Flexible AC Transmission Systems (FACTS) Devices
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Lecture - 35
UPFC

Welcome to our lectures of in NPTEL lectures. Today we shall continue our new topic that is UPFC. We have discussed in details of UPQC that is for the solution of the mainly for the distribution level and there is a power quality is the issue.

Now, we shall connect UPFC essentially in the transmission level, where flow of power in the level of the megawatt required to be handled and see that how it is does principal of operations will be the same of same as this you UPQC.

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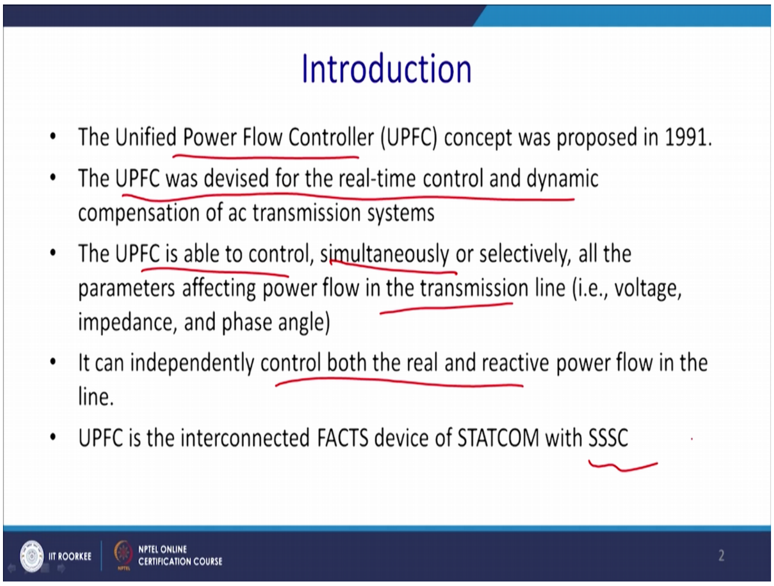

So, of course, is abbreviations of UPFC is not quality as a flow. So, Unified Power Flow Controller; this concept was proposed in 1991 by (Refer Time: 01:24) and all UPFC was device for the real time control and dynamic compensation in ac transmission system. So, it can and is very versatile device will see that, it can actually control the power and control the phase angle; it causes all the solution you require.

UPFC is able to control, simultaneously or selectively all the parameters for this, I was trying to say that it is essentially a punisher almost; for the power flow in transmission line that is voltage, impedance and the phase angle we have studied. We have seen the series injection, there will try to control the impedance of the inject of series voltage and thereafter we have a shunt compensations we can have a voltage source solution as STATCOM or actually there is VC solution.

And also you have seen the power angle regulator; we tried to control the phase angle. It is the combination of all, it can independently control; thus both the real and the active power. Active power cannot be controlled by the sag compensation and same way actually the voltage regulations all those things series compensation is better in that way cover it, because it can control the flow of the active power. So, here it can, but series cannot independently control the flow of active and reactive power.

Here, it is possible to decouple the flow of the active and the reactive power by this UPFC and thus, UPFC or the FACTS devices is essentially the STATCOM is in shunt path and we can model results SSSC in the series part. So, in the practical cases of implementation UPQC consists of the two voltage source inverter as we have seen in case of this is actually UPQC same for the UPFC.

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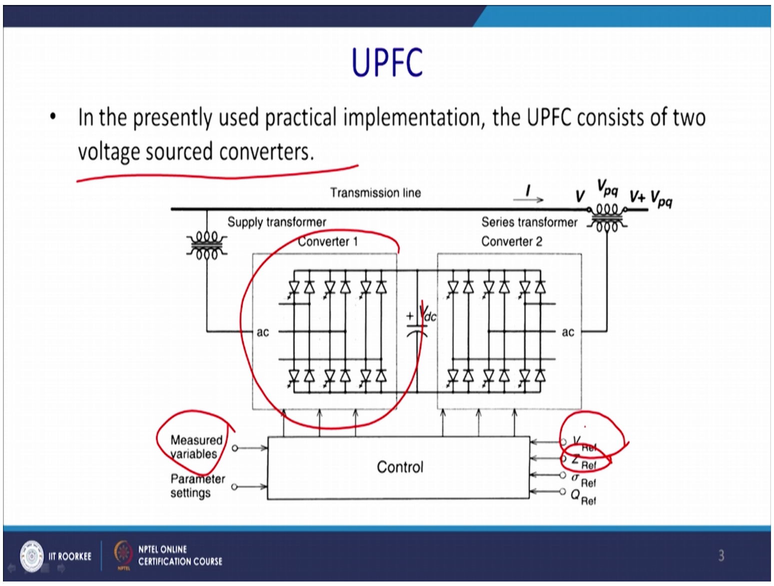

So, this was basically the series part and this is a supply transformer it will inject the voltage in series with the supply and depending on the different phase angle and this is basically the shunt part of it and since it is connected in a transmission network. So, the rating of these switches is quite low. We require a coupling transformer to step down the current level and you have a measured variable that is actually the voltage, power V p q and delta.

So, we have to have a parameter setting for all an accordingly control setting will be there; we can actually set V ref there is a voltage mode control, we can set in impedance power control, we can set sigma mod of control and we can set reactive power mode controls. So, there is a different mode of operation that you can choose from this UPQC.

