Flexible AC Transmission Systems (FACTS) Devices
Dr. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Roorkee

Lecture – 10
Shunt Compensator Analysis

Welcome to our video lecture series FACTS Flexible AC Transmission System Devices. This is our 10th lectures, this lecture actually we will began we will discuss about the FACTS devices and previous 9 lecture actually we were discussing mostly the power electronics. And now we shall start with the shunt compensation shunt FACTS devices.

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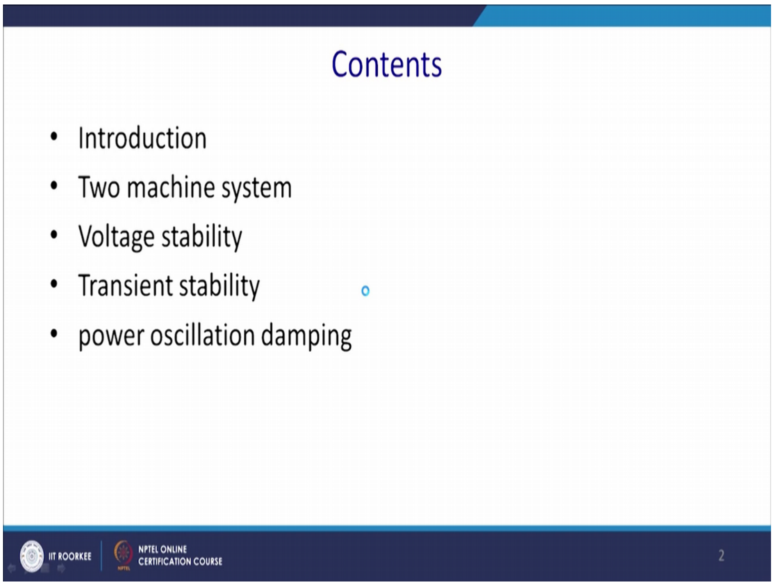

So, my presentation layout will be following that will be introduction, two machine system, voltage stability, transient stability and the power system oscillations and damping. These are the content and we shall see that how it can be done by the shunt FACTS devices or discussions today will be on the shunt FACTS devices.

So, the main advantage of the shunt devices to support the reactive power demand and our assumption is that this shunt devices does not content any real power. But with the invent of the or the rather penetration of high level of distributed generations, this statement required to be state connected. But till now in our initial assumptions we will assume that this FACTS device does not content any real power, shunt power.

So, for this reason what will happen the major object of the shunt devices to support the reactive power demand, which will be actually oscillating into the power system. To increase the yield the steady state transportable power as well as stability of the system and the voltage profile required to be controlled and it should be within a stable region.

Shunt power compensation actually which is a device that is used for the voltage regulation at the midpoint. We shall see the next slide how does it, how does it controls or intermediate position? It will be placed to the segment of the transmission line and an end of the line to prevent the instability, as well as the dynamic voltage control will be placed. So, we will place it to damp out the power circuit oscillations that may arises due to the load change or is the fluctuations of the fluctuation of the power supply or due to maybe the huge fault.

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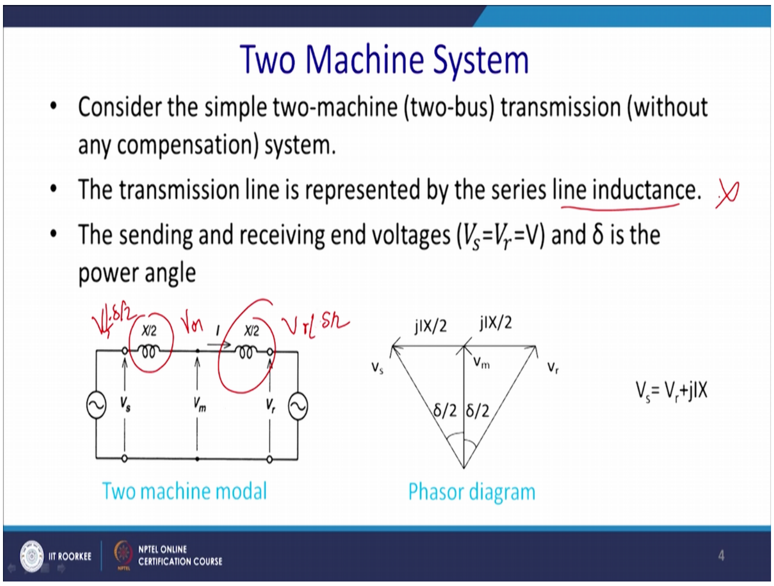

Now, consider the two machine system. So, consider the two machine system and overall transmission line had impedance X. So, which has been spitted in between X 1 and X 2 and this point the voltage is assumed to be actually assumed to be V m and we assume that here angle is V s minus delta by 2. Here it is V m and here it is V r delta by 2 and the transmission line represented it by the series line impedance of value X, and it has been spitted between X by 2 and X by 2 in two halves.

And our assumption is that the sending and receiving voltages are V s equal to V r that equal to V magnitude wise and delta is the change of their power angle. Here it is minus delta by 2, here it is 0, here it is plus delta by 2 and this is the phase and where current I is seems to be the perpendicular by sector of the voltages.

