Flexible AC Transmission Systems (FACTS) Devices
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Lecture – 02
Introduction

Welcome, to the Flexible AC Transmission System, second lecture. In first lecture, we have discussed about the course content of this FACTS devices and little history and the background and its evaluation of the FACTS. Now, we shall discuss in detail actually the concept of FACTS and what is its significance?

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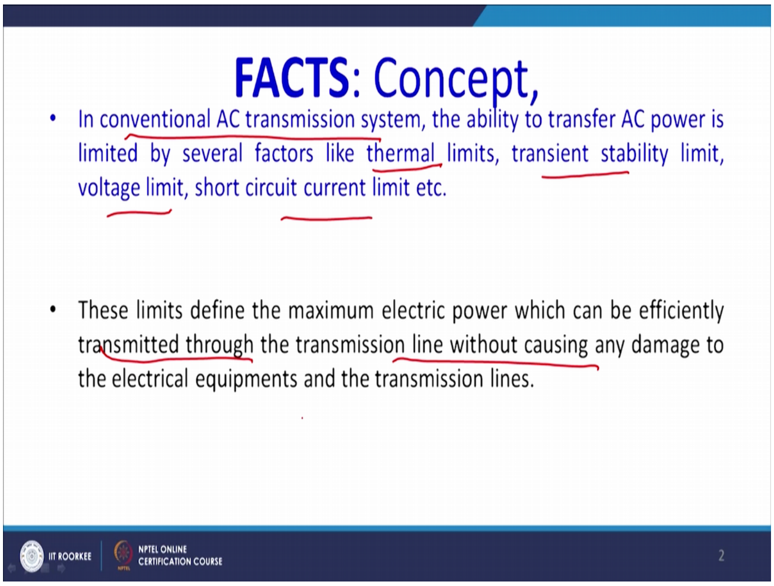

As we have understood it actually the conventional AC systems that is its transfer power transfer capability is mainly actually limited by few constraint. These are thermal limit transient limit, voltage limit and the short circuit limits and this limit can be enhanced by the FACTS devices, that is what it is said. This limit define the maximum power transfer capability can be efficiently transmitted through the transmission line without causing damage of the equivalent without damage of the equipments of the transmission line.

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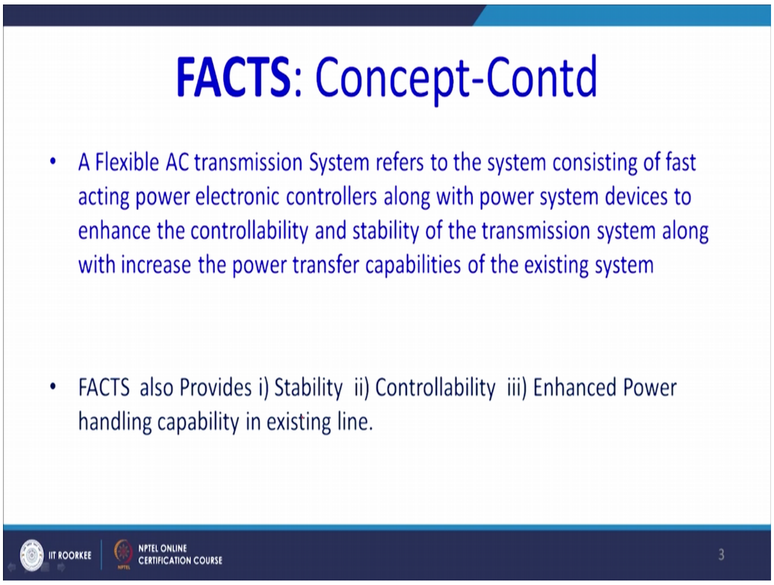

Now, FACTS device is an avenue that FACTS devices refers to the system which consist of the fast acting power electronics controller along with the power system devices to enhance the controllability and the stability of the transmission system and it increases the power transfer capability of the existing system. And, what is the advantage of FACTS? FACTS provide stability, controllability and enhance power handling capability of the existing system. In a subsequent discussions, we will elaborate this topics.

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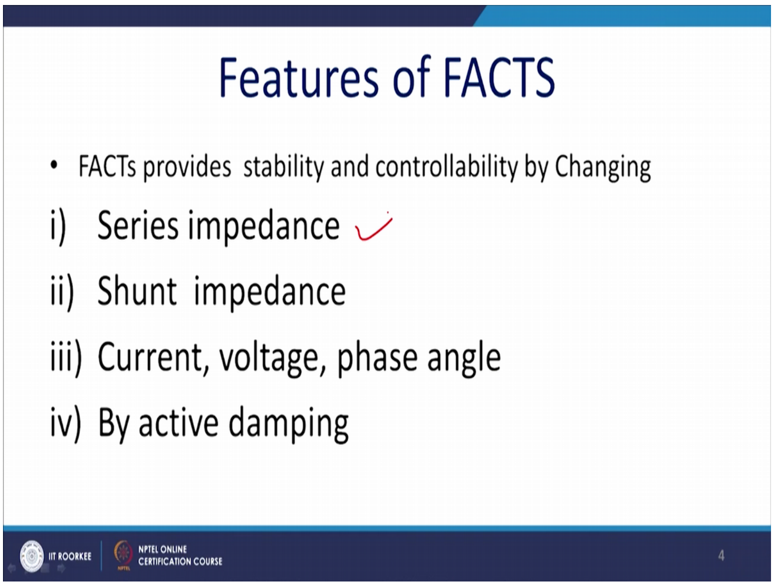

Now, FACTS comes with few features, that is, series impedance. We can change the series impedance of the network by a FACTS controller, thereafter shunt impedance and current voltage and phase angle control and it can also damp actively the oscillations power oscillations.

