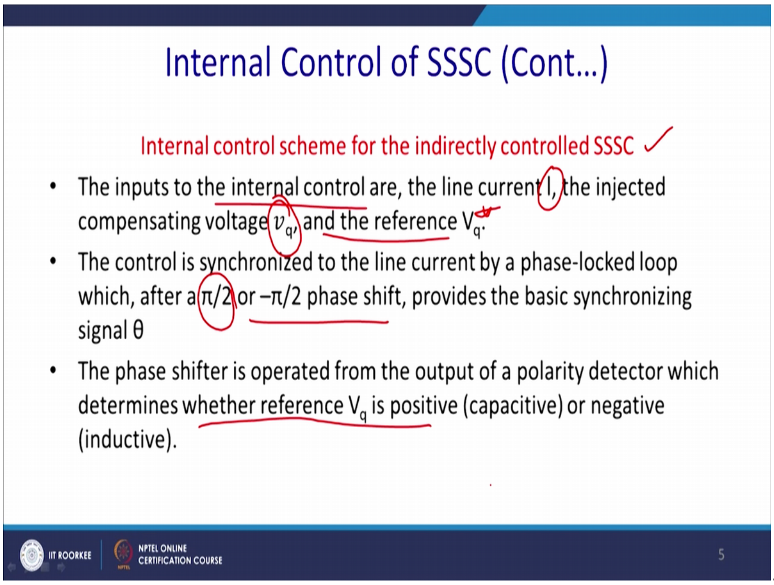

The inputs of the terminal voltage are please note that line current the injected compensating voltage v q and the V q star or V q capital. The control is synchronized with the line current by a P L L or the phase locked loop. After plus pi by 2 or minus pi by 2 phase shift, provides the basic synchronizing signal. The phase shift shifted is a operated from the output of a polarity detector, which determines whether reference V q is positive in case of the capacitor or negative, in case of the inductor or the inductive kind of loop.

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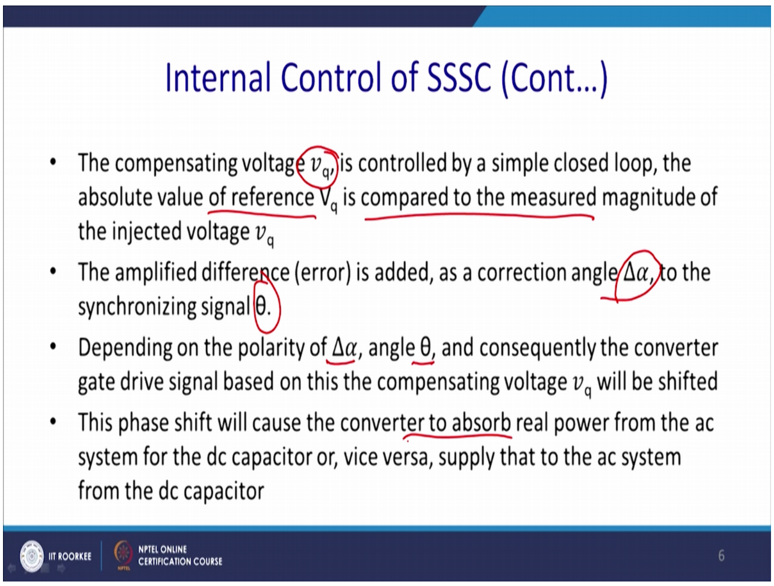

Then, the compensating voltage in the v q is controlled by the simply a closed loop, control the absolute value of the reference V q is compared with the measured magnitude of the injected V q. And, thus we have a error and we fed this error to the P I controller. The amplified difference or the error is added and as a correction angle alpha.

So, output of the P I controller will be the change of the phase angle that is del alpha to the synchronizing signal that is coming from the P L L to theta. So, angle becomes then theta plus del alpha. Depending on the polarity of del alpha and angle theta consequently the converter gate drive a signal based on this compensating voltage v q will be shifted.

This phase shift will cause the converter to absorb real power from the a c system for the capacitor or vice versa or you can inject the real power if you have a storage capability, supply to that of the a c system from the d c capacitor.