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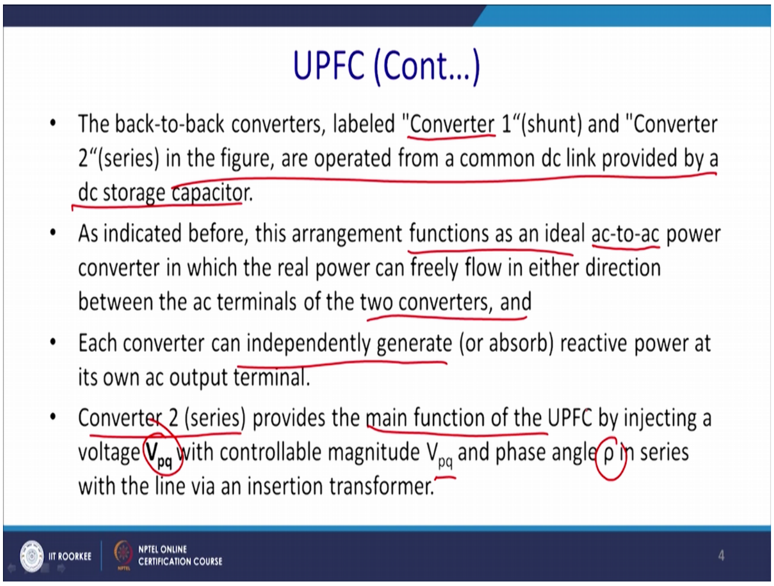

So, what essentially the UPFC? It is a back to back converters, labeled as “Converter 1” that is shunt is right portion of it and the “Converter 2” in series in figure, are operated form common dc link provided by the dc storage capacitor. So, instantaneous difference of the power has to be fit through the dc link.

As indicated before the arrangement function as ideal ac to ac power converter in which the real power can freely flow in either direction between two ac terminals of the converter. And other converter can independently generate or absorb reactive power at its own a c output terminal.

The converter 2 that is basically series is it acts as a SSSC provides the main function of the UPQC by injecting the voltage V pq as desired by the different mode of operation; do the control magnitude pq and the phase angle rho in series with the line by the insertion transformer.

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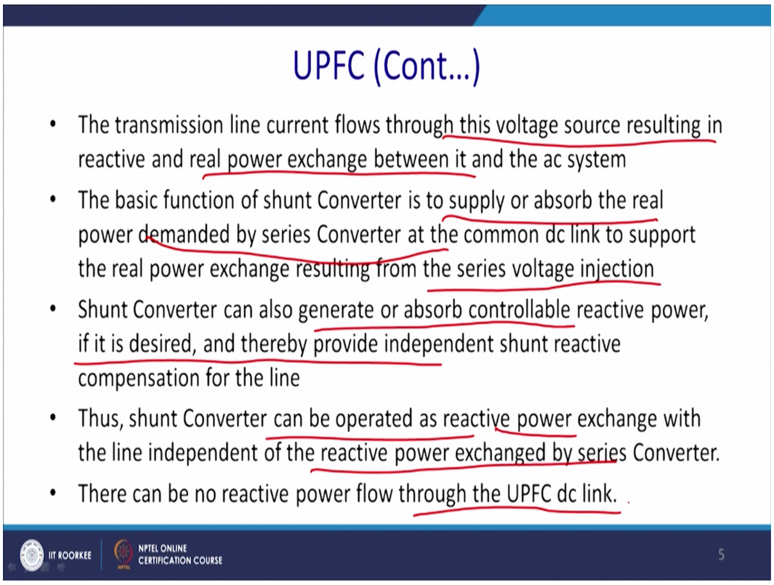

The transmission line current flow through its voltage source resulting in reactive when the real power exchange between the UPQC and the UPFC and its ac system; The basic functions of the shunt converter is to supply or absorb the real power demanded by the series converter at the covered dc link to support the real power exchange resulting of the series voltage injection.

Similarly, shunt converter can also generate or absorb controllable reactive power, if it desire thereby provided provide independent shunt reactive compensation for the line. Thus, shunt converter can be operated as reactive power exchange with the line impedance of the reactive power exchange by the series converter. There can be no reactive power through UPFC dc link. So, that is something we required to understand it.

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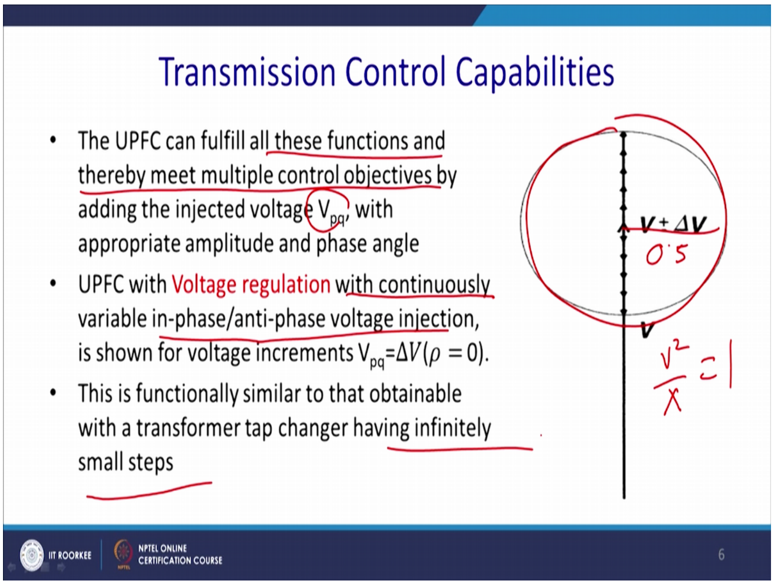

So, we can operate UPQC in a different mode; one is basically the voltage regulator mode and it is just like a tap changing transformer. We say this circle as a sphere of influence of the circle of influence and it will have a magnitude of 0.5 where V square by is considered to be the one per unit.

