Flexible AC Transmission Systems (FACTS) Devices
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Lecture- 37
Comparison of UPFC with PAR and Series Compensators

Welcome to our lectures on FACTS devices. We are continuing with the control of the P, Q techniques control, these are two some discussion is left; thereafter we shall discussed about the Comparison of the UPFC with the Power Angle Regulator. First will take out that control of free flow power control, we were discussing basically the basic control system of the P, Q control in a previous lectures.

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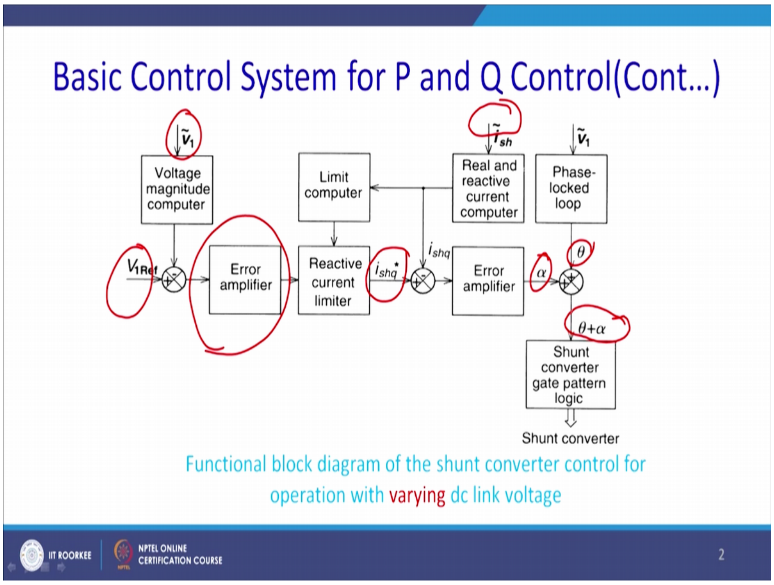

So, this is V 1 and V 2 ref essentially it is a sag control. So, we have to check it out, if there is a sag or not, or sag or swell. But, most of the cases, the problems i arises from the sag. So, you have a power amplifier. And from there actually you will compute that what is basically the shq limit, so that is the sag compensation limit.

And thus form the error amplifier P i controller, you will get an alpha. And again, so form the P l l you will generate theta, so you will sense the actual i sh that you are trying to inject. And you will have a limiting computer, because if it is very high should restricted, and that will be subtracted from the i shq; and with this subtraction i alpha will be generated. And it will be fitted to the get signals of the shunt converter, and with the desired theta coming from the phase lock loop.

So, in that way, actually we will maintain the voltage sag compensation so which is a functional block of the shunt converter control for operating varying dc link voltage. There we are not actually maintaining the fixed dc link voltage, as discussed in the previous class. So, here actually you have to sense, and from the sag, we will be maintaining the dc link voltage.

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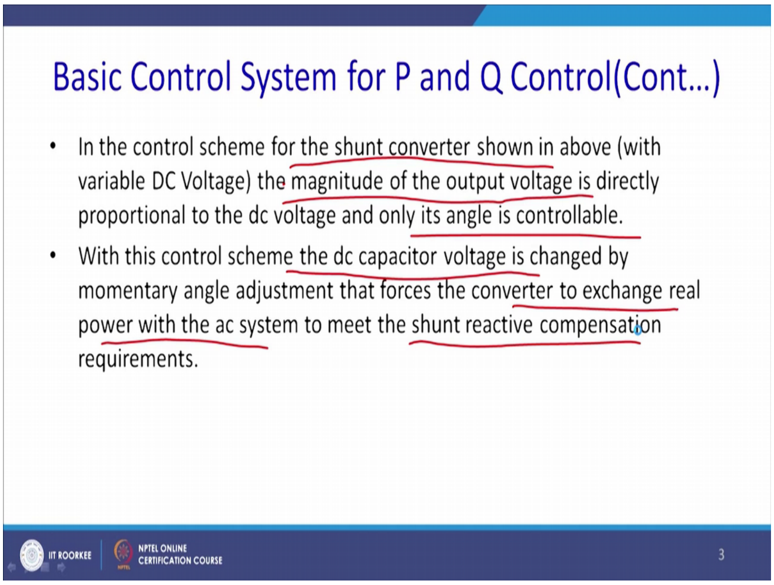

In the control scheme of of the shunt converter shown in the previous slides, with variable dc voltage the magnitude of the of the output voltage is directly proportional to the dc link voltage, and all its angle is controllable. So, there is a change in mechanism of these two. With this control scheme, the dc voltage capacitor is changed by momentarily the angle adjustment, and thus forces converter to change the real power, so that actually instead of maintaining the dc bus voltage, and a control loop, you basically change the phase angle, and thus we change the power actually passing through it power with the ac system to meet the shunt reactive compensation requirement.

Now, let us come to the point, we have seen that the previous discussions that this UPFC can work as a shunt as actually power angle regulator. In case of thus actually in previous slide, where actually voltage is not maintained dc voltage is not maintain, and it is fixed.