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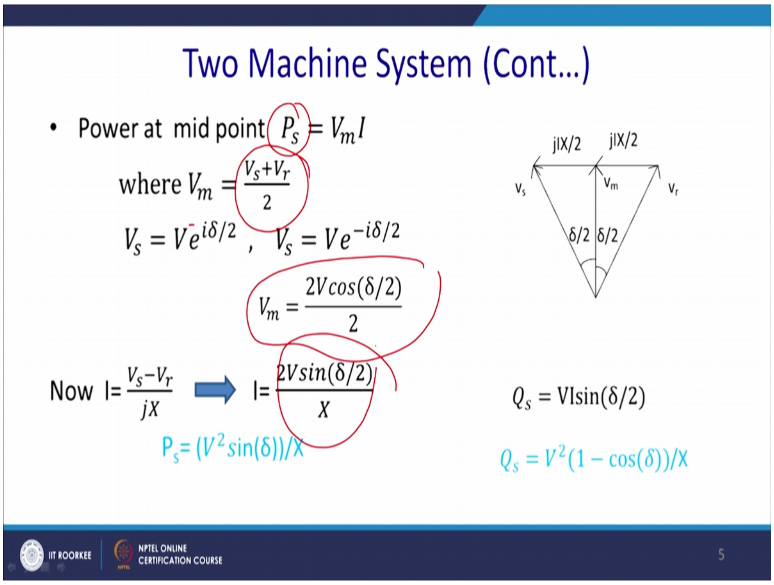

Now, let us see that at the midpoint the power available it P m V equal is P s should be equal to the sending and power that is P m into V I, where V m should be actually instantaneously, it should be V s plus V r by 2. And we have assume that you know V s equal to minus sorry there will be minus delta by 2. So, similarly we can find that this value V m is 2 V cos delta by 2 by 2. Again I flowing this point to this point is V s minus V r by j X.

So, you substitute this value equal to I ultimately from there you can derive the actually the reactive power available into the networks that is VI sin delta by 2 that is V square 1 minus cos delta by X. So, this is the reactive power in case of the in two machine model.

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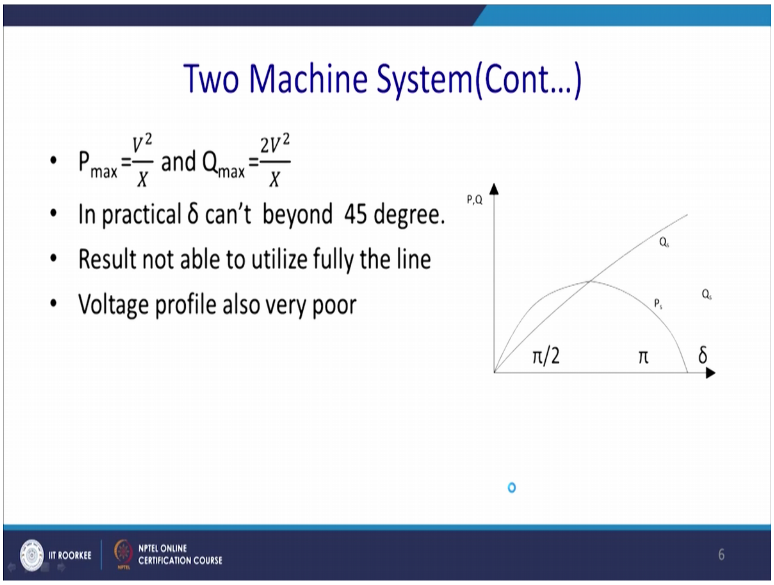

So, maximum value of the power we know that sending an voltage, receiving an voltage by the angle between them sin of angle between them. So, maximum value of power will be V square by X that is real power and the reactive power will be 2 V square by X in this case. And most of the cases you know practically delta we should restrict to the range of the 45 degree. So, otherwise there will be a stability issues. So, we can find what is the stability issue and thus it is not utilising the proper power handling capability of the devices. So, and thus voltage profile also remains very poor.

What happen you can see that it cross there so, this is the point where the value is basically in this case it is actually 90 degree. So, you have to operate somewhere here this is 45 degree and this value is your actually V square by X into root 2, 1 by root 2 should be the power. Similarly, this will be the reactive power this line corresponds to the reactive power.

So, how the reactive power can be enhanced and thus how in this way we can increase the stability limit to the system, let us see. Again we shall continue the two machine model and the shunt compensation is input at the midpoint. This is the shunt compensation and it does not contain any real power, thus no power real power is coming from the source.