So, you will have you can compensate with in this anything in a sphere of influence. Let us see that how it will compensate the voltage sag limited to 0.5 and the minus 0.5 swelling of minus 0.5 UPFC can fulfill this functions and their by meet multiple control objective by adding the injected voltage p q with appropriate amplitude in the phase angle. It can inject in any phase and any angle within this circle. UPFC with voltage regulation with continuously variable in phase and the anti phase voltage injection is shown in the figure for p q equal to del, where it is in phase thus row equal to 0.

This functionally similar to the tap changing transformer having infinitely small step change; so, you can inject very precisely and thus, container the harmonic is greatly reduced; you do not have a problem of the harmonic. So, you can inject any value with the voltage in phase with the UPFC.

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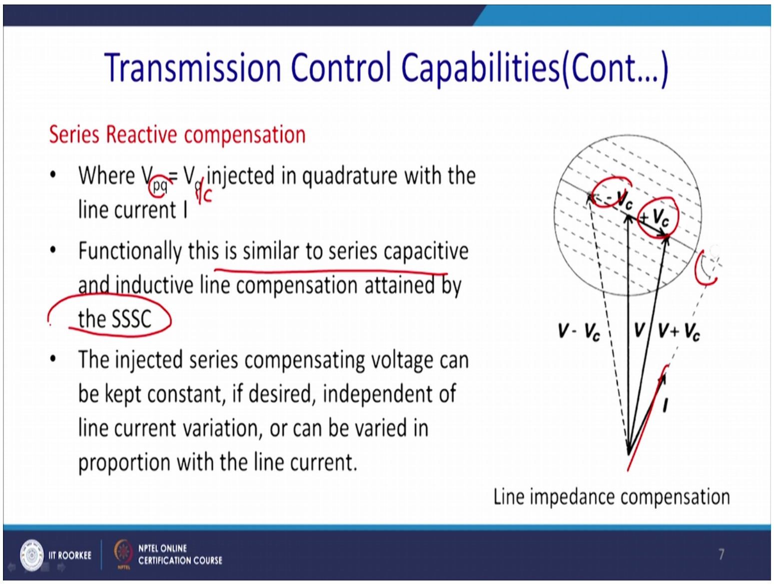

Similarly, series reactive compensation you want to compensate V q and thus you inject the voltage perpendicular to the current. So, this is the current I and you inject the voltage perpendicular to current either minus V c or plus V c or some books also refer as a V q. So, where this is the p q equal to V q and we make it V c here or slash V c is injected it quadrature with the current because I have chosen this no more discussion because we have actually discuss at as V c in SSSC with the line current. Functionally, this is similar to the series capacitance and the inductive line compensation is attained by SSSC.

Students are require set to actually refer our discussion in SSSC, you will find that it is a similar thing that it can be achieved by also UPQC. Injected series compensation voltage can be kept constant if desire independent of the line current variation or can be valid in proportional to the line current; this is a line impedance. Phase angle regulation; so, it will change the sigma.

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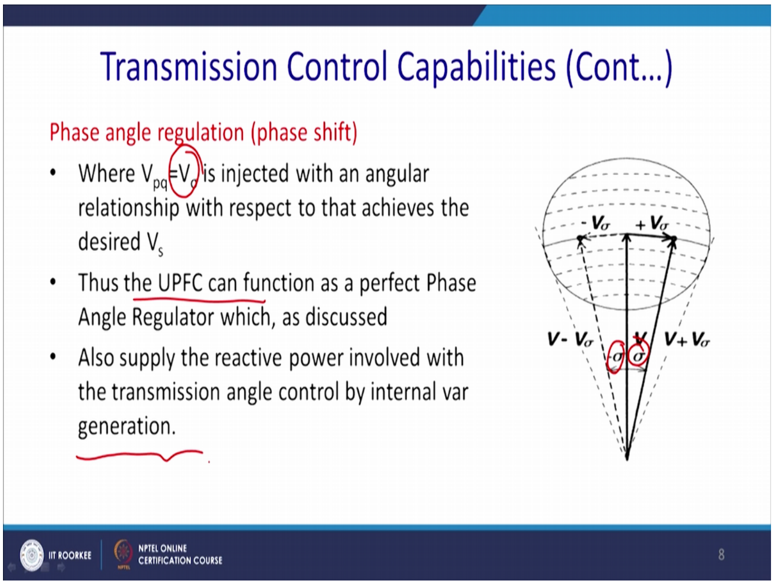

And it will keep the magnitude send; where p q equal to V sigma is injected with the with an angle relationship with respect to that achieves the desired V s. Thus, UPFC can function as a perfect phase angle regulation as discussed here; also supply the reactive power in fault in transmission line angle control by internal var generation; only by this series compensator.

