Flexible AC Transmission Systems (FACTS) Devices
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Lecture – 24
SSSC II

We shall continue our lecture with our triple S C. So, we start the point where we have left in our previous class.

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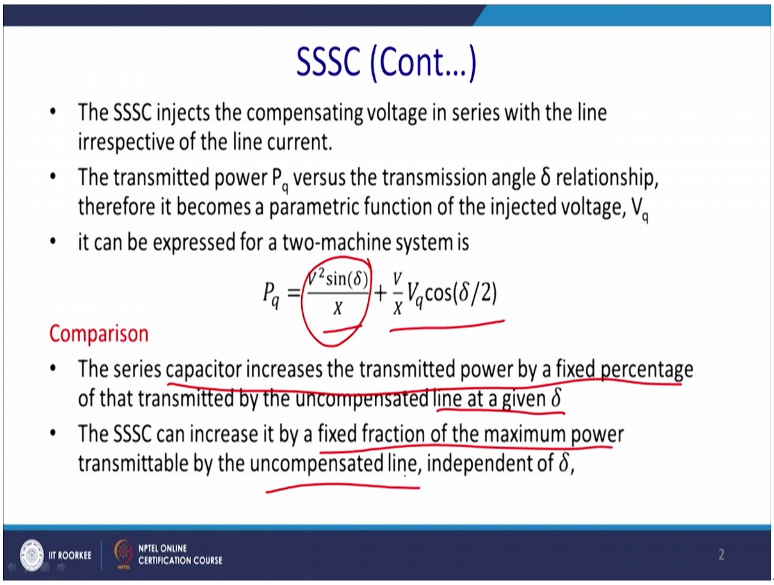

So, this is the expressions, that this is the actually the observation we was discussing. So, you can see that; so, there is a part here and this is the uncompensated one and this is due to the compensation ultimately the power handling capability of the transmission line increases, the value of the V q. And, one of what is a beauty of it even you can transmit power at 0 delta.

So, this a enhance power handling capability in percentage is huge, while delta is very low. So, it is a very suitable kind of compensation when delta is very low. So, this series capacitor increases the transmitted power by a fixed percentage with the fundamental with the transmitted power of the uncompensated line at delta, more over SSSC can increase the fixed fraction of the maximum power.

So, you can see that when it can increase transmitted by the uncompensated line and this is actually independent of the delta. So, for this reason this is the k while it is uncompensated line.

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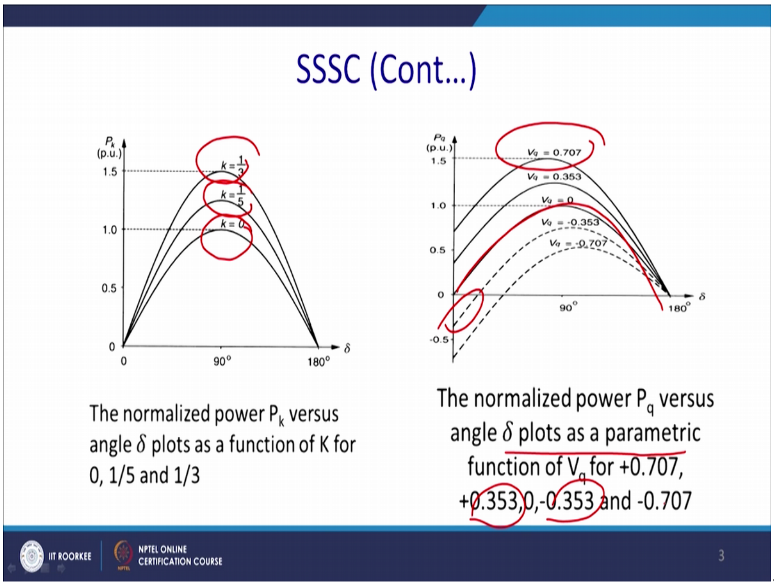

Where k equal to 1 by 5 is a ratio of is a ratio of V by V q and this is one third you can see that at even at one third voltage and 90 degree power handling capability increases to 50 percent.

So, this is the delta verses power and power graph, you can see that you can make the power negative also. So, this is the V q equal to 0 uncompensated line and you can make V q negative and thus you can bring power in reverse direction. And, similarly you can increase the power to 1.5 per unit at 0.7 V q.

The normalized power P q verses angle delta plots the parametric function for V q for different values of the V q that is 1 by to 0.707, 3.53 minus 3.53 and minus 1 2 or 0.707. And, this is the different value for the k. So, what is the principle operation of S S S C?