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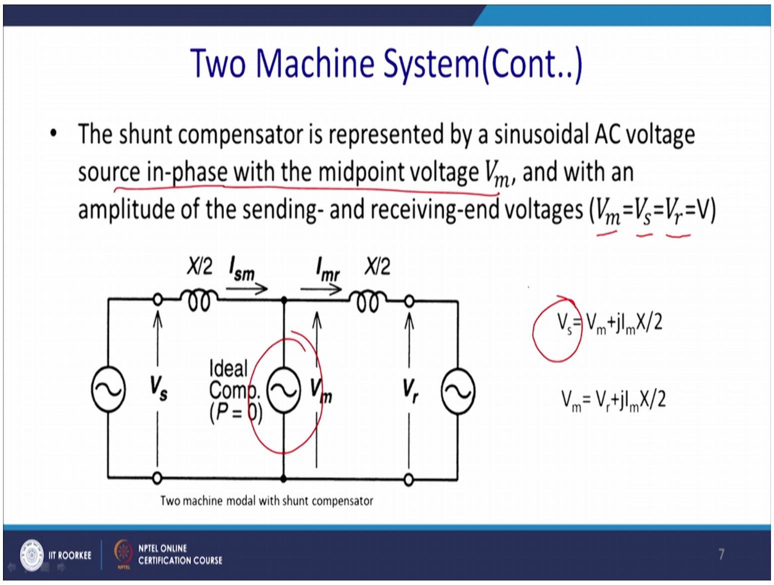

So, shunt compensation represented by the sinusoidal AC voltage and the source in the mid source in-phase with the midpoint V m, and with the amplitude of sending and the receiving end voltage V m equal to V s equal to V r equal to V.

Similarly so, we can write from the phased previous phased diagram. So, here V m equal to V s plus j I into X. So, this will be X by 2 similarly so, you can rewrite this equation V m equal to V r plus j m into X by 2. Thus, we can equate V m both side and see that what you will get.

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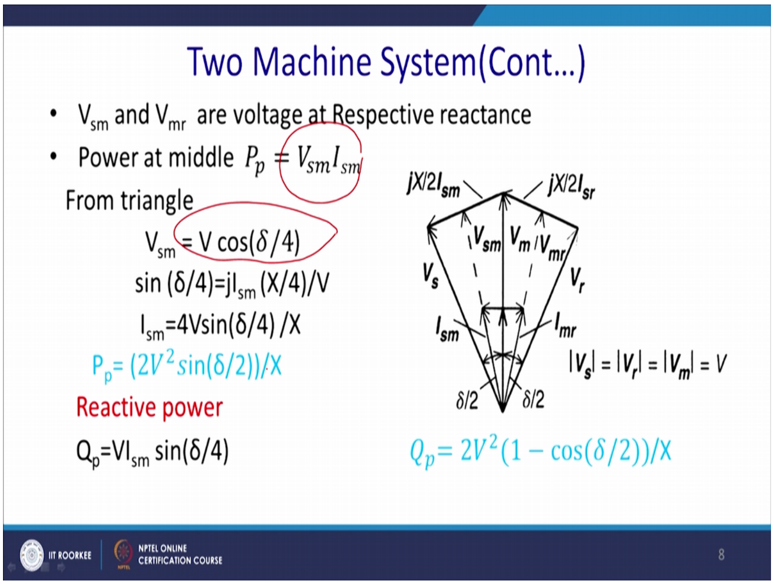

And at the midpoint power is that is actually V sm into I sm. So, from there we can see that if you multiply that actually V sm. So, it is it becomes cost delta by 4 and thus the power becomes 2 V m square sin delta 2 by X.

So, what happen here you can see the straight away for the though this angle is decreased, but power also with doubled. If you can increase some way the value of the delta because you had a restriction to the value of delta and you make the delta little bit more and so, you can also handle the power handling capability. Same way you can actually let us talk about this Q p so, you will find that it is 2 V square 1 minus cos delta by 2 X. So, straight away we can find that this power equation has been modified.

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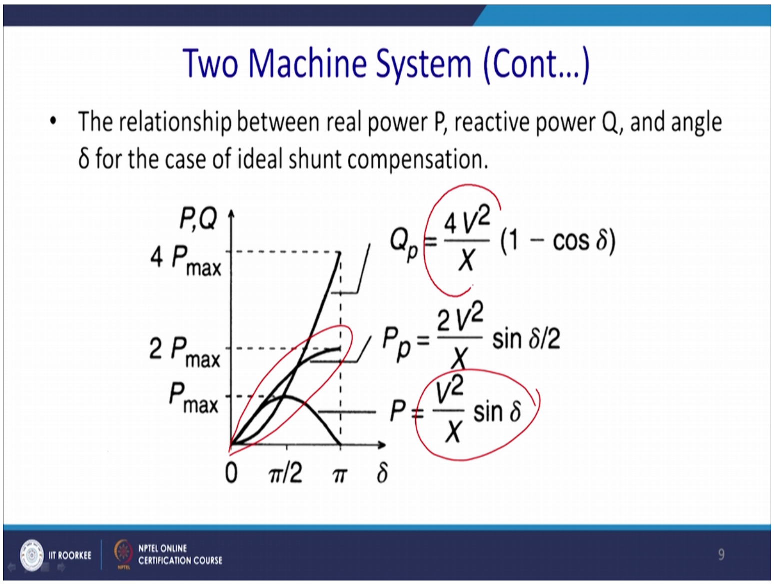

Now, let us plot it. So, with the normal fashion this value will be V square by X sin delta and with the midpoint shunt compensation this value will be 2 V square by X sin delta by 2 and ultimately this will be the curve. And similarly, with shunt compensation reactive power becomes 4 V square by X 1 minus cos delta. So, straight away power handling capability had been enhanced by using a midpoint shunt compensation. Mind it does not generate any power; it increases the power handling capability.

