Flexible AC Transmission Systems (FACTS) Devices
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Lecture – 21
Series Compensator

Welcome to our NPTEL lectures series of Flexible AC Transmission System. We have already discussed shunt compensation. Now, we are going to discuss today the series compensation. So, Series Compensation is another important aspect of the shunt compensation. So, our presentation layout of the discussions will be on the following talk with introduction of the series compensation.

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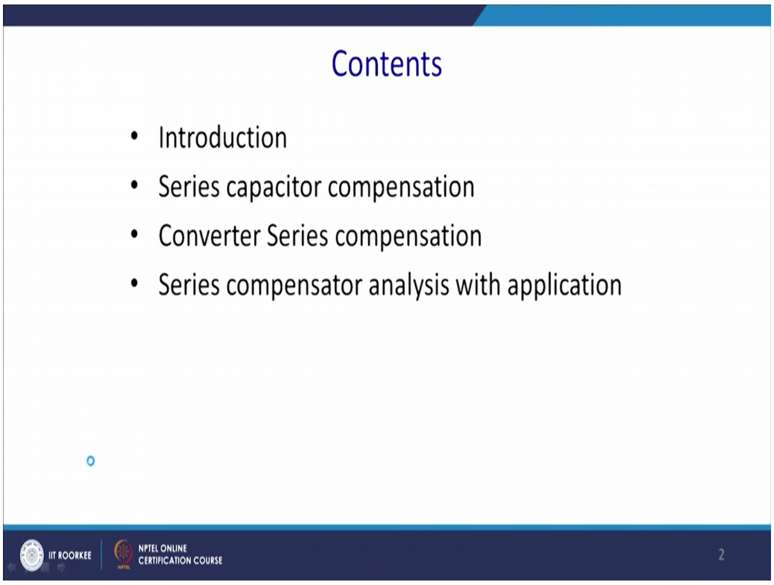

They are the different type of the series compensation that is series capacitor compensation, converter series compensation and series compensator analysis and with its applications. Now, why you require a series compensation, the we should start with the we should start with the actually the limitation of the shunt compensation.

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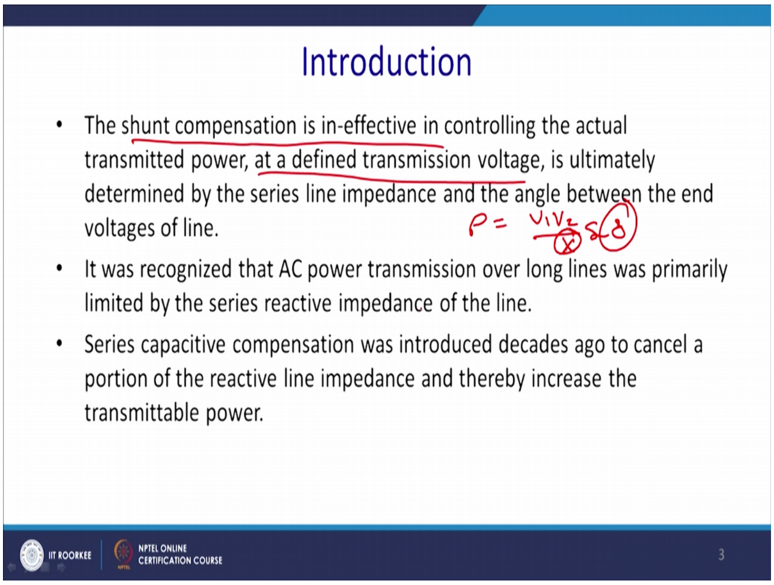

Shunt compensation is an ineffective is ineffective in controlling the actual transmitted power real power, it can actually control over the reactive power, as well as it can maintain the voltage regulation of the receiving end, but it cannot control the flow of the real power into the system.

At a definite at a define transmission voltage, it is ultimately determined by the series impedance. Because P equal to V 1 sending end voltage receiving end voltage by X into sin delta this is the equation. So, ultimately depends on the X and, the angle between the angle between the sending and receiving voltage that is delta. So, that is the power transmission and, shunt impedance does not starch either this or this ok.

It was recognized that the AC power transmission over the long line, primarily limited to the series reactive impedance of the line. So, ultimately it is depending on the X, if you can control the X the you can also control the flow of the real power with the transmission system. So, what it is been introduced you know, we have discussed in a will power in our first or second lectures, that is series capacitive compensation was introduced a decade ago, to cancel a portion of the reactive impedance and thereby increasing the power handling capability of the power line.