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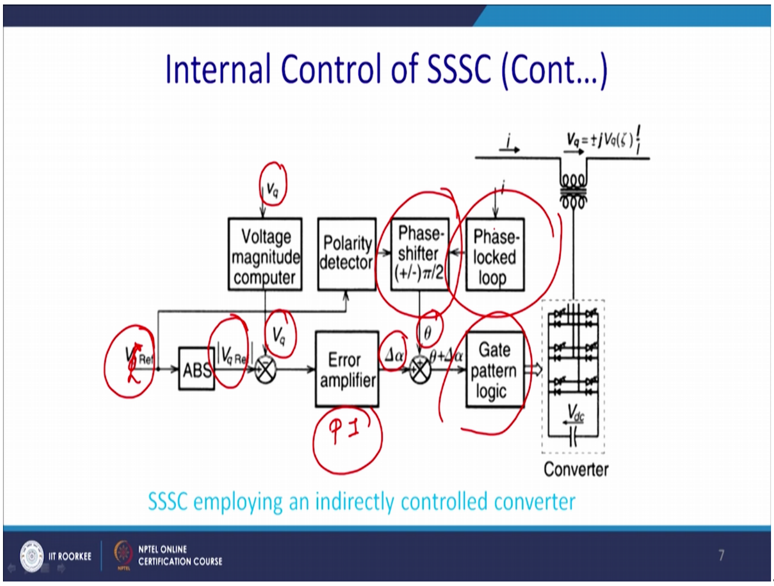

So, this is the internal control circuit of the triple S C and this control circuit is almost common all the 3 types of S S S C. So, you have the V q reference you can calculate the magnitude of it, generally it is a (Refer Time: 07:51) data circuit. So, you got a V q Ref. And, you have the V q and from there you have a actually sensors so, voltage magnitude computer. So, that measures actually the V q.

So, you can write capital V q or V q star then it is being subtracted from the actual V q, then it is faded to the P I controller, P I controller is essentially an error amplifier and ultimately there will be few inputs.

So, there will be a polarity detector whether it is a positive phase on negative phase and accordingly there will be a P L L. So, that will give a phase shift by plus minus pi by 2. So, from there theta will come theta will added up with actually del alpha from this error amplifier.

So, ultimately this become theta plus minus alpha depending on kind of compensation you are doing, then you have a gate logic to give the firing of the thyristors sorry this schedule we can also use I G B T for the lower rating. And, there will be a P L L from P L L actually you can generate the information of the 0 causing and from there actually you fed ultimately phase shift will take input from both the polarity detector as well as the P L L.

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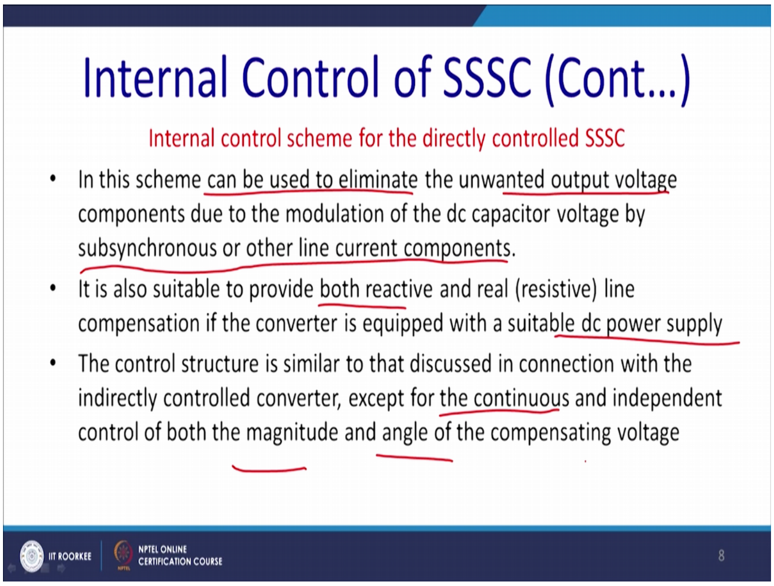

So, from this discussions of the internal control technique we can conclude this scheme can be used to eliminate the unwanted voltage component due to the modulation of the d c capacitor voltage by sub synchronous or other line component, that is one of the biggest problem in power system sub synchronous oscillation that can be camped out by the triple S C.

