Flexible AC Transmission Systems (FACTS) Devices

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Lecture – 28
Voltage and Phase Angle Regulation

Welcome to our lecture of the Flexible AC Transmission System. Today, we are going to discuss a new topic, that is Voltage Phase Angle Regulation or the in abbreviation we shall use the term phase angle V P R or P A R.

So, our discussion will be based on the understanding of the P A R, that is the introduction followed by the voltage and the phase angle regulation functioning and the power flow of phase angle regulator that is P A R reactive and the real power loop of and the power flow.

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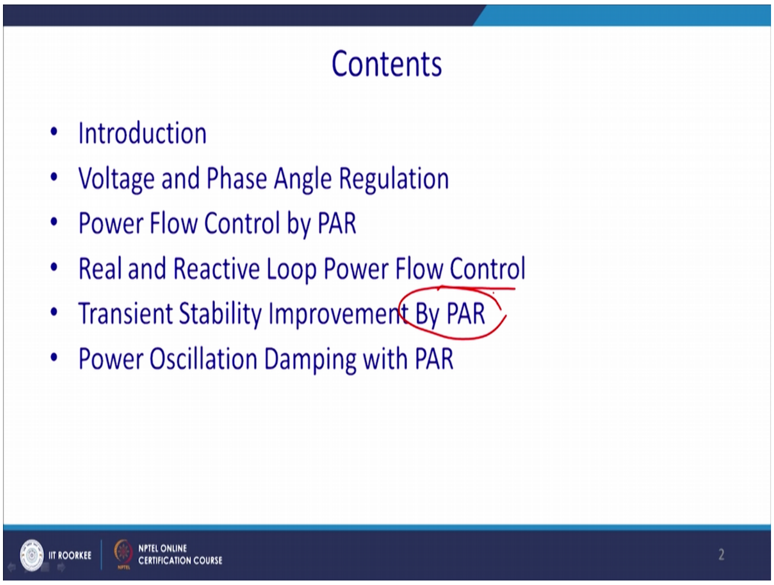

And, the reactive power flow control then the transient stability improvement by P A R that is same we have discussed for the series and shunt and we are continue with the also with this P A R, and the power angle oscillation also with the phase angle regulator.

So, why we choose phase angle regulator?

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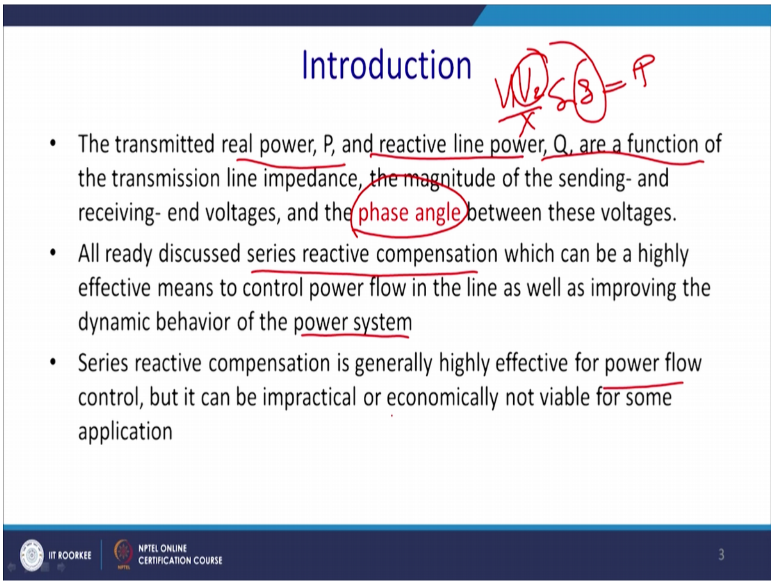

Essentially you know that sending an voltage receiving in voltage by X into sin delta is the power sent through the transmission line. So, instead of you have advantage and disadvantage of both of course, you can increase the sending n power by changing the actually the voltage V 1 or V 2 or X that we have seen in case of the series compensation real power, but we can also do the same thing by changing the delay angle alpha, delay angle delta, and thus power can be enhanced or decreased as you wish by not touching other parameters line V 1 V 2 and X.

The transmitted so, the transmitted real power P and the reactive power line Q, are the function of the transmission line impedance, the magnitude of the sending and then the receiving end voltage and the phase angle between these voltages.

So, now we shall deal with this part that is phase angle, already we have discussed the series compensation which will which can be highly effective by means of the power flow in the line as well as the improving the dynamic behavior of the transmission line of the power system. And, this series reactive compensation is generally highly effective for the power flow control, but it is impractical or you know you know or economically non-viable on non-economical for some applications.

So, where you actually you have to increase the power rating of the devices and you require to have a different devices with a high power rating problem involves, control of the real and reactive power flow in a meshed network.

