Flexible AC Transmission Systems (FACTS) Devices
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Lecture - 22
Series Compensator II

Welcome to our second lectures on Series Compensator. We have already discussed and impedance time series capacitor and the converter based series compensator.

Now we shall see that; what are the features of the series compensation; we have touched up in a previous lecture and we shall continue from that point onwards. So, you know that actually we have discussed it is possible to actually this possible to have enhance voltage stability by the shunt compensation.

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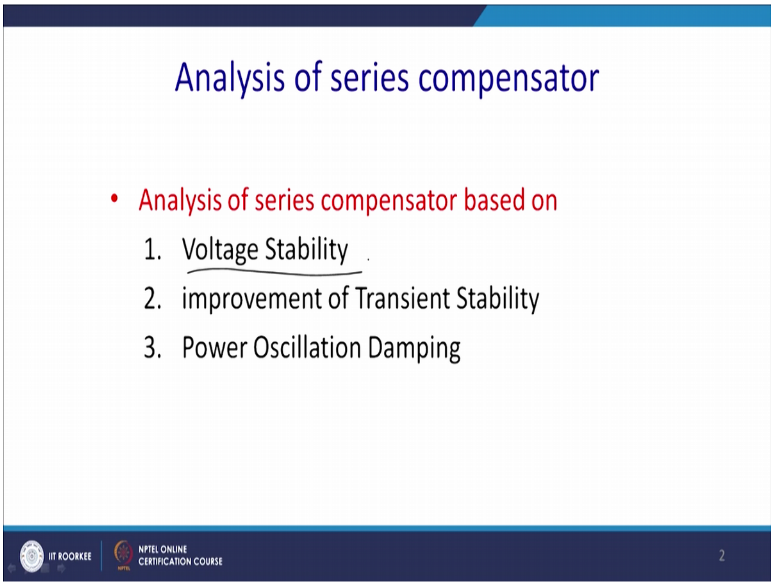

We shall see that how it can be achieved thereafter improvement of the transient stability same has been discussed in case of our shunt compensation. Same will be actually designed here and see that what happened difference between these two and why do you will fit what and power oscillation damping. These are the most these are the most desirable features that can be enhanced or mitigate by the series compensation.

So, let us consider that you have a variable impedance inserted and what about the voltage stability?

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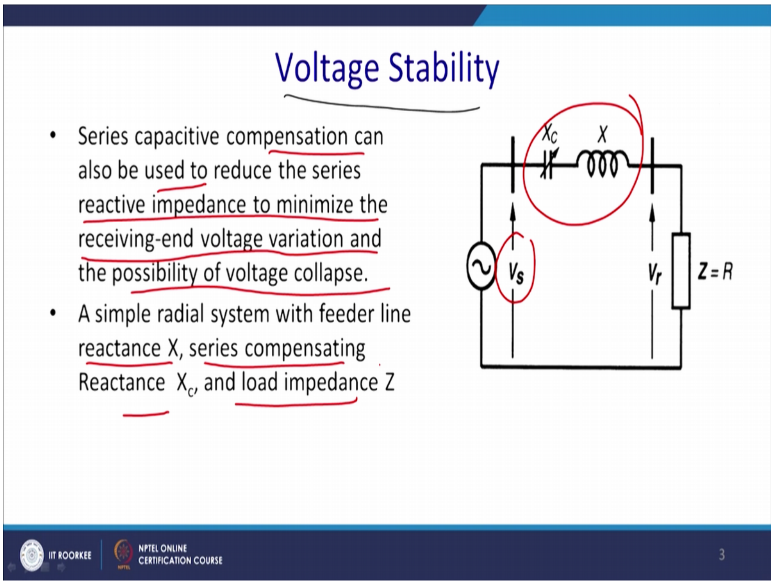

So, serious capacitive compensation can be used to reduce the series reactive impedance to minimize the receiving end and the sending end variation. Since you know this impedance value is decreased; so, V s become close to V r that is the basic principle. And that is what happen if previous the possibility of the voltage collapse a simple radial system with feeder line reactance X series compensating reactance X and the load impedance Z r is been considered.

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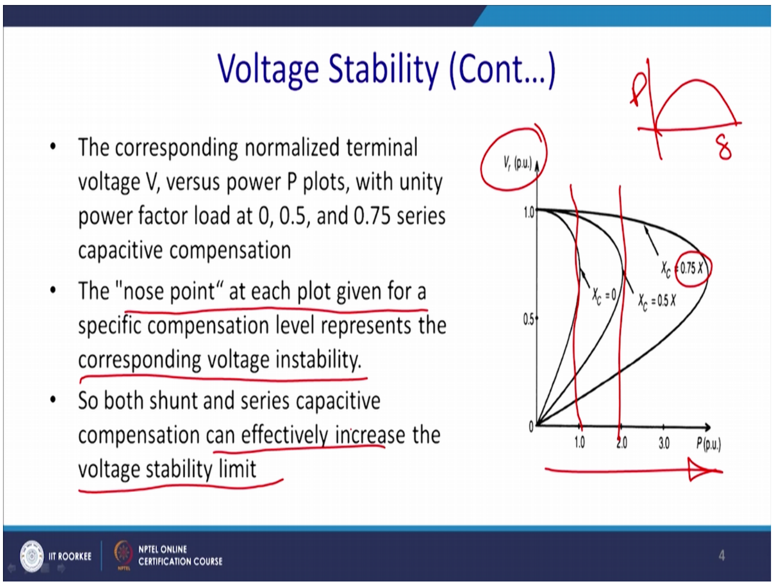

So, see that what happen with the different values of X. So, this is basically the power in x axis and the voltage transmitted in the y axis. So, it is just you know you have familiar with actually this graph delta versus P graph. So, and you have also the V graph; so ultimately you can change the value of the voltage and further some values of the delta. So, what happen we can see that this is the uncompensated one; so ultimately you can transmit the power and thereafter if you increase the value of the X. So, it will be double and if you increase the values of X actually 0.5; so it will be double and if it is makes 0.75; it will be 3 4.