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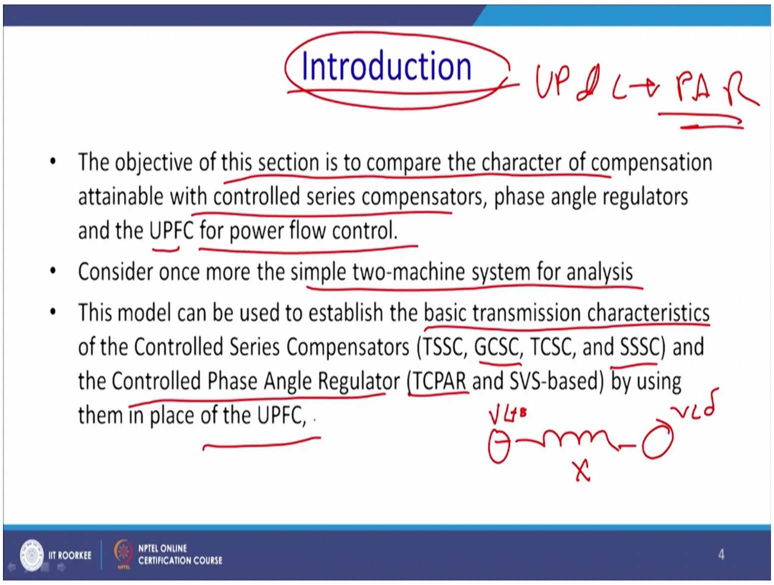

Why, then we will of course, the comparisons comes, why cannot that UPFC will be actually used as a power angle regulator. So, what is the scope of UPFC of using is a power angle regulation, and why is it advantage and the disadvantages. So, UPFC, it is introduction to the UPFC as PAR, and its comparison that is what we have shown, because two, three slides, where remaining in previous discussions, so we are feeding attained.

In objective of this section is to compare, the character of the character of compensation, attainable with the series compensator, phase angle regulator, and the UPFC for power flow control. Consider once more the simple two-machines analysis. We shall have a actually sending-end voltage, there after actually X, we have a dc link voltage, since V angle delta V angle 0.

This model can be used establish, the basic transmission characteristics of the Controlled Series Compensator, these are we have discussed thoroughly TSSC, GCSC, TSC, and SSSC, SSSC definitely is a superior among the other passive component. And the control phase angle regulator that is thyristors controlled phase angle regulator, or SVS-based by using the, and now by using in place of the UPFC.

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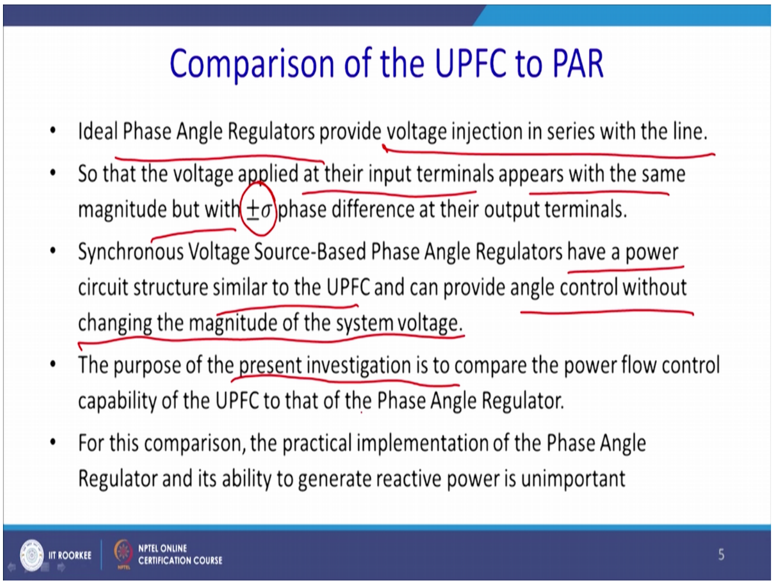

So, what will be the changes here. The ideal phase angle regulator provide voltage injection in series in the line. So, that the applied, so that the voltage applied at the input terminal appears same with the magnitude for delay or leading; but, with the plus minus sigma phase difference with the output terminal.

The synchronous voltage source or SVS based phase angle regulator have a power circuit structures similar to the UPFC, and can provide an angle control without changing the magnitude of the system voltage. The purpose of the present investigation is to compare the power flow control capability of the UPFC, so that the phase angle regulator, it can behave as a phase angle regulator.

And for this comparison, the practical implementation of the phase angle regulator, and its ability to generate reactive power is unimportant. So, we shall only see that whether, it can give a desire phase shift or not whether, it can control the P, Q the, which we have same that is not actually domain of considering the utility of PAR.

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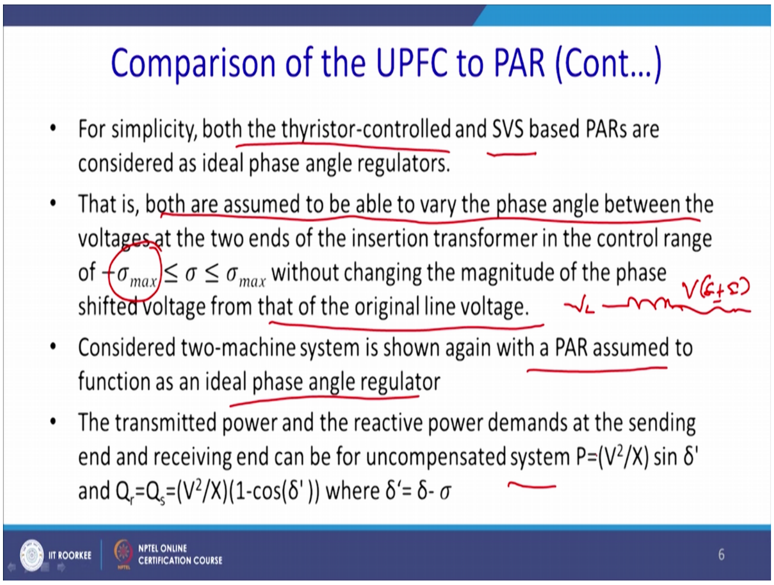

Thus what happened for the simplicity, both thyristors-controlled and the SVS based PAR is considered as ideal phase angle regulator. That is, both assumed to be able to vary the phase angle between the voltages at the two ends of the two ends of the instruction transformer in the control range of plus minus sigma, so maximum sigma max to minus sigma max. Without changing the magnitude of the phase shifted voltage from that of the original line voltage. So, it will just will have a V here, and somewhere you got a PAR, here it will change delta plus minus sigma, and so on that will be the case.