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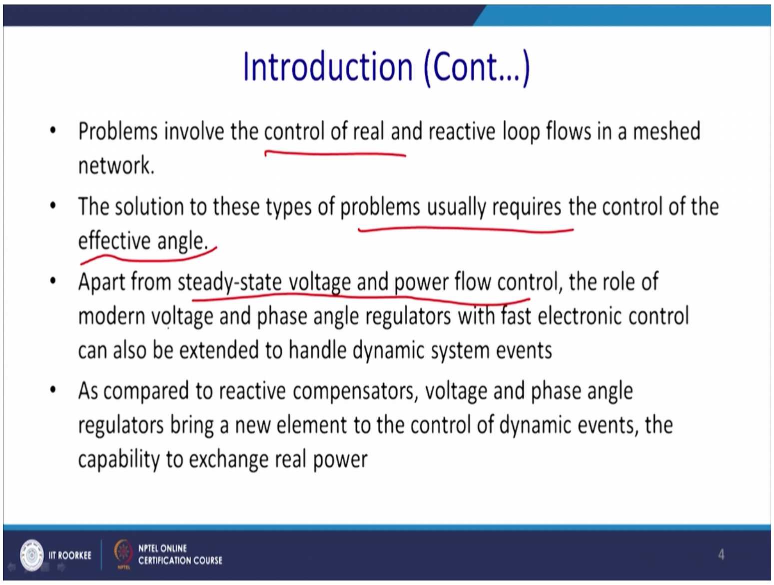

So, there actually you have to find it out where the maximum sac occurs and have to compensate that, solution of this type problem requires the control of the effective angle delta it is not that V and X you have to control the delta. Apart from the steady state voltage and the power control the role of the modern role of this phase angle regulator with a fast electric control can also be extended to handle the dynamic system events like oscillation falls, sub synchronous reactance all those.

As compared with the reactive compensator, voltage and the phase angle regulators, brings a new element to the control dynamics event and the capability of this power lines and with this enhance. So, it is a one of the new member and it has shows a huge potential to increase the or effectively control the power handling capability of the transmission line.

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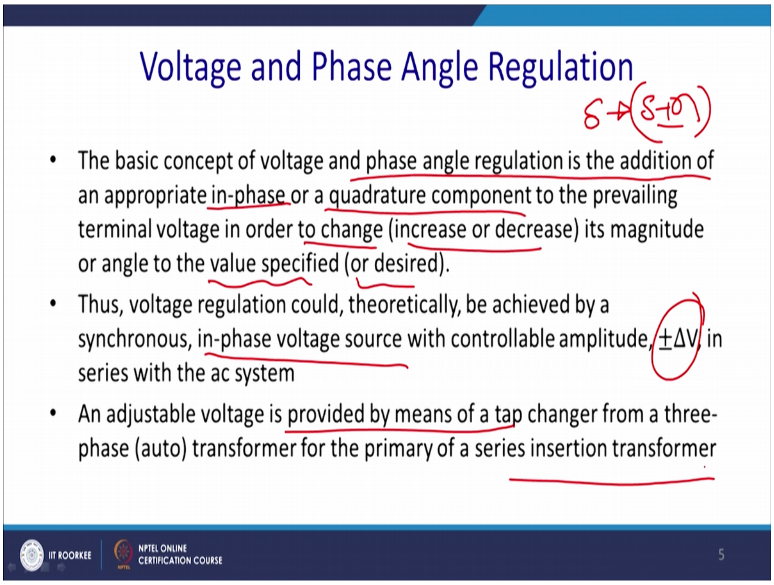

Now, what is the concept the basic concept of the voltage angle regulator is addition of the appropriate phase angle. So, you got a delta; delta will be modified by delta plus sigma or minus sigma that is that is what you wanted to do, appropriate in phase or adequate quadrature component to the prevailing terminal voltage in order to in order to change increase or decrease the magnitude or the angle of the value is specified or desired. Thus the voltage regulation could theoretically be achieved by a synchronous in phase voltage source with controlled amplitude plus minus delta V in the series with a c system.

An, adjustable voltage is provided by means of the tap changing 3 phase auto transformer for the primary series injections or insertion of the transformer, we shall see this circuit here.

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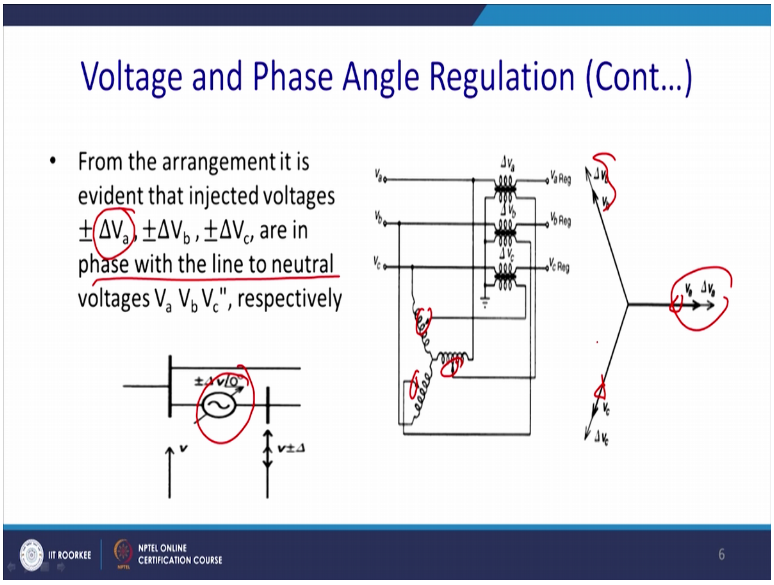

So, this is the in phase voltage regulator. So, what happen you have the actually step changing or auto transformer. So, from there you will tap this thing and ultimately you will add up a voltage in phase.

So, what happen the transmission capability increases and same way you can actually reduce the phase? So, you can add up del V del V a del V b del V c for this arrangement it is evident that, injected voltage del V a del V b and del V c are in phase with the line to the neutral voltage V a V b V c. So, you can actually have a voltage regulator, which can inject the voltage or take out the voltage in the same phase.

