Flexible AC Transmission Systems (FACTS) Devices
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Lecture - 38
Interline Power Flow Controller (IPFC)

Welcome to our lectures on FACTS devices. We have already UPFC. Now, we shall continue with a new topic.

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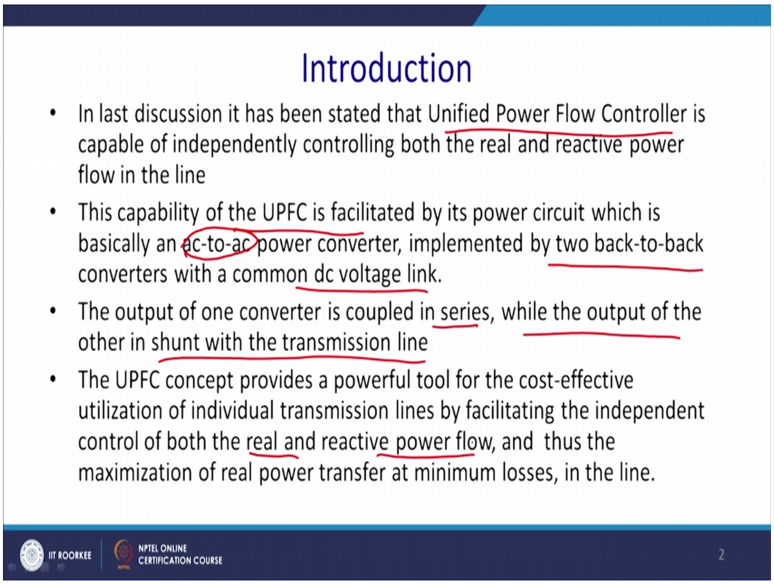

So, in last discussions it has been stated that the Unified Power Flow Controller that is UPFC is capable of independently controlling the both real and reactive flow of the line, it is possible to control independently flow of power. But, that for this session we required to both shunt and series compensation together. But there is a limitation of only series compensation, mostly in case of the impedance injection.

The capability of the UPFC is facilitated by its power circuit, which is basically ac-to-ac power conversion. So, it takes power maybe through the shunt root, and inject power to the series root in case of the sag condition and vice versa, in case of the maybe the swell condition. Implemented by two back-to-back converter which we have seen in our discussing, when we discuss the UPFC with the common dc link. The output of the one converter is coupled in series, while the output of the other shunt is connected with the transmission line.

The UPFC concept provides powerful tool to cost-effective utilizations of the individual transmission line by facilitating independent control both real and the reactive power flow. And thus maximum thus it actually optimizes basically the real power transfer, and minimize the losses. So, it is be optimizing the all the operating criterions.

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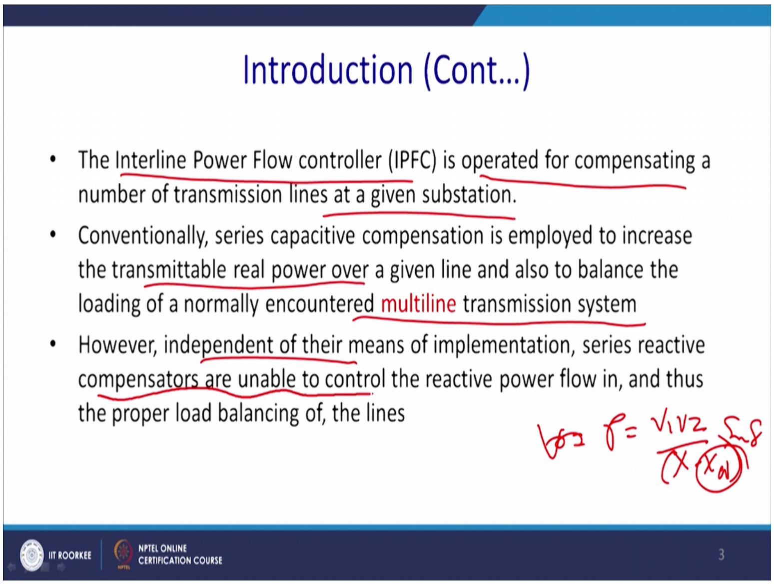

Now, we shall discuss, now the Interline Power Flow Controller. And we see the, limitation of the normal shunt compensations, series compensation, mostly series compensations, because power flow can be handled at by the series compensation. And will find the limitations of it.

Then from that limitations, we try to derive the necessity of the interline power flow controller. It is operated for the compensating number of transmission lines at a given substation, maybe is a three-phase three-wire system of three-phase four-wire system. Conventionally, the series compensation is employed to increase the transportable real power over a given a balance loading of a normally encounter multiple line system.

So, we know that actually, we have steady-series compensation in detail. Ultimately, V is given by ultimately, power is given by V 1 V 2 by X, where X will be X q into sin delta. So, X q is a injecting impendence in this mode mostly. We actually increase the power flow, or get X enhancement can be done.

However, there is a there is a problem in it. Independent power flow of p and q is implemented by the series reacting compensator are unable to control the reactive power flow, where it can increase the real power flow, but it cannot actually control the reactive power flow in the line. And thus, it cannot be properly balance the loading of the line. So, this is the limitation of the, actual impedance mode series compensation.