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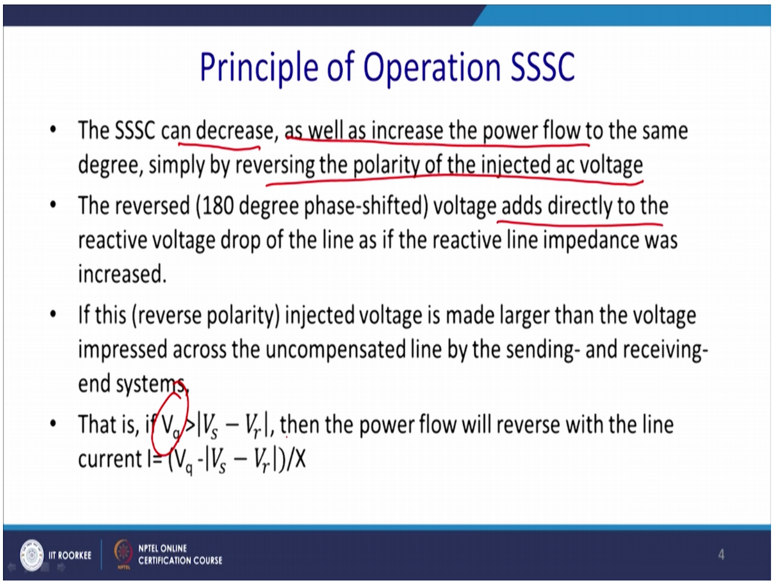

The SSSC can decrease this is a one of the best features of it. As well as increase the power flow in same degree by simply reversing the polarity of the injecting AC voltage. So, it can inject plus V q or it can inject minus V q if plus V q inject increases the voltage capability, you can reduce the capability of the line by injecting minus V q.

The reversed or 180 degree phase shifted voltage adds directly to the reactive voltage drop of the line as if reactive line impedance is increased. So, power transporting capability will decrease. If this reverse polarity injected voltage is bit larger that the voltage impress across the uncompensated line, by sending another receive in voltage that mean if V q is actually more than V s minus V r then power will reverse with the line current will also reverse an I equal to V q minus mod V s minus V r by X. So, current will flow into the negative direction.

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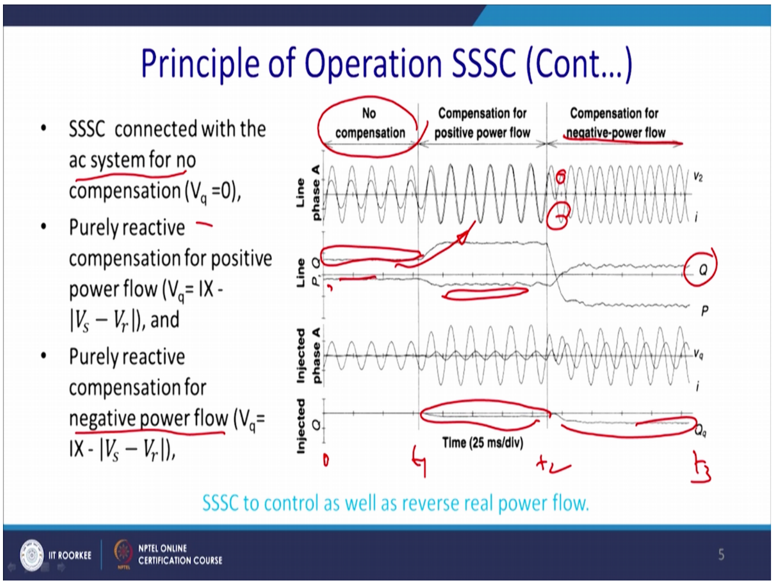

So, that is also possible please see the compensation. So, let us try to understand this graph this is actually without compensation, while voltage in current assumed to be in a phase.

Now, you will have a positive compensation and that is you know current increases and what happen there after, you will have compensation for the negative power flow. So, it will be it will become 180 degree phase shift. So, this is voltage and this is current. So, current is flowing in a negative direction, what happen to the P and Q?.

Here, actually the Q was this here P was this and Q was this. So, here you have increase the p. So, power handling capability of the line has increased. Now, here it will come down. And this is the reactive power reactive power initially will be low. Thereafter it will increase as increase little bit thereafter it will be actually in the positive nature because here P Q is positive and this is the injected phase initially you are not injecting almost any current.

Now, you are adding some amount of voltage in quadrature. So, they are out of phase by 90 degree and see that here also it is same thing will happen, but there will be in outer phase by minus 1 minus 90 degree. And, this is the curve for injected q initially it is almost 0 there after there will be a little bit of small q and this will be actually little bit of more q that we add up this Q.

So, this is the principle of operation of S S S C. SSSC connected with the AC system for no compensation V q for the time say let us say 0 to t 1. And, purely reactive compensations for positive power flow P Q equal to I X minus V s minus I r and this is for t 2 and purely reactive compensation for negative power flow, where V q equal to I X minus mod V s minus I r it is for the time t 2 to t 3, this is the principle of operation of S S S C.

So, what we can conclude from this discussion apart from the bidirectional compensation capability the basic operation characteristics of triple S C also have some additional advantages.