So, what is the take away from this discussions the midpoint shunt compensation can significantly increase the transportable power; both reactive as well as the real. And it doubles the maximum value at the expense of rapidly increasing reactive power demand at the midpoint of the compensator. And why midpoint, why not at the beginning or that end point. It is best location for the compensator, we can find solve the problem and find it out what to be placed this optimisation will be studied some next classes. But we will discussed all kind of compensation that is shunt compensations, series compensation thereafter PAR power angle regulators.

Thereafter you will find unified power quality or power quality conditioners, then an internally power quality conditioners. Then we shall revisit these problems where it should be optimally placed and we will find that the shunt finds the best position of the midpoint. Because the sag voltage along the uncompensated compensator line is largest at the midpoint, that is the reason. And it and it breaks a transmission line into two equal segment for each and the maximum power capability remain same; each portion of the transmission line. Otherwise some portion will have a more capability and some portion have a less capability. And thus, you can continue to two split half by half and this in each compensation you can increase the power by 2.

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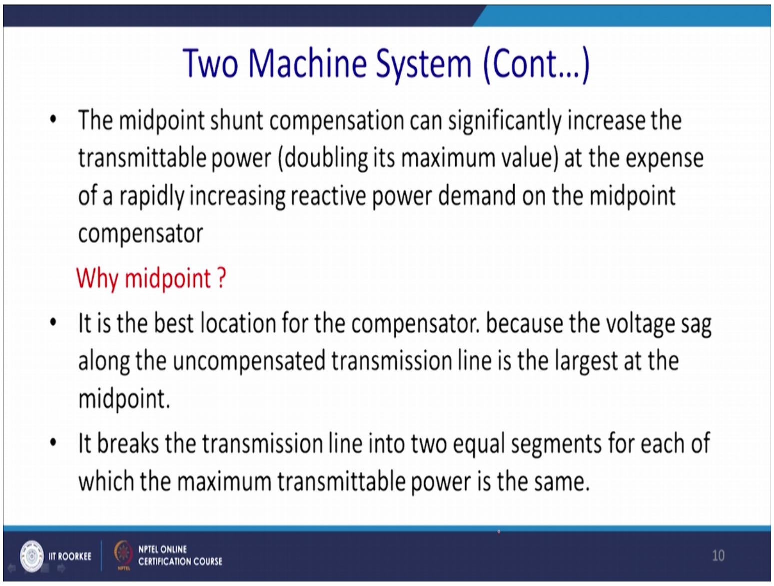

So, how many time you can split that is an issue, but you also increase the cost of the you cost of the putting the shunt device a shunt devices, moreover the reactive power also get increased. To get better voltage profile transmission line segment can be expanded to use multiple compensator, because you know that if you are terminated a capacitor then voltage generally swells ups a line. So, it is something like that multiple capacitor located at the equal segment of the transmission line.

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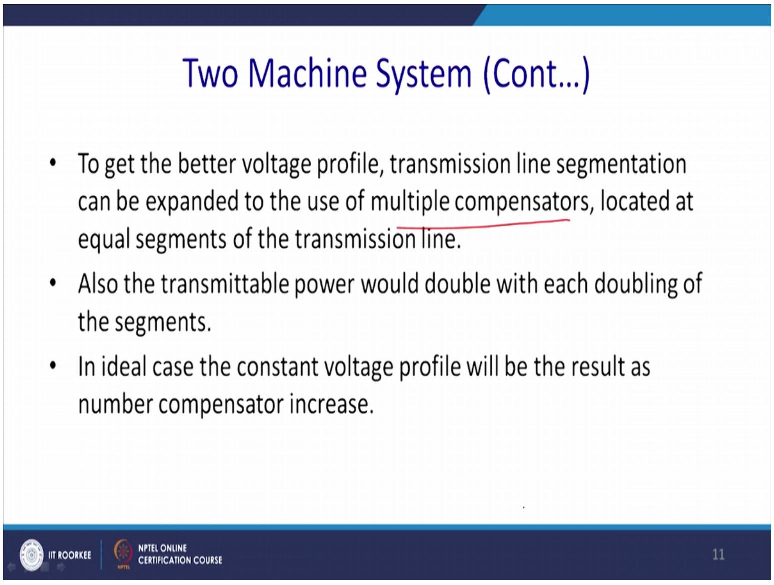

Also transmittable power would be double that is what I saying doubling each of the segment. In ideal cases cost and voltage profile will be result as number of component as increased, but our assumption is that voltage profile remain same. But it may not be same if it is a very long transmission line.