So, thus you know power handling capability of this line increases similarly, but you know what happened you can see one thing here the value of the voltage does not increases. So, receiving end voltage will remain same, but the power handling capability will increase this is one of the biggest advantage of it. We have discussed about the compensation of the leading and lagging in shunt compensation.

You can see that state away power is been increased without and within the rating of the voltage. The nose point at each plot given for the specific compensation level represents the corresponding voltage instability. So, this is something we are we required to discuss. So, both the shunt and the series compensation can effectively increase the voltage stability limit. Now, let us see the next.

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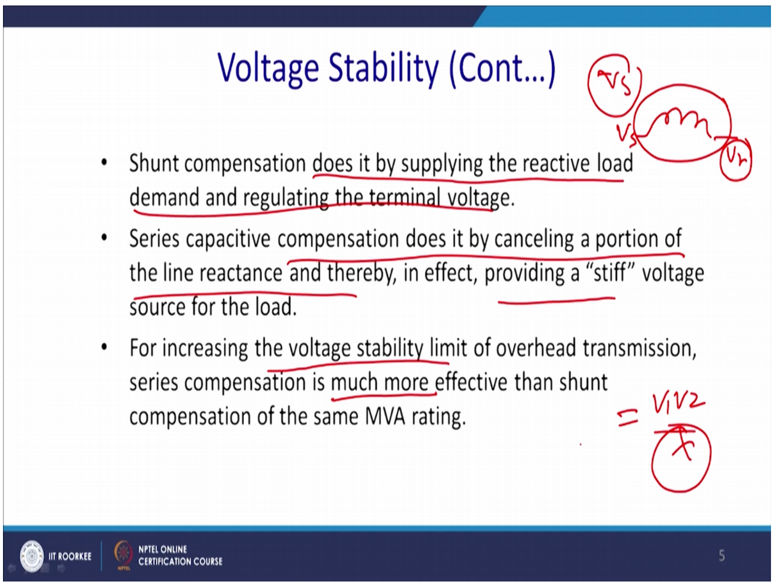

So, what is the comparison of the series compensation and the shunt composition? Shunt compensation does it by supplying the reactive load demand and regulating the terminal voltage.

So, it will play with the reactive power at the receiving end voltage of with the voltage regulation and thus it will control the flow of power. Series capacitor compensation does it by cancelling the portion of the line impedance. Line impedance and thereby effectively providing the stiff voltage source to the load because we have assume that V s is stiff we have a stiff gate and the value of inductance will be reducing. So, V s will be actually more formally will be connected to the will be connected to the receiving end voltage. For increasing the voltage stability limit; the overhead transmission series compensation must have compensation is much more effective than the shunt compensation for same power rating of the impurity; we have seen the plot for the series and shunt both.

So, shunt will actually associated with it is specifically controlling the power by the V r. So, for this (Refer Time: 06:24) we will find that actually straight away you know if you really you are basically dealing with the denominate. So, V 1 V 2 by X; so, reducing the X by 50 percent you straight away jump the power handling capability by 50 percent; so, thus you know shunt compensation is a great advantage. And also you can show stability because it reduces the impedance between the sending end voltage and receiving end voltage and thus it is very closely coupled with the mostly pre coupled with this receiving and voltage.

Now, let us talk about the transient stability.

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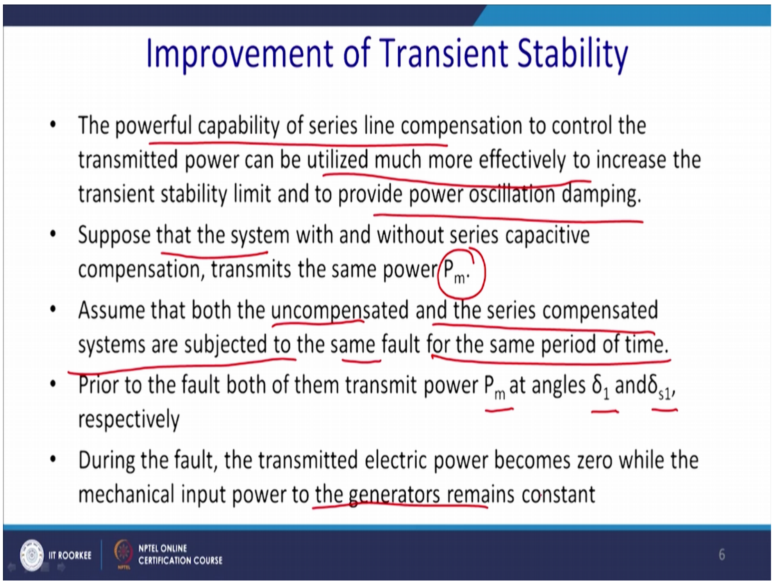

So, powerful capability of this the powerful capability of the series line compensation to control the transmitted power can be utilized for mass effectively increase the transient capability. If there is a sudden load change then the transitions comes into the system; then accordingly you can actually change the power handling capability of the line dynamically that we will see when we will discuss about the devices that actually do the job.