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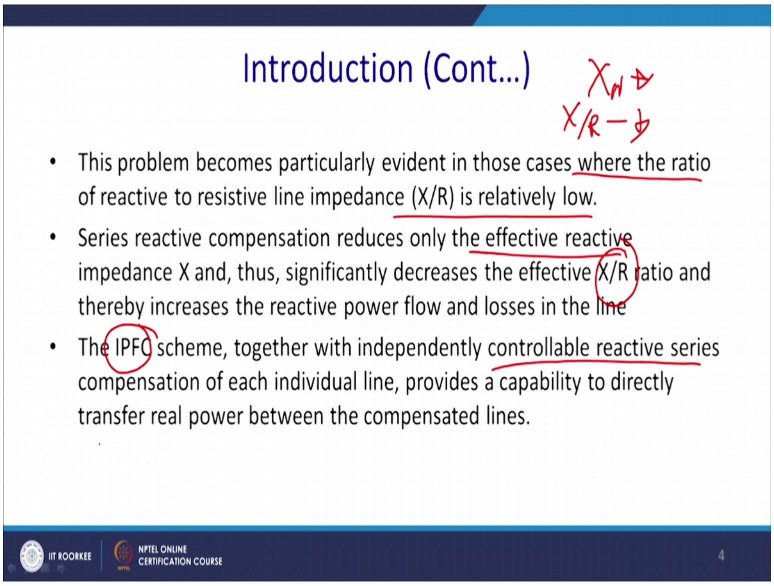

Moreover, what happened, when your when actually you are injecting the value of X q, mostly you actually subtract the value from the X l, then value of the X by R ratio get reduced. So, this problem becomes particularly evident, in those cases, where the ratio of the reactive and the resistive impedance is quite low during the injection of the X q.

Series reactive compensations reduces only the effective reactive impedance X. So, what happened, thus significantly decreases the effective X by R ratio, and thereby increases the reactive power flow and the losses in the line. Essentially current get increase, so i square losses will definitely is going to increase here.

So, but we will then actually, now we should discuss about the IPFC. So, you see that what is advantage of it scheme. Together with the independently control of the, here it is possible to have a independent control of the flow of the real power and reactive power that is what, we can state that. The together with independently controllable reactive series compensations of individual lines, provides a capability to directly transfer the real power between the compensated lines. So, this is the advantage of the IPFC.

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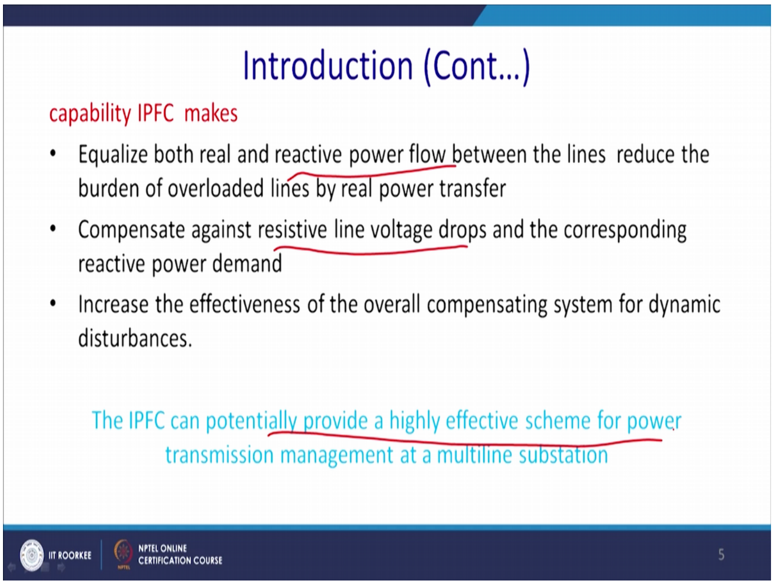

So, what we can state what is actually its capability. IPFC makes equalized both real and reactive power flow between the line, and reduces the burden of the overloaded line for real power transfer. It is a typical case in railways, where may be the one line is heavily loaded, because of the there has a the trucks is running in a particular line, and other lines are not so much overloaded So, IPFC finds huge application in this kind of system.

Compensate against the resistive line voltage drop, and corresponding to the reactive power demand. So, it is does not change X by R ratio, so it can does this compensation also, increases effectiveness of the overall transmission system of the dynamic disturbance. Because, if there is actually if there is a sag in a particular line, they need can acts very fast compared to the series or shunt compensation.

Thus, what we can say that IPFC can potentially provide a highly effective schemes for the power transmission management of the multiline substation. Ultimately, if there is a sag in one line, and swell is in another line, so it can transfer power from the, one transmission line to the other transmission line.