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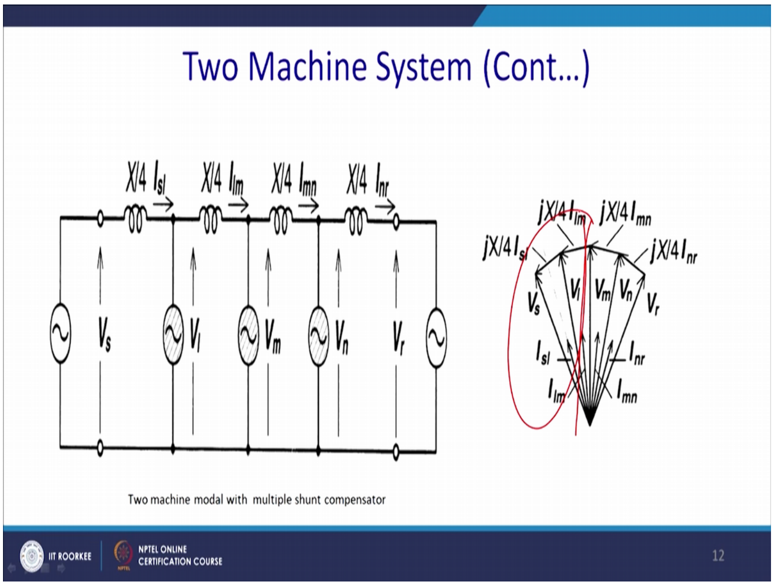

So, for this reason let us split this two machine model into 4 so, the what happen then. So, there will be a 4 segment you can carry on each segment like a like previously done. So, ultimately it will be multiplied by 4 and delta and it power transmission will be delta by 4.

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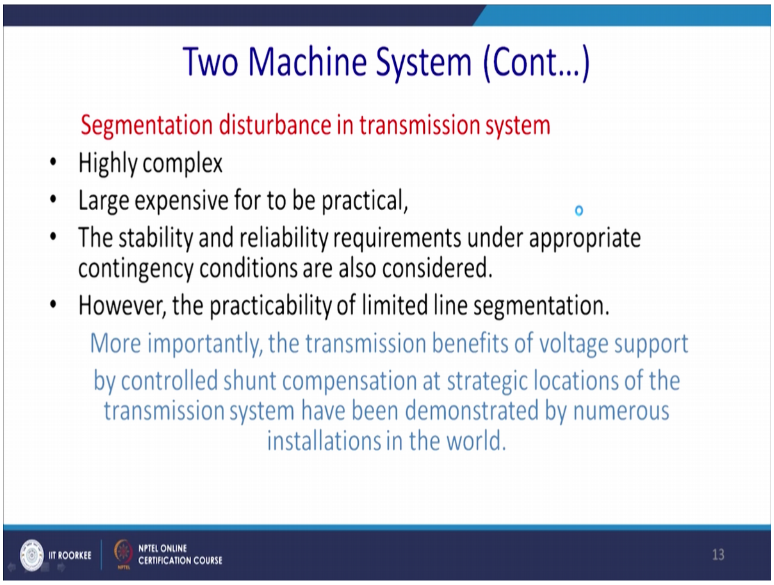

So, why we do not segment them? Generally segmentation of the distribution network system is highly complex lot and it is expensive and it is not practicable also.

The stability and reliability of the segment under appropriate contingency condition is also considered. However, the practicability of limited segment is the following; More importantly, transmission line this transmission line benefit the voltage support control by the shunt compensation at strategic location that is very important. We require to compensate the voltage profile and the strategic network. So, it should so, that it consumer gets the better power better actually power qualities and transmission system has been demonstrated by the numerous in installation, in numerous places by the FACTS devices.

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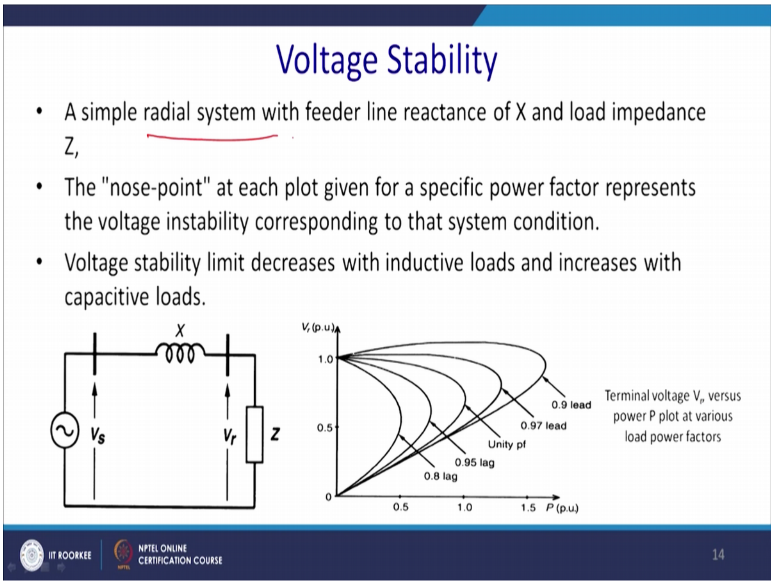

Now, let us see the how a shunt device can stabilise the voltage. So, let us consider a linear network a simple radial system feeder reactance X. The "nose-point" of the each plot is given a power factor; power factor represented by the voltage instability corresponding to that system condition. And voltage stability limit decreases with the inductive loads and increases with a capacitive load.