So, it will be add up or decrease it will add up or decrease the same amount. And, you can have a quadrature voltage regulator; let us understand how can you make a quadrature it is very simple you know, actually all are wanted in phase shift it is V a this is V b and this is V c.

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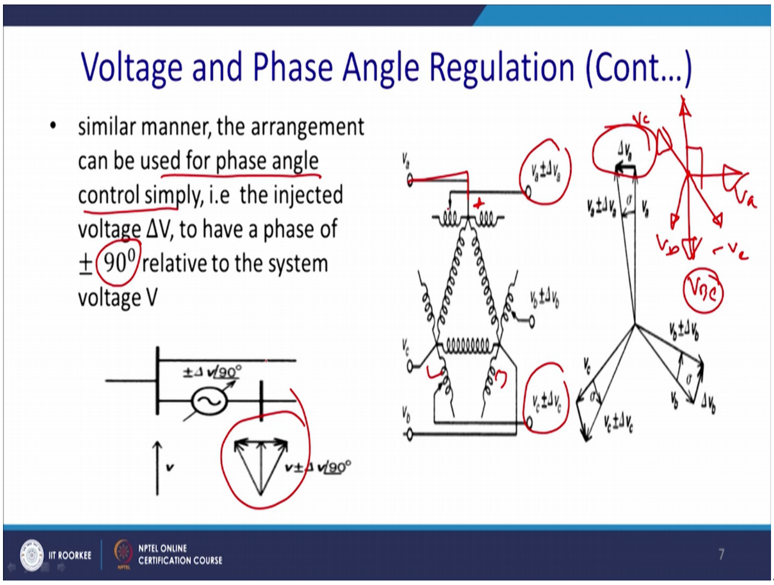

If, I want to make this voltage which is actually perpendicular to the V so, ultimately you just these is minus V c and take the resultant of it and scale it. So, you know actually V c if you inject V c in phase a that will be leads to the 90 degree phase shift same way for the other phase, that is what it is been done here? You know actually this is the V a and this is the del V a and what happen you will you can add this phase here and here you can add this phase here and here. And so, that you can have this 3 voltages, ultimately you have to see that you know when you are it is in a star combination it is in a delta combinations.

So, ultimately it will have a 30 degree phase shift. So, this will lead to the 60 degree phase shift or the voltages and ultimately you get a voltages at quadratures of the current. So, ultimately A B C so, this is point is A. Similar manner the arrangement can be made used for the phase angle control that mean the injected voltage del V to have a phase of 90 degree relative to the system voltage. And, this is the combination with the line you will have a 90 degree phase.

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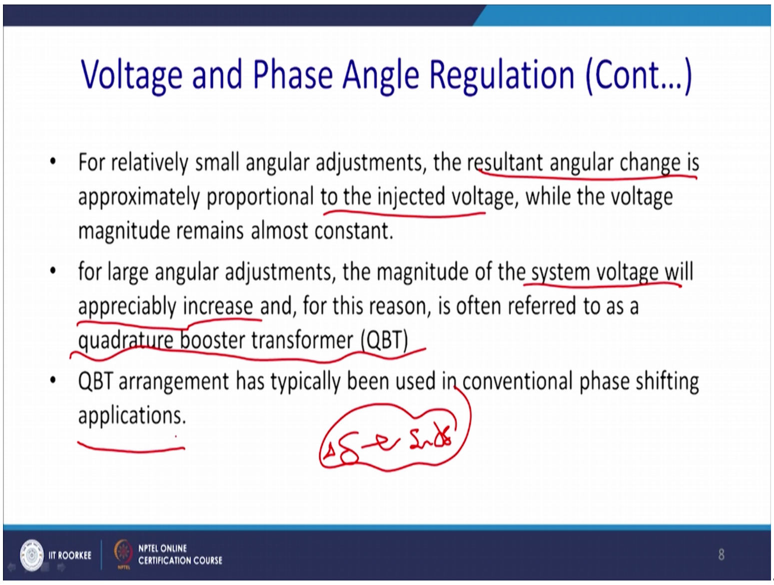

For relatively small angle adjustment the resultant angle angular change is approximately proportional. So, in when delta and sin delta is almost same or that the, this value change rather. So, then the result the angular change is proportional to the injected voltage while the voltage magnitude remains almost constant.

So, this value will change. For large angle adjustment then voltage will change the magnitude of the system voltage will appreciably increase or decrease for this reason this often referred to as a quadrature boost transformer, generally it is enhanced. So, we shall use this term very frequently Q B T and it is may this typically has been used in conventional phase shifting application power flow control by Phase Angle Regulator or PAR.