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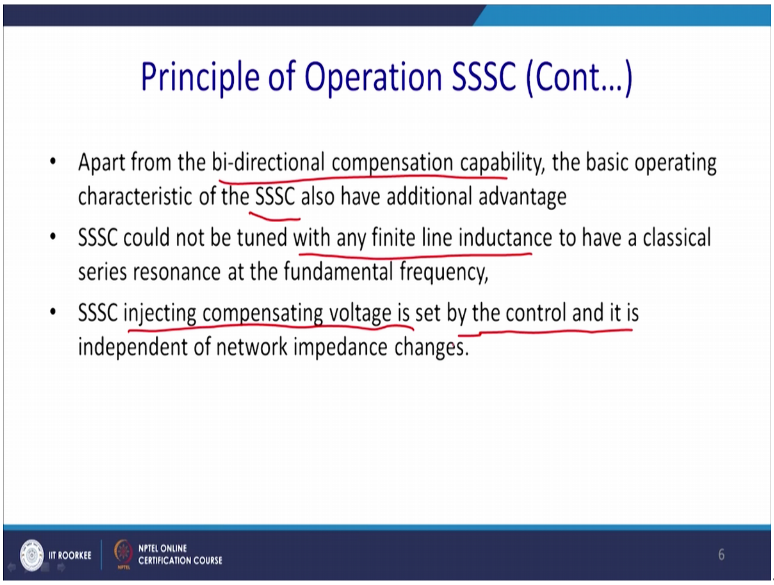

SSSC should not be tuned to any finite line inductance to have a classical series resonance at the fundamental frequency. So, never resonance will occur and high current will flow. This one of the disadvantage of this small system, SSSC injecting compensating voltage is set to keep by keep the control and it is independent of the network impedance changes.

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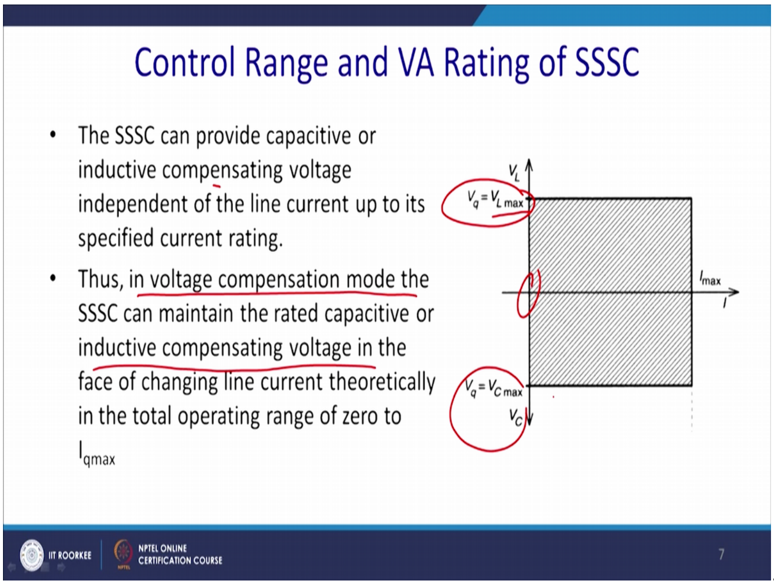

So, the control range of the S S S C. So, ultimately what we can see that. So, you can make V q minus and plus. So, it can go either direction, but current has to be here in uni direction. So, this is the this will operate in first and the fourth quadrant of the I V characteristics. So, SSSC can provide the capacitor and the inductive compensation compensating voltage, independent of the line current up to it is specific current rating as chosen by the device rating.

So, thus in voltage compensation mode the triple SSSC can maintain the rated capacitor or rated inductive compensation voltage, in in the face of changing the line current and theoretically the total compensating current ranges from 0 to I q max. So, it can compensate this voltage V q V L to V q to any level of current and this is restricted by the this current limit is restricted by the device rating.

And, corresponding to the now let us come to the last aspect of it corresponding to the loss as percentage of that, capacity towards the inductive rating of a triple S C, this is this is the characteristics of the triple S C this is the loss characteristics.

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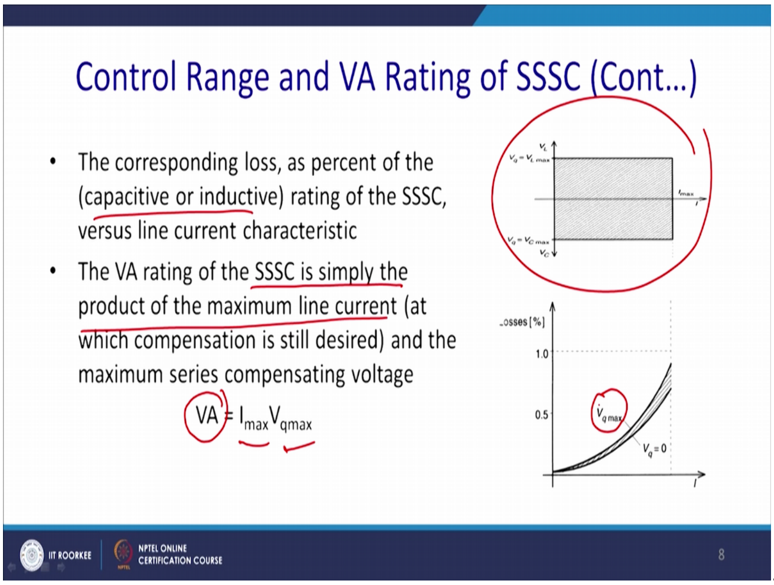

Of course, loss highly depend on current since you have employed the switches so, it is lineate with the current. So, V r rating of the SSSC simply the product of the maximum line current at which the compensation is still desired, and the maximum series compensating voltage that is a V a rating that is I max into V max.

So, this is the this rating and we require to find this rating and this will be I max into V max is a constant. So, thus it is gives you a almost a rectangular high parabola. So, ultimately we require to operate this V q below the V q max the control range, and the V a rating switches up the triple S C.