So, you can see that what happen; this is the power handled by the system and if it is load is inductive till this point; you know if you increasing the inductive load it degrades the value of power unit value of it of the voltage. But if you trans to the leading power factor so, this is the leading power from this onward it is the this is the capacitive and you will find that voltage regulation is better.

So, this is understandable that putting a shunt device in a reactive mode, in a capacitive mode can help to restore the voltage or regulate the voltage in the sending and better. So, for this reason churlish shunt devices is been placed close to the sending end voltage.

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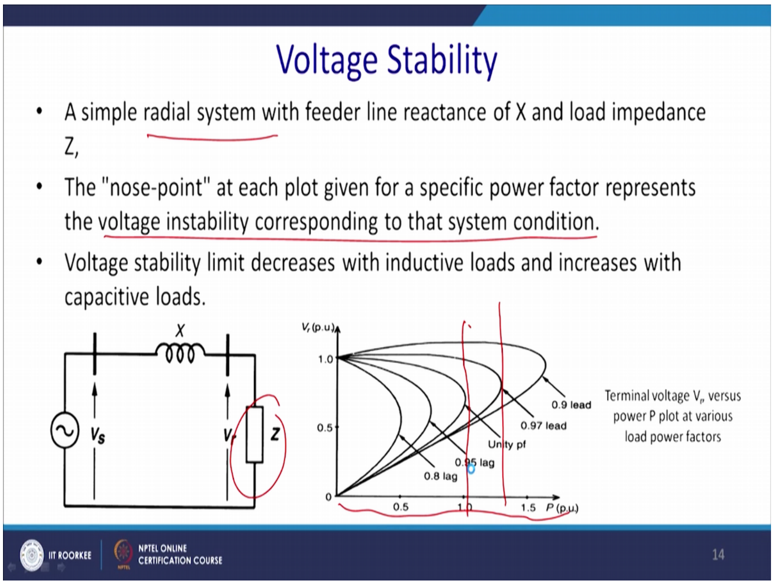

Shunt reactive compensation can effectively increase the voltage stability limit by supplying reactive power to the load and regulating the terminal voltage.

What happen you know the power required by this inductor load inductor can be actually compensated by the work compensator? Thus we will find the better voltage regulation and ultimately you will find that, this is the overview characteristics. So, you can see that at this is the unity power factor line and then after what happen in case of the uncompensated line generally, this voltage generally swells up and that transmission thermal limit and insulation limit and others issues.

But shunt can ensure that this line is strictly at 1 per unit and thus it increases the power handling capability of the line. So, this is strictly 1 and it increases the power handling capability of the line, the transmission this is the terminal voltage versus power factor or power plot. So, now required to discuss about the voltage stability, we can see that we it can stabilise voltage with the help of the shunt compensation.

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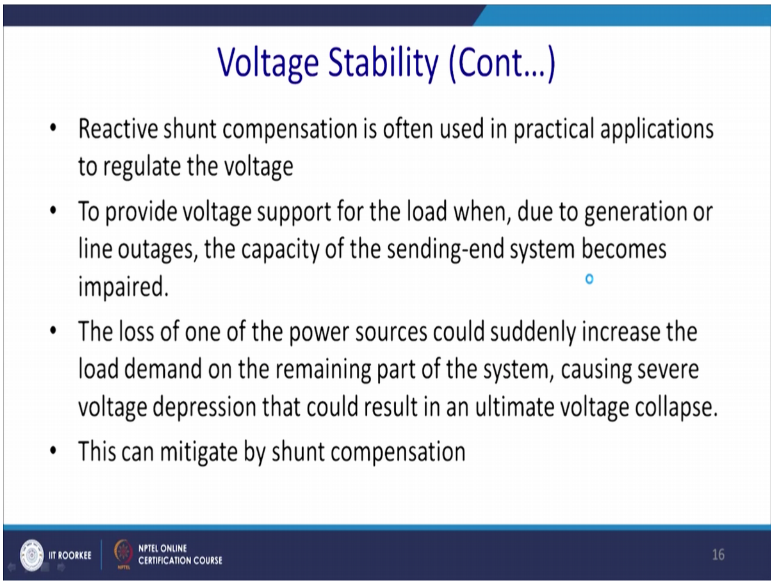

Reactive shunt compensation often used for the practical application to regulate voltage. To provide voltage support for the load and due to the generation of the line outage, the capacity of the sending and system becomes impaired.

The loss of the loss of the one power sources could be suddenly increase the load demand of the remaining part of the system, causing several voltage sag or depression and that could results an ultimate voltage collapse. And those are can be mitigated by the shunt compensation by better monitoring or regulating the voltage.

Now, let us come to the transient stability. We have discussed transient stability in before and now let us see that how transient stability can enhance by the shunt compensation.