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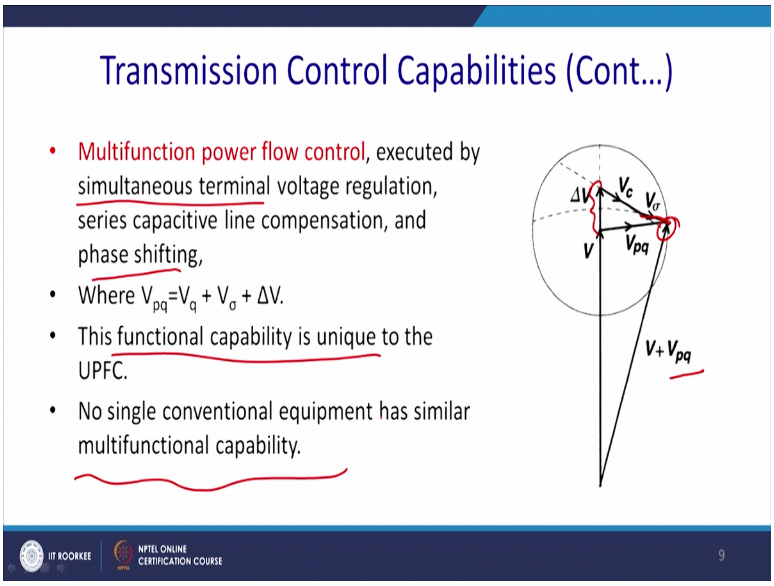

So, for requiring for optimally use the rating of this UPFC, we made required to take all those parameter into the account. For example, in this case let us considered that you required to inject the value p q and you inject some voltage in series that is del, you inject some voltage in quadratures that is V c or V q and there after some portion as p var that is power angle regulator and ultimately you get it and that gives you the optimal compensation. Because the rating actually been reduced maybe; then we can find it out what should be the level of del V V c and actually the V sigma.

So, that is possible here. Multifunctional power flow control executed by the instantaneous terminal voltage regulation, series capacitance line capacitance and the phase shifting by del V sigma; where, actually the functional capacity is unique for the UPFC mainly you optimize the rating here; no single conventional equipment has the similar multifunctional capacity, if you wish to achieve it by the different FACTS devices.

Then, you required tap changing transformer for this part. In this part you required actually SSSC and in this part you require a PAR power angle regulator. So, all those stars can be combined and can be successfully executed by UPFC that is a one of the unique advantage of the UPFC. So, how power flow because we see that is a quite versatile device how does this power flow and it is powerful can be controlled.

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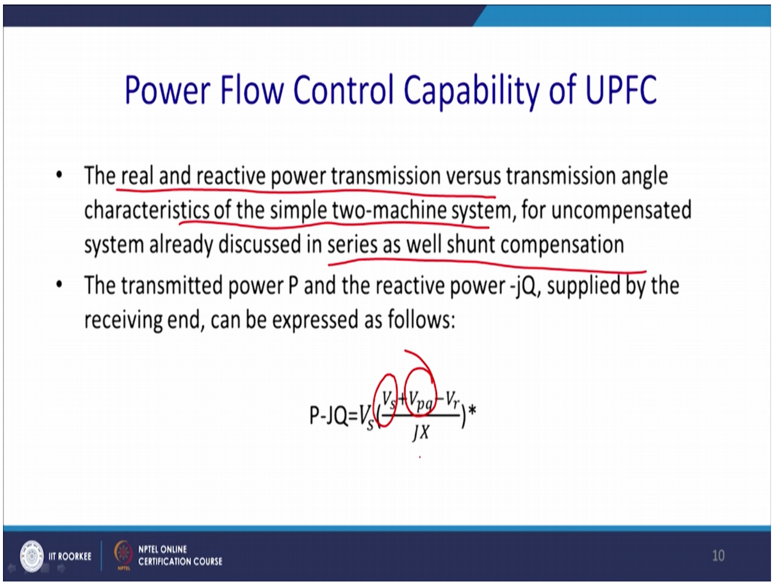

The real and the reactive power transmission versus the transmission angle characteristics we should have to go back to our two-machine model the characteristics of the simple two-machine system, for uncompensated system which already discussed in this series shunt compensation; that same will be the take away because essentially the which mode of operation you select if you got that if you select this mode operation this is basically the tap changing transformer that equation will come into the picture.

If you take this mode of operation, then you have to say that actually the SSSC operation and if you say V sigma operation that will usually p r operation and accordingly the rating will change. So, where it is combined; so, we can express in the solving way that is V s that is injected voltage is p q that may it is a combination of all the three type of compensation that can be achieved by the UPFC. By thus, the sending end voltage by JX.