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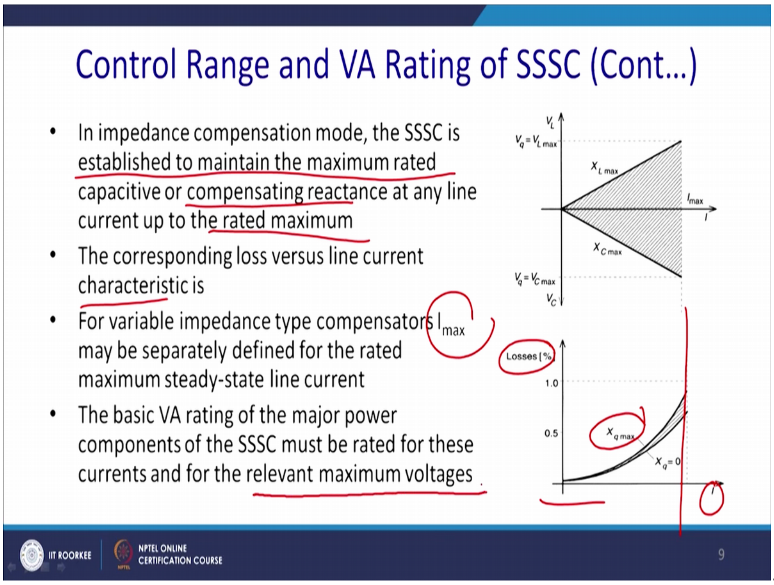

The impedance compensation mode, the SSSC established to maintain the maximum rated capacitive or compensating reactance at any line current up to it is rated voltage up to the rated maximum voltage. Thus what happen the corresponding loss versus line current characteristic is shown here? For this reason this is the I q max and ultimately this is I and this is the loss and this is the current rating of the devices and thus what happen, that is actually will change accordingly.

So, we have to keep this below the I q max otherwise the maximum voltage of current limit may cause. For variable impedance type compensator I max may be separately defined by the rated maximum steady state line current.

The basic V a rating of the major power component of S S S C, these are mainly now days I G B T S or sometime G T os must be rated for this currents or this is GT os chosen and for the relevant maximum voltage.

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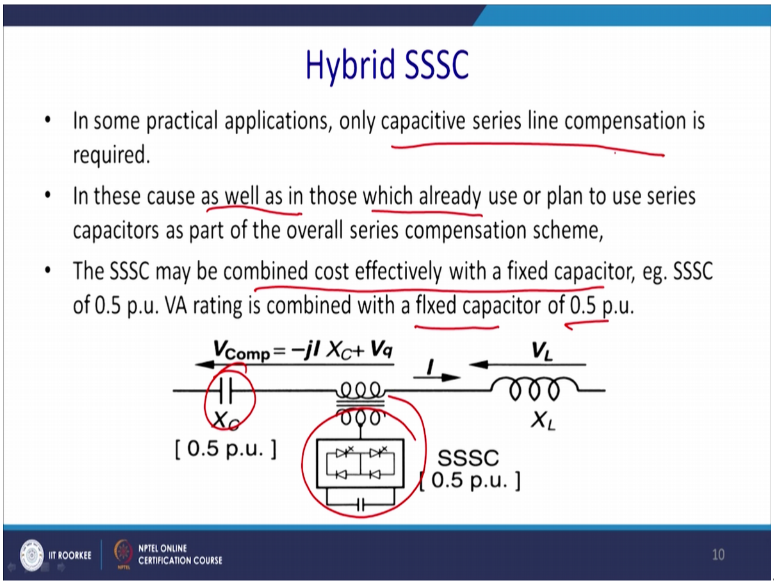

So, let us take some practical application of the triple S C in some practical application only capacitive series line compensation is required. So, inductive is not generally required and back flow of power is not also require, this is just to show we have shown that curve to show that it has got that capability yes it can do that. In these cases as well as in those which, which already use or plenty use the series capacitor as part of the overall series compensation scheme will be followed in this case.

So, triple S C may be combined a cost effective of fixed capacitor, that that mean triple S C will be have a rating of 0.5 p u and the rating is combined with the fixed capacitor of 0.5 p u. So, total compensation will be 1 5 p u 0.5 p u and this one is a gives you the 0.5 p u and other this SSSC will give you the 0.5 p u. In most of the cases we require to compensate we, we require to have only series compensation for the capacitive kind of thing. So, you can put this kind of thing. So, it can go positive and negative and thus add up and this will go this can make it 0 by actually injecting minus V q.

So, this is the way we can operate and thus what happen we can reduce the rating of the switches that used for the triple S S S C. So, this is called definitely as we have seen that hybrid T C R or hybrid statcom. So, it is actually the hybrid triple S C. So, this is the V L and this is V L max.