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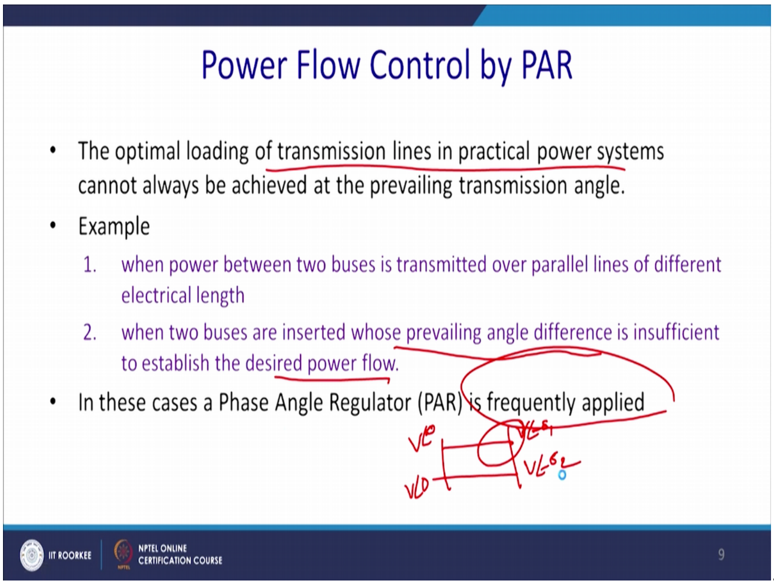

So, the optimal loading of the transmission line in practical power system cannot be achieved due to the following reason mostly the delta we have a limitation on the delta, achieve at the prevailing transmission line. For example, when power between the 2 buses is transmitted over the power lines of different electrical length, it is sometime difficult to have the same electrical even though they are coming from the 2 points.

Then, 2 buses are inserted whose prevailing phase difference is insufficient to establish the desired power flow. So, one will supply power angle delta minus 1 assume that it is 0 that this is reversed and if it is V 0 it will be minus delta 2. So, there you require to have a phase correction.

And the 2 buses inserted prevailing the angle difference of insufficient to establish a desired power flow, because someone will carry more current and someone will carry the less current. In this cases phase angle regulator or par is frequently applied to actually make this there phase voltage this angle sign.

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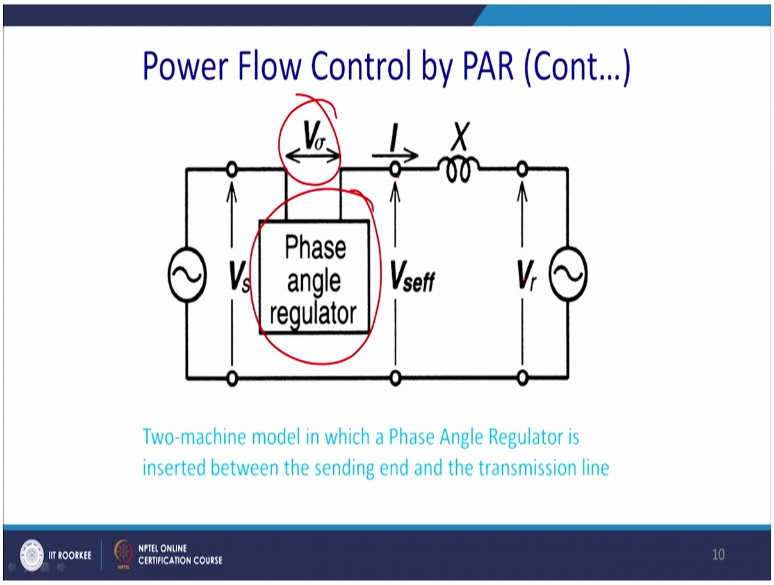

So, thus this is the 1 line diagram of P A R in the from the 2 machine model this is the supply voltage in between you have a phase angle regulator and that will actually change the phase angle by sigma. So, ultimately it will inject the sigma and thus this is the sending an effective voltage after the phase sigma, and you got a X and you got a r. So, this is the way of representation of P A R.

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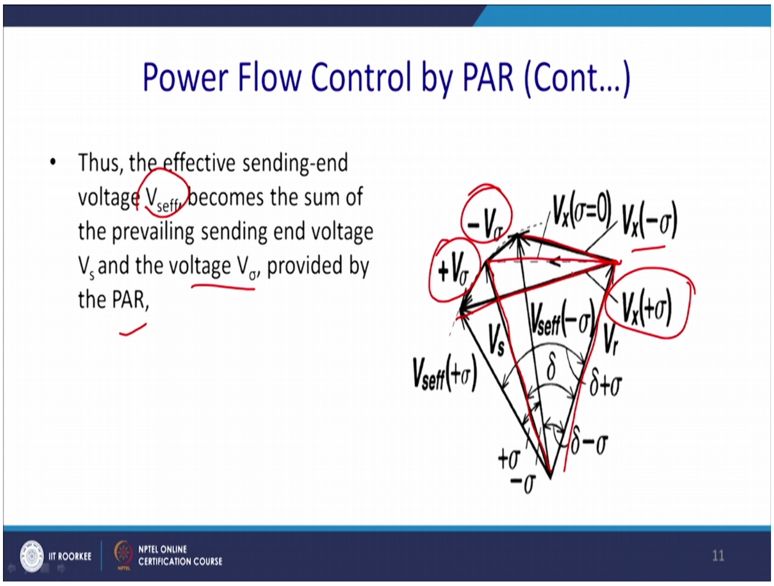

Now, how does it work let us understand the phasor, phasor of P A R, the effective sending an voltage V s effective becomes sum of the prevailing sending end and the V s voltage and that is sigma is provided by the P A R.

So, what happened let us assume that this was your initial V s and this was your initial V r, and you can add or subtract V sigma with that supply voltage and thus effectively you can make it minus sigma or plus sigma.

And, ultimately V X is a k s where it is sigma is added and V X is the case where sigma is subtracted and V X is the case, where actually you have the when actually it is uncompensated V sigma equal to 0.