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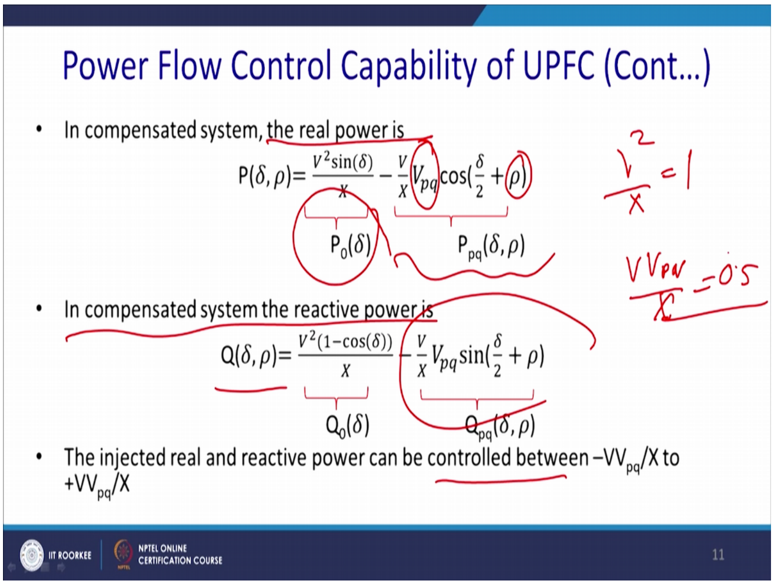

So, we can see that for the compensation system with the real power that is now is a function of row and delta. So, it is V square by X sin delta which is uncompensated one and there after you have a compensated one, where V by X p q cos delta by 2 plus rho; where, V squared by X is 1, we generally considered V p q by X as 0.5.

So, this is something will assume and we will consider this is the radius of a circle and that is your sphere of influence of the this kind of UPFC; Similarly, for the compensated system. So, you can see that actually you have a huge term to monitor. So, you can play with the row and also you can play with the V q and thus, you can have a quite big range of controlling of this p and similarly, you go back to the equal area criteria and established that is transient stability and the you can damp out the power angle oscillation all those things.

So, that will be an extension what you have done in series which right we just actually we are we cannot actually now discuss it. A student can take it that reference also here. So now, so, what happens for the same way similarly this value Q delta row will be given by V square by X 1 minus cos delta by X; there is a uncompensated one plus or minus. So, another term will come that is V by X p q sin delta by 2 plus rho. So, we can see that we can inject or inject real and the reactive power control between minus V X V p q by X 2 plus V q by V p q by X. Generally, this magnitude we considered to be 0.5 per unit.

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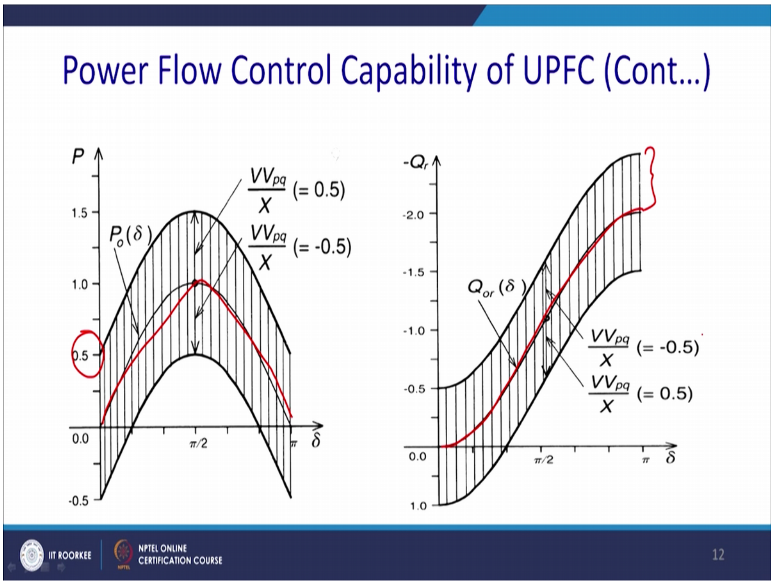

So, thus considering this value to be 0.5 per unit, this is uncompensated line or real power and this is the compensator line for power V l power and you can see that you can set power even at 0 delta; as well as it can be you can send the power back, there is also very important aspect of it. Similarly, this is the uncompensated power for your for your reactive power. So, you can increase by the sphere of influence of 0.5; where, this is the sphere of influence.

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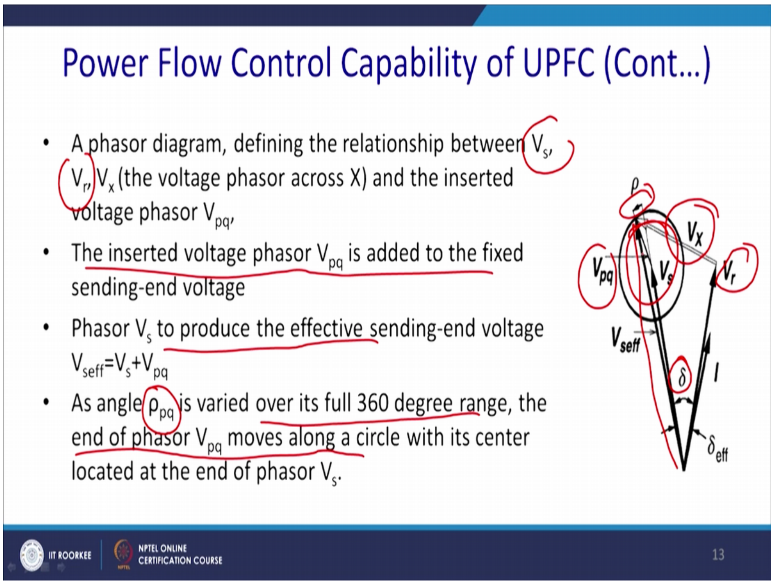

Now, the phasor diagram defining the relationship of V s V r. V x the voltage phasor with X and inserted phasor p q. Now essentially this is your receiving and voltage and this was your sending end voltage and you have injected this voltage p q. Thus effective with this becomes a new voltage that is a V effective sending and thus there will be a new delta. And thus, you have injected actually base value V x.