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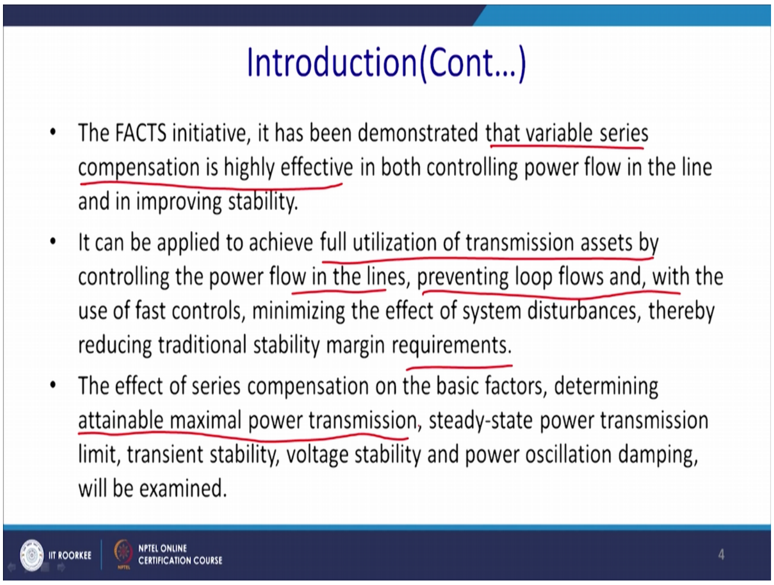

But it has got some limitations the facts initiative, because you know it will insert the capacitive volt impedance, in casually and with the mechanical switches and that mostly most of the cases it leads to the sub harmonic oscillation.

The facts initiatives has been demonstrated that a variable series compensator, is highly effective in both controlling the flow of the power flow in the line and improving the stability. We shall discussed and we shall prove it, more over it can be applied to achieve the full utilization of the transition asset, by controlling the power flow in the lines preventing the loop flow and with the use of the fast control minimizing the effect of the system disturbance and thus reducing he traditional stability margin requirement.

So, in a in a nutshell or in a one sentence, we can say that it is possible to enhance the stability limit with the series compensation. And, the effect of the series compensation on this two basic factor determining the attainable maximum power transmission. So, we can see that there are we have discussed there is a thermal limit there is a isolation limit. So, we required to check those aspects.

So, we can use the thermal limited optimally by using this actually optimally using the value of the impedance and, the steady state power transmission limit, transient stability, voltage stability, and power oscillation damping also will be examined with the series injection.

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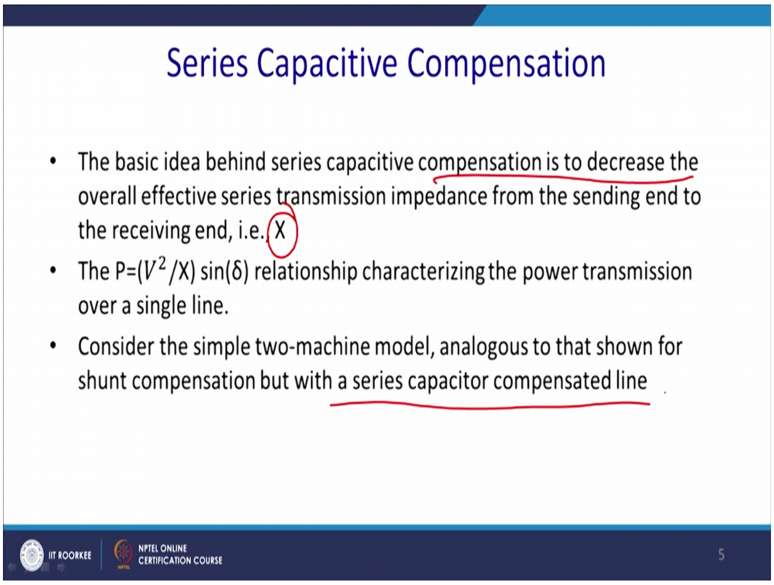

Now, the basic idea is to control the impedance, the basic idea behind the series capacitive a compensation is to decrease the overall effective series transmission impedance, from the sending end to receiving end that mean the impedance X, they P the V square by sin delta relationship characterizing the transmission line of a single line system.

And now let us consider a simple two machine model, which are already discussed in case of the shunt compensation analogous to that shown for the shunt compensation, but they will be a series capacitor compensation in the line itself. So, there is a little change what we have discussed in case of the shunt compensation. So, what happened see the circuit this is the same to machine model, we will insert the extra capacitance here.