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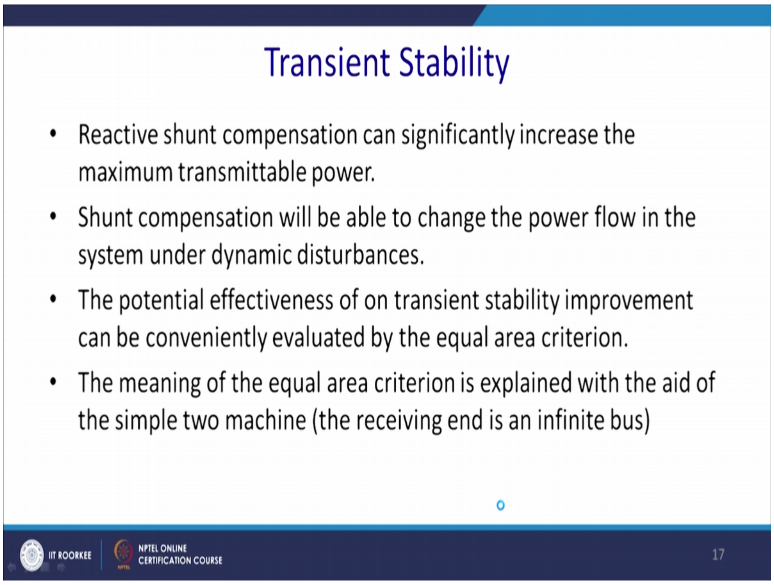

Reactive shunt compensation can significantly increase the transferable power in the line. So, shunt compensation will able to change the power flow in the system under dynamic disturbances. If there is a slight increase in the into the power demand, then it can increase the power handling capability and it can actually bring down this perturbation into the steady state limit.

The potential effectiveness of the transient stability improvement can be conveniently related by the equal area criteria that we are going to discussed in next class. The meaning of the equal area criteria we have already studied equal area criteria in our power system stability and dynamics so, same thing has been actually extended. And the meaning of the here equal area criteria explain with the idea of the simple two machine model and the receiving end considered to be a infinite bus.

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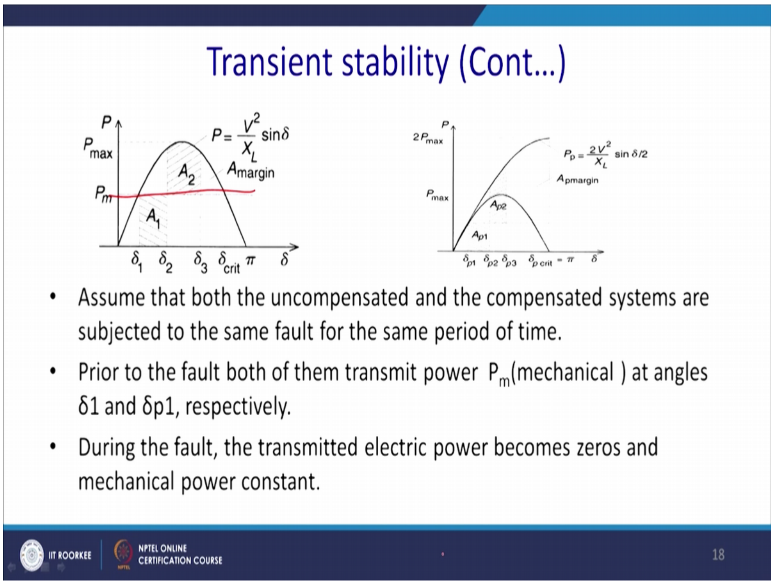

So, this is the equal area criteria and ultimately this is the load, this is the generation why it is matching all of all of a sudden you have a fault or something and due to that actually power demand increased. And this is A 1 is your accelerating area and A 2 is your decelerating and if you can stabilise A 1 A 1 equal to A 2 is a limit of stability. And previously you are operating del 1 and you should be able to actually close your breaker by delta 3, otherwise your system will lose the synchronous.

But in this case you know as this power handling capability of the line is with enhanced to this. So, it will from this curve V m V square by X sin delta. This curve changes to V square by X sin delta by 2 and thus you know previously this A 1 equal to be A 1, but with this shunt compensation A p 1 and A p 2 that you can find that A p 1 has a huge angle to clear. So, it can go as high as critical should have been previously was 180 degree minus delta 1; here it should be equal to delta 1 also power handling capability is double. So, this is a huge decelerating area to bring down the system in a controllable zone.

So, what we can conclude the assume that the both the uncompensated and compensated systems are subjected to some kind of fault for the same period of time. For the prior to the fault both this both of them was feeding the mechanical input was P m and its angle was del 1 and during the fault transmitted power become 0 and mechanical power become constant. And for this reason what happen, you have an accelerating potential and this results of the results to sending in actually generator accelerates to the steady state with an angle delta 1 to delta p 1 and to angle delta 2 to angle p 2. And accelerating energies are represented by the A 1 and A p1 respectively with and without FACTS devices.

After fault caring what happens? The electrical power exist the mechanical power input and the sending and machines decelerates. The accumulative kinetic energy further increases until the balance of the power occurs, the area matches until the balance between the accelerating area and the decelerating area matches. So, corresponding to the area for the energy balance is A 1 and A 2 and in with the facts devices it is actually A p2 and when it is reaches delta 3 and delta p 3.