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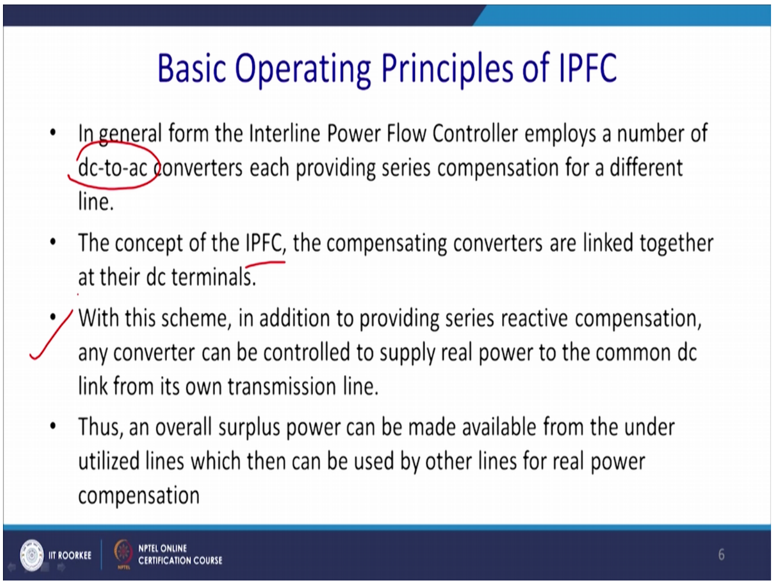

So, in general form of intermit and power flow controller implies is the same number of dc-to-ac converters, each providing series compensation of different lines. The concept of IPSC IPFC, the composite converter is linked together by the terminal. And the dc links are common, will come to this actually the picture in next slides.

In this scheme, in addition to providing the series reactive compensation, any converter can be controlled to supply real power to the common dc link, form its own transmission line. Thus, an overall surplus of power can be made available from under the utilize lines, which can be used other lines over the real power compensation. So, these are actually the basic operating principle of the IPFC.

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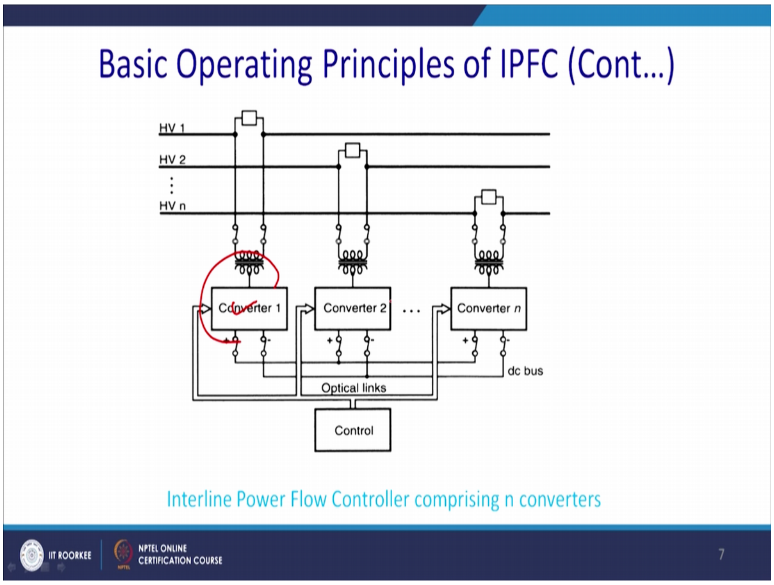

Now, this is a line. So, this is converter 1. And all generally have a common dc link. And this is connected via transformer, because of the rating, because it is connected in the high voltage line. So, power electronic device cannot directly sustain that rating for this will be required to have a step down transformer.

And thus, you have a converter 1 that will be injecting the power or flow of power in line 1 that is HV 1, same way HV 2 and HV 3. So, if there is an in exchange of power, and sometimes it may be actually have a six lines, because there might be a parallel line accordingly. It can be actually made to operate in this fashion. There can be a multiple high voltage transmission line.

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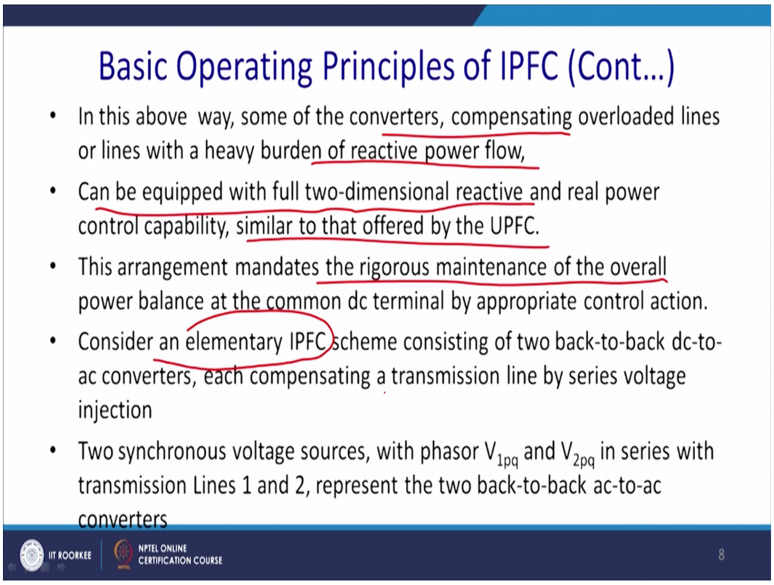

So, let us continue with the basic operating principle. In this above way, as discussed in previous slide, some converters converter compositing overload lines, on the other with a heavy burden of the reactive power flow. And what happened, then it can be equipped with the full two-dimensional reactive and the real power flow control capability that is what we have discussing in case of the railway that burden in a particular line is heavy. If the current is heavy definitely, you know actually with the current reactive as well as real both the parameter becomes heavily. Similar to the similar it can be offered by the UPFC.