Considered the two-machine system as shown again in the PAR, we have done there. In case discussing PAR to functions as a ideal phase angle regulator. The transmitted power, and the reactive power demand at the sending-end, and the receiving-end can be compensated system that is V square by X sin delta, and uncompensated line is V square by X sin delta. Similarly, P s equal to similarly Q r equal to Q s equal to V square by X 1 minus cos delta, and where it will be actually change now by this new delta, there is delta plus minus sigma.

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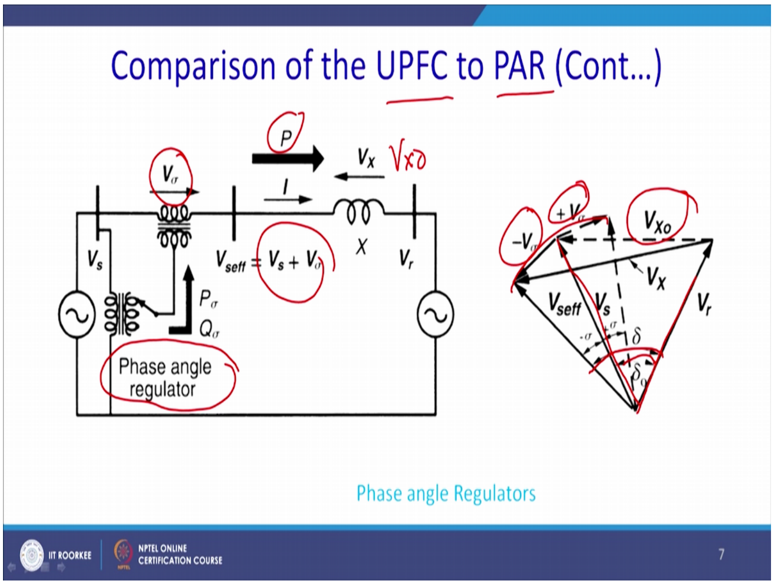

So, this is the case of the comparison of the UPFC to PAR. So, now, this is the phase angle regulator. So, it will take some amount of power from here, and it will inject the V sigma, so that actually effective voltage source become V s plus V sigma, and thus real power flow changes.

So, previously this was a value of the V s, and this was the value of the V r, and this was angle. Now, with the injection of V sigma it can be either of it in a, so that you know actually the magnitude of this value of V s effectively remain same. So, this became the new value of V effective, or this value of the V effective. So, what happened then and accordingly sigma changes, and thus this becomes your new delta. So, in that way, this will operate, and this becomes your new voltage across this actually, the inductor.

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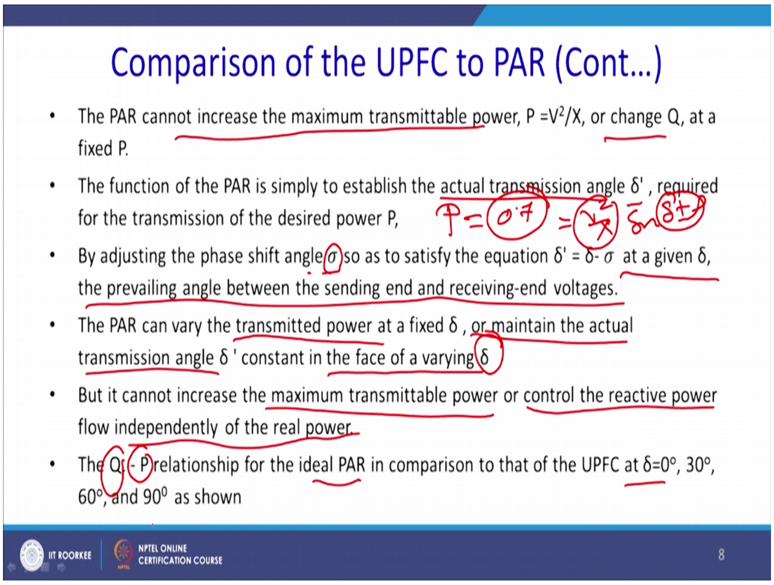

Thus what happened, PAR cannot increase the maximum transportable power, it is restricted to V square by V X, it will be V square by X. Only it can actually change the point occurring the maximum, it can make it the maximum power 30 degree, 60 degree, even at 120 degree that we do not know operated 120, or change Q, at fixed P, so it not possible.

Function of the PAR is simplest to establish, the actual transmission line angle delta required for transmission of the desired power. Let say, P required to be 0.7, and you have V square by X, this value to be 1, and sin delta. And this delta can be anything, when you can add a row or sigma to it. So, you have a wide range of flow of power, and you can deliver with this independent.

Almost independent of the delta, you can send your desired value of the power, that is why it is saying, adjusting the phase shift angle sigma. So, that to satisfy the equation that sigma bar equal to sigma minus sigma delta bar equal to delta minus sigma is given by delta, is prevailing angle between the sending-end and the receiving-end voltages.

The PAR can vary the transmitted power at fixed delta, or maintained actual transmission angle delta constant in the phase of varying delta. But, it cannot increase the maximum transportable power, or control the reactive power flow independently of the real power. The Q r, and minus P relationship for the ideal PAR in comparison with that UPFC at delta equal to 30, and delta equal to 60, and delta equal to 90 is been shown here.