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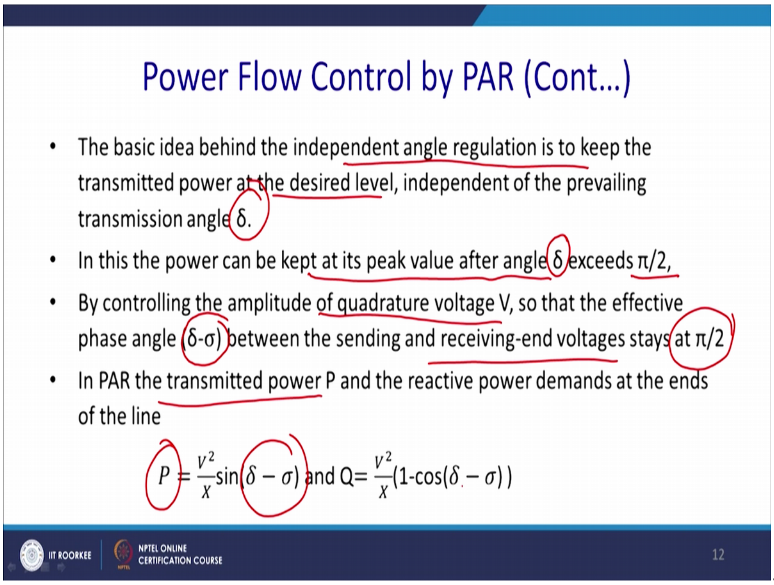

So, from this understanding of the phasor the basic idea behind the independent angle regulation is to keep the transmitted power at desired level, independent of the prevailing transmission angle delta. In this power can be kept at the peak value after the angle delta decreases by pi by 2 by controlling the amplitude of quadrature voltage V. So that, the effective phase angle sigma minus delta between the sending and the receiving end voltage stage as pi by 2. The P A R the transmitted power P and the reactive power demands at the receiving line will change in this fashion.

So, you had P that is V square by X sin delta in this case it becomes delta minus sigma and the reactive power also changes V square by X 1 minus cos delta minus sigma.

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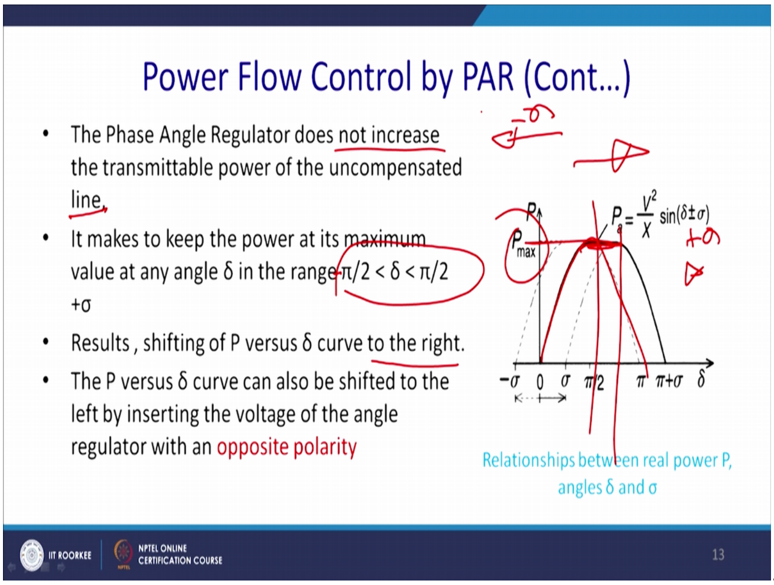

The phase angle regulator does not increase the transmittable power of the uncompensated line please understand that angle does not increase the value of the P max, but it can shifts the P max. So, it was uncompensated line. So, that here it is pi, but you have added sigma. Now new power will come at this point, and within the region you know there are it can change the maximum power. The, it makes or keep the power at a maximum value at any delta that is the advantage. So, you can make the power maximum and even 30 degree even at 45 degree even some other values.

So, these ranges to actually sigma should be less than minus pi by 2 to plus pi by 2, and that is actually the range for sigma the result shifting P versus delta curve to the right will what will happen. So, you can increase the delay angle the P versus delta curve can also be shifted to the left side by inserting voltage to the angle regulating in a opposite polarity. So, you can shift to plus sigma voltage this way you can get this voltage by injecting minus V c.

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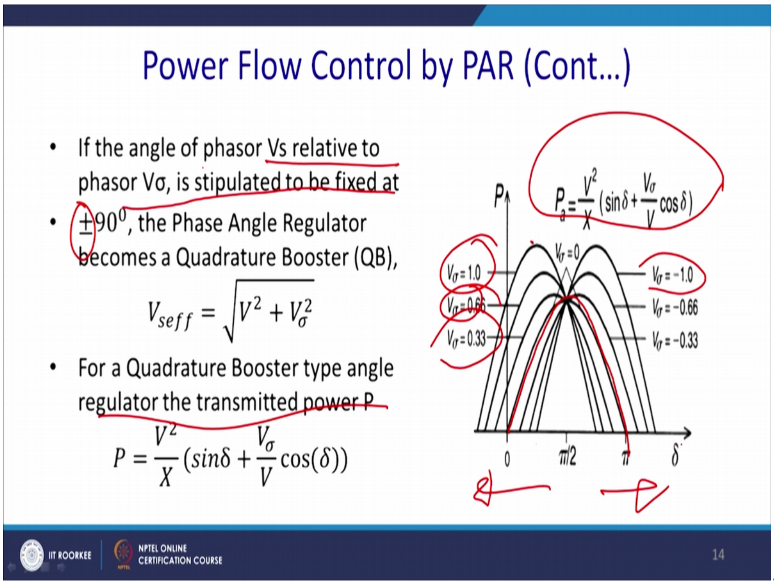

Now, let us see the characteristics of the P A R if the angle of the phasor V s relative to the V sigma is stipulated to be fixed at plus 1 90 degree. So, you have a 90 degree injection.