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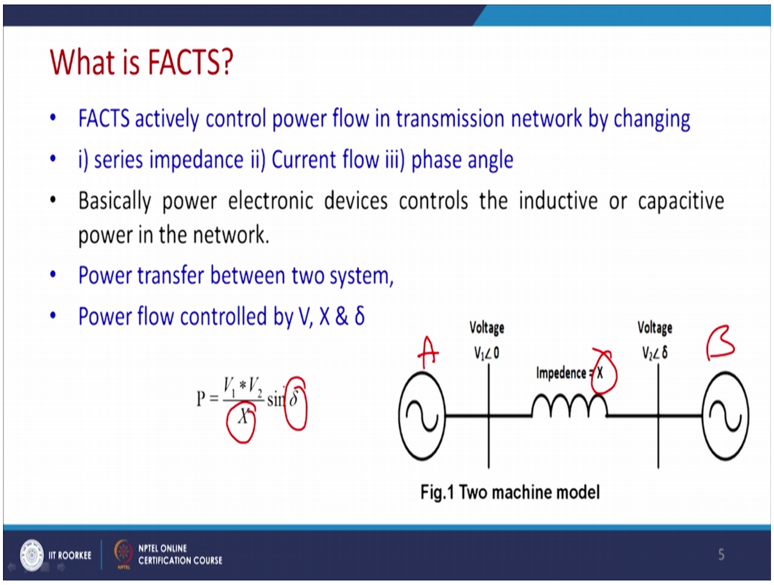

Look this is a simple two machine model, where actually energy is transferred to the point A to point B with an impedance X. Transmission lines is considered to be the loss less and this is the series impedance X.

So, power electronics can control this inductive and the capacitive power network and thus control the X and thus it can control the power flow between the two line. Moreover it can change the delta and it can control the power flow between through this line though. Thus in a series compensated transmission line it can change the series impedances, it can change the power angle and thus it can control the flow of current point A to point B.

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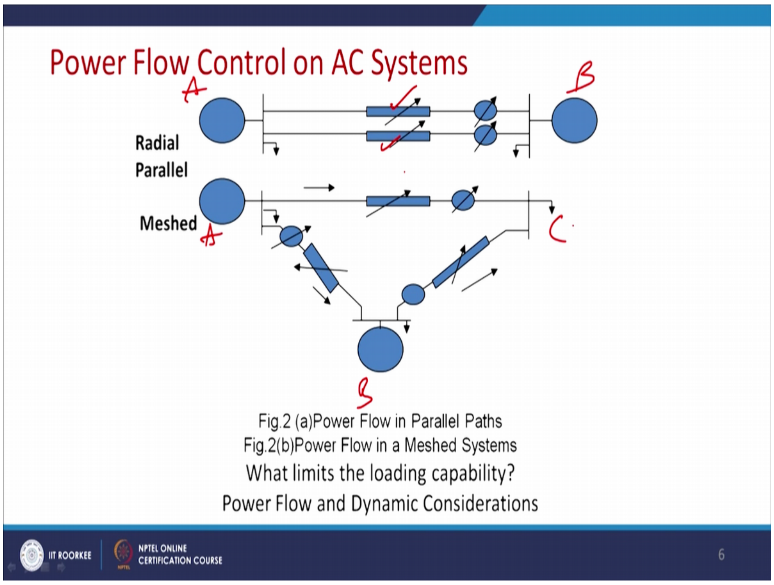

Now, let us take a typical example; upper one is a radial parallel system and another is a mess system. These two act this impedances is basically transformed this series impedance while this impedance can be actively controlled by the shunt by this FACTS devices and these are basically the series injections of the voltage or the phase angle and thus power flow from this point A to point B can be similarly be controlled.

Another is a meshed network, say point A point B and point C. So, it A and B are the generating unit and C are the C that consumer load point. We require to send power point A to point B FACTS device can monitor the power flow between A, B and C line.

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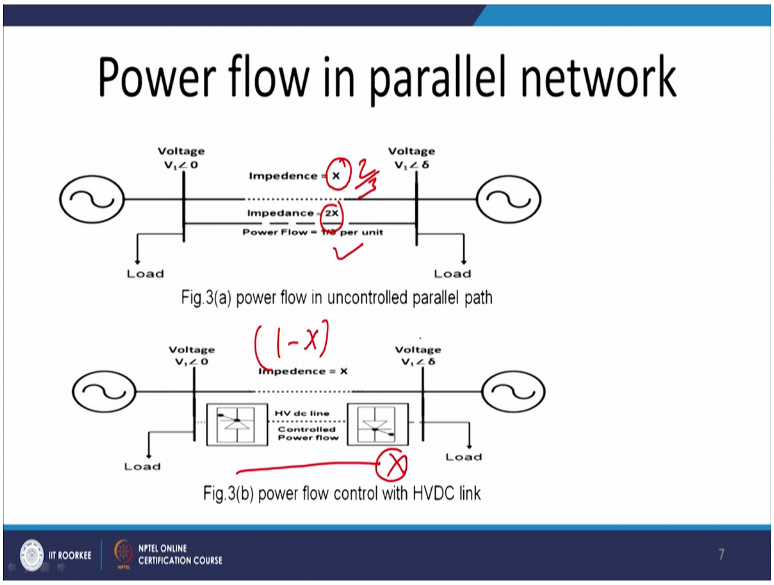

Now, let us consider the simple power flow between the unparallel uncontrolled parallel paths. Here the impedance of this of this line govern the power flow between this point A to point B. Since it upper one have a impedance X, another has been 2X this power flow will be actually two third of the power will be flow. So, this upper line and one third of the power will flow to the lower line.