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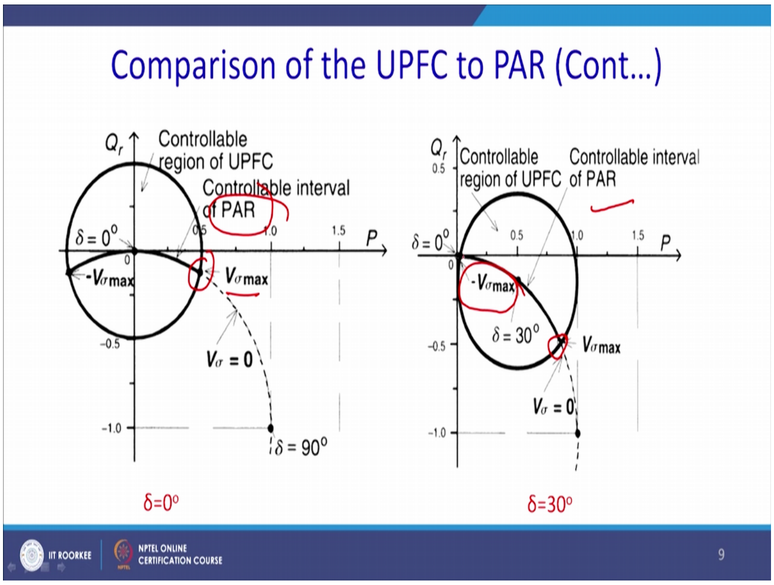

So, this is the controllable UPFC with PAR, and this is a limit with the V sigma. And this is the uncompensated one, and similarly this is the controllable region. So, you can deliver up to 0.5, and you can change the delta accordingly to any point, this is with the power angle regulator.

But, in case of this in case of delta equal to 30 degree, so thus there is not much change of there is not much change of PAR for and the PAR, and the UPFC at delta equal to 0, they are same. But, in case of the 30 degree, this is actually the Q max, and what you can inject. And thus you can see that this is basically the controllable area of UPFC, whole area. And this is the area of PAR.

So, here it will intersect, so at this point PAR and the UPFC will have a same kind of compensation. But PAR can compensate in this curve, and UPFC has a versatility. And moreover, so it can compensate in this region, as well as the upper region.

So, definitely for higher angle, soon the angle is increasing, the compensation of the PAR will decrease, because it is closing near to the 90. So, ultimately, it is delivering the maximum power, so no point of a having any phase shift, in a PAR ok. We shall see to the next slide, this is for 30 degree. So, power handling capability of the PAR will be inferior, only it is same for delta equal to 0.

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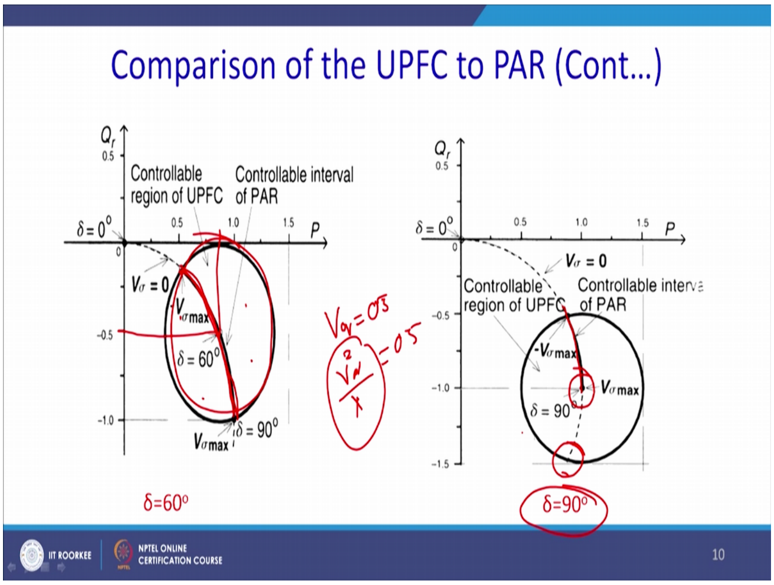

So, now, this is the case, now the origin will shift, because delta is at 60 degree, delta equal to 60 degree that mean, the real power become 0.866. So, this is the 0.866, and 1 minus cos delta will accordingly come, so then that will be the value.

So, this is the case of the origin, and you have a point of intersection, you consider that actually value of V q is 0.5, so V square, so ultimately this value, is basically 0.5 per unit. So, you have a circle of radius of 0.5 per unit. And ultimately, this is the range of the PAR, and this is the range of the V q of this actually the P UPFC.

So, UPFC can make it 1, definitely it cannot go beyond 1, so it can composite in this line PAR. But, UPFC can send power within this circle any point. So, maximum power handling capability, even at the 60 degree, it is same. But, it has a more versatility, it can compensate power this point, this point, this point, this point. But, PAR has to go through only this line; this is a P and Q line.

Now, let us consider, when it is 90 degree, it is already at its maximum position. So, origin will be shift centre will be at the 0.11. PAR can reduce the power, not increase the power. So, PAR can act in between in this region, depending on the maximum value of the sigma.

But, here you can go to make the power of 1.5, in case of the UPFC. So, you can have a more transportable power, in case of the UPFC, when delta is more. So, thus UPFC is suitable and advantages solution than the PAR.

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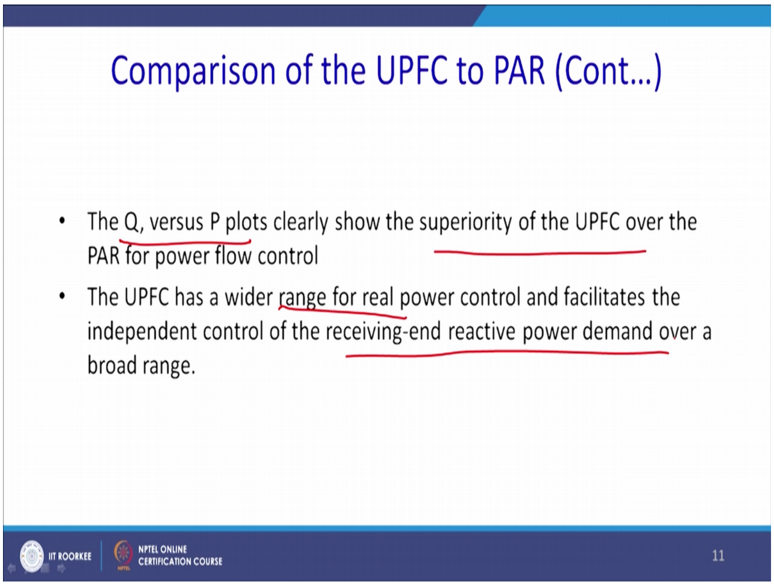

So, what are the take away from this discussions. This UPFC versus, P plot clearly shows, the superiority of the UPFC, over the PAR. UPFC has a wider range of the range of real power control, and facilitates the independent control of the receiving-end reactive power demand over a broad range.