So, the inserted voltage phasor V q is added in a fixed angle voltage. The phasor V s produces the effective sending in voltage that is V s effective is given by V s plus V q. The angle row p q is valid over the full 360 degree you can inject at any point that is this is the rho it can be it can be actually injected anywhere in this sphere of influence. So, it can be any angle. 360 degree range the end of the phasor p q becomes along the circle with this centre located at the end of the phasor V s. So, that is something we required to do that.

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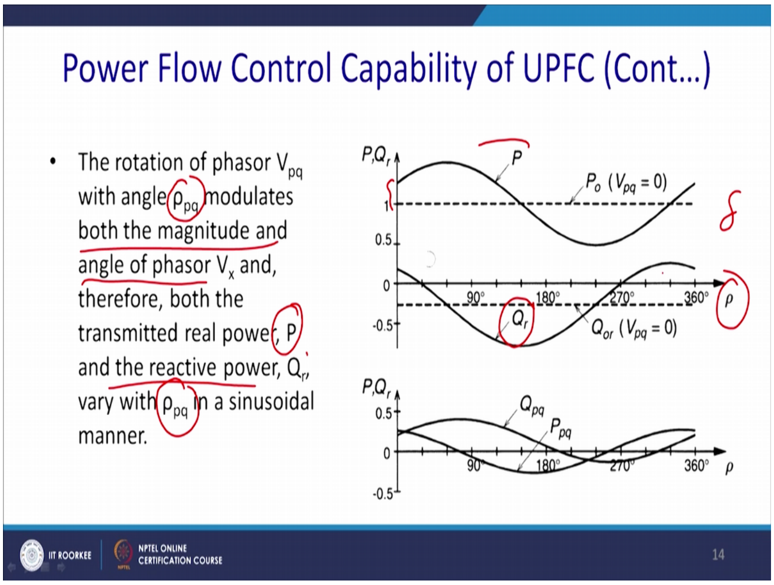

So, thus what happen? By doing it, what will happen? Let us consider that how this power changes. You know this is the delta. So, this is the p and this is actually the per unit value 1; you can actually increase the value of the p to 0.5 and at delta it can go to very high value. Similarly this is basically the q r. So, q r will be like this and this was the uncompensated one and you can make it a compensated one by this way.

The rotation of the phasor p q with an angle row p q modulates both the magnitude and the phasor angle V x and therefore, both transmitted real power p and the reactive power q r vary with the angle row p q in a sinusoidal manner. So, it will vary like this; this is basically the plot of row. So, it will change like this.

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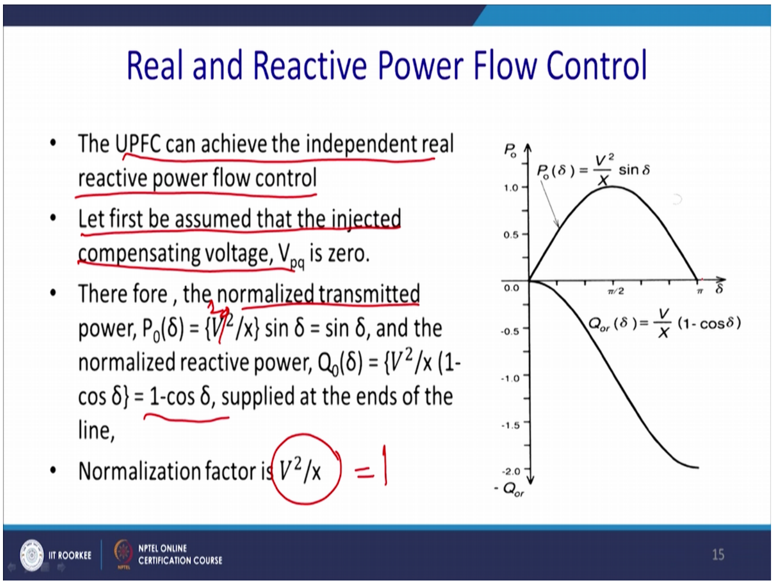

The UPFC can achieve the independent real and the active flow of the power to the transmission line that is one of the basic requirement. Let first assumed that the injected voltage compensating voltage, V pq is zero. We are not actually injecting any voltage. Therefore, the normalize transmitted power it is V square by X sin delta. We consider these value to be 1.

Thus, we left with the sin delta and the normalized reactive power is V square by X 1 minus cos delta. So, we left with it is 1 minus cos delta and supplied by the end of the line and we actually normalize these value to be 1. So, we have these two curve which we discussing from the beginning of the classes. So, what happen here? Now, see the locus of it.