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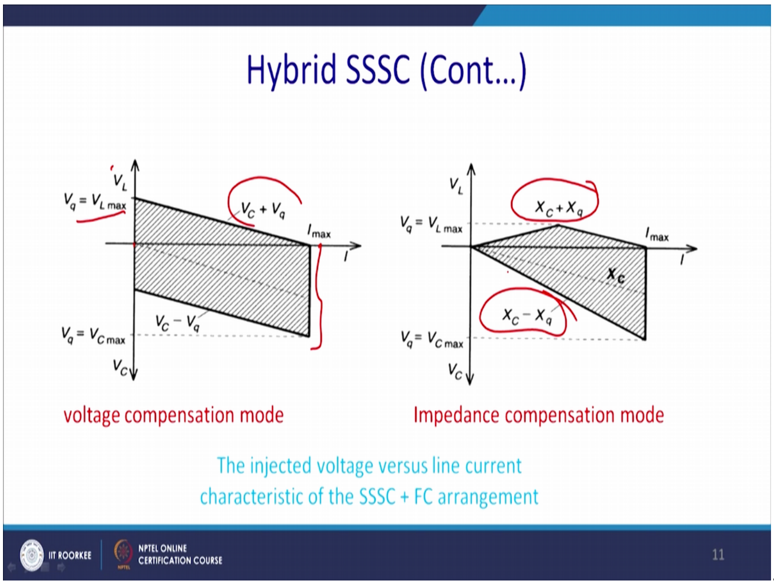

And, this is a V q max I c ultimately constant amount is been added by V C. So, thus it is shifting like this. And, otherwise if it is V l net line become 0 and when both the constant V C and this changes. So, this gives you this much of V C. Similarly V q equal to I L max and effective equivalence impedance becomes V C plus V q and in this case it become V C minus V q. So, this is the impedance compensation mode in case of the hybrid triple S C.

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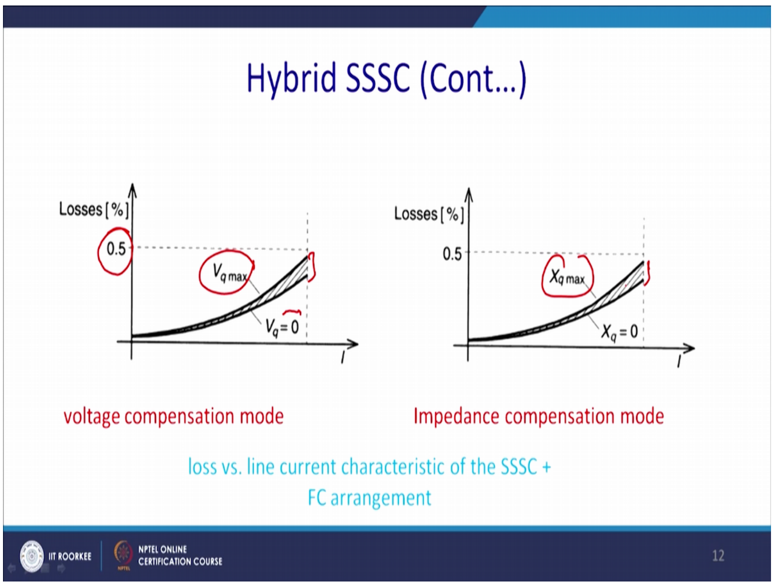

Now voltage compensation mode similarly and what about to the losses; since loss also will be reduced because this rating is 0.5 not 100 percent. And, this is the new V q max rating and it will and this is a V q 0 rating and it has to be operate within this. Similarly, this is for the impedance compensation mode and this is actually V q max the upper trajectory and lower trajectory, if V q equal to 0 were they it is not injecting any current it is a capacitive kind of thing and losses is due to the flow of current.

So, so this will be the lower one, I have this band essentially is for switching losses verses line current characteristics of triple S C and fixed capacitor enhancement now real power compensation with triple S C.

So, it can compensate for a real power. So, this is the one of the basic features of the triple S C or any series compensation.

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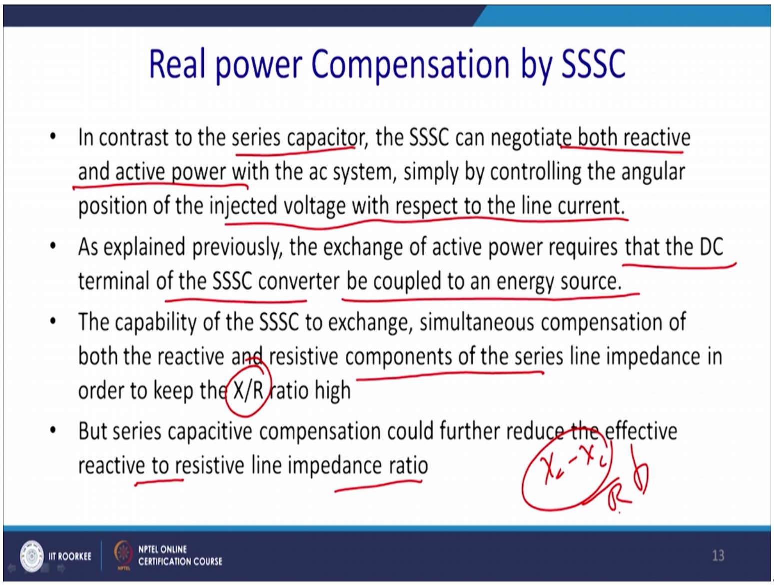

In contrast to the series capacitor triple S C can negotiate both we have assume that actually V q is perpendicular to the I, that is thus current for this is then it is only compensating the reactive power, but we can have a real power compensation. SSSC can negotiate both reactive and the active power with the SSSC system.