But, if we increase try to increase this actually the capability of the line of the lower transmission line it is sometime it is self defeating because you know ultimately the power cutting capability will be ultimately returned made by the impedance of this line. And, another solution we can think about that is the with the uncontrollable line which is power governed by the impedance of the line we can put a HBD ceiling in between. This HBD ceiling is controllable, thus it can take X amount of power and 1 minus X amount of power will be flown to the uncontrolled line.

Since X is controllable then 1 minus X is controllable and we have to maintain we have to maintain the power flow of this line by it is governed by its thermal point operating point by thermally thermal limit dielectric limit and its steady state limit.

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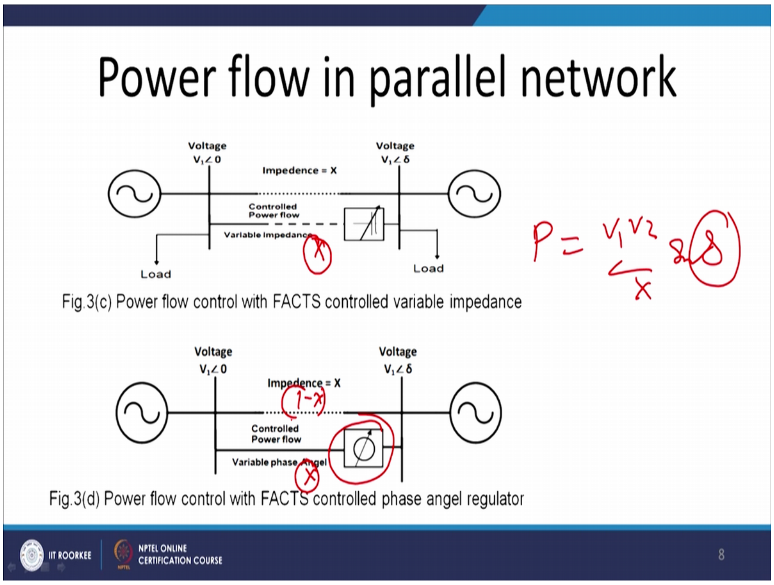

Same way, we can we can go for the solution of the FACTS devices also. Let there be uncontrollable line upper one which is which may be the old one. Now, we can place a new controllable line with the FACTS device placing a FACTS devices. So, this is a variable impedance this variable impedance can be controlled that power X amount of power which is flowing through this lower line the thus it is controllable and thus 1 minus X should be actually the limited to the thermal limit and other limit as governed by the authorities.

Now, same way instead of controlling the impedance as we know that P equal to V 1 V 2 by X into sine delta we can change delta and this is called power angle regulator. This works better when power angle is very low it is less than 30 degree something like that. Then it can by changing the delta we also control the power flow X through this actually FACTS control line and ultimately other part will carry 1 minus X amount of the control power.

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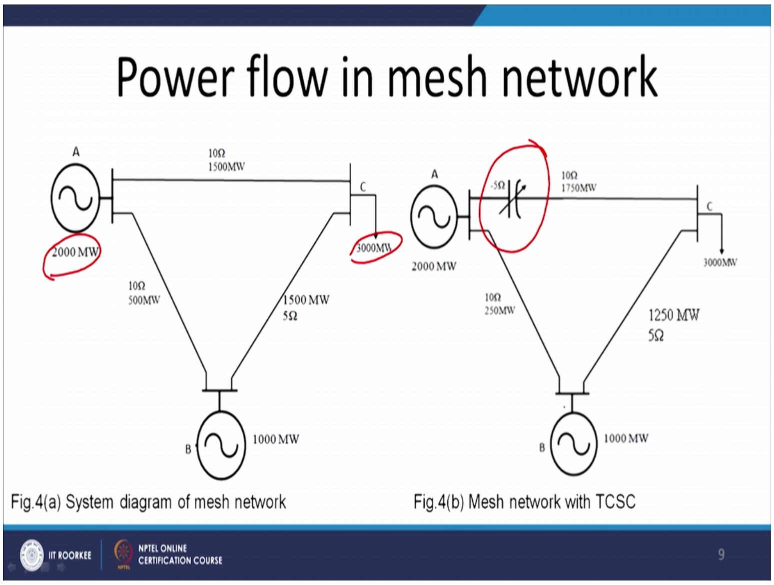

Next, let us consider the mesh network. Taking a critical case why generation point A has a generating capability of 2000 megawatt and it has been connected by the line C and which has a which have a limit of power turning capability is given by 1500 megawatt, but ultimately the consumer require 3000 megawatt of power. Unfortunately, since this line AC cannot take that amount of power ultimately power require to which through the network AB and AC.

Now, in a power system where there is a different stakeholder and different network owned by the different people it may be so that, this line AB owned by the another distributor network and they may charge while carrying current through this network. Smaller amount of current is connect then less amount of power will be then less amount of tariff will be there and thus power available to the consumer will be costlier.

So, we can reduce the power flow through the line AB by injecting by having a solution given by the FACTS. We can we can insert a series impedance variable series impedance to reduce this actually impedance of the line that it will enhance the enhance the power carrying capability of the existing line and it is it actually reaches to actually another 250 megawatt of power. Thus only 250 megawatt of power is actually will through the line AB and thus it reaches through C. So, the actually the wheel power cost decreases in this case while using a FACTS devices.