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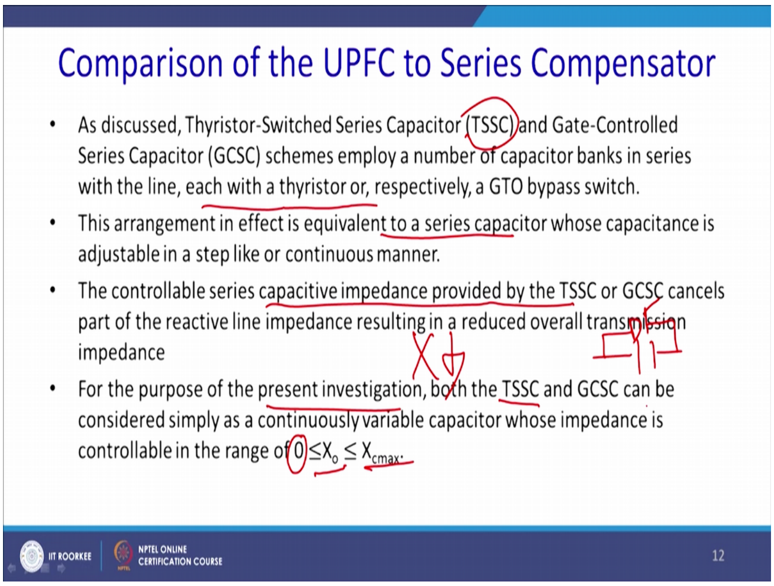

As discussed, thyristors which capacitor that is TSSC, and the gate control series capacitor a these capacitor that is basically mostly it is GTO based, GCSC schemes, employed under the capacitor bank in series with the line is thyristors, or a GTO to bypass the switch.

So, what happened then, this arrangement in effective to equivalent to a series capacitor, whose capacitance is adjustable, and in steps like the continuous manner. So, you have a capacitor, and you have a switches. So, this can be switch can be (Refer Time: 20:17) trigger fully, then this capacitor is got bypassed. We have discussed in case of the series compensation in detail.

Controllable series capacitor impedance provided by the TSSC, GSSC cancels part of the reactive line impedance resulting reduced overall transmission lines impedance. So, value of the X got reduced. So, there is a different kind of problem, we have discussed, while discussing the series compensation.

For this purpose, the present investigations, both TSSC, and GCSC can be considered simply as a continuously variable capacitor, whose impedance is controllable within a range of 0 to X 0 to X c max. So, you can it is fully switched, so capacitor is bypassed, so it is 0. And accordingly (Refer Time: 21:24) you control the switching on this thyristors, and you got a control about the capacitors.

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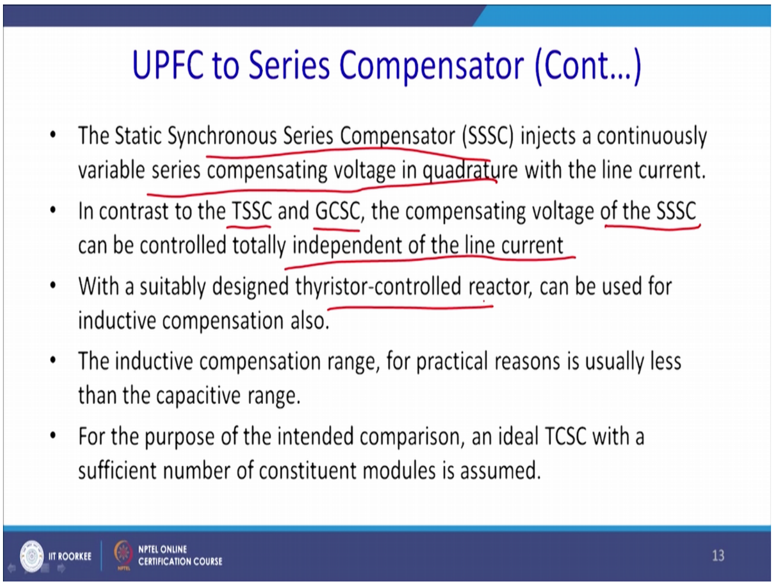

So, what will be the comparisons with that series definitely can increase the power flow. The static synchronous series compensator injects a continuously variable series compensating voltage is quadrature with the line current. In contrast to the TSSC and GCSC, the compensating voltage of the SSSC, where is the series compensator again can be controlled totally independent of the line current. There is one of the biggest advantage of the SSSC, over other kind of series compensation.

With suitable design thyristor-controlled reactor, can be used for the inducting composition also. We have seen that TCR, can we also insert into the system. Inductive compensation range for practical reasons are usually less than the capacitive range, because most of the energy is consumed in drives, and these are inductive. For this purpose, the intent of comparison, and ideal TCSC with the sufficient number of constituent module, we assume that. So, we have seen that huge number of TCR capacitive compensation, and only one actually inductive compensation.