It, also suitable to provide both reactive and the real line compensation if converter is equipped with the suitable d c power supply. So, we have a storage element that is all. The control structure is similar to the similar to that discussed in connection with the indirectly controlled converter except the continuous and the independent control both of the magnitude as well as angle of the compensation of the voltage is required.

So, there will be little change in the control circuit and it will be more complex and since we have to give a measured value of actually V q and alpha. So, control technique will differ little bit.

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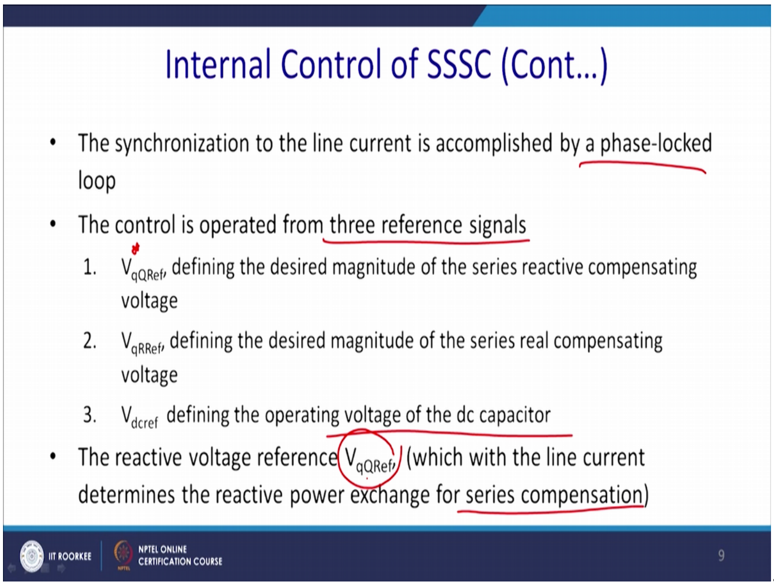

So, the synchronizations of the current is accomplished by a phase lock loop. So, we have to sense the current from there we will actually generate the phase lock loop. The control is operated from the 3 reference signal that is V q reference or V q star defining the desired magnitude of the series reactive compensating voltage, that require to be inject in quadrature with the line, V R q reference it defines the magnitude of the series real compensating voltage, in practical cases it should be 0, but to meet the losses this has to be fed and d c reference defining the operating disable voltage of the capacitor.

The active voltage reference this one V capital Q small Q Ref will change dynamically depending on the magnitude of the injected voltage, which with the line current determines the active power sorry the reactive power exchange with the series compensation. So, that is actually the term that will decide the amount of the work compensation with triple S C.

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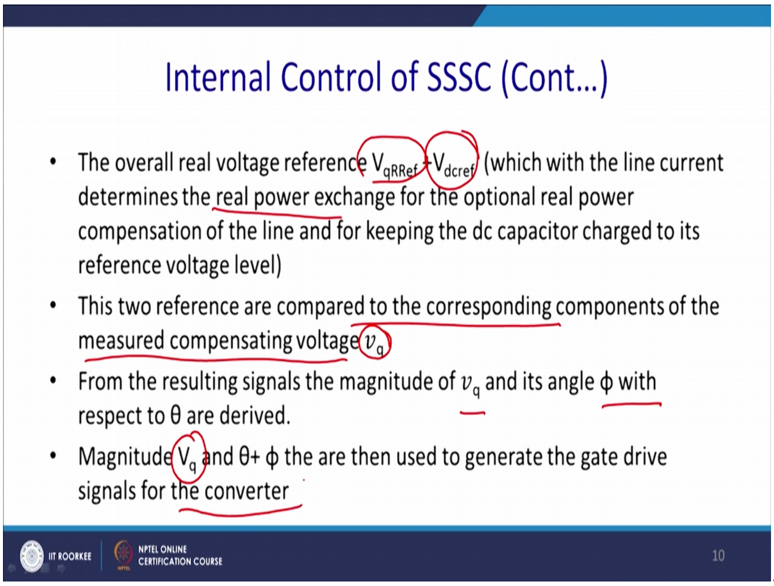

So, overall voltage reference for this direct control will be actually V q R ref plus V d c ref. Which with the line current determines the real power exchange, for the proportional real power compensation of the line and for keeping the d c capacitor charged to the some reference voltage, this is the requirement.