Simply by controlling the angular position of the inject and voltage with respect to the line current. So, thus the voltage was convert and play an important role to generate a voltage that require to be injected in such a way that it can also inject the real power. As explained previously the exchange of the reactive power requires that the DC terminal of the SSSC converter or we require a storage element and we coupled with the storage element or the storage source. So, it can be battery or solar panel or any kind of thing.

The capability of the triple S C to exchange simultaneous compensation of both reactive and the resistive component of the series line impedance in order to keep the X by ratio high. So, this is the one of the desire features of the triple S C. Generally X by ratio taken to be 10 or something like that, but series capacitor compensation would further reduce the effective resistive to the resistive line impedance on ratio, that is one of the problem of it, because you know when you are basically it is become X l minus X c. So, this ratio by R get decreased, but we cannot, but in this case this possible to maintain the X by R ratio.

So, then what happen the line impedance ratio progressively increasing the reactive power demand of the line and the associated line losses and the possible voltage depression, would start to limit the transmittable reactive power.

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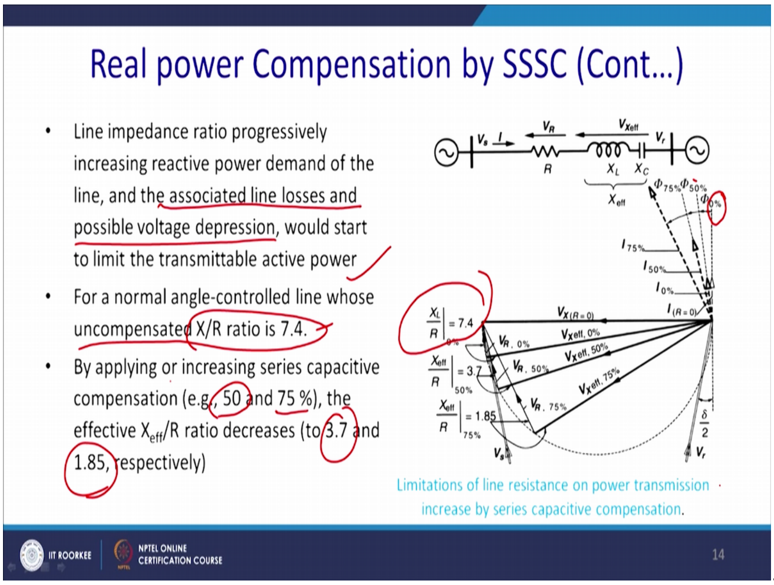

So, voltage sec and other for normal range of control the line whose uncompensated X by R ratio is chosen to be 7.4 that is what I am saying that in previous slide the this ratio is around 7. And, now let us understand this actually the facer as well as the circuit. By applying or increasing the series capacitive impedance let us say 50 percent or 75 percent the effective X by R ratio get decreased to this percentage and as well as this percentage then what will happen then.

So, see that this is actually the 5 equal to 0 this is the compensation and this is the 75 percent, this is 50 percent, and thus what happen you can see that this is R equal to 0 and this ratio is actually 7.4 and this is X by eff ratio is 3.7 this is 1.5 and that is in this way changes.

Then what happen this posses the line resistance power transmitted increased by the series capacitated compensation, and our assumption no longer hold good that actually line is predominantly resistive predominantly inductive.

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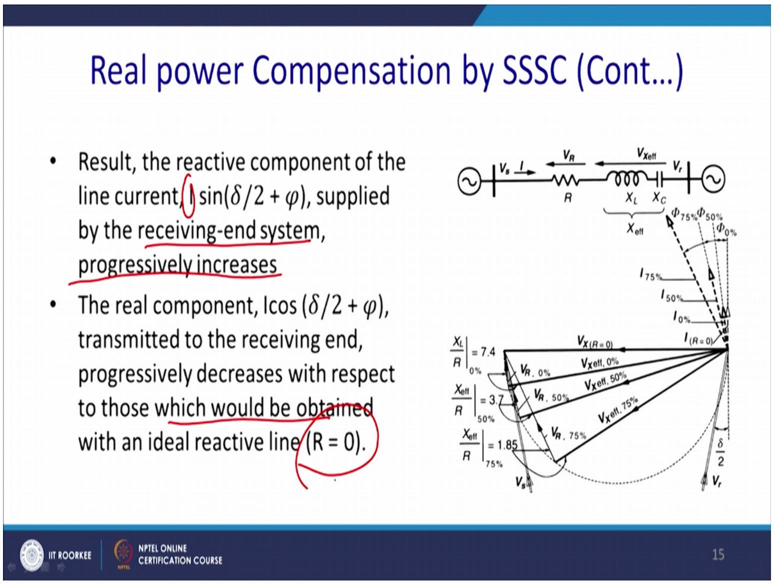

Now, the result of this reacting compensation of the line current sin I sin delta by 2 plus phi supplied by the receiving end system progressively increases, that is the one of the disadvantage. So, so the real component that is I cos delta by 2 plus phi transmitted to the receiving end progressively decreases with respect to those would have been obtained in the ideal reactance line when R equal to 0.

So, this is the disadvantage suggestive power handling capability decreases, if the X by R ratio decreases. Thus what will happen so; we have to change this value.