So, one of the advantages that is a component counts; so it can only actually have interline power quality, so it does not have a series shunt path to compensated sorry. The arrangement mandates, the rigorous maintenance of the overall power balance at the common dc terminal by appropriate control action.

Here you required to control the dc link voltage quite effective means. Let us consider an elementary IPFC scheme consisting of two back-to-back dc-to-ac converters, each compensating a transmission line in series voltage injections. Two synchronous voltage, let us with the phasor will discuss in next slide with V p that is that is in having a voltage of V 1 p q. And similarly, the second one will have a p 2 p q, in series with the transmission lines, 1 and 2, and it has been connected back-to-back with ac-to-ac converters.

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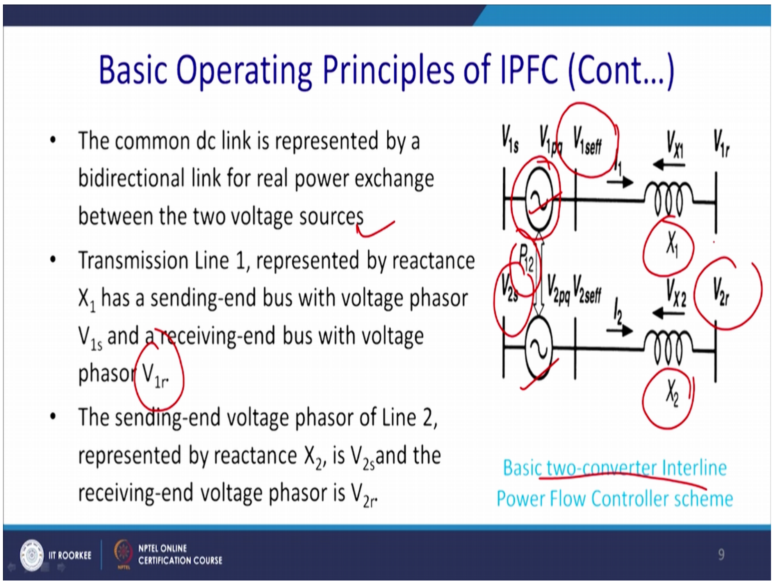

So, let us take us these pictures. So, this is a basic two-converter intermit and powerful line conditioner scheme. So, this is basically your V P 1, so actually it will inject it will inject the voltage same way, the series compensation of p q. And effectively these voltage become V 1 effective, and thus you can same power.

And one of the major benefits is that it can exchange power P 1, P 2 between this line, to compensate this lines. If one line is heavily loaded, it can take some of the power transfer to the second line. And thus, overall power handling capability of the line gets increase, because this line will not touch the thermal and insulation limits.

The common dc link voltage is represented by a bidirectional link of real power exchange between the two voltage sources, this is that the case. The transmission line l 1 represented by the reactants this one reactants X 1 and has the sending-end bus voltage, bus voltage phasor V s 1, and receiving-end bus voltage phasor V 1 r.

The sending-end phasor line for same, it will be for the, thus the nomenclature will be changed with a suffix 2. So, you have a V s 2, you have V 2 p q, you have x 2. Similarly, the voltage drop across the inductor will be V x 2, and the receiving end is V r 2. So, this is the case.

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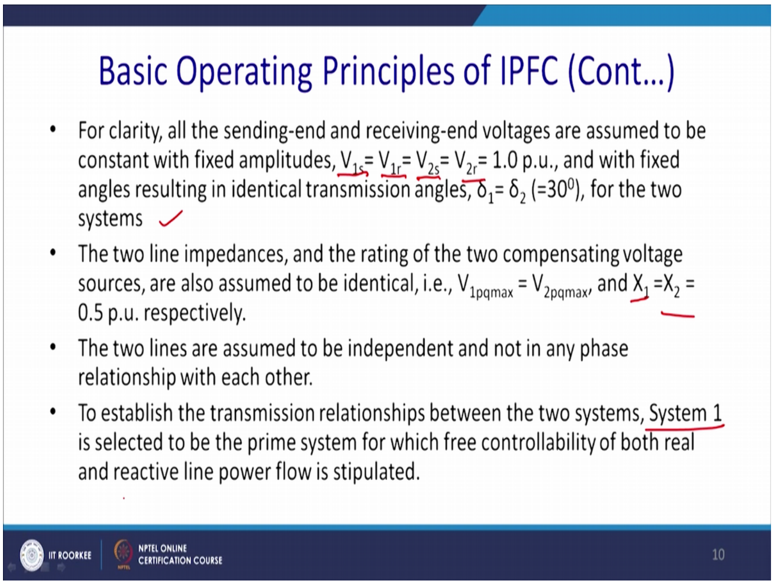

Now, for clarity, let us let us take all those condition in advance. All the sending-end and the receiving-end voltage, assumed to be constant with the fix amplitude, that mean V s 1, V r 1, V s 2, V r 2 all are at one per unit at its base values. With the fix angle, resulting the identical transmission angles, let us say delta equal to delta 1 equal to delta 2 equal to let us say to 30 degree or 45 degree, for the two machine model.