So, then what will happen then ultimately we might get the oscillation; we increase the transient stability limit to provide the power oscillation damping. Let us take a case suppose that the system with the without the series capacitive compensation transmit the V l power P m and let us also assume that both the uncompensated and the series compensated system are subjected to the same fault; for the same period of time ok. Prior to the fault both of them transmit power P m at an angle delta 1 and delta s 1 respectively. During the fault the transmitted electric power becomes 0; while the mechanical input power to generate and the mechanical input power generated remains constant this is our assumption.

So, what will happen then? Same we shall analyze with the 2 machine theory with the equal area criteria.

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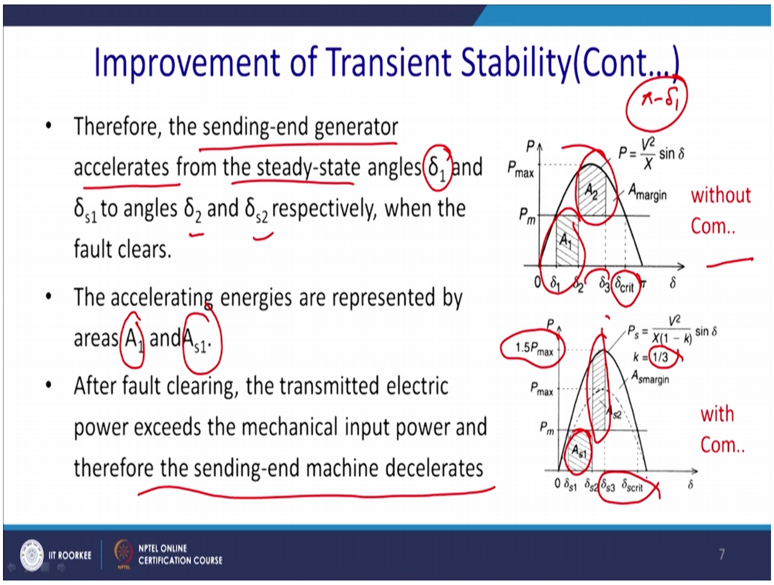

Therefore, the sending end generator accelerated from the steady state angle delta 1 to the delta s 1 and 2 delta 2; 2 delta s 2 respectively and when the faults get cleared by the brackets. Thus this is this one is our accelerating area and this is a deescalating area same has been discussed in the shunt compensation, this is without the series compensation.

Thus we require to compensate you know the critical angle delta delta critical. And value of the delta critical would be actually pi minus delta 1. So, you have to compensate within that limit so, but what happened in case of this series compensation? So, ultimately what happened this was your accelerating area and since the power can be increased depending on the depending on this actually the impedance value, you can change the impedance value. And let us assume that this value is k equal to 1 by 3 and thus the transmitted power handling capability increases to the 50 percent 1; so 1.5 per unit.

So, (Refer Time: 10:21) is you can see that huge area is available for deceleration and thus huge gap remains for critically cleaning the faults. The accelerating energies are replaced by the area A 1 and A s 1 and after the fault clearing; the transmitted electric power exceeds the mechanical input power and therefore, the sending end machine decelerates. So, we have to match these 2 area and here the huge area huge machine is available for clearing the faults.

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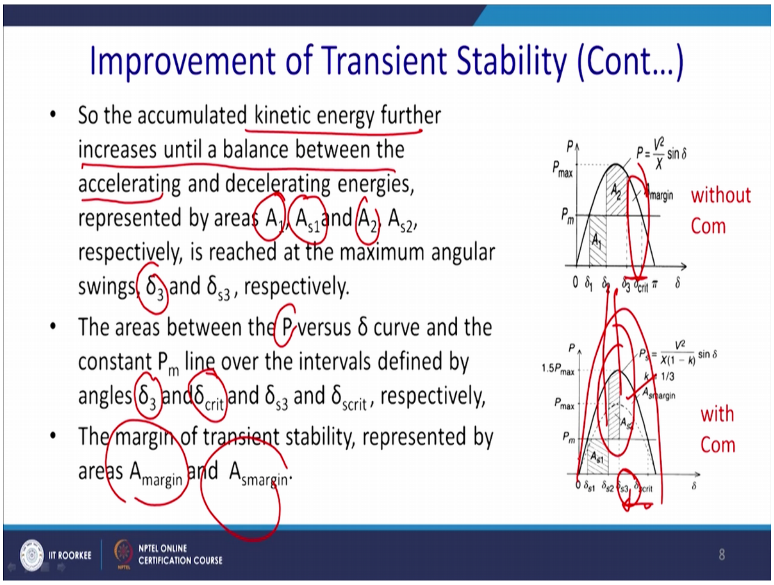

So, the accumulated kinetic energy further increases until a balance between these 2 accelerating and the decelerating energy represented by the areas A 1 and A s 1 and A 2 and A s 2 respectively is reached the maximum angular swing angle delta 3 and delta s 3 respectively. And thus what happened? The areas between the between the P versus delta curve and the constant P m line over the interval is defined by this angle delta 3 and delta critical and it is delta 3 and s delta critical respectively.