The phase angle regulator becomes quadrature boost so, QB. So, effective voltage becomes V square plus V square plus sigma square or quadrature boost type angle the regulator of the transmitted power have this logic V square by X sin delta plus V square by V X cos delta. And, thus this will be the power curve real power curve and this is for sigma equal to 1, this is for sigma equal to 0.66 for this sigma equal to 0.6 6, in this case voltage also increases because it increases the sending in voltage.

So, this is the case and this is the case for sigma equal to 0. Similarly, this is the case for sigma equal to minus 1 and this is the case of the sigma equal to plus 1, if you make it minus if it make it sigma plus this curve will shift in left hand side and if you make it sigma minus curve will shift to the right hand side.

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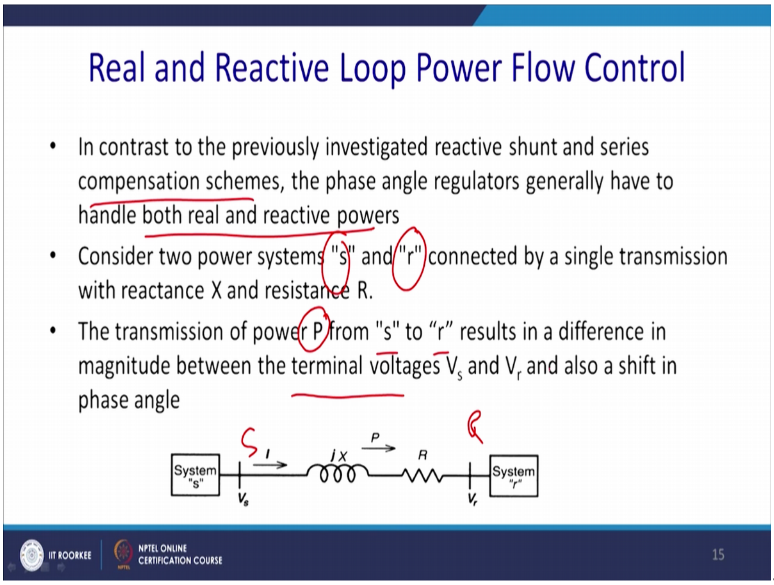

So, the contrast in contrast to the previously investigated shunt and the series compensation scheme, it has a major advantage the phase angle regulator generally have to handle both real and the reactive power in same manner. So, it has a property that it can handle the active as well as real power consider the 2 machine system same thing we have discussed. So, s and r connected by a single transmission with reactant s and the resister r. The transmitted power P from “s” to “r” results in a difference in magnitude between the terminal voltage V s and V r and also a shift in phase angle. The factorial or the pressure representation of the voltage difference V I is given by V s minus V r.

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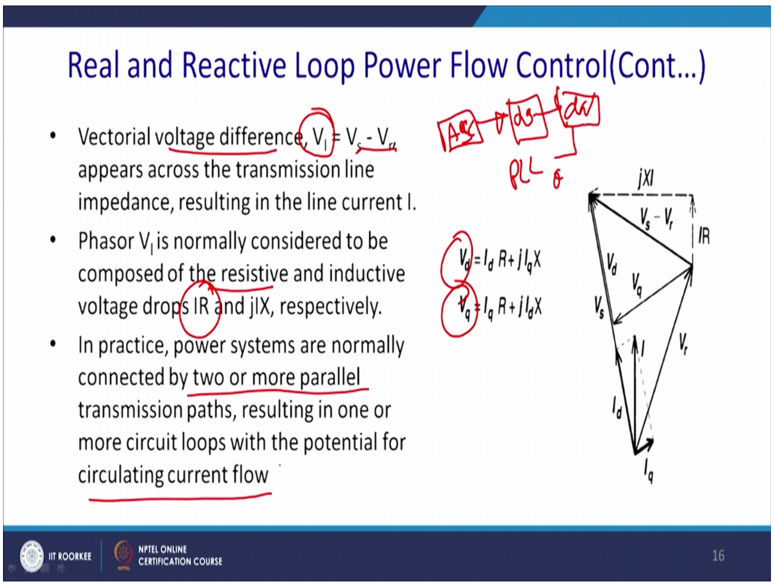

So, we can speed this voltage into the, we have discussed this V q model we can slit this voltage by the pulse transformation by V d and V q in real and the quadrature axis.

Thus it becomes a synchronous model when you actually 3 phase A B C system from A B C to you have stationery transformation that is alpha beta, then you feed the P L L theta and thus you get the t q. And, d q they are d coupled so, analyzations is easier. The phasor V I is normally considered to be composed of the resistive and the inductive voltage drop of I X and I R, in practice the power systems are normally connected a mode than the 2 mode machines.

So, more than the 2 machine in parallel in a transmission path, resulting in the one or more circuit loop with a potential of the circulating current flow. So, there might be instantaneous power difference between 2 lines. So, for this reason there will be a circulating current here.