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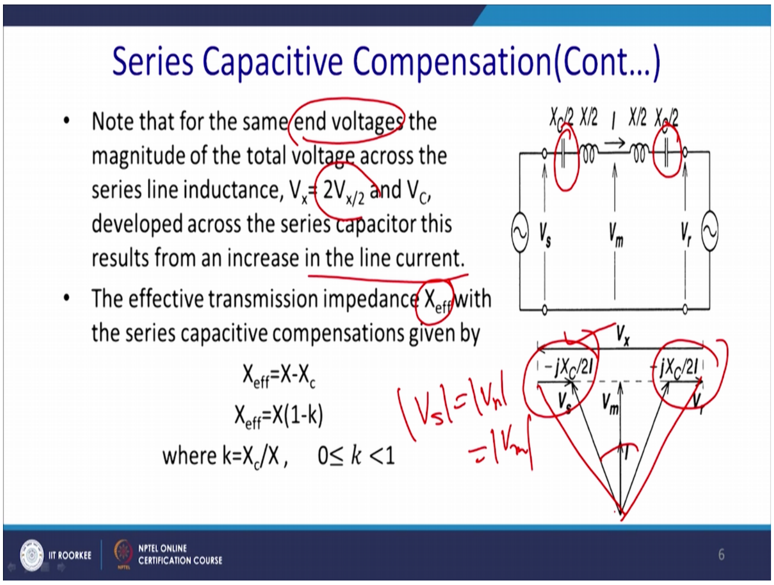

And we will split this inductance by 2 and this is V c and this value is V m and this value is V r. So, thus note that the same sending end voltage and the magnitude of V s equal to V r equal to V m. So, this is our assumption so, we can state that note that the same end voltage that we receiving, end voltage. And the magnitude of the total voltage across the line inductance is V x and V x is given by from this trigonometry, we can find out what is the value of the V x. So, this value essentially is the V x. So, V x is basically 2 V x by 2 and V c develops V c developed across the series capacitor this results from an increased in the line current.

So, what happen overall impedance decreases, since a overall impedance is decreased so, current will increase. The effective transmission impedance e effective with the series capacitive compensation will be given by X the previous with the uncompensated impedance. Most of the cases will be minus it will minus X c and thus e effective will be you can take X common this is 1 minus k per k is X c by X and k can be ranges to 0 2 1.

And ultimately we whatever same compensation, we have seen it will be there this is V s and this is V r and you can add up hear, or you can add up here and ultimately it will be stretching. So, power angle on the new actually V s, V r will be this and, that it will also increases the sometime the angle between these 2 sending and receiving end voltage. And that is what we said little bit earlier that V s equal to V r that may be equal to mod V.

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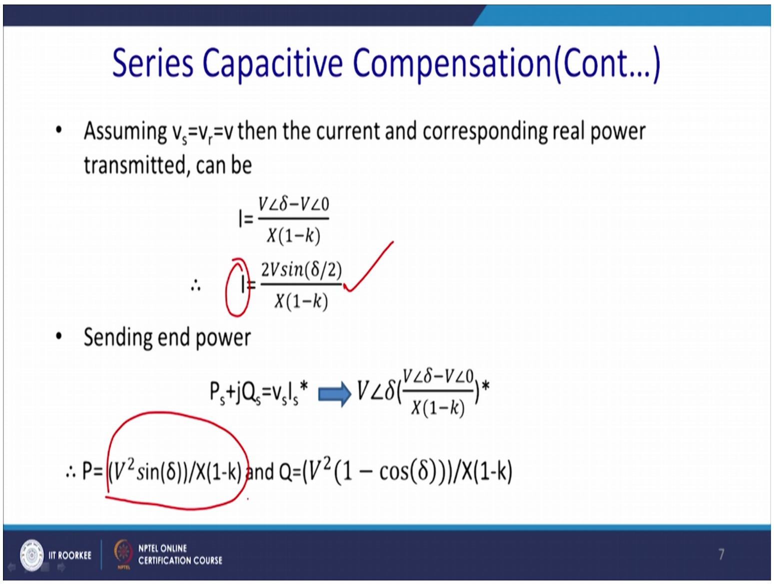

And the current corresponding to the real power transmitted by actually i that is V minus delta by V 0 by X. Now, it is been changed to 1 minus k that is you know current changes to 2 V sin delta by 2 X k minus 1. And the we can write the sending end power. So, it is actually V s into I s star so, you have to multiply this V dealt with this quantity.

Ultimately this quantity becomes for the real power become V square sin delta by X and, we you have to equate the real and imaginary term, segregating the real and imaginary term, we can be see that this value of the real power becomes V square by sin delta by X 1 minus k. And similarly the reactive power becomes V square 1 minus cos delta by X by 1 minus k.

So, if k is 0.5 state away you have actually 2 4 increase of your real and the reactive power. So, same way whatever power has been send that will be received.