So, you can see that huge margin here with the compensation; the margin of the transient stability represented by A margin without compensation this one. And A s margin with compensation. So, this area is A s margin; so you can see that it has enhanced the transient stability. Now what we can conclude?

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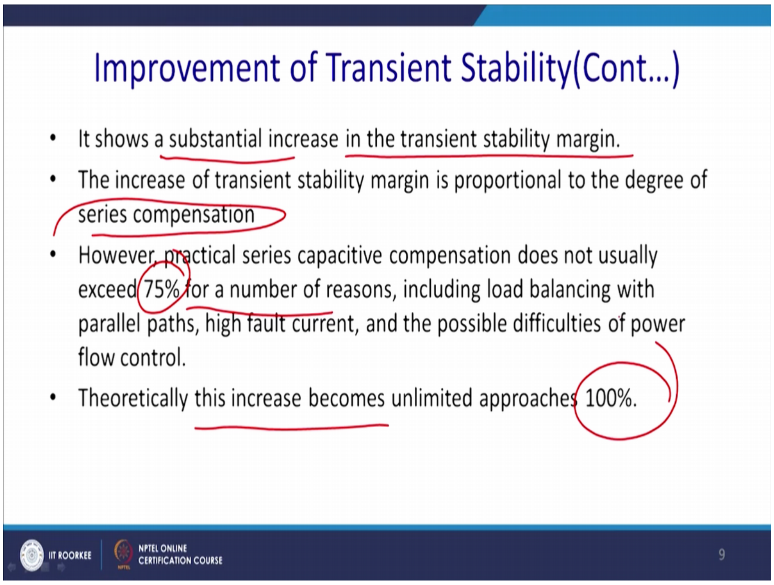

So, this equal area criteria shows that a substantial increase in the transient stability margin; so, you can go back and see. So, this is the area and this is the time available; the increase in transient stability margin is proportional to the degree of series compression. Why? Because if you can make it say 1.5 to 2; so, these area can be more bigger. So this value will be shifted to the left end.

However, there is a practical issues because current will be so high so; however, the practical capacity compensation does not usually exceed 75 percent; that is also then if you compensate the 75 percent. So, it will have a fort time power handling capability. So, that is not less if you are dealing with the MBA label power 1000 MBA power goes to the 4000 MBA. So, that is a huge amount of enhancement of the power handling capability anyway.

So, 75 percent for the number of reasons including the load balancing with the parallel paths and the high fault current and possible difficulties to the power flow control; these are the limitation imposed by the power system people. So, we do not we generally restricted our series control with the capacitive series control to the 75 percent. And of course, it is possible theoretically increases increase become unlimited and approaches to the 100 percent.

Now, let us see that how it will actually damp out the power oscillation that is also very important aspect of it. The controlled series compensation we have seen also in case of the shunt compensation; then let us see and compare with the with the series compensation.

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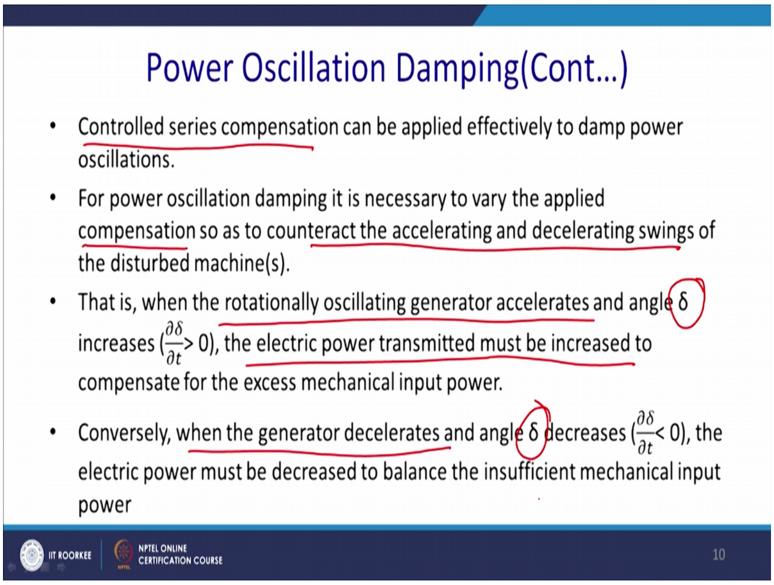

Control series compensation can be applied effectively to damp power oscillation. The power oscillation damping it is necessary to vary the applied compensation so, as to counteract accelerator and the decelerating swing of the distributed system. So, cause of this power oscillation is overthrow or a over throw of a heavy load or insert of the heavy load in a power system or overthrow of the any generated due to loss of synchronization.

So, what happened then? Then rotationally oscillating generator accelerates an angle delta increases and thus electric power transmitted must be increased to compensate the extra mechanical power. So, you required to do the needful to increase the power handling capability of the line as supplied by the mechanical devices. Conversely when actually power generation decreases in the line; so, you have to also reduce the power handling capability of the line otherwise it will lose the synchronization.