The two line independence impedances of the ratio of the two compensating voltage sources, are also assumed to be identical, that mean V 1 p q max that is maximum amount of the compensation, that be that should be equal to V 2 p q max, and that should be X 1, that should be equal to X 2. These are all identical with 0.5 per unit base value.

The two lines are assumed to be independent and not any phase relation between each other. We should assumed that there actually independent lines, it is not that. If it is a, and another line is b, so there is a 120 degree phase shifted, something like that. To establish the transmission line relationship between the two systems, system 1 is selected with a prime system, which is a controllable by both real and reactive power line as stipulated or as designed.

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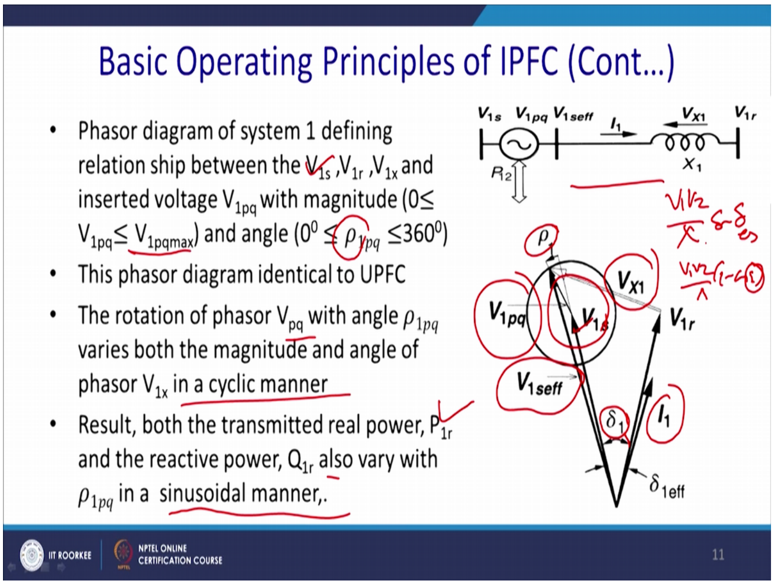

So, let us discuss about the actually the first line of IPFC. So, this is the one line diagram of IPFC with single a, and this is a phasor of the IPFC. So, you can see that actually before compensation, this was the V s 1, this magnitude was V s 1. And effectively that angle was delta 1.

Now, you have injected the voltage V 1 p q, if you see that it is need not be a quadrature, need not be a phase, it is a angle desired to optimize the rating. So, ultimately this is the angle, and ultimately this is this is basically the amount of the rho composition rho 1. So, effectively this voltage we can V seff 1, and effectively this voltage drop across this impedance become V x 1. And thus, current is basically I 1 that remain unchanged, please note that and effectively with a delta also changes.

So, we can see that value of V 1 increases effective it becomes V 1 V 1 effective and also, the delta 1 effective. So, from this discussion, let us see that what happened here. Phasor diagram of the system 1, defining the relationship between V s 1, V r 1, V 1 x, and inserted voltage V 1 p q with the magnitude that is that is a V p V q 1 have a magnitude of greater than 0, and less than V p 1 q max. And the angle that is the maximum angle of compensation that is V rho 1 p q that is that is 0 to maximum 360 degree, it can have all the angle of injection.

The relation of the phasor p q with angle rho 1 p q, where is both magnitude and the angle of the phasor V 1 x in a cyclic manner. So, it can rotate inside, the sphere of all the circle of influence. Thus, what happened, the transmitted power, P 1 r, and the and the transmitted reactive power, Q 1 r also varied with the actually rho 1 p q in the sinusoidal manner.

So, as this angle changes, since delta changes, and thus the power flow both power reactive as well as real get change. Why, because actually V 1 V 2 X by sin delta effective, and it is V 1 V 2 X 1 minus cos delta by (Refer Time: 18:49) transfer by delta effective. So, it will be varying sinusoidally.

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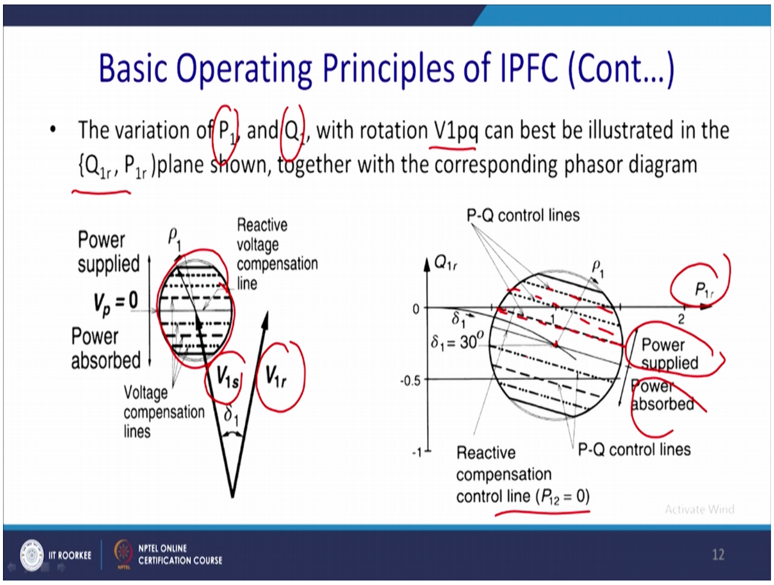