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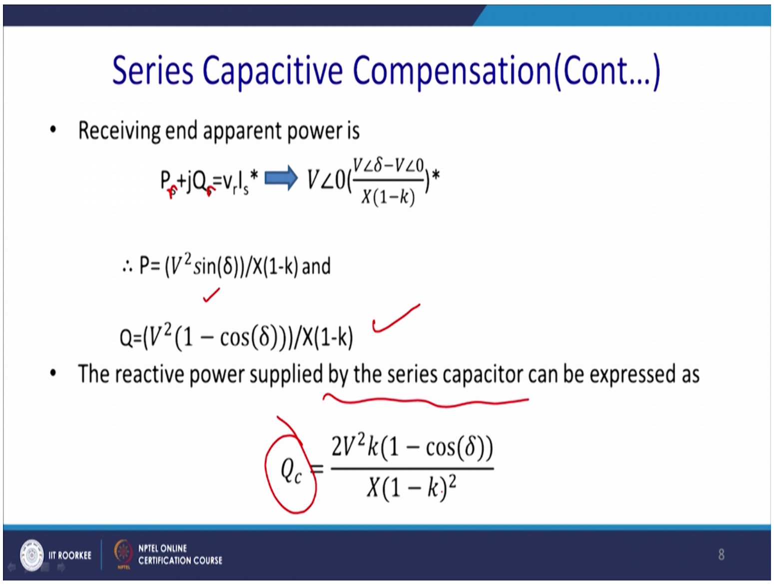

So, that is you know we can write receiving end power P r and Q r it is will be given by V r into I s, because I s will be same because it is knows shunt compensation is there, current through the all the element would be equal. So, same value will get and ultimately you get this V square sin delta by X 1 minus k similarly this 1.

That is what we can say you know the reactive power supplied by the series capacitor will be this reference of the sending end power and receiving end power and so, the reactive power supply by this series capacitor will be 2 V square by k 1 minus cos delta X 1 minus k whole square.

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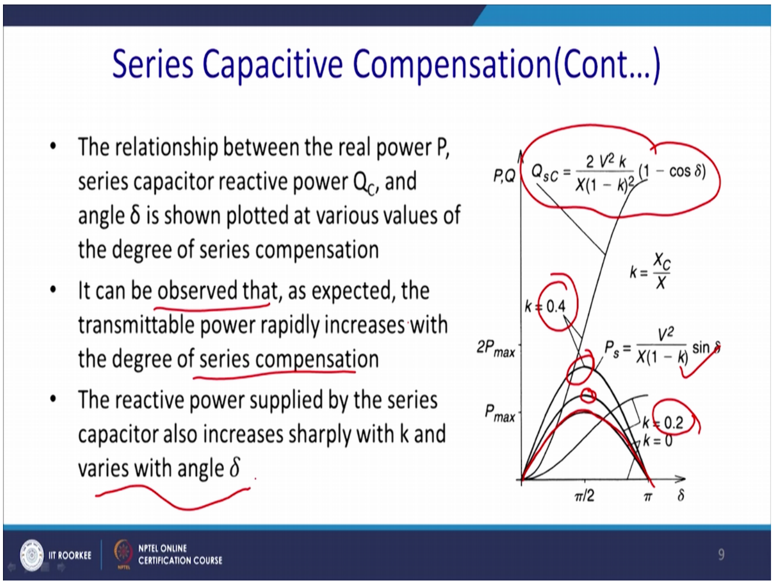

So, let us see what is the implication of this expression now, this is the actually X axis we have plotted phase angle delta and P and Q are plotted. So, this value corresponds to k equal to 0.4. So, you can see that for k equal to 0 corresponds to this graph with no compensation. If you make k equal to 0.2 you can have this graph.

And if you makes k equal to 0.4, you have this graph and same way k equal to 0.4, you have this is the power handled by this series capacitors so, it will be Q c. Thus, what we can state the relation between the real power and the series capacitor reactive power Q c and the angle delta, is shown plotted at a various values of the series compensation starting from value equal to k equal to 0, 0.2 and 0.4.

It can be observed that has express the transmitted power rapidly increases, with the degree of the series compensation of course, you know and if you can if you make this k theoretical. If it is possible 0.9 so, you have a 10 hold increase in this transmission of the real power. The reactive power supply by the series capacitor also increases sharply, with k and k and the vary k and variation of the angle delta.

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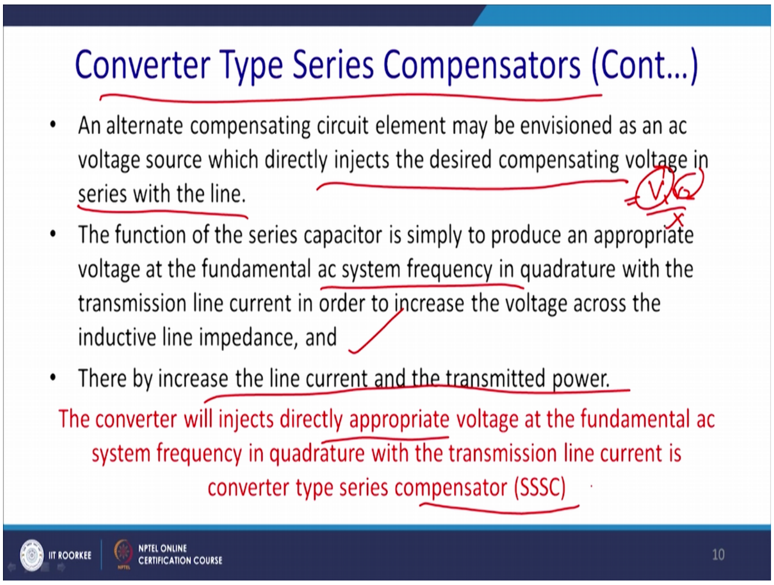