This 2 reference are compared to the corresponding component of the measured compensation voltage of v q. From the resulting signals of the magnitude v q and it is angle phi with respect to theta is derived. The magnitude V q theta plus phi are then used to generate the gate drive signals to the converter.

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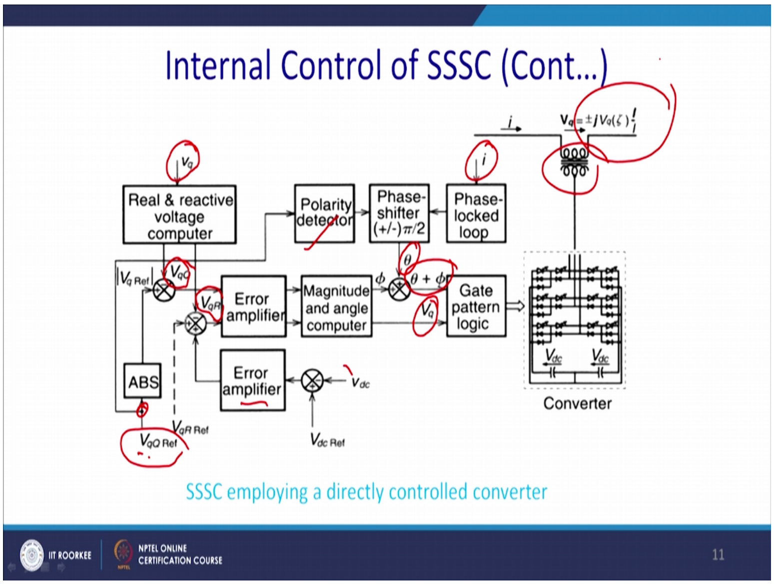

So, this is the internal control of directly controlled circuit and we have to actually have both phi plus theta and the V q. So, you have to fed both this logic to the gate pattern. So, let us see that what are the difference from it is internal from it is indirect control technique. The real magnitude of the computer actually will compute the V q and you have a V q reference, and you have V small q capital Q reference and from there actually you subtract you get V small q capital Q.

Similarly, you have to have a real power reference that is V q R reference that you will feed. And, since you require to maintain a deceive bus voltage as desired level. So, from V d c and V d c ref you will fed to P I controller this P I controller this error will be added up, and you should have a actual calculation of V q R that has to be subtracted.

So, then you fed this value to the error amplifier. This again from this point of V q V small q capital Q Ref it fed to the polarity detector. Similarly, there will be an that this input of the polarity detector, whether it is in a positive phase on the negative phase will be fed to the phase shift and that will make the phase shift 90 degree with the i so, current.

So, similarly there will be of phase lock loop. So, that also fed the input. So, from there actually theta will be generated. And from this error amplifier you will have a actually the both the magnitude. So, essentially you will have a instead of the 1 P I controller you had in this case you will have 2 P I controller.

And, thus you will have theta plus phi will be the effective compensating angle and you require to inject the magnitude V q, and that information will be fed to the gate drive circuit and that will be fed to this actually voltage control current source converter. And that will inject voltage in V q will have this logic plus minus j V q sigma I by mod I.

So, this is the actually the principle operation of direct controlled triple S C and it is the sophisticated and the most advanced series compensator, it compensate very accurately the amount of the reactive power. And, also it can actually inject the amount of V q required in different purpose of operation.

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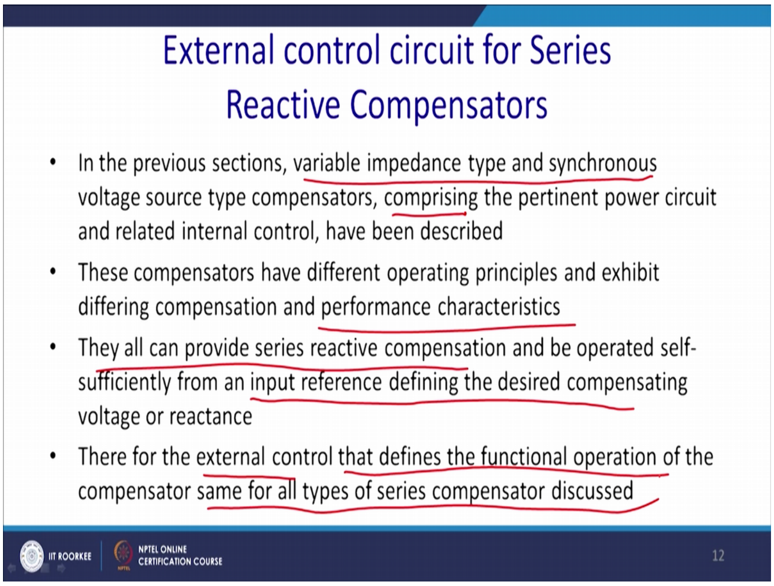