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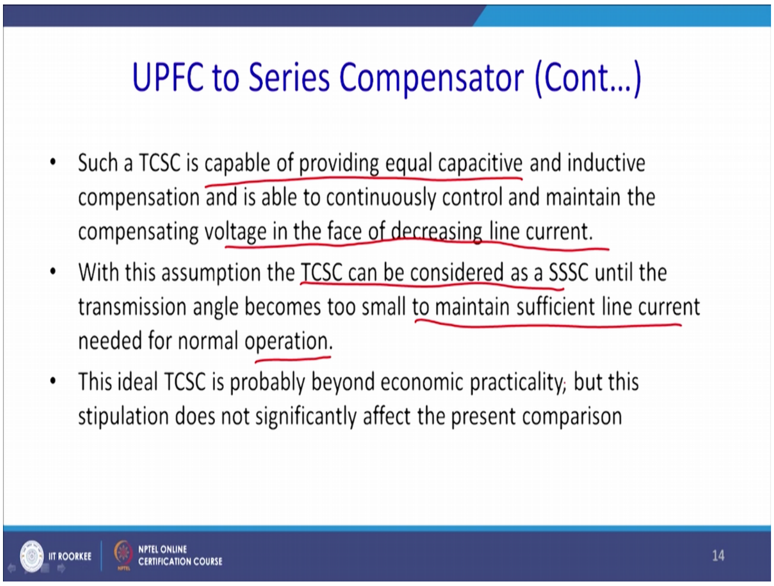

Such TCSC is capable of providing the equal capacitive and the inductive compensations, and able to continuously control and maintain the compensating voltage in the phase of the decreasing line current. With assumption that TCSC can be considered as SSSC, until the transmission line angle becomes the small to maintain the sufficient line current needed to normal operation. In ideal TCSC is probably beyond the economic practicality, but stipulation does not significantly affect the present comparison.

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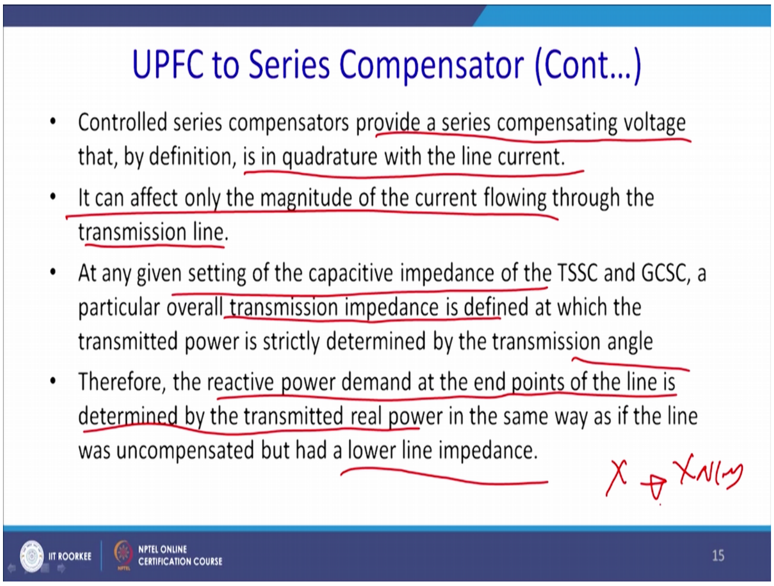

So, control series compensations provided as series compensation voltage that by definition, is in quadrature with the line current. So, but what is the difference of UPFC, so it can be in any phase. It can affect only magnitude of the current flowing through the transmission line. So, that is the, that is something that it can control. At any given setting, the capacity of impedance of the TSSC and GCSC, are particular overall transmission lines impedance is defined at which the transmitted power is strictly determined by the transmission angle.

Therefore, reactive power demand at the end point of the line is determined by transmitted real power in the same way, as if the line was uncompensated, but had a lower line impedance. So, we can assume that with the compensation, it looks like actually X is modified by the X reduced. So, it can take it a uncompensated power.

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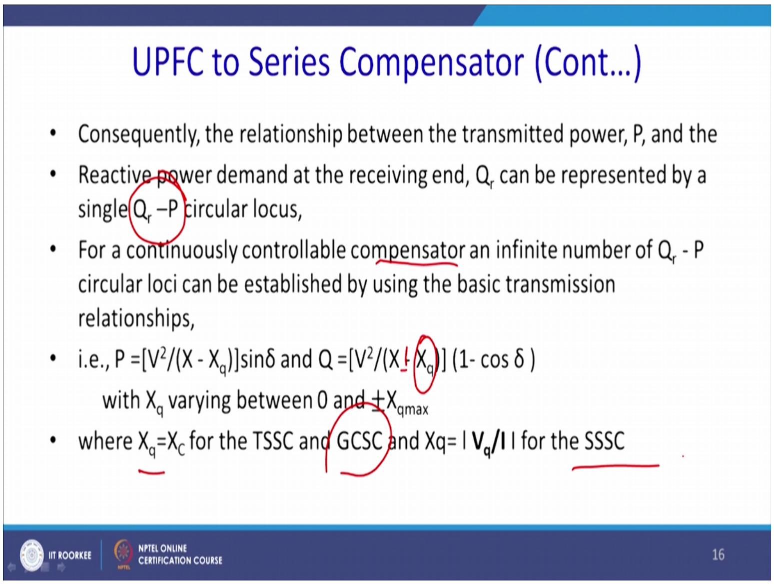

Consequently, the relationship between the transmitted power. And the reactive power demand of the receiving end, Q r is represented by the single circular loci of the P, Q circle, we shall see right now. For continuously compensative controllable compensation and infinite number of Q r, and the P r circular loci can be established by using a basic transmission relationships, that is P equal to V square by X minus X q sign delta.

Similarly, it will be V square by X minus X q the inserted impedance, it can be plus minus ideally, and into 1 minus cos delta with q varying between 0 to plus minus q max. So, where X q equal to X c for the TSSC, and for the GCSC, and it will be V q by I for SSSC.