When the generator decelerates an angle delta decreases, the electric power must be decreased to balance insufficient mechanical input power. So, these are the 2 condition and accordingly the impedance of the line required to be changed to accommodate the change of the mechanical input. So, the required variation with the degree of the series compensation with under damped oscillation system shown with the undamped and damped oscillation with an angle delta around the steady state value of delta 0.

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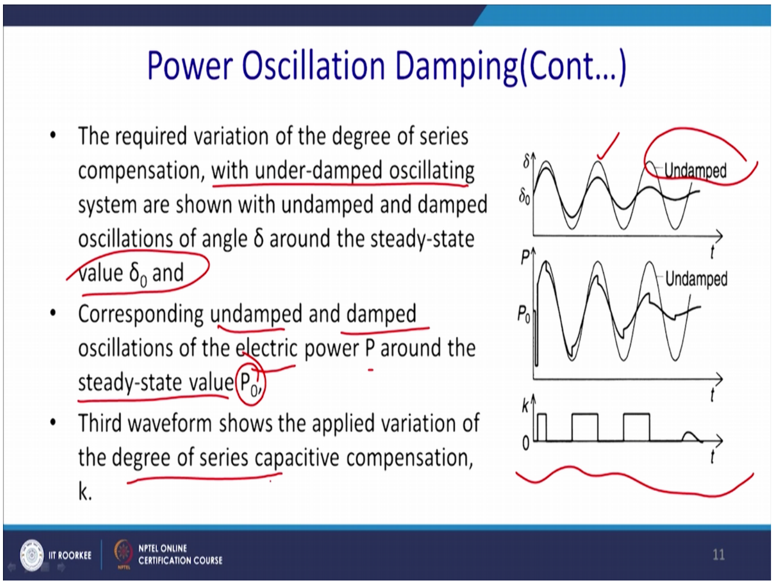

So, this is the undamped without any compensation; so, it will constitute oscillate this is called hunting in the machine problem. And we have to damp out oscillation there is a damp out winding of course, is there in case in the alternative, but facts can also do the damping by switching.

So, what happened you know we shall; so we can gradually damp out the oscillation. So, we can do that that is something will be discussing when we will talk about the devices series compensative devices. So, this is the undamped one and this is the damped one. So, gradually it will reach the steady state value of the delta 0 where actually it prefer to settled.

And this is a power swing and that also will settle to the damping and where k is the degree of the capacity of compensation gradually it will change to increase or decrease to accommodate the change of the mechanical power. The corresponding undamped the damped oscillation of the electric power P around the steady state value is P 0 ok.

So, the third waveform shows the amount of the reactive shows the variation of the degree of the series capacitive compensation; so k will be changing in each of the cycle. So, there is a fastracting devices is required to aconite; of course, you change the (Refer Time: 18:28) angle. And thus, you can control the actual amount of the reactive power injected into the system, as well as the compensate the value of the impedance into the system; either of it you can have a converter base solution; you have also a impedance base solution.

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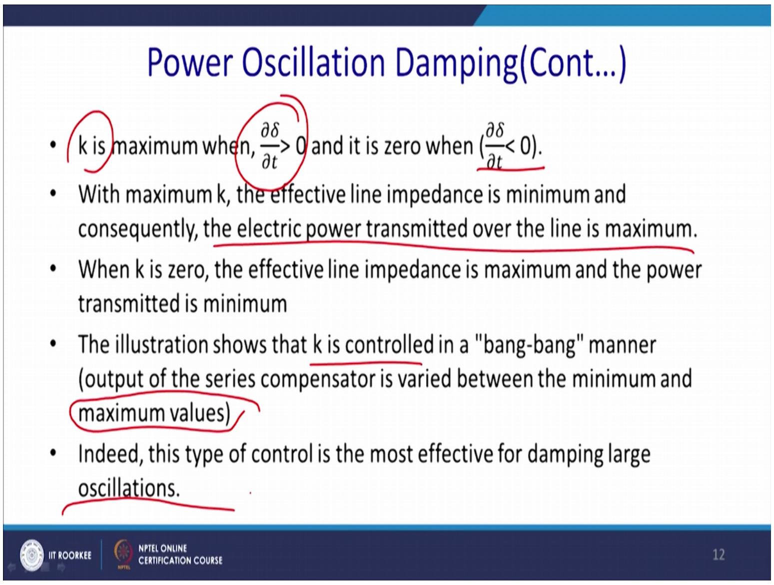

So, k is maximum when this one is actually more than and when it is 0 and it is 0; when actually it is negative. With the maximum k the effective line impedance is minimum and consequently the electric power transmitted over line is maximum. When k is 0 then effect impedance is maximum and the power line transmitted is minimum and the power transmitted by the line is minimum. The illustration shows that k controlled in a bang bang manner; bang bang manner means actually positive and negative like your ACs ok. You set it actually at 25 degree centigrade or 26 degree centigrade. So, how it will be controlled? So, there is a hysteresis band above which it will be on big depending on the sensibility and below which it will be off.

So, it may be on when actually temperature goes little above than 26 degree well 26.2 and then it will not close at 26 degree and it will bring the temperature may be to 25.8 and then it will close; so on and off in that manner discount bang bang control. So, bang bang manner output of the series compensator is varied between the maximum and minimum values and for this is we decode hysteresis loop corporate it. So, what happened then? Indeed this type of control is the most effective for damping large oscillation. So, now we have talked about the theories of the series compensation.