Now, converter type series compensator this type of compensation is called actually it is analogues to the (Refer Time: 13:12) in case of the in case of the shunt compensation. So, what you generally do, you will generally minimize the value of the impedance and, thus you get the enhance power handling capability real as well as the reactive power handling capability of the line, at the cost of the reduced impedance. So, current will be high and the thermal (Refer Time: 13:36) will be high these are the few issues will be there.

Let us see another type of the series compensation. So, this is called converter series type compensation and, alternate compensation compensating circuit element may be investigated as an ac source voltage, which directly injects the desired compensating voltage in series with the line. So, it will inject the voltage. So, same way it will manipulate the actually the a converter and, it will inject the voltage may be in series with the quadrature with the sending end voltage. And ultimately what will happen you know that the power is given by V 1, V 2 by X so, these value or these value may change depending on the position of the converter.

The function of the series capacitor is to simply produce, an appropriate voltage at the fundamental ac system frequency in quadrature in the transmission line in order to increase the voltage across the inductive line impedance. So, this is the function of this capacitor.

And thereby it increases the line current of the transmitted power. So, ultimately it reduces the value of X and this current increases ultimately extra current is the cause of extra transmitting power. So, if you are transporting ten times more that mean you are sending 10 times more current. So, you would be touching the thermal limit very soon, for this is this is not effective solution because, your because of the high current flows through the system.

Converter will inject directly the appropriate voltage at the fundamental ac system frequency in quadrature with the transmission line current, converter type series compensation for triple SC. So, this is the case here for triple SC it will inject the voltage in quadrature. Now, what happened?

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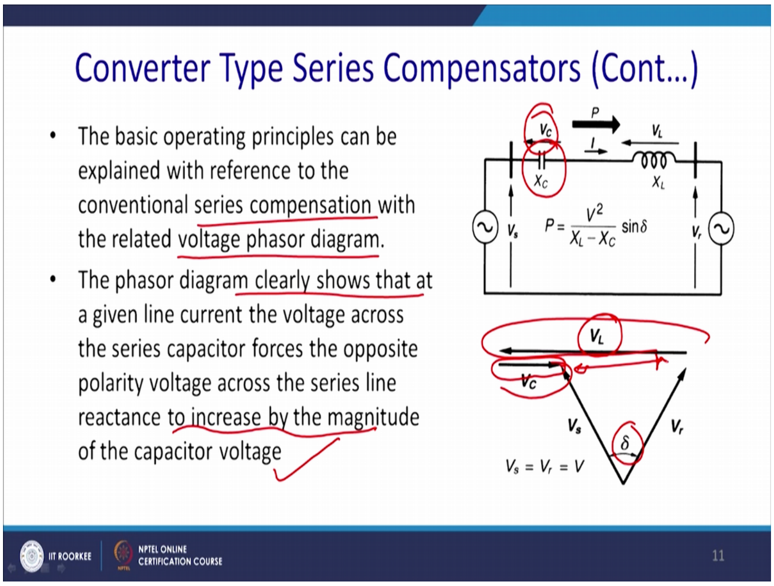

Let us see this is the actually the system background of this capacitor compensation. So, you have a X C ultimately there we have voltage V C and, ultimately you got the power V square X L minus X C sin delta. So, basic operation principle can be explained with the reference to the conventional series compensation with the related voltage phasor diagram.

So, what happen you know this is the angle delta this is V S and this is V L and, ultimately what will happen V C will be in this direction and, V L will be in this direction. So, what we can infer from this actually this phasor diagram. The phasor diagram clearly shows that at a given line current, the voltage across the series capacitor forces the opposite polarity voltage, across the series line reactance to increase reactance to increase by the magnitude of the capacitor voltage. So, this one was V L and this one was V C that is ultimately this became V L minus V C this voltage.