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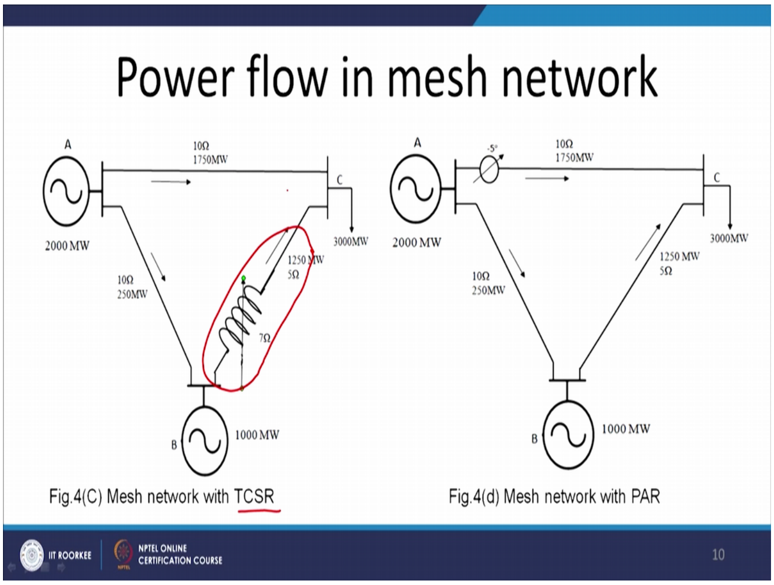

Similarly, we can also increase the 4 C is a network with a TCSCR. So, previous slide it uses actually TCSC. it is thyristor control series compensator. Now, it is thyristor control series resistor, these are the nomenclature of TCSR we all the nomenclature will be given in a subsequent type. In this case instead of this putting the line TCSC in this line we will put a TCSCR in the line PC and we will actually and thus power flow since this imp since the impedance of this line was leased it will carry a most amount of power. So, inserting and exerting impedance it will actually degrade the power handling capability of this line. So, thus regarding to the impedance matching more amount of power flow will cause through the line AB.

Now, this is a what is the actually disadvantage of the previous advantage of this previous advantage is that it has increased the power handling capability. So, it may touch the thermal limit and here without inserting this device and we have inserted a device here and we have increased the extra impedance then also the same has been rep deplicated to the line AB.

Now, here advantage of it that here stability is more, but since impedance has been increased thus losses will be more. And, another solution can be given by phase angle regulator. Instead of actually injecting series reactance capacitor or inductor so, we can insert a power angle regulator which will increase the delta in between the phase in between this a point A to C. Thus, it will can increase the power handling capability of the line.

So, these are the three solution available and depending on this actually thermal limit, depending on the AB environmental condition, dielectric limit, current values all those consideration different solution will be chosen. So, same point it in a different ambient we may choose so different solutions. So, different kind of FACTS devices will provide a unique solution for a particular case.

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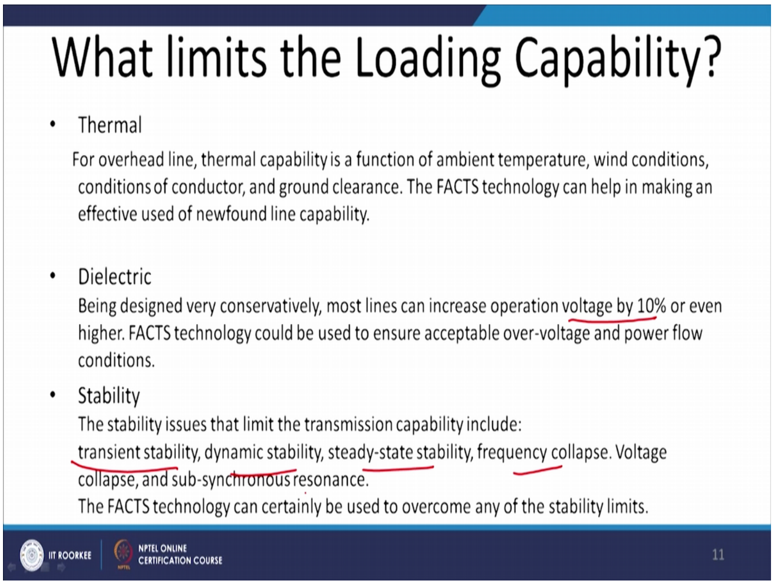

Now, what governs this limits? One is thermal limits and generally thermal limit is designed considering the worst ambient condition and overhead thermistor line is a function of the ambient condition at the and so, there is lot of leave way to take advantage of the present ambient condition. If you note actually actively the what is the present ambient condition then we can overload the line and smartly and by a spot handling capability of the line can be increased. Same way dielectric; dielectric comes with the actually the voltage level since actually we can increase the dielectric limit by because dielectric also limits also works in a purpose of the voltage shredding and it is also for the worse environmental condition.

For a normal operation condition we can easily increase the voltage limit by 10 percent, thus FACTS enables us smoothly more smoothly carry a 10 percent extra power without any much change in the network. And, stability; stability is a very big issue in the power system. These are different kind of stabilities for example, there is a transient stability, there is a dynamic stability, there is a steady state stability, there is a frequency collapse there is a issues like voltage collapse sub synchronous reactance and so on. Facts devices can improve on all those aspect of the stability.