Now, we are actually going to discuss different type of series compensator and these are the first we will take the impedance for series compensator that will change the impedance of the line; that we see we will see that actually the converter based series converter for actually inject the voltage. Both will be discussed let us first take the different type of impedance type series compensator.

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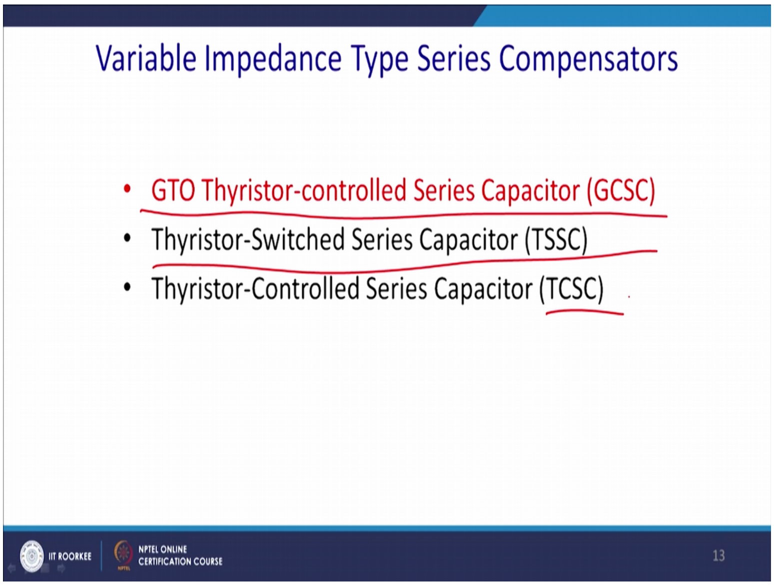

That is basically GTO controlled series capacitor. So, you have advantage of switching on and switching off. So, it is GTO based; so, you have a on off control. So, you can have a; since it is full control device; so you can use this GTO. Otherwise you have a thyristor switched series compensator; you can only change the alpha to control the flow of the current to the capacitor in that way you actually control the impedance. So, action will be taken after 10 mili second only in case of our system like 50 hertz.

And excuse me Thyristor Control Series Capacitor; TCSC that is also thyristor control; let us see how does it work. So, we will place this capacitor in a transmission line.

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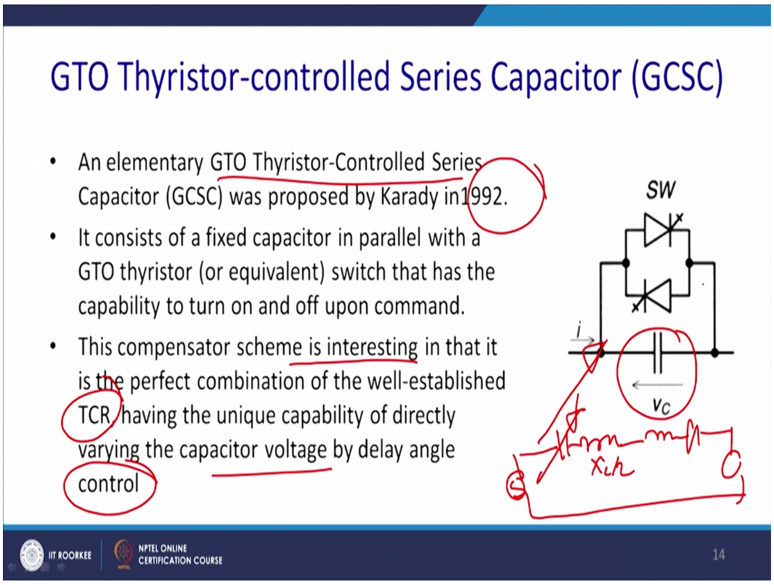

Let us recall our first diagram that we have our 2 model theory there after we have put a capacitor their respited the inductor X l by 2 thereafter again X l by 2 and this our model and here it will be a variable capacitor. So, and elementary GTO Thyristor controlled series capacitor that is in abbreviation; we will see there is a lot of abbreviation and so, are student requested to familiar with the application when it will be very much useful and practiced also in industry.

So, TCSC was proposed by Karady in 1992; so this solutions came around 25 years ago. So, it contains a fixed capacitor in parallel with the GTO or the equivalent switch that has the capability to turn on and turn off according to the command of the current signal. The compensation scheme is interesting in that is that perfect combination of well established TCR.

So, we have discussed is TCR; so, that is same as that is TCR; Thyristor Controlled Reactor and having a unique capability of directly varying the capacitor voltage by delaying the control. So, we recall our TCR; so we will be having Thyristors in parallel what happened it is very simple; you do not turn on this switches ultimately the total capacitor will be inserted into the transmission line and gradually you can bypass it; you delay it by an angle alpha. So, I know the angle alpha you have a maximum capacitor and after alpha you have shorted this capacitor. So, thus accordingly you can change it ; so, it work on a little negative logic.