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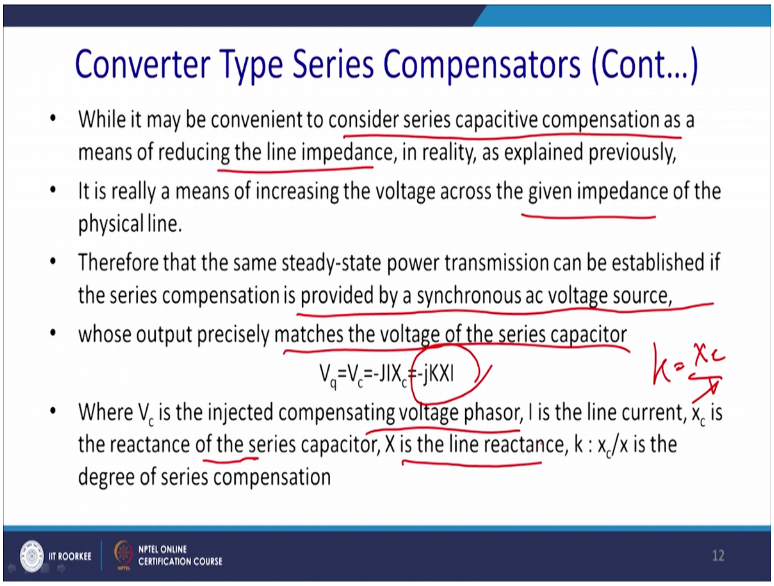

So, what we can conclude for this phasor, while it may be convenient to consider series capacitance compensation as a means of reducing the line impedance. As we have explained previously, it is really means to increase the voltage across the across the given importance of the physical line.

So, because you know voltage increases and, that is you know you make touch the insulation level. Therefore, what happened the same steady state power transmission can be established, if the series compensation is provided by the synchronous ac voltage source. So, we can we had a STATCOM, that is had a synchronous condenser and, it can be actually replaced by a series injecting a voltage source, but facts is a static solution mind it and we would not talk about any rotational solution, that was previously used for the putting long time.

Thus whose output precisely matches with the voltage of the series capacitor so, V q equal to V c equal to JIX c, ultimately we can write that value equal to minus j K into X I, because you know that k equal to x c by x. Where the V c is the injected compensating voltage phasor and, I is a line current X is the reference of the series X is the reactance of the series capacitor X is a line reactance and where k is x c by x and, it is a degree of compensation.

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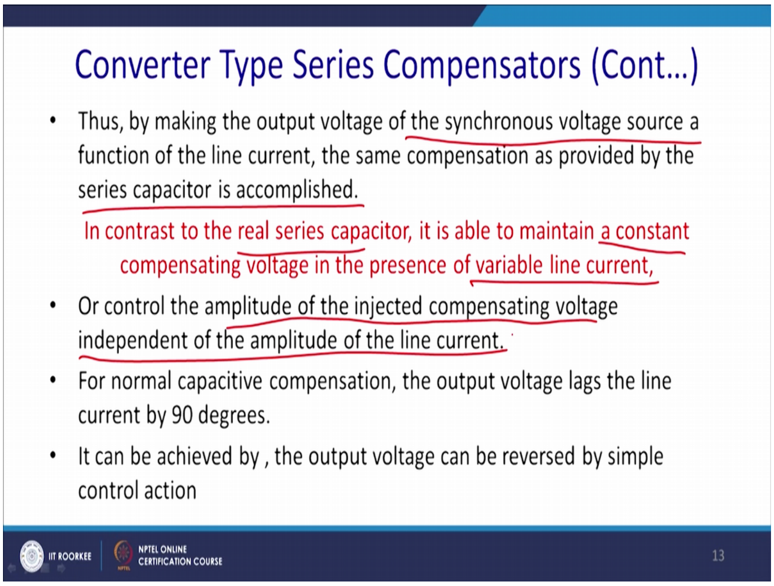

So, thus by making the output voltage of the series, output voltage of the synchronous, voltage source a function of the line current the same compensation as provided by the series capacitor is accomplished; In contrast to the real series capacitor so, this is a converter type capacitor, you can have a control over it.

It is able to maintain a cost and compensating voltage. So, we can control its voltage across a capacitor by the converters. And in the presence of the variable line current, this is a advantage of this actually instead of the passive device we have a converter control voltage source, or control the amplitude of the injected compensating voltage independent of the amplitude of the line current.

So, that something depend on the load. So, you can vary the value of the V q by the by the converter control technique. And for normal capacitive compensation the output voltage lakes a line voltage current by 90 degree and, it can be achieved by the voltage and that can reverse simple by the local control action. So, converter type series compensations has the following characteristics.

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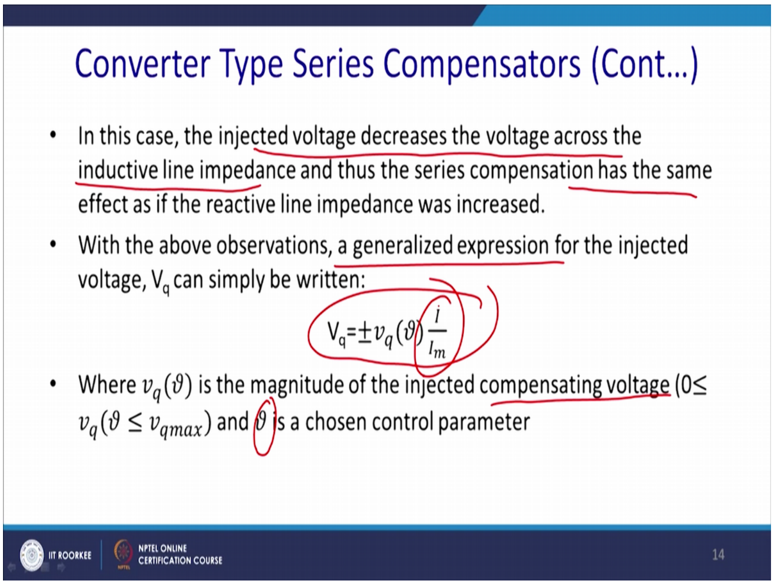