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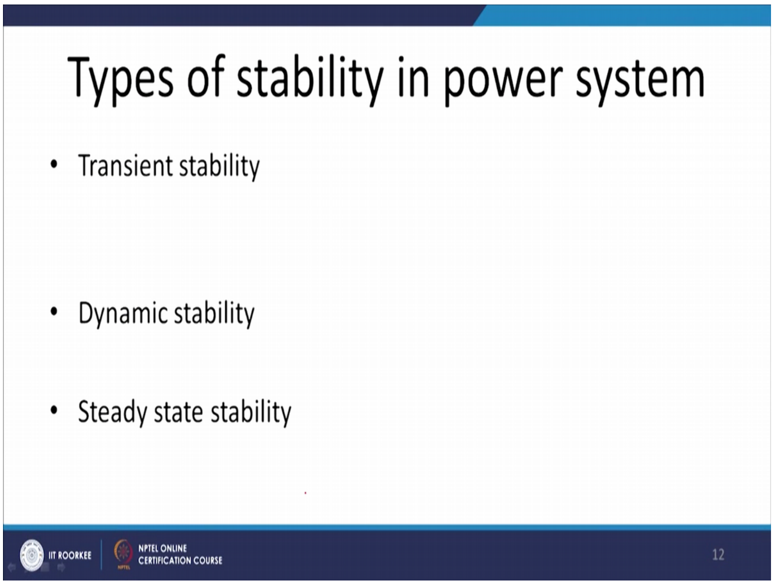

Now, let us talk about transient stability, dynamic stability and steady state stability. This all will be discussed probably now and this I am noting down in separately.

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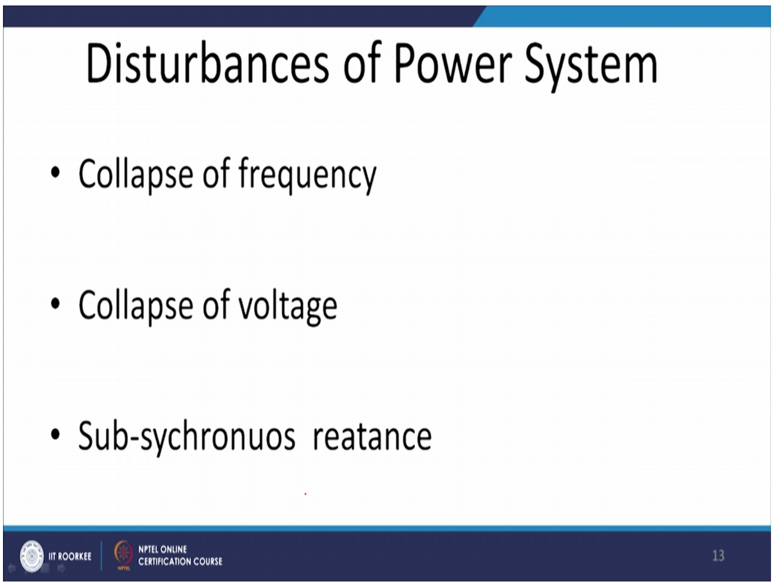

So, that these are the very important aspect of the power system; collapse of the frequency, collapse of the voltage and sub synchronous reactances.

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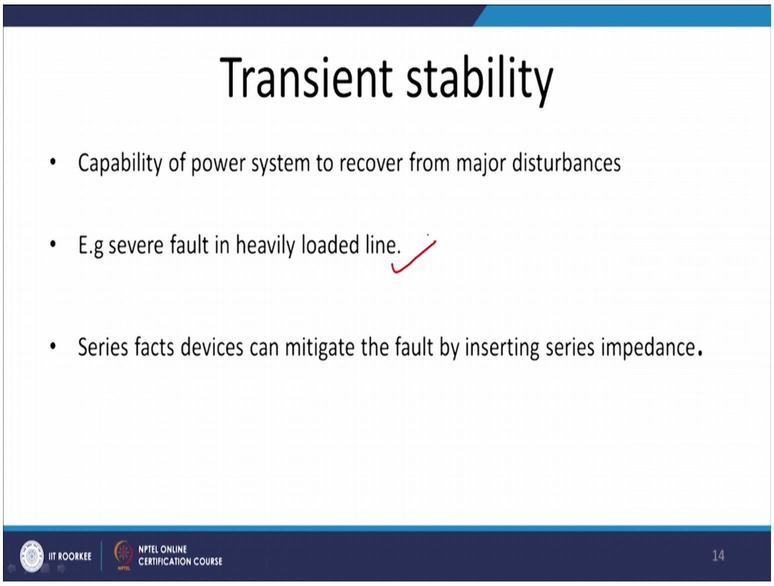

Now, transient stability; Example of the transient stability will be actually when load at when a when a loaded line have a LG fault or line to line fault then all of a sudden there is a huge change in the dynamics of the power system. So, this is actually severe fault in heavily loaded line. Then FACTS device can be used to mitigate this fault and increase the stability of the system.

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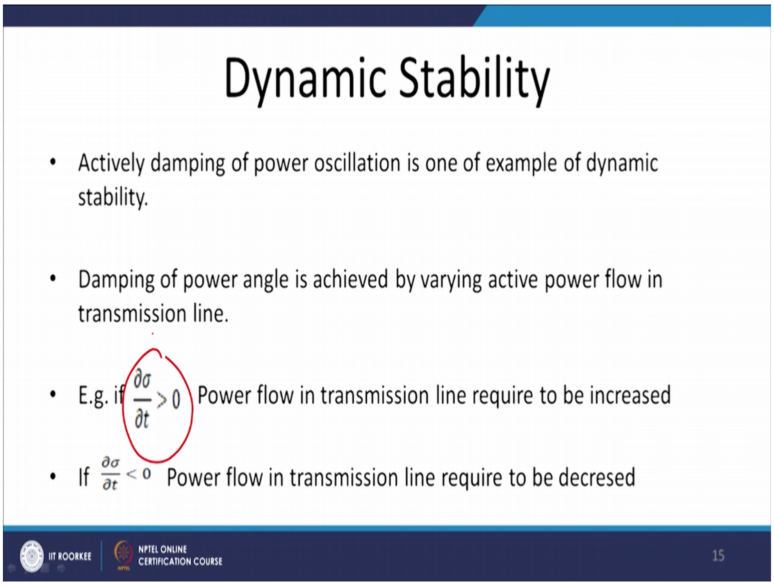

Same way dynamic fault; If the system has a power oscillation and thus the torque angle oscillates we require to damp out that oscillation actively and that is also possible the FACTS devices. Since the stump if it is more than is positive, it means that power is increasing and considering that is actually dent actually sigma is actually less than 90 degree then in that case we require to increase the transmission line capability.