So, what we can conclude from this control circuit discussions.

The in the previous sections, variable impedance type of the synchronous voltage source type compensator, has been discussed again we shall discuss another impedance type compensator after this class also. The type of compensator compromising of the power circuit related to the internal control has been discussed.

The, compensator have a different operating principle and exhibit actually differing the compensation and performance characteristics. So, it will have a different way to up control, we have seen that actually impedance control is very simple. So, we have to control the actually delay angle of the G T O so, that actually turn of angle of the G T O in case of the G C S C.

But, here it is control is quite complicated you have to have a instantaneously feeding that value of the V q and the phi from there actually getting pattern will be controlled. So, actually as you we have discussed this an while discussing this facsifices we have discussed few control technique of the voltage source inverter you can see that actually space vector is best phase to this solution.

So, we will provide we shall try to feed actually phase vector modulation technique for basically triple S C. So, they all can provide series reactive compensation all say whether it is a impedance method or the voltage controlled or you are injecting voltage source both can control the series reactive power compensation. And be operated self-sufficiently and input reference defining the desired compensating voltage and reactance.

Therefore, for the external control that defines the functional operations of the compensator are same for all type of the series compensated discussed, ultimately it will inject some amount of the far to the system. So, it is whether it is a impedance method or the voltage method the actually externally they look equal.

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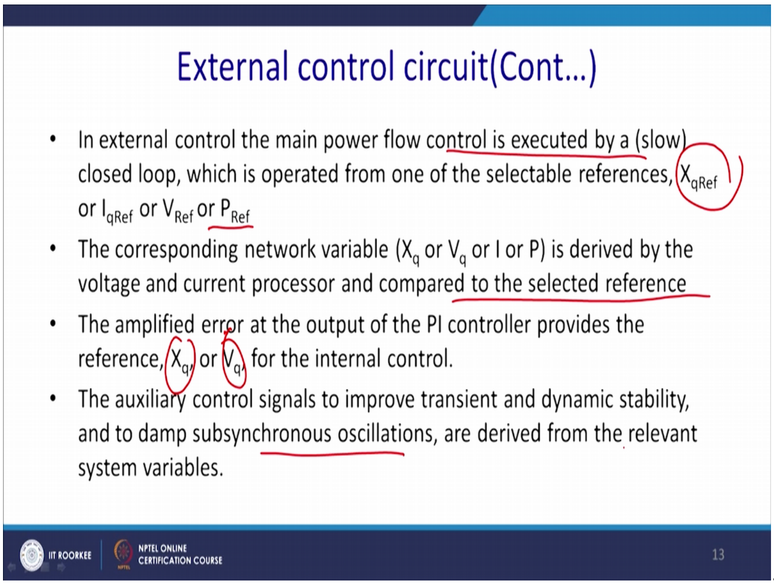

So, in in internal control the main power flow control is executed by a slow closed loop, which is operated from one of the selective reference that is X q Ref I q Ref V Ref or P Ref whatever will be, the corresponding to the network available the X q V q I or P is derived by the voltage current processes and compared to selected reference.

The amplified error at the output of the P I controller provides the reference V q and the X q and the V q for the internal control. The auxiliary control signals is also there to improve the transients that will be discussed soon dynamic stability and to damp out the sub synchronous oscillations, are derived with the derived from the relevant system variables that will see soon.