In this case the injected voltage decreases the voltage across the inductive line impedance. So, ultimately net a voltage become V l minus V c so, V l decreases. And thus the series compensation has the same effect of the reactive line impedance compensation, but you got an advantage that you are not changing the value of the current value of the current and the V q are the independent to each other.

With the above observation it generalize expressions for the injected voltage V q can be simply written as actually v plus minus depending on the kind of compensation you are doing. If you use to reduce the voltage you can also reduce the voltage i by I m why it is called unit vector compensation, where V q is the magnitude of the voltage injected the compensating voltage and this one is a chosen control parameter and, this is the basically gives you the direction of it.

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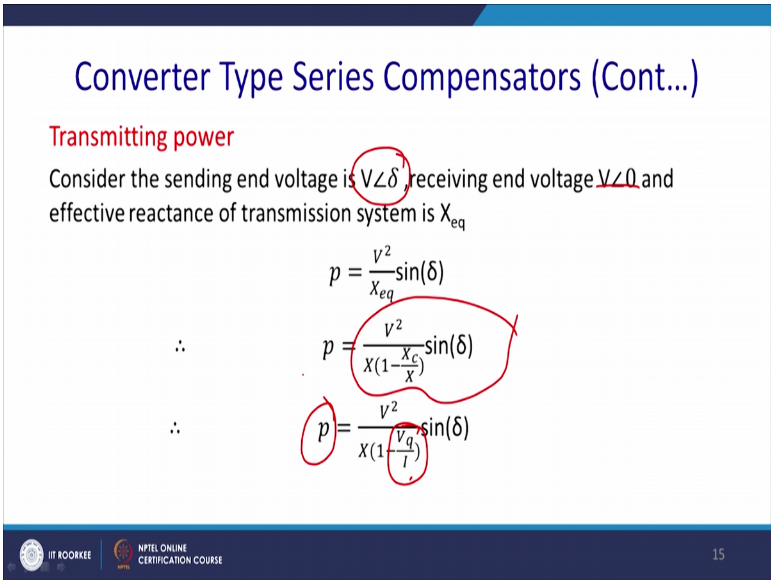

So, what happened with this type of compensation, with their power transmission. Considering that sending end voltage is a V angle 0 and the receiving angle is actually V 0 and the effect in inductance is e effective. So, V squared equal to e X q into sin delta and thus you know it is V square by X 1 by 1 by x C sin delta. And here we will be actually replacing because V X is a function of actually V q here. So, we can write the V square by X 1 minus V q by 1 into sin delta. So, thus you can see that you know this quantity plays an important role to control the sending end and receiving end power.

So, ultimately and V q is an variable quantity and you can control and, thus you can control the power flow in the transmission line. And you are not touching the value of the current.

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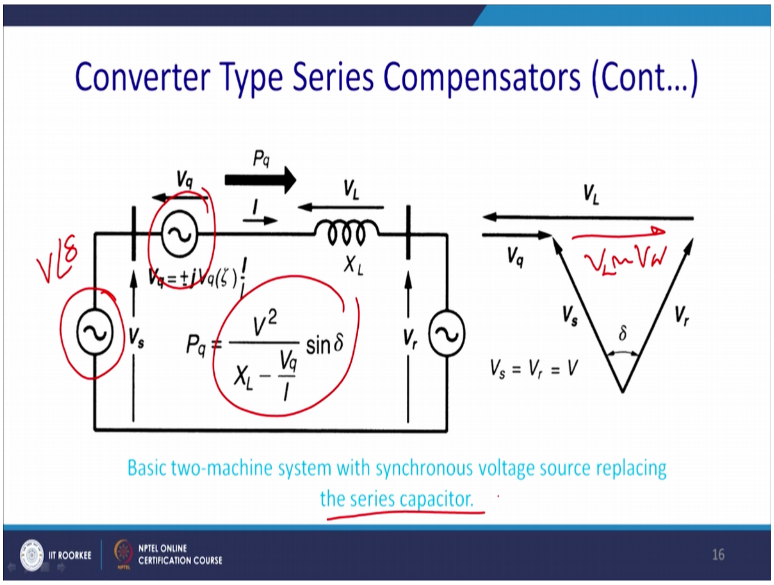

So, this is the converter type series compensation circuit diagram. So, you have to this similar two machine model, you are sending end voltage V angle delta. So, there after you can assume that you have placed a series compensator V q as a voltage source added in series. So, far this is series capacitor and, it will have a property of plus minus j V q I by I I by mod I that is the unit vector.