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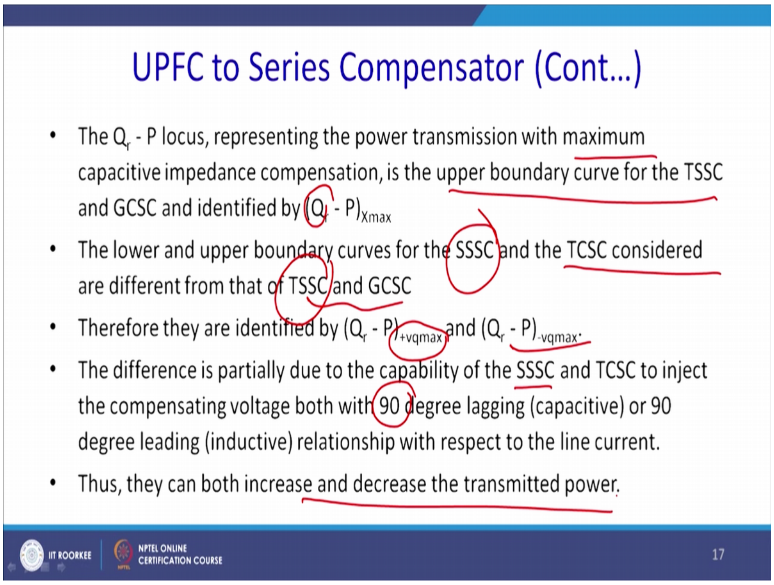

Thus the Q r locus, representing the power transmission with maximum capacitive impedance compensation is the upper boundary curve of the TSSC and GCSC, and it is identified by Q r P max. The lower and the upper boundary curves of the SSSC, TCSC is considered are different from TSSC and GCSC, where these are shunt compensation, these are basically the passive compensation. And this is basically the active compensation.

Therefore, they are identified by Q r minus P plus minus max to this max, so it can have a both the range. The difference is partially due to the capability of SSSC, and TCSC to inject the compensating voltage, both with 90 degree lagging, or 90 degree leading relationship with respect to the line current. Thus we can increase and decrease both the transmitted power by the series compensation.

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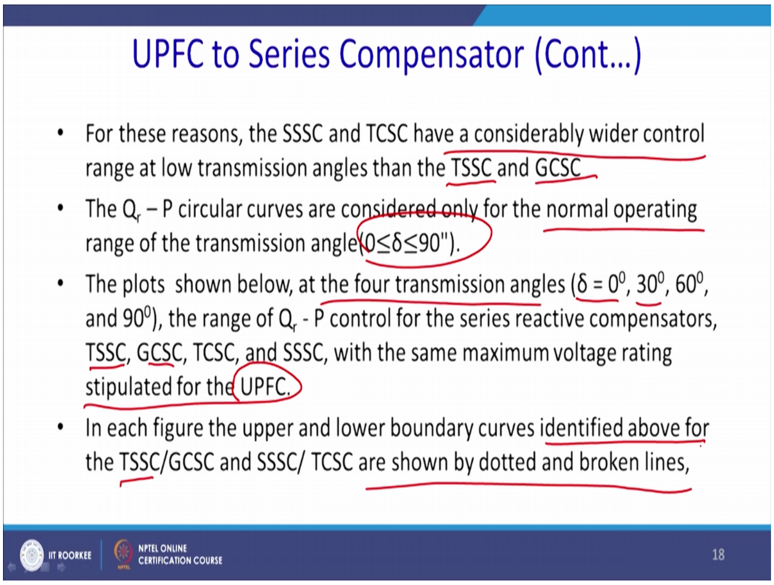

For this reason, the SSSC and TCSC have a considerable wider control range at low transmission angle than the TSSC and GCSC. The Q r P circular curves are considered only for the normal operating region of a transmission line, and where theoretically it should be 0 to 90 degree.

The plot shown below at four transmission angle, delta equal to 0, delta equal to 30, and delta equal to 90. Same we have done in case the PAR, we are going to repeat the same thing with the with this actually series compensation for TSSC, GCSC, and TCSC, and SSSC, with the same maximum power rating as stipulated by the UPFC, we should have a (Refer Time: 28:49) comparison. Each figure of the upper and lower boundary curves is defined above for the TSSC, GCSC, SSSC, and TCSC, are shown by the dotted, and the broken line. So, this is something you will see.

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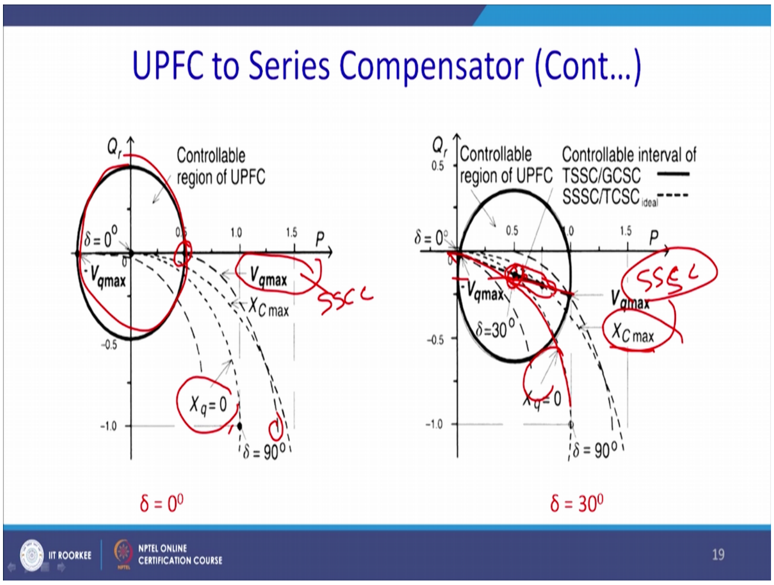

This is the circle essentially the control area of UPFC. And this is basically q max that this is the control area of SSSC. So, this is for angle delta, and you can inject current, you can take it to any point.

And thus you can see that ultimately, it is crossing at this point. And this is a line for x q equal to 0, and you can add and decrease a X q, and thus you can increase the power of the system. So, we can see that a low angle maximum compensation, you can make through UPFC, is 0.5. But, you can make it in a higher value, with the help of the series compensation.