Similarly, if it is less than 0, we require to decrease the transmission line capability and thus by doing that we can actively damp out the dynamic oscillation and thus enhance the dynamic stability of the system.

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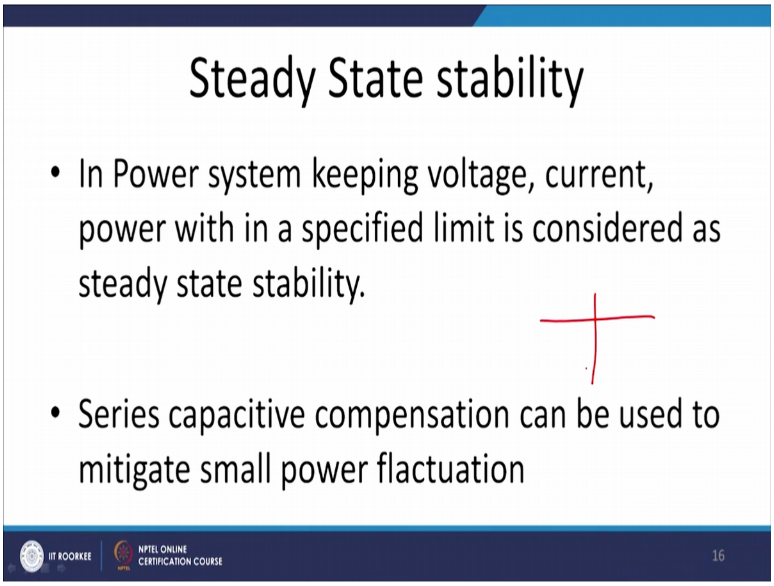

So, it is a stability we require to maintain the voltage and current and power in a normal to the operating condition. We all of a sudden certain disturbance is there certain sac is there let us say a transmission line actually touches by a tree then after every 10 millisecond or 20 millisecond you got a voltage sac. So, in that concision series injection can actually actively mitigate that sac. So, for example, series capacity compensation can be used to mitigate small power fluctuation.

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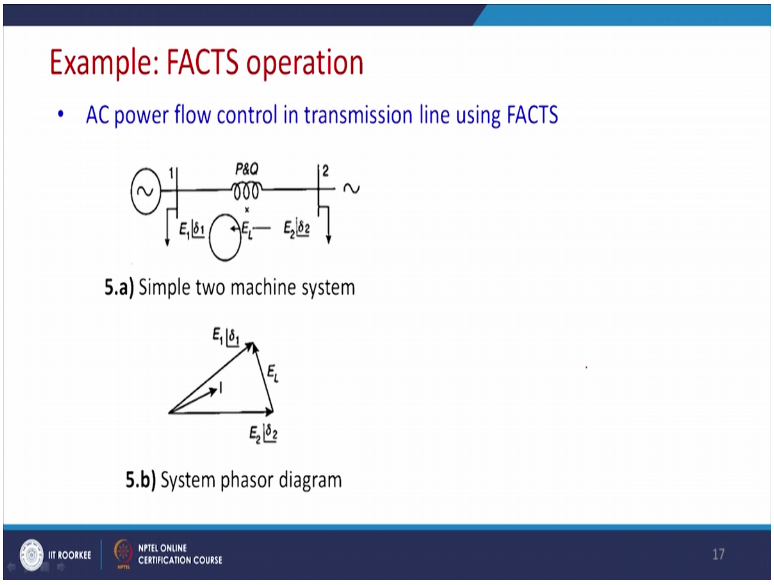

Now, let us come into the again the two machine model and we assu and this is a phasor diagram of it and where the angle between them is delta and I almost perpendicular to the E L.

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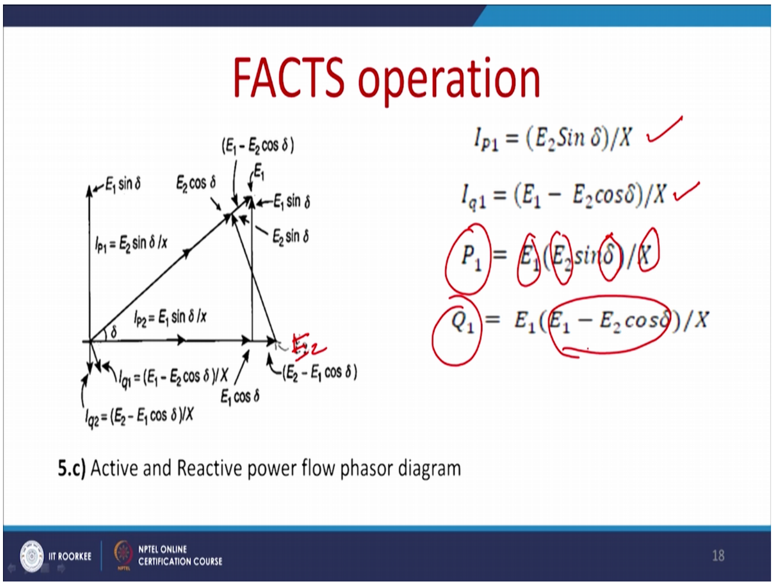

Now, we shall calculate the power of a receiving end, same way we can calculate the power of the sending end. So, this is E 1 and this is E 2. So, from there an angle between them is delta. So, real power of the sending it is I P 1 it is given by E 2 sine delta by X. Similarly, the reactive component of the current is given by E 1 minus E 2 cos delta by

X. So, P 1 equal to E 1, E 2 by sine delta by X this is a sending end power. Similarly, reactive power from the sending end will be given by E 1 minus E 1 into E 1 minus E 2 cos delta by X.