The constant P m line over the intervals defined by the angle delta 3 and the delta critical. And to determine the margin of the transient stability that is “unused” represented by area as area of the margin. So, you can see that this is your area of margin without FACTS devices and this big chunk is area of the margin with your FACTS devices. Thus, it makes a system stable with and its factor of safety is quite large. This is the advantage of the transient stability with the shunt control FACTS devices.

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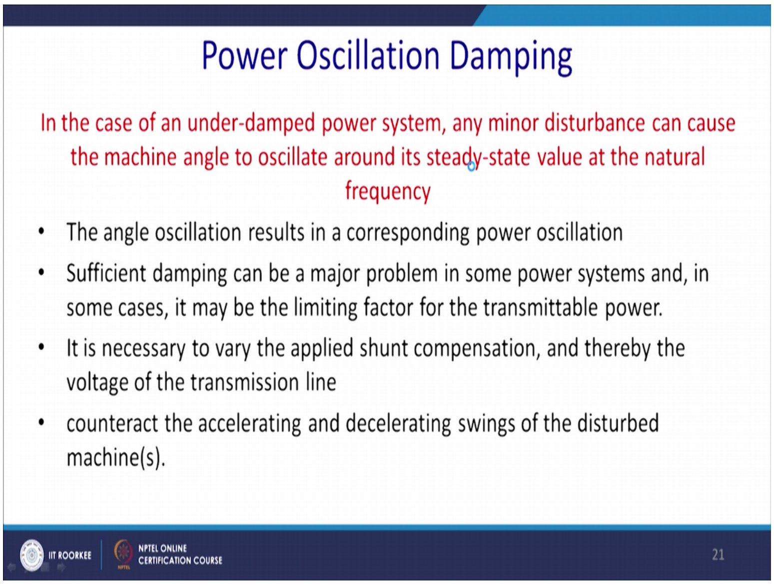

Let us continue with the power oscillation and the damping. In case of the under damped power system, there might be a minor disturbance when there is a sudden change in load or any step change in load or there is a certain small fault occurring. Or any minor disturbance can cause a mechanical angle change around the steady state and thus, gives you the torque angle ripple. This angle oscillation results for the actually oscillation also in the power, since the delta change is also the power changes.

Sufficient damping can be a major problem in some power system and, in some cases, it may be limiting factor for the transmittable power. So, we would not want that low frequency oscillation, low frequency oscillation is very dangerous because power system itself is a low pass filter. So, it will allow the slow pass low frequency power to be corrupt into the system and it will be very difficult to actually and it will very difficult to handle with the slow pass low frequency power. For this reason we required to actively damp out this low frequency and it can be undone by the shunt active power filter or shunt compensation.

The this side to vary the applied shunt compensation here by the voltage of the transmission line and counteract the accelerating and the decelerating strings of the machines.

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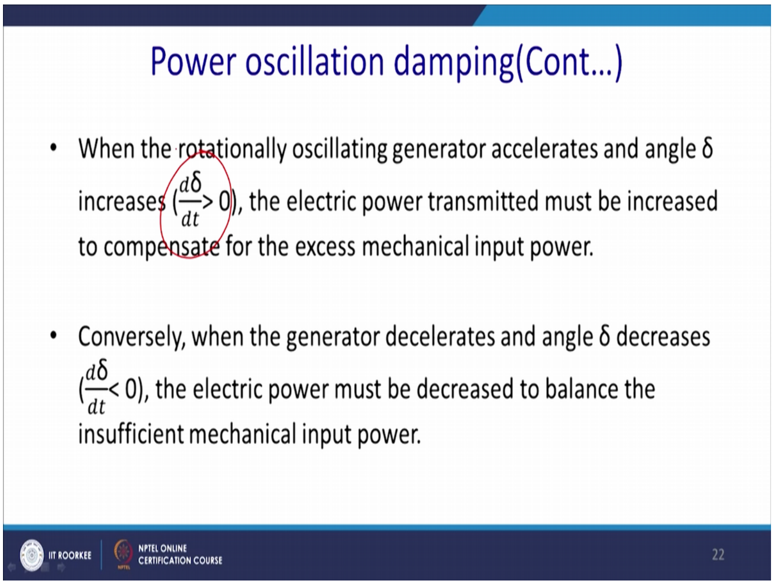

So, what happen you know it will come into the picture when this means that this power is actually when it is more than this means this power is positive. So, power handling capability of the line required to be decreased and thus it will damp out and reverse we required to do in case of the when actually when this d del t by dt is less than 0; that mean it is decreasing the power sin delta is changing, reducing delta is reducing and of course, the del delta is around 45 degree.

So, what you required to do when the rotationally oscillating generator accelerates at an angle delta and with the rate of change of angle is positive, the electric power transmitted must be increased to compensate the excess mechanical power input.

Similarly, when it is decreasing, gradually it will be actually reduced the power handling capability of the line otherwise there will be a problem of stability. So, that is actually to damp out the actually actively damp out the tangent. We shall continue in the next class with the power oscillations damping.

And, thank you for your attentions.