Now, let us consider the case, when delta equal to 30 degree, so original shift P at 0.5, and q 1 minus delta, it will be 0.18. So, you are at this original, this is the the circle is a locus of compensation of the UPFC. Now, this is the line for q equal to 0, and it will pass through the origin, and the way actually you change the delta.

Now, this is the I q max. So, you can see that at this point you can have this much of extra power for this much of extra power for these reactive compositions, there is for TCSC and all and this much of extra power handling capability for actually SSSC. So, SSSC will be actually much much superior, and we have this much to this much power handling capability by TCSC.

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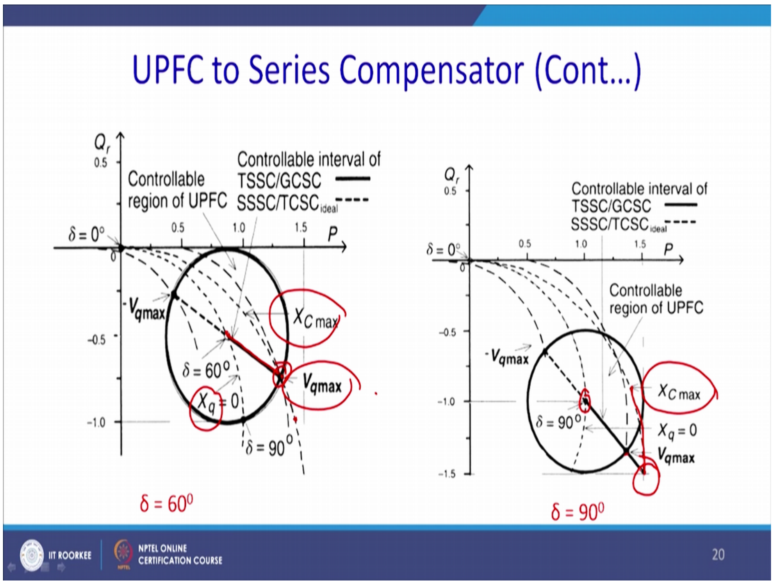

Now, see that why it is 60 degree. So, now there it will be same of this is the line of the maximum C max, this is a line for uncompensated X q, and this is the line for V q. And ultimately, this much of extra power, you will get it.

And here, we cannot claim superiority; here also actually superior is the UPFC, because you can inject any power in between the circle by the UPFC. And ultimately, if you are operating here as uncompensated line, if you use the passive series compensation, you can go to this point, and if you use the active series compensation, you can go to the this point. So, within the within the range of this actually, the boundary of the circle only, but, when it is changes to 90 60 degree, you can see that both this curve is meeting at this point.

So as per as power handling capability is concerned both this V q, and the x SSSC that is a active series compensations, and the passive series compensation, does not have much change. So, it is operating the same point. But, power handling capability of these three devices are almost same, so it will be it can handle this amount of power, this is for the both, the three cases.

Now, for that when actually it is 90, here there is an clear cut advantage. It is an uncompensated line, and this is the line for X q, and this is the line for the explain.

Now, you can see that this line splits, and ultimately, the passive solution will have a superiority, [vocalized-noise\ and it can go to this point. So, only for angle at 90 with generally never operated angle 90 theoretically; we will have a passive solution, we will have more advantage, and active series solution. And zone of control, it is less, in case of the UPFC than the series solution.

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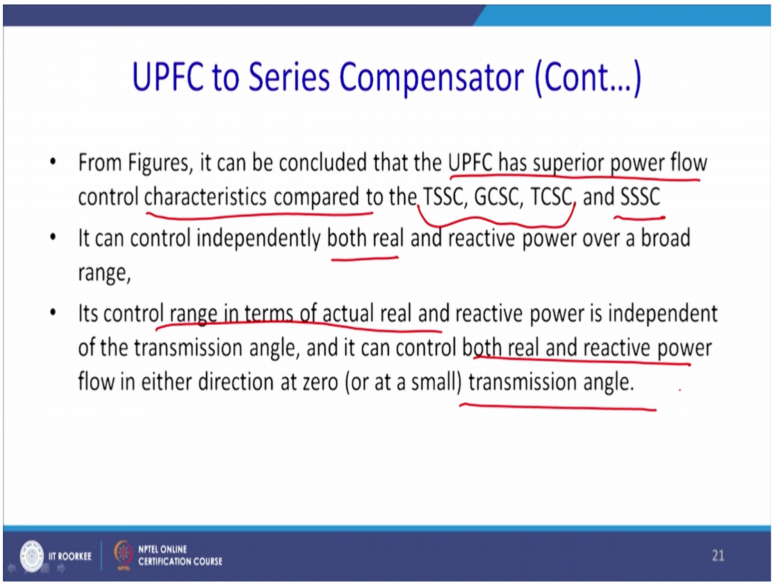

So, these are the discussions. So, let us these are the takeaways. From this figure, it can be controlled that the UPFC has the superior power flow characteristics compared to the passive; these are passive series compensator, and this is one is a active phase compensator. It can control independently both real and the active power over a broad range. If you that is circle of influence is taken as 0.5, you can increase it to 0.6, 0.7, but rating will be increasing.

Its control range in terms of the actual real and the reactive power is independent of the transmission line angle. So, it does not touch the transmission line angle, and the does not touch other parameter. And it control both real and the reactive power flow either direction that is at zero to the small transmission line angle also.

So, thank you for your attention that is all about our comparison with the UPFC with power angle regulator, and the series regulator. So, what we can conclude here that power angle that you know all the cases, the activity of the power angle regulator and the series angle regulator that all the activity we require that can be effectively and more efficiently possible to do with the UPFC.

And thus UPFC is a future trend, and it will replace other kind of series compensations. And once, if you have a origin location that is you have you have not really not fixed any kind of the fact devices, of course, we will prefer UPQC, instead of this different kind of series and power angle regulator.

Thank you for all your attention.