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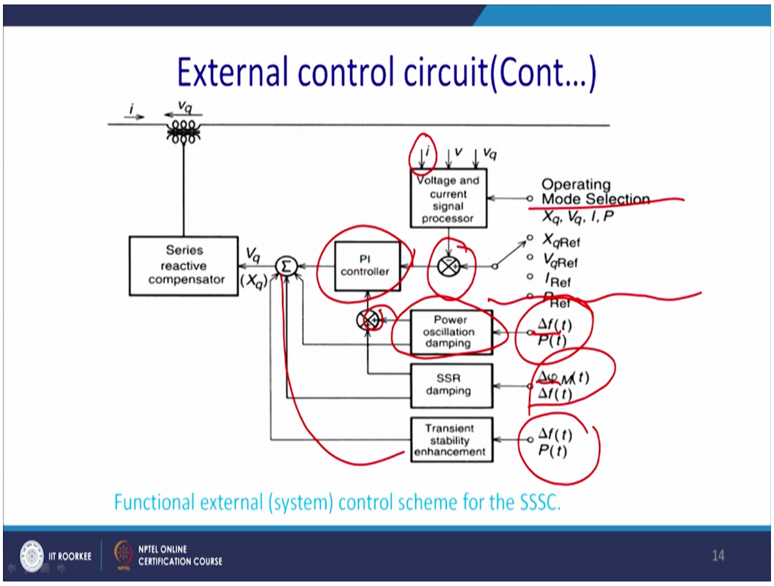

So, this is the overall structures. So, this is basically for the transient stability this is for the sub synchronous oscillation this is for the power frequency oscillation damping. So, this is the mode of some operant d of different mode of operation. So, this is the overall external control circuit for the any kind of series compensator.

Ultimately, you have V i V and V q and from there you will process the data what you require to compare. And, thus and operation mode selection can be as follows it can be X q Ref you want that actually for the impedance mode of operation there you want to actually inject the value of the V q, where value of the X q and if you have to have a voltage mode of operation you will choose the value of the may be the V q.

So, similarly you can choose a I Ref as well as the power Ref. So, accordingly you will actually have a control. So, both will be controlled and compared an ultimately there will it will fit to the P I controller assuming that this disturbance are not there.

We shall take these disturbances after that. So, thereafter, what happen? So, will feed it to the P I controller, and from there actually we actually have a measured value of the V q and the bar X q and that will that actually that insert that will insert the series impedance of the series voltage into the system.

And, if you have a this problems you know the if there is a change in frequency so; that means, it is a power oscillation has to be damped out. And from there actually you will feed this input whether power in the system is actually oscillatory or constant and also there is a variation of frequency or not.

From there actually then the term power oscillation damping will come into the picture, and ultimately you will feed this value you can you can know that you can write it down the differential equation we shall show in the next class or we shall give you some assignment on it.

That it will be a second order system under second order system. So, we have to add the damping and ultimately this triple S C or this kind of series compensator can add the effective damping. So, what will happen due to that actually? So, it will be adding up some amount of the signals to this P I controller and it will this input will be fed. So, that it will mitigate the oscillation of the del f.

Similarly, when you have a sub synchronous oscillations that require to be damped out so, you will change this alpha in such a way that will damp it out. So, so, del phi if there is a change in del phi and there is also the frequency oscillation, then it is leads to the actually sub synchronous oscillation. This information also will be fed to this actually the sum of lock and it will be fit to the P I and thus it will actually try to mitigate the sub synchronous oscillation, then you have to enhance the transient stability if your transient is present. So, you require to increase the power handling capability of the line and thus for this is in this flux adds up you know directly with this actually the sum.

There is no input to the P I controller. So, it will be increasing the overall power handling capability of the line and thus or increasing or it will change if the power demand is syncing. So, accordingly it will change this value and this will actually fed this through the gate logic circuits of the impedance or the voltage source converter and accordingly it will generate the V q.

So, this is the external control circuit and this is this actually theme is common for all series regulator. So, what we have already we have already discussed this and this now we have left with another series control regulator that is actually series thyristor controlled series capacitor.