So, the variation of the P 1, and Q 1, with rotation of the V 1 q can be best illustrated in sending-end power that is P 1 r, and P q r, shown in the plane, together that correspond to the phasor diagram. See that this is the V s 1, and this is actually V r 1, and this is circle is basic essential is a sphere of influence. And the compensating voltage line are this dotted quads. And the reactive power compensation lines are basically the board lines.

So, let us take this figured here. And assumed that it is operating some value of the angle, so essentially you have the plot of P in x axis, P 1 r in x axis, and Q r in a imaginary axis, and ultimately, your operating here, this is your sphere of influence, this whole is a sphere of influence. And ultimately, this dotted quads are essentially your are the P-Q line.

You can actually go from point here, you can go to this point, you can go to this point, you can go to this point. And this represents you know, if this is that is diameter represents actually, if it is above the diameter, then essentially then IPFC is supplying power to the second source, second line, second UPFC IPFC.

And if it is operating below this diameter, then actually it is essentially absorbing power from another IPFC. So, this is the principle operation of the IPFC. So, reactive power compensations in this line is 0 for this compensation. And here, we have assume that delta to be 30 degree. So, for this session, we have this mode of operation.

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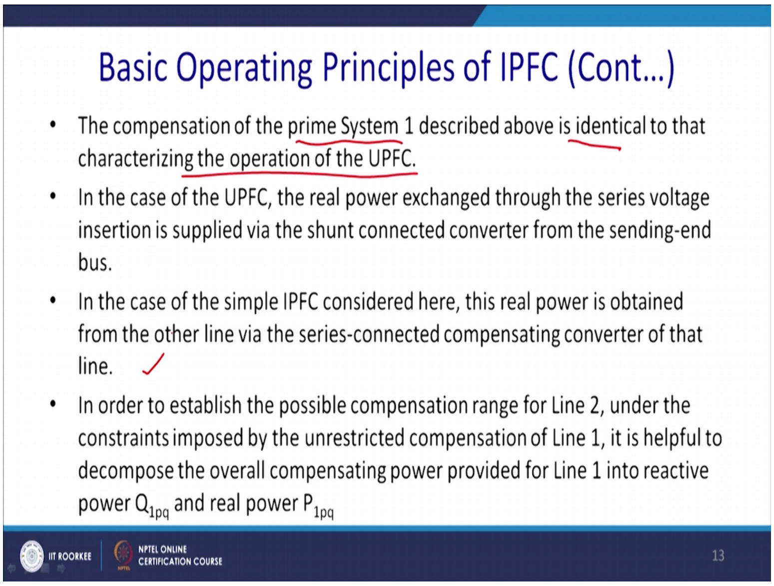

Now, so from this discussions, we can conclude that compensations of the prime system 1, described by the previous slide. So, that is identical to that characterization operation of the UPFC that we have discussed in the, when you were discussing UPFC. In case of the UPFC, the real power exchange to the series voltage insertion is supplied by a shunt-connected converter from the sending-end bus.

So, whatever extra power is required to be supplied or managed, this is done by the shunt compensation, but here, there will be a another IPFC to do that. In case of the IPFC, in case of the simple IPFC considered here, the real power is obtained from the other line via the series-connected compensating converter of the line. So, that will be fed to another convert, another series converter. So, there is no concept of the shunt compensation, you have seeing that actual value of the current remain I 1 only, before and after competition.

In order to establish the possible compensation range of line 2, under constant imposed by the unrestricted compensation of the line 1, it helps to decompose the overall compositing power provided for the line 1 into reactive P 1 q r and Q 1 p r. So, we can split into these two component and individually they can be controlled.

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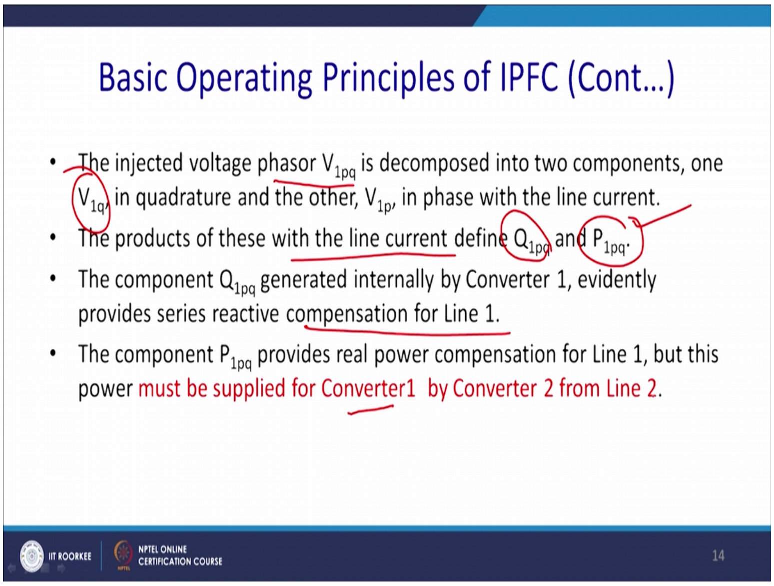

The voltage injection of the phasor V 1 p q, it decompose into the two components, one definitely V 1 q that is a reactive component of it, then quadratures, and other V 1 p, in phase with the line current. The product of these with the line current defined, Q 1 p q, similarly with a in phase component with I give you P 1 p q.