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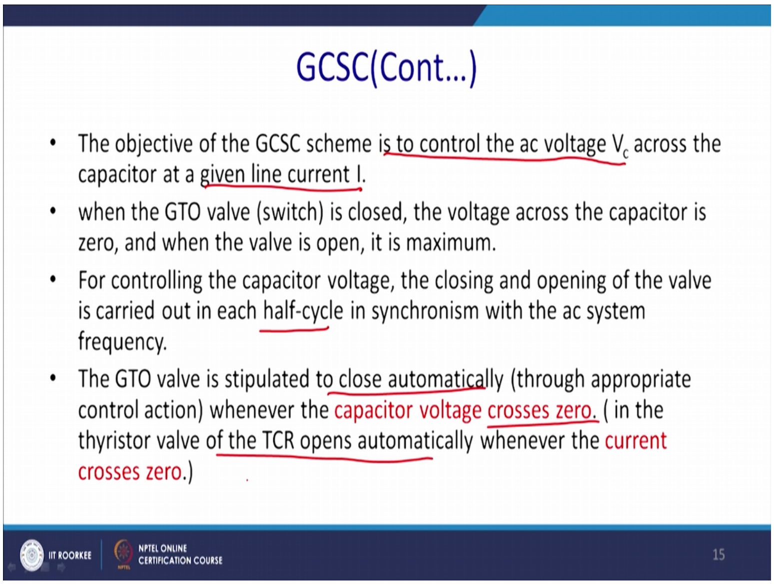

The objective of the GCSC scheme ss to control the ac voltage which is V c across the capacitor at a given line current I, when GTO of the of the high rating (Refer Time: 25:05) valve is closed the voltage across the capacitor is 0 that is what I was telling and when the valve is open it is maximum; for controlling the capacitor voltage the closing and opening of the valve is carried out in each of the half cycle in synchronism with the with the supply frequency.

So, you require a PLL also; Phase Lock Loop, the GTO valve is stipulated to close automatically through the appropriate control action, wherever the capacitor voltage crosses 0. In the Thyristor valve the TCR opens automatically whenever it current goes 0. So, that is the way it will operate.

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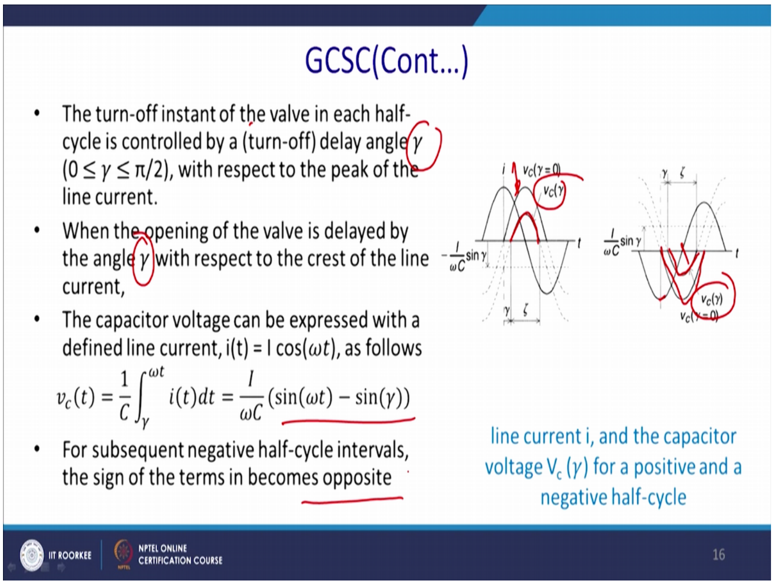

So, let us see the wave form of it; so this is the current and ultimately it leads the voltage by 90 degree. So, turn off of instantaneous instant of the valve of the each half cycle is controlled by the turn off delay angle gamma; where actually gamma is basically 0 is less than pi by 2 with respect to the peak of the current.

If you see that because it will be turn off by it will be a delay angle will be 90 degree. When opening of the valve is delayed by an angle lambda or with respect to the crest of the line signal then the capacitor voltage can be expressed with the definite for 1. So, it is v c will be basically 1 by C integration of lambda to omega t; so i d t; so 1 by omega C.

So, it will be omega t minus sin lambda; so for the subsequent negative cycle same will be followed. So, ultimately you know this is actually V lambda; so this is the voltage and which you can control and if you do not; do not give any triggering. So, this will be the case; so you can have a control over it by this. Similarly, same thing happens in the negative half cycle; so ultimately this is the current and ultimately this is ultimately this is the voltage uncompensated or when actually you do not trigger.

So, total capacitor comes into the picture and this is the actually the receive with lambda for subsequent half cycle intervals the sin of the terms become opposite. So, it is quit common and this is the application of the negative half cycle. So, what we can talk about the GCSC?.

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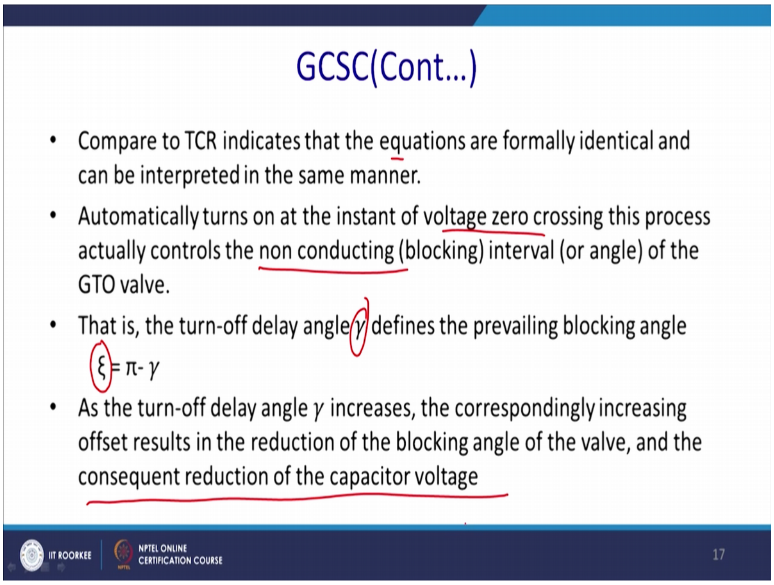