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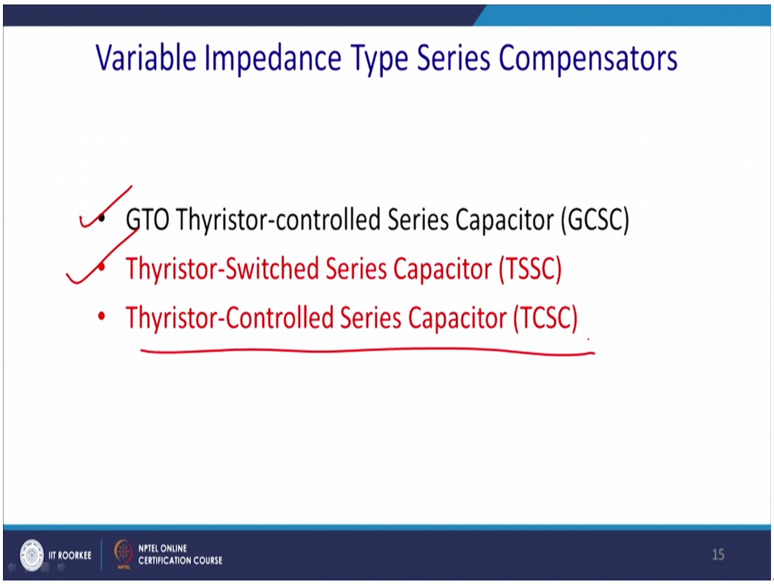

So, we shall continue with it now and we shall also try to will continue with the next class because it is time left is very small now.

The basic circuit arrangement of the thyristors switch capacitor, basically see the logic here.

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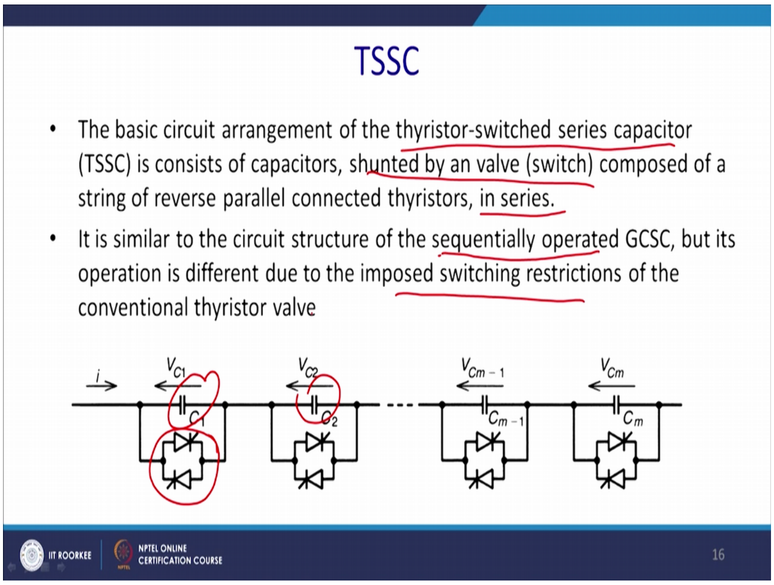

You know you will have a series capacitor and there is a anti parallel thyristor connected with it this just is a very just is opposite of this actually T C R. So, we know that actually thyristors has to be put in parallel with the capacitor for this is put parallel to the capacitor. If you wish to short this capacitor, then actually you put this alpha is such a big that it will almost short this capacitor. If you do not trigger this capacitor thyristors then total capacitor will be injected to the system.

And, accordingly if you will change the alpha triggering angle on the delay angle, then the value of this actually the capacitor subsequently the voltage across it will change. So, this is the way you inject different amount of the voltage V q in the into the into the actually the line voltage.

So, the basic circuit arrangement of the thyristor-switched series capacitor that is triple T double S C is consist of the capacitor, shunted by a valve and composed of a string of the reverse parallel connected thyristors in series. It is similar to the circuits structures sequentially operated G C S C. So, there is normal difference for it is thyristors operated, but it is operation is different due to imposed switching restriction of the conventional thyristors valve. So, you can turn it on you can turn it off see G C S C is mostly controlled by turn off. So, principle operation here will be different because turn off is not in your hand.