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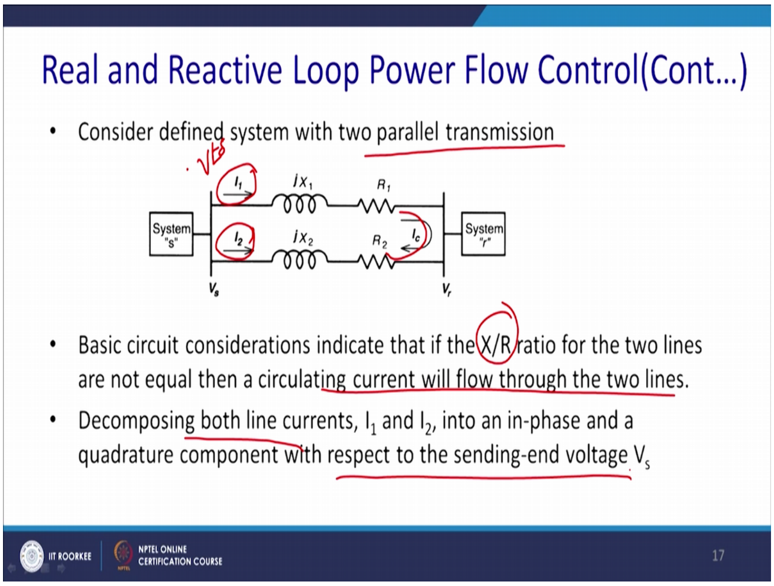

Consider that defined system with 2 parallel transmission line and since this angle is angle delta 1. So, an I 1 and I 2 will have different. So, for this reason you will have a different current flow. The basic consideration indicate that X by R ratio of this 2 lines are not equal, then circulating current will flow through the transmission line this is basically the wist and (Refer Time: 22:19) kind of thing.

The we shall decompose this both the current decomposing both the current I 1 and I 2 in phase and the quadrature, which was I was trying to explain in previous slide quadrature compensated it is expect to the sending an voltage V s, this will see this equation in next slide. So, this is the in phase component.

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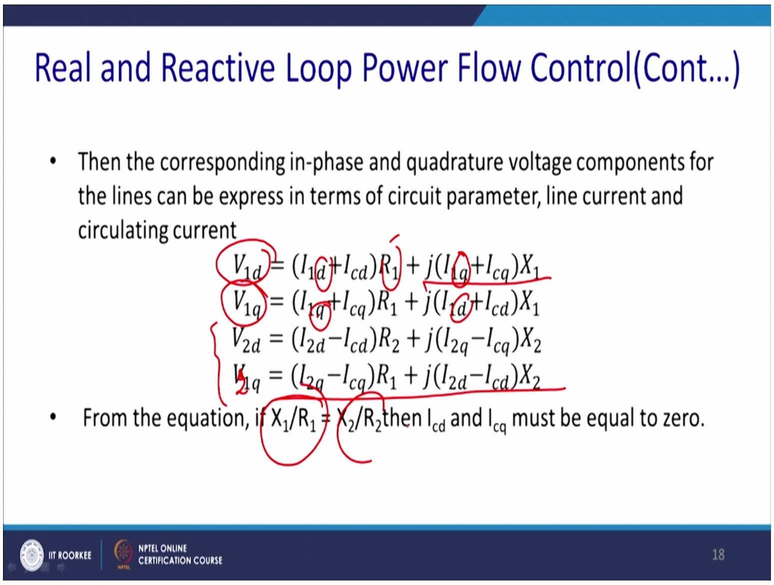

For I d 1 will be I d 1 plus the circulating current in phase with a d axis into R 1 and plus this actual reacting component there is X 1 I q into c q.

Similarly, you will have V 1 q V 1 q will be I q I 1 q plus c q into R 1 plus j I d 1 plus I c d into X 1. So, there will be a cross component of it ok. So, here it will have a real component this q with X and d with R and it will have a cross component q with r and I d with X.

So, similarly the terms of V d 2 and I q and can be written. So, this will be 2 here. So, for this reason this equation will be as follows and from this equation it is quite clear that, if this ratio X 1 R 1 and this X 2 R 2 is same then I c q and I c d both will be 0.

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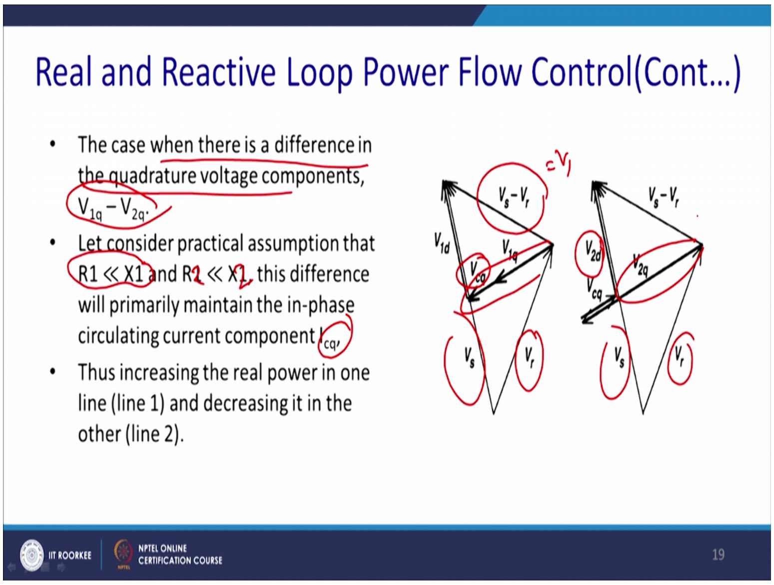

The k s when the series and the difference in the quadrature voltage component are this one V 1 q minus V 2 q let us consider the practical assumption that you know we have we know that actually X y r ratio is are on 7 or 10.