And that is the real power transmitted in this case is V square X L minus V q by I sin delta. And ultimately this will be the phasor so, effectively this voltage become V L difference V q. So, this is a basic two machine system of the synchronous voltage source replacing a series capacitor. So, you can have the same control with a voltage source instead of having inject instead in actually reduce the value of the impedance.

Now, what happened here so, let us draw the analysis what we have done little bit earlier for the impedance type series compensator. Now, it has advantage.

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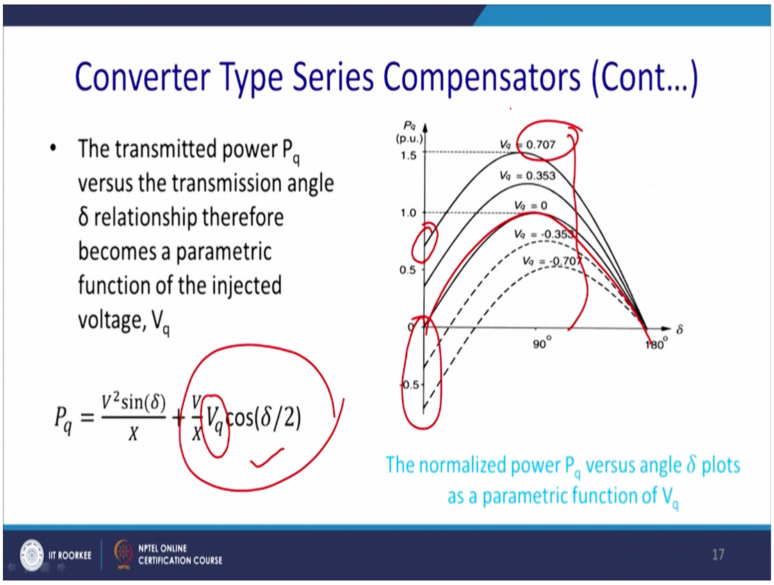

So, value of this V q you can make it positive and negative and, it is actually delta by 2 for this reason. This is the expression of the power, you have an a term added to it. So, assuming so that value of the V q 0.5 or 0.707 so, what happen, you can see that. Even it has a 0 phase angle, you can transmit actually 0.7 root 1 by root 2 amount of power. And thus it will increase to the at 90 degree close to 90 degree almost 1.5 unit of power. And gradually it will come to 0 at 180 degree.

So, straight away you get around 50 percent more power for 0.707 compensation and, also you can go to the negative variation. So, it has a huge power handling capabilities so of minus 0.52 almost minus 0.707 to 1.5. So, what we can conclude the transmitted power an a transmitted power V q, verses the transmission line angle delta relationship. And we have this following equation and this will be the changed power dimension, what was initially just this value for V q equal to 0 ultimately, it can go up and down with the help of this series compensation. And it is a very superior competition compare to the impedance change of impedance.

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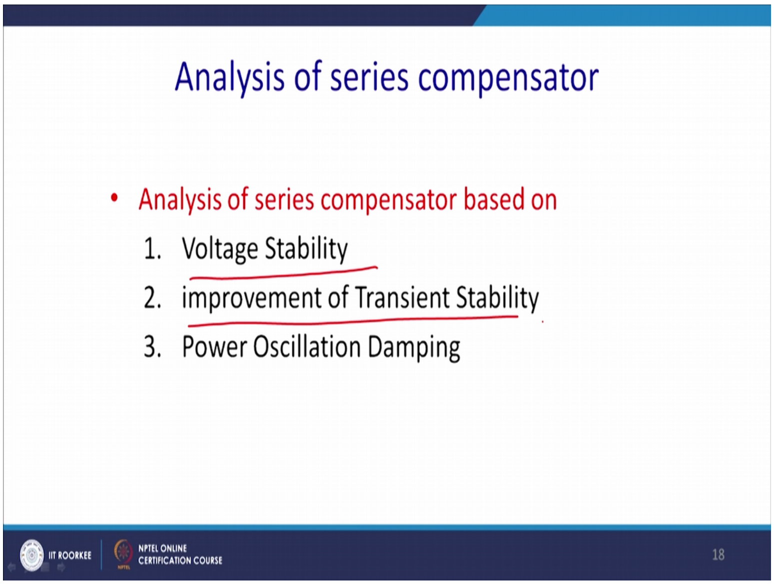

Now, next course of action will be the stability. So, these are the we will see that how the series compensation will actually enhances the few desirable features of the of this transmission line, that is voltage stability improvement of the transient stability and, the power oscillation damping. We shall continue to our discussions actually with those topics in our next class thank you for attention.

Thank you.