Thus, as well understand by changing X we can change the transmission capability of the line. Similarly, by changing delta we can change the transmission capability long line. By increasing or decreasing the value E 1 and E 2 we can change the transmission capability of line. Same way by actually controlling this term we can control the value of E 1 and E 2 in the line.

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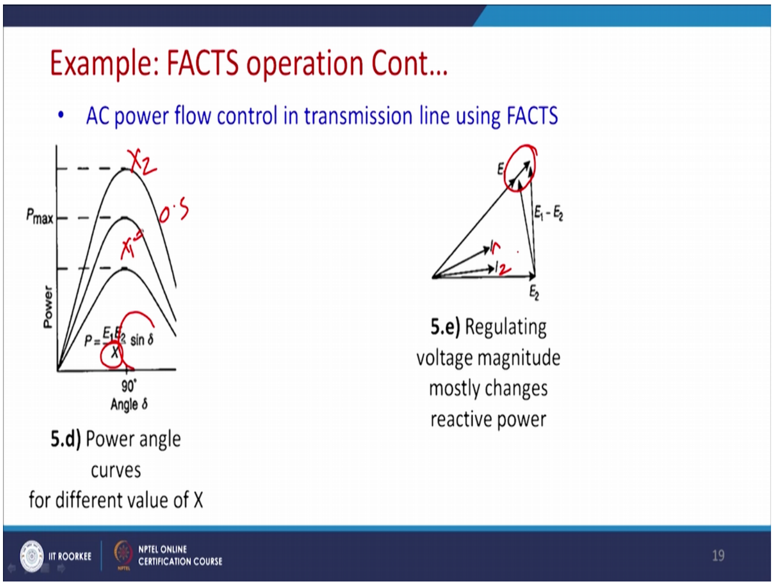

So, if you wish to increase the power limit or decrease and we require to change the series impedance of the line this will be the power curve. Since E 1, by E 2 sine X is signed E 1, E 2 X by X sine delta is a curve and thus if you increase the in decrease the value of X subsequently for X 1 you will get this one, subsequently X 2 we will get this one, when X equal to actually 0.5.

So, this a power handling capability ultimately governed by the thermal and other stability issues of the system. Same way we can inject the voltage in phase it can be easily done by a (Refer Time: 17:55) transformer and thus also the value of in between E 1 and E 2 changes reactive power as well as the real power can be changed and the new current change this to I 1 to I 2.

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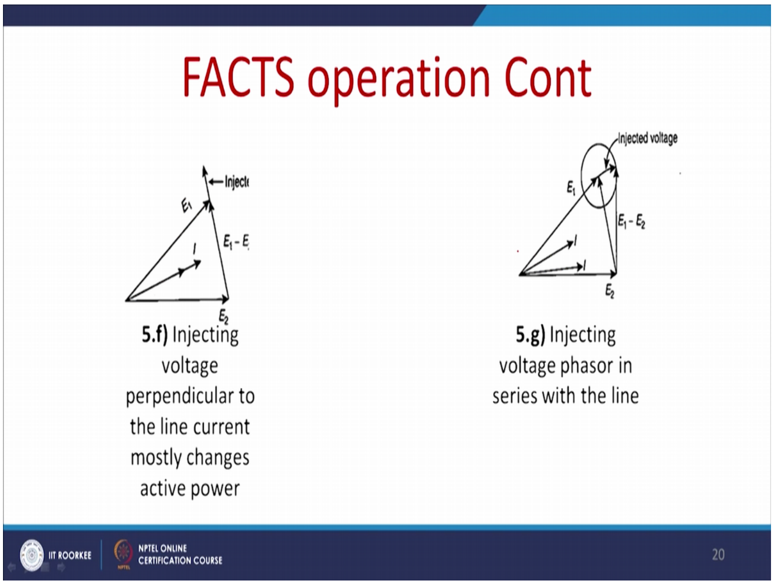

Now, we can inject current perpendicular to we can inject voltage perpendicular to the current. So, in that helps us to change basically the phase angle. So, when we inject the actually perpendicular to the line voltage is mostly changes the active power of the system and when we inject the current in series with this actual E 1 and injected voltage almost in the phasor then voltage regulation can be done by this method.

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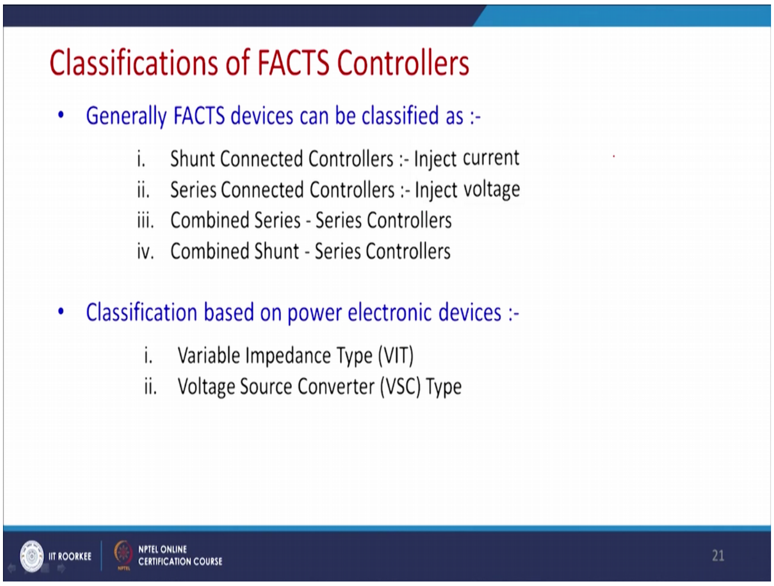

Now, there are different kind of shunt devices shunt connected controller it inject current series connected controller. It inject voltage this combined series-series controller and combined shunt-series controller. And, another type is it injects basically the impedance these are called variable impedance type VIT and another type is source voltage converter. So, classification can be done based on based on what kind of whether it is increased a inserting impedance or the voltage source into the system.