The component Q 1 p q is generated internally by the converter, because it can because it can generate the reactive power, and evidently provides the series reactive compensation for line 1. But, real power this component, whether it will be absorbed or supplied. So, it has to be fed or donated by the second converter. The component P 1 p q, provides a real power compensation of line 1, but this power must be supplied for the converter 1 by converter 2 of the line. So, second one should actually compensate the real power requirement of the first one, and vice versa.

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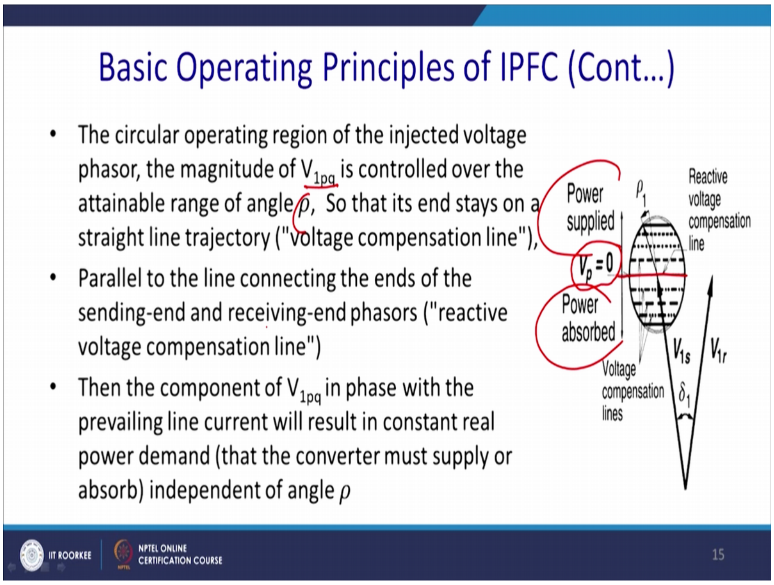

So, operate the circular operating region that is a circle of interference. Region of the injected voltage of the phasor, at and the magnitude V p 1, V 1 p q is controlled over the attainable angle rho. So, that its end stays on the straight line trajectory, that mean you have to operate in this line.

So, this line you know, this line is actually there is no compensation for real power. So, you are injecting no real power, thus it need not have to exchange any power from another converter, but if you are operating above it. So, you have to supply the real power, if you have operate below it, you have to supply the real power to another IPFC. And essentially, these dotted lines are the voltage compensations. So, you can take it to this line, anywhere in between. So, you do not have any compensation, you are essentially changing the delta.

The parallel to the line connected the ends of the sending and the receiving end phases, the reactive voltage compensation line. Then the component of V 1 p q in phase with the prevailing line current will result in constant real power demand, and that the converter must supply or absorb independently the half angle rho 1. So, this is the angle rho 1. So, this is way it should be operated.

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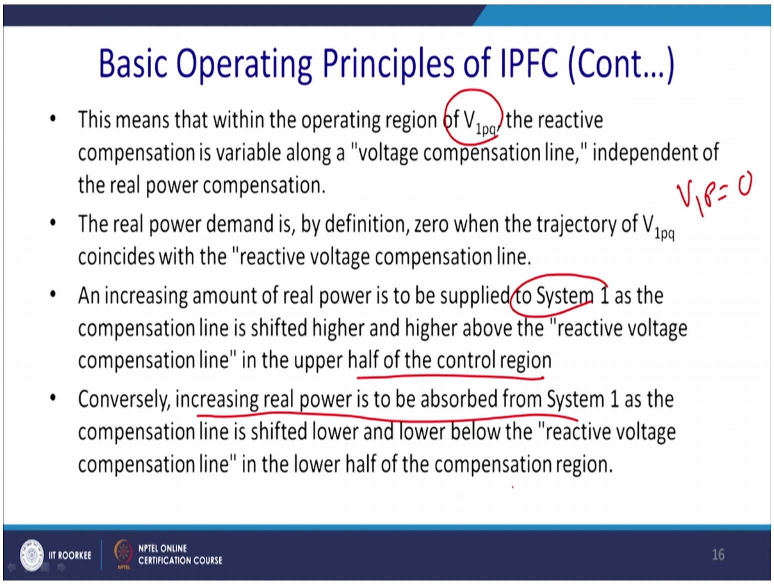

So, this means that within the operating region V 1 p q, the reactive compensation is variable along a voltage compensation line, independent of the real power compensation. The real power demand is, by definition zero, when trajectory of V 1 p q coincide with the reactive voltage compensation line. So, we when you are actually V p 1 essentially is 0, then your real power compensation is 0.