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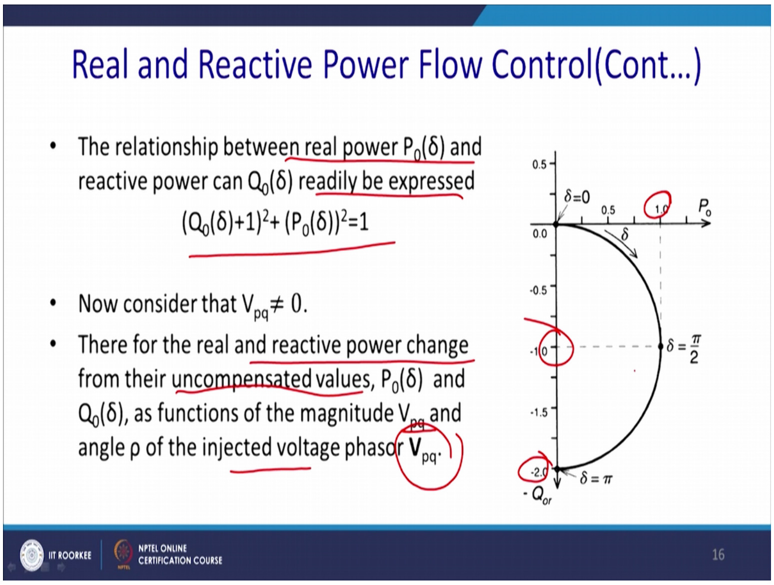

So, we just plot P in x axis and Q in y axis. So, you can go maximum 1 in case of the in case of the real power and this equations you know 1 minus cos delta at pi is value becomes 2. So, you can go to 2 per unit with the real power. So, what happen? This is a mode of operation. Now, the relationship between the real power P delta and the real power Q delta; it can be expressed in basically a unit circle form and you know what happened Q squared delta plus 1 square plus P square delta equal to 1.

So, thus you have a center at this point. Now, consider that p q not equal to 0; then you are actually not we basically you are injecting some voltages and therefore, the real and the reactive power exchange from the uncompensated values of P delta and the Q delta as the function of the magnitude of the p q. And the angle row is injected with the phasor and third value is shall tell there it is V p q and thus this actually this circle will shift.

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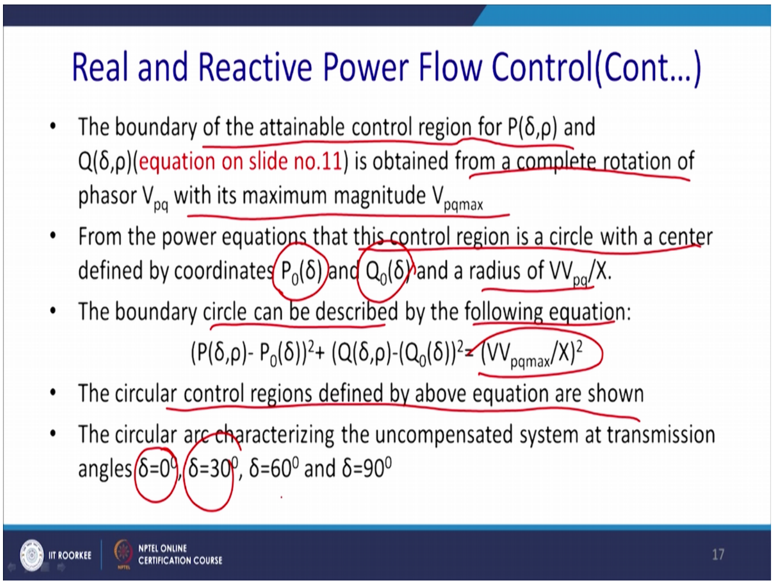

So, as shown in the equation is slide number 11 the boundary of the attainable voltage region P delta rho and Q delta rho is obtained from a complete rotations of the phasor V q with the maximum magnitude of pq max. From the power equations that this control region is a circle with the centre defined by the coordinate PQ delta and the Q delta with radius V pq by X that equal 0.5 generally chosen. Thus, what happen? The boundary circle can be described by the following equation that is p that will modify in case of the your injecting the value pq pq is non-zero.

So, P delta rho minus P 0 that is uncompensated power square plus Q delta row minus Q uncompensated power that should be equal to the your V by V q max by X square. The circular current reach and defined the above equation will be shown. So, we shall take different values of compensation delta equal to 0; delta equal to 30 degree and delta equal to 90 degree and see that what happens.

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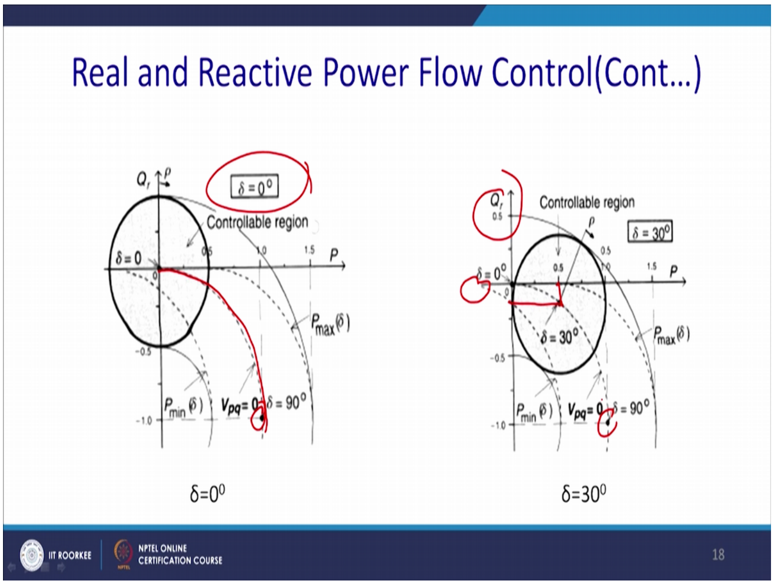