So, this much is the constraint X 1 is much greater than R 1 and similarly X 2 is much much greater than R 2. This difference is primarily will maintain the in phase circulating current component of I c q. Thus increase in real power in 1 line and decreasing lower real power in other line.

So, you will find that more line will actually flowing through the line 1 and less power is flowing to line 2. And, this will be the phasor this is basically the V I what we have represented at this is V s minus V r, this is basically V q that you have injected and ultimately this is V r and this is V s.

And, similarly what you can do you can actually you can have this opposite for the phasor for the line 2 this is actually V r and this is V s and this is V s minus V r and ultimately c q will be in this directions, and thus you know this value of this voltage will be actually more here and this will be s.

So, due to that what will happen? So, conduction will takes place in different line different manner. So, for this reason we require to compensate it.

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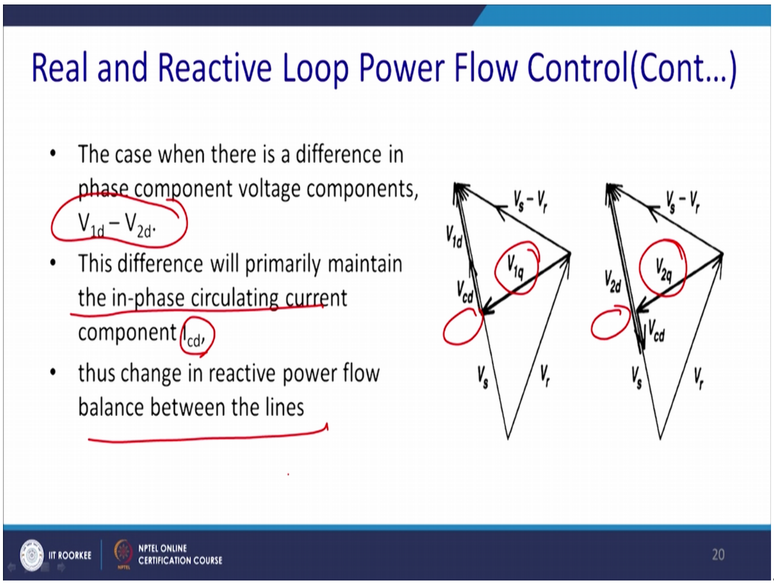

And, we write to make it this value equal and you see that we have eliminated the component actually the c q. In case when there is a difference in the phase component of the voltage component V d 1 and V d 2. The difference will primarily maintain the in phase circulating current components c d assuming and we can compensate actually these V q and this V 1 q and V q are same. And, thus change in reactive current flow will balance, but there will be a difference of the real power flow.

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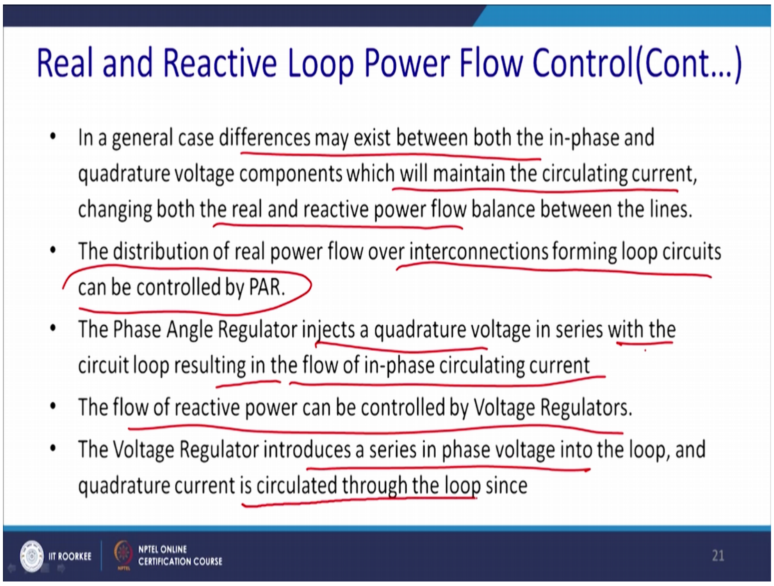

We actually come to this point then in general case the difference may exist between the both in-phase and the quadrature and the voltage component, which will maintain the circulating currents, changing both the real and the reactive power flow balance between the lines. This distribution of the real power flow over the inter connection forming the loop circuits can be controlled by P A R.

The Phase Angle Regulator injects a quadrature voltage in series thus it can effectively control the V q better, in series when with the circuit loop resulting the flow of the in phase circulating current. So, it will increase the, I d 1 and I d 2, flow of the reactive power can be controlled by the voltage regulator. So, P A R can control the current regulator, voltage regulator introduces the series in phase voltage into the loop and quadrature current is circulated through the loop. Thus both by operating with the P A R and the V A R, we can regulate the power flow between this 2 line.

Thank you for your attention I shall continue with our discussions with the power angle regulator in our next class.