And increasing amount of the real power is to be supply to the system 1 as compensation line shifted higher and higher about the reactive voltage compensation line, the upper half of the control region. So, this is the case. So, it will shift to the upper half of the control region. Conversely, the increasing real power to be absorbed by the system 1 as a compensation line shifted lower and lower and the lower below. The reactive voltage line reactive voltage compensation line, the lower half of the composition region, more and both power will be absorbed.

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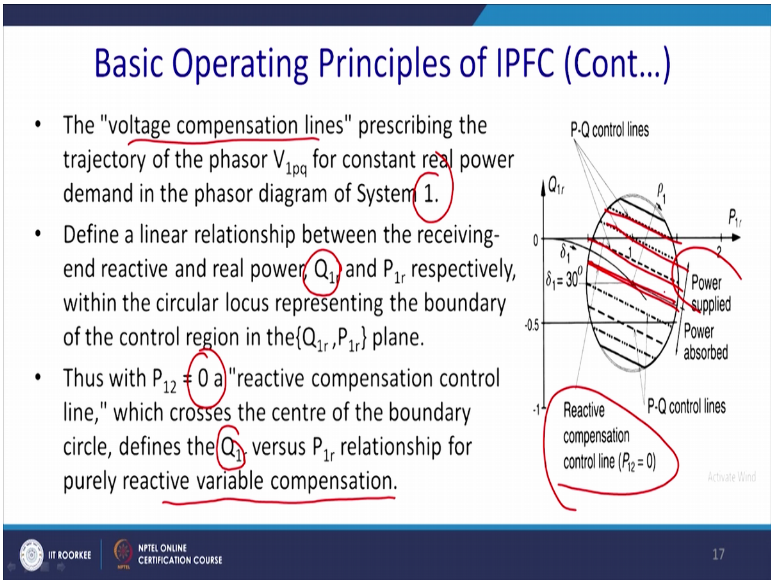

Thus, voltage compensation line prescribing the trajectory for the phasor p 1 q for the constant real power demands in the phasor diagram of system 1. So, this is the power supplied above it above the diameter, and this is a power absorbed, and this is the P-Q line, these are the constant P-Q line with if it operates in this P-Q line, you know this is a constant P-Q line.

Define a linear relationship between the receiving-end reactive and the real power of Q 1 r and P 1 r respectively within a circular locus compensating the boundary of the control region of Q 1 r, and P 1 r plane. Thus with P 1 2 equal to 0, what happened then it only compensate the reactive power; the reactive power compensation control within the line, which crosses the center of the boundary. So, this is the line of the circle defines P 1 Q 1 r versus P 1 r relationship, purely reactive variable compensation. So, this is the line corresponds to purely reactive variable compensation, where no real power exchange between two IPFC, this is the line essentially, this become the diameter of the circle of influence.

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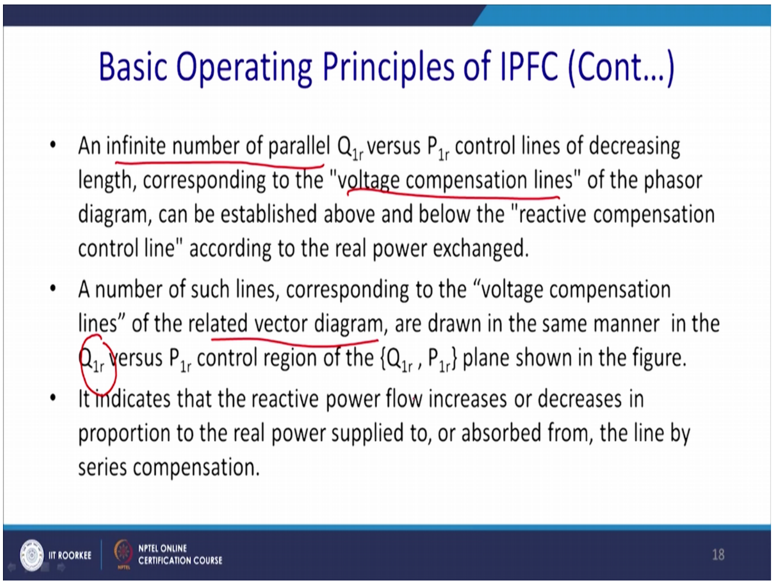

So, from the discussions, we can say that an infinite number of parallel lines, parallel P parallel Q 1 r verses P 1 r lines of decreasing length corresponding to the voltage composition line as you go up for the phasor diagram, can be established. So, what happened, you know this length decreases as we go up the compensation increases. Similarly, also you decrease.

Number of such line corresponds to the voltage compensations lines of the related vector diagram, as shown into the previous two slides, are shown the same manner in the in the Q 1 r verses P 1 r control region of Q 1 r, and P 1 r plane, as shown into the previous figure. It indicates that the reactive power flow increases or decreases in proportional to the real power supplied or absorbed, from the line by the series compensation.

Thank you for your kind attention. We shall continue with the IPFC also in the next class.