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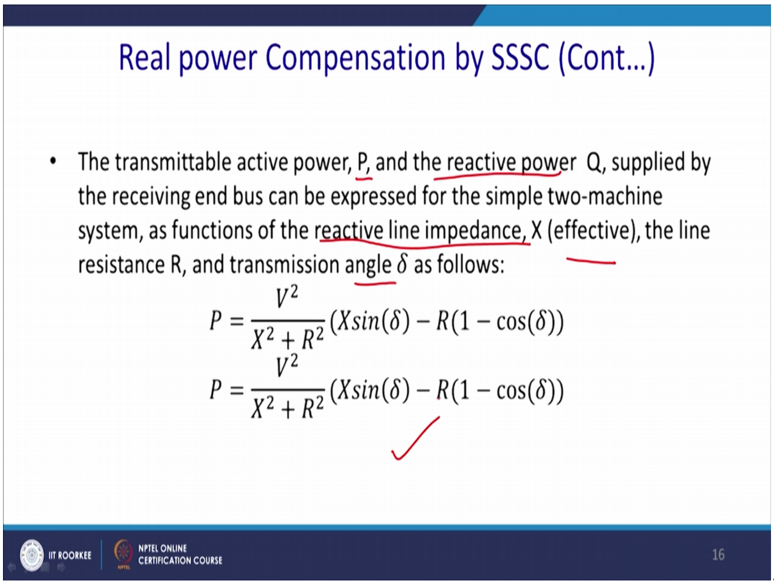

The transmittable reactive power P, and the reactive power Q, supplied by the receiving end bus can be expressed for the simple 2 machine system, as a function of the reactive line impedance effective.

So, we have to incorporate now the value of R in the line resistance R and the transmission line angle delta as follows. So, it will be V square by X square plus R square into X sin delta minus R 1 minus cos delta effectively you can coupled it. So, this will be the new equation for transmitting power with reactive power compensation.

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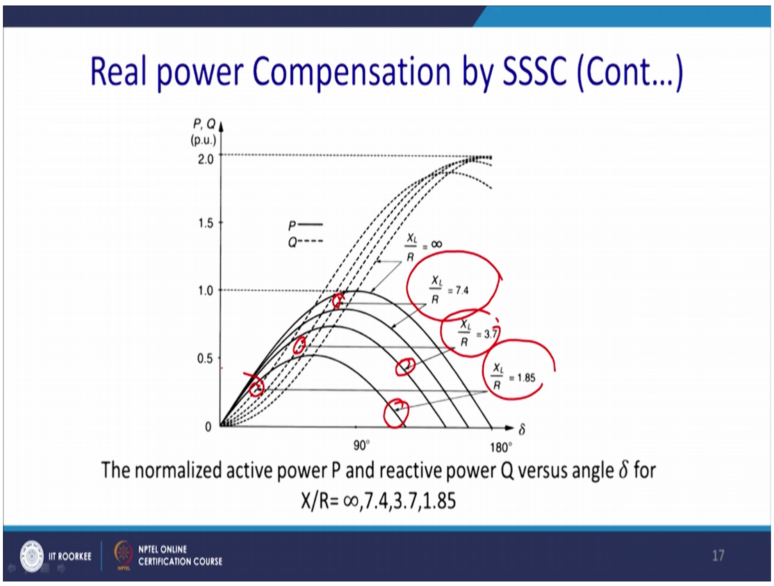

And, thus what happens you can see that line changes. So, this is the uncompensated line where actually X by l ratio X l by R ratio is and on certain 0.4, but when this ratio changes in a compensated line then, what then this is the case for uncompensated line having X by l ratio equal to 3 by 7. Similarly this is the ratio uncompensated line for X by l ratio equal to 1.8 5.

So, you can see that drastically power changes and thus if you can make this thing to the walk properly with compensation, it will go to this point having X by l ratio 7 4 and it will be actually here it will be shifting this direction and similarly it will be shifting further here. So, what happen? So, real power compensation capability will drastically decreases. And, this is the case where X by l ratio is very high. So, this will be the actually the ideal case why to machine theory hold good.

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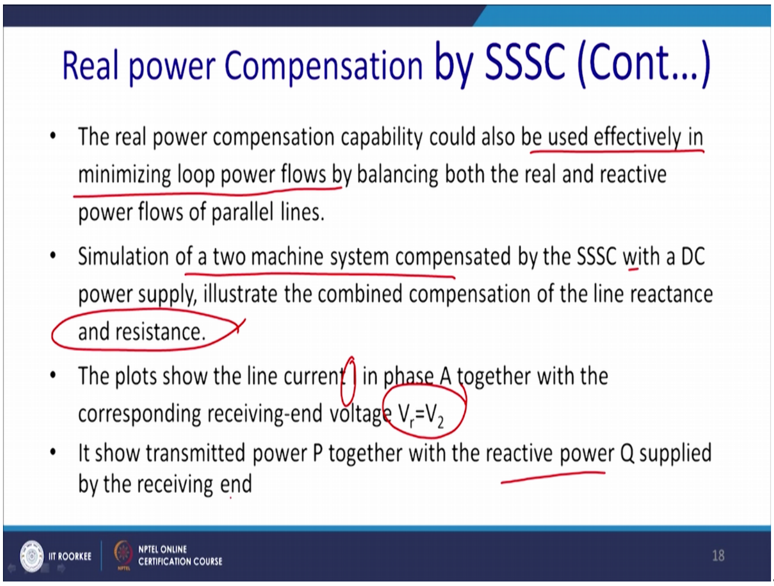

Now, with this observation what we can conclude. The real power compensation capability could also be used effectively in minimizing the loop power flow by balancing both the real and the reactive power flow in the power parallel lines.