This is a case of delta equal to 0 degree and you see that there is a unit circle and this is a controllable region and thus, what happen? This is a case of the line, where actually p q is 0. So, you have this line. Ultimately, this circle will fit (Refer Time: 25:41) will move like this, if you change the value of the delta. Similarly, what happen if you make delta equal to 30 degree. So, real power will be 0.5 and imaginary power you can calculate.

So, it will shift at this point and this circle will be actually coming like this. This is a this is a line actually the p q equal to 0 and this is a line actually p q negative and this a line equal to actually the V p q is the positive. So, ultimately this is the amount of the compensation you will achieve for delta equal to 90 degree you will be here and delta equal to 90 degree you will be here. Similarly we can make it for the 60 degree.

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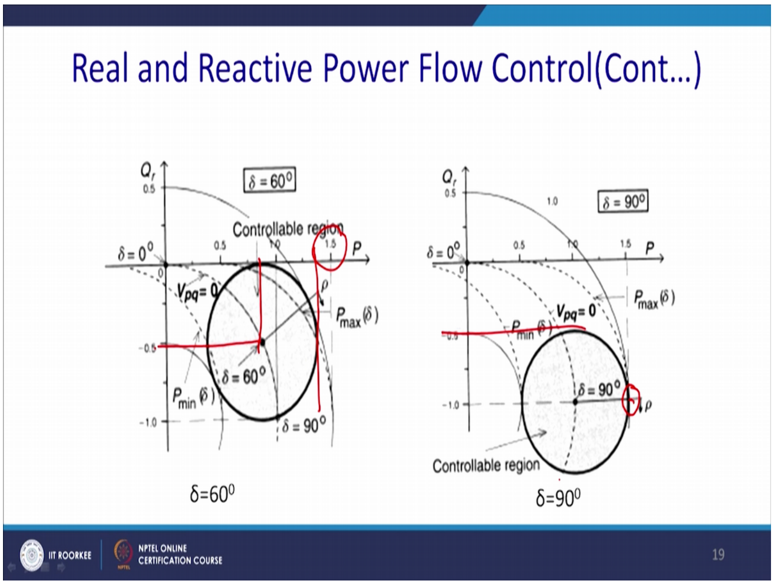

So, this original will shift to for accommodates value of the 60 degree and then, you see that how you are changing its locus. So, ultimately your real power value can touch to the little less than 0.15 because if you can go to that level.

So, your compensations point increases; typical case is of 0.9 a delta equal to 90 (Refer Time: 27:07) or original come at 1 1 and definitely you can compensate the you can make this the real power compensation 0.5 to minus 0.5 similarly reactive power also 0.5 to minus 0.5. So, this is a controllable region for dealt equal to 90.

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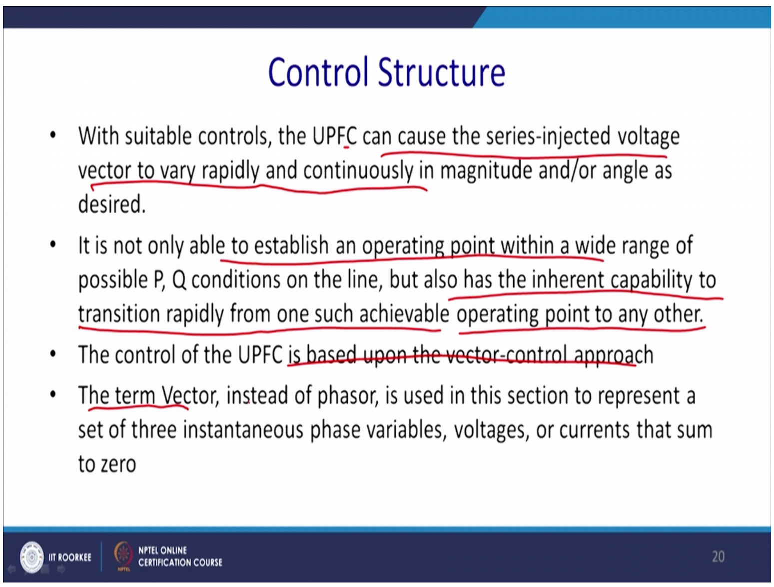

Thus, what we can control it. So, let us understand this zone of control and these are the take away. So, with the suitable control UPFC can cause serious injection voltage vector to vary rapidly and continuously in magnitude and the phase angle as desired. It is not only able to establish an operating point with a wide range of possible P and Q condition on the line, but also has inherit the capability to transmission line rapidly for one such achievable operating point to other.

The control of the UPFC is based up on the vector control approach. The term Vector, instead of the phasor, is used in this section represents the set of instantaneous phase voltage, phase current and the sum zero. So, this is actual the zone operation and control of the UPFC.

We shall continue or next class with the UPFC with its different mode of operation and control.

Thank you for your attention.