Compared to the TCR; we have discussed in the shunt competition indicates that the equations are formally identical and can be interpreted in the same manner. So, automatically it turns out that the instant of the voltage zero crossing; this process actually controls the non conducting or the blocking interval of the angle of the GTO.

So, the turn off delay angle lambda defines that the prevailing blocking angle; it is a conduction angle that is pi minus lambda. As a turn off delay angle increases; the correspondingly the increasing the offset result in the reduction of the blocking angle of the valve and the consequent reduction of the capacitor voltage; so, capacitor voltage can be controlled in that way.

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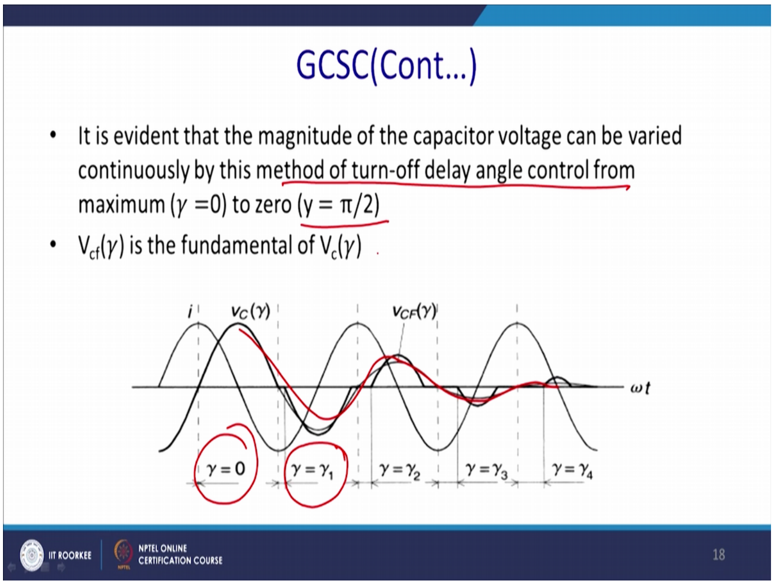

So, what happened this is our form for GCSC; so this is the current and current this is the V c c. So, this is actually it is not been triggered and there after you change this angle to lambda 1 and lambda 2 gradually current gradually this is voltage we will reduce and this is a V c c and ultimately effectively you get change in V c c as required. So, this is the obedient that magnitude of the capacitor voltage can be varied continuously by the method of the turn off delay angle control with the maximum lambda equal to 0 to lambda equal to pi by 2 and where effective capacitor voltage fee lambda is having a fundamental value of V c lambda.

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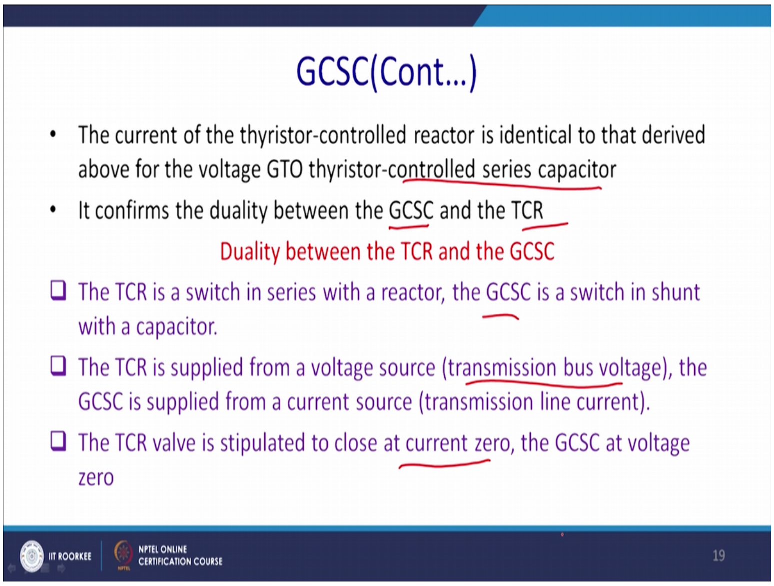

So, what are the take away? So, this is the take away the current of the thyristor control reactor is a identical and derived from the voltage source GTO thyristor and controlled the series capacitor. It confirms the duality between GCSC and TCR; duality between GCSC and TCR.

So, TCR is a switch in series with a reactor and GCSC; since it employs the capacitor it is dangerous to put capacitor in series. So, GCSC is a switch in the shunt to the capacitor TCR is supplied form the voltage source and the transmission bus voltage. The GCSC supplied form the from a current source the transmission line current and TCR valve is stipulated to close at current 0 and it operates such voltage 0; so GCSC at voltage 0.

So thus, we conclude the GCSC; we shall take other impedance based series compensation in our next class. Thank you for attention.

Thank you.