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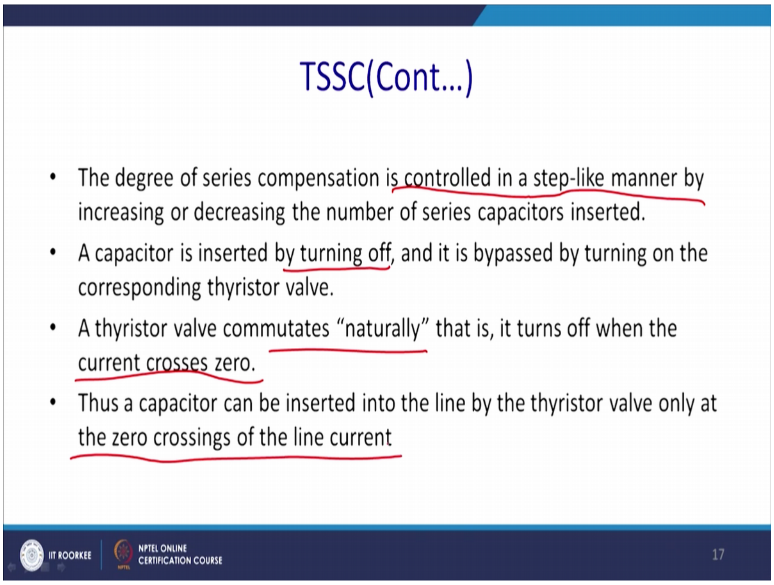

So, degree of the series compensation is controlled like a step manner by increasing or the decreasing the number of the series capacitor inserted into the line.

Capacitor is inserted by turning off and it is bypassed by turning off the corresponding thyristor valve. So, you by a you actually change the current through the capacitor and the sub voltage across the capacitor by changing the delay angle. Thyristor valve commutes “naturally” so, this is so, this is it is a very simple circuits, that is turn off when current becomes 0 across this devices.

Thus a capacitor can be inserted into the line by the thyristor valve only at a 0 crossing of the line current. So, this is the principle of operation. So, please recall that we had a 0 voltage when you turn off in G C S C. Since, the insertion takes place a line current 0 a full half cycle of the line current will charge the capacitor, zero to the maximum voltage and 0 to the maximum and successive opposite polarity half cycle to the line current will discharge from maximum to 0.

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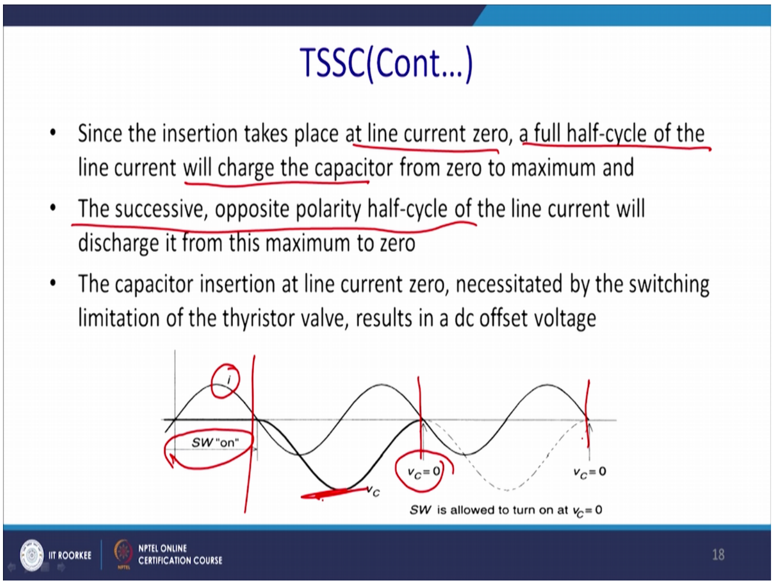

So, see this curve. So, this is basically i and this is one is V c. So, you see that V c will again become 0 this moment actually voltage was 0, because thyristor was triggered and at this moment thyristor was put off and thus what happen actually it is swells up to goes to the maximum voltage V c.

Thereafter again when current become 0 then voltage become 0 and subsequently again here V c will be 0. So, this is the oscillation pattern across this voltage capacitor. The capacitor insertion at line current 0, necessitated by the switching limitation of the thyristor valve results in a d c offset voltage. This is one of the problem you see that there is a d c offset voltage ultimately if you take the peak and ultimately it is shifted here.

And, this will change you know while actually this current is going actually positive to negative. And, for this you have negative d c offset. If, you actually just in this moment you can find that you may have a positive d c offset. So, we shall continue to discuss d c S C in next class.

Thank you for your attention.