Simulation of the 2 machine system compensated by SSSC with a DC power source or the storage element illustrate; the combined compensation of the line reactance and, the as well as the resistances.

The plot shows in the previous curve that the line current I and the phase a together with the uncompensated, together with the corresponding receiving end voltage where V r equal to V 2. It shows transmitted power P together with the reactive power Q supplied by the receiving end.

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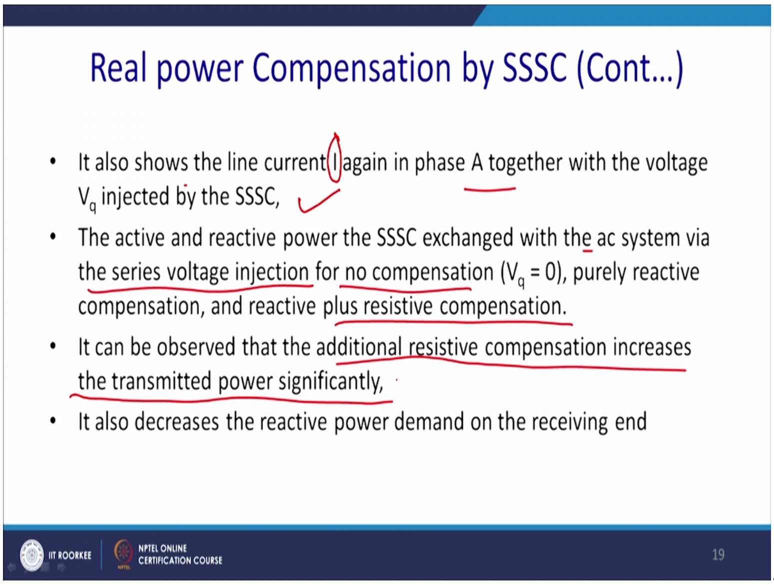

Moreover, it also shows the line current I again in phase a together with the voltage V q injected by S S S C. The active and the reactive power in the SSSC exchanged with the a c system via series voltage injection for no compensation when V q is 0, purely reactive compensation and reactive plus resistive compensation can be also done here.

It can be observed in the previous graph that the additional resistive compensation increases with the transmitted power significantly, it also decreases with reactive power demand at the receiving end.

So, this is the few characteristics of real power flow through the triple SC. So, let us see that same thing this is with no compensation.

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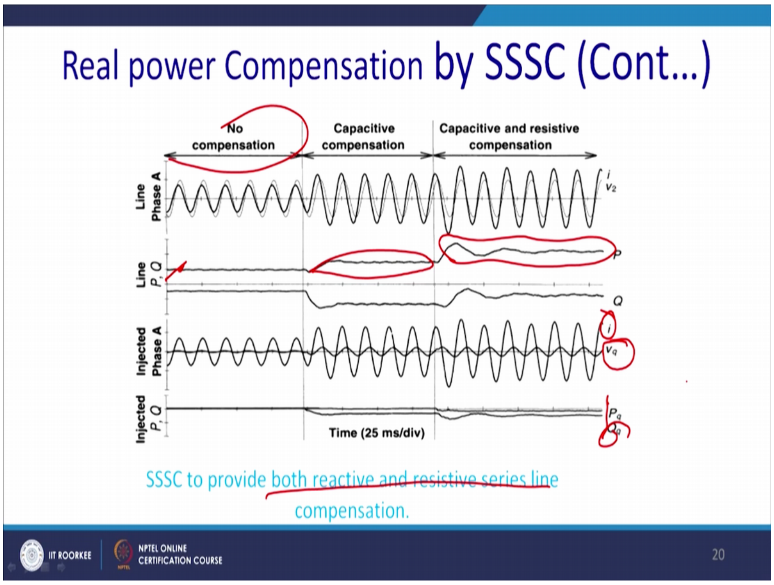

So, there is a little bit this is a line voltage and what happen? Then SSSC provide both reactive and resistive power line compensation and ultimately it is providing the P this is actually P. Now, and this is the Q there after capacitive compensation comes. And so, this is then actually the power rate increases then capacity as well as reactive compensation comes, that is through the actually injection from the DC source or the storage element. Thus actually power handling capability of this triple S C has increased. And, this is the phase line and initially current was small injecting current thereafter, it is increasing and simultaneously continue.

This corresponds to V q the voltage injected and this corresponds to the line current I. And this is the injected real power and the imaginary power, initially there is no compensation. So, this not injecting any P Q and this is the capacitive compensation. So, it so, there will be a Q there is no P and here both P and Q is present since it is inserting port.

Thank you, for your attention we shall continue with our next discussions a few slides few discussion left also with our triple S C. And, thereafter we shall go to the next called actually P r power angle regulator.