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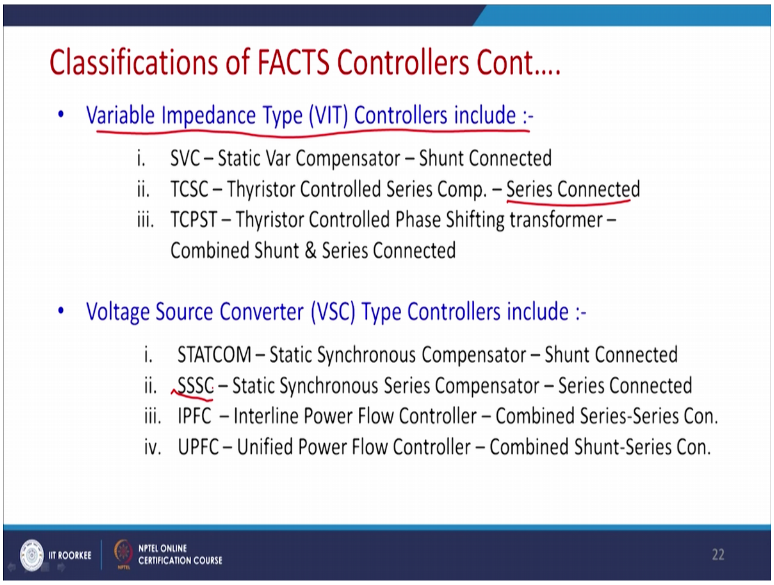

Now, these are the few nomenclature which will be frequently used in our subsequent discussions. Students are required to note down and familiar with this acronyms. So, this is specifically the variable impedance type controller. So, it insert a impedance so, VSC it is a static word compensator and it is a shunt connected device. And, TCSC in few slide before we have seen TCSC, that is thyristor controlled series compensation as an active capacitor and it is a series connected device.

Similarly, thyristor control phase shifting transformer, it is used for PAR power angle regulator and other type of the FACTS devices are voltage source converter. These are STATCOM, this is shunt connected, this is SSC, SSSC it stands for static synchronous series compensator. Thereafter, you have interline power flow controller, that is, combined series combinations and thereafter you have UPFC that is unified power flow controller or UPQC unified power quality conditional for power quality we say power quality condition and the FACTS we say power flow controller.

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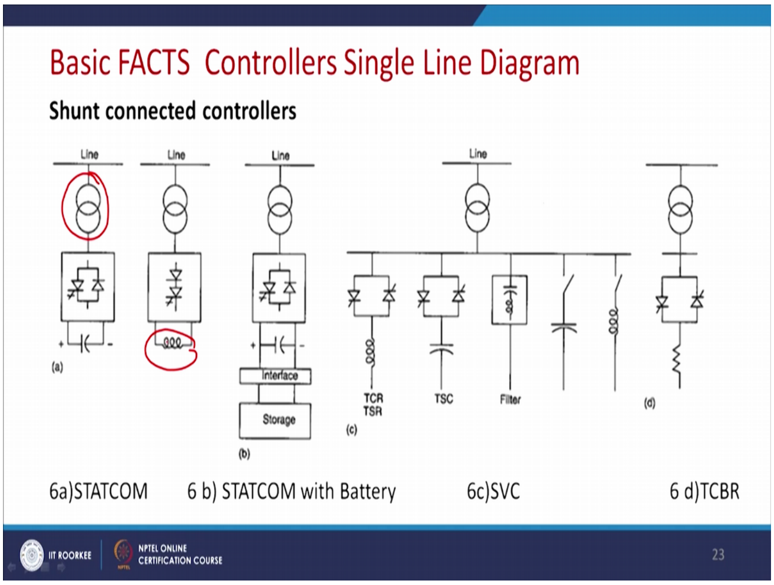

Now, these are the pictorial representations of different acronym which I have just explained. This is the STATCOM, this stands for the step down transformer, since operating devices cannot match the existing power line voltages so, it will require to step it down. It is a basically static solution of synchronous over exited synchronous generator. A synchronous generator can provide this solution also compensate the acting power and also control the war of the line, but it can actively do that, but advantage is that only it has to feed the switching loss, there is no power there is no prime over is required thus efficiency of the system is quite high in this case.

And, while we use a voltage control current source inverter then we shall use this kind of topology and followed by a DC link capacitor. If we use current source inverter generally we use an inductor current source current source require a high value of the inductor and for this is an this voltage source solution is cheaper and effective that most of the application we found a STATCOM is operated by this voltage source inverter.

Voltage source inverter or current source inverter if it carries a storage device in a distributed generation like solar cellular battery, then it can also inject the active power it can also compensate or give the active power to the system. Then it will be a storage device with the FACTS devices and this is the STATCOM with the battery.

And, now let come to the figure is SVC static wire compensator; Static wire compensator consisting of family of the FACTS devices and the power quality devices. So, this is actually TCR, this is TCSC, thereafter you may have a line filter, thereafter you have a uncompensated capacitor, uncompensated inductor and this is actually the TCBR this stands for the actively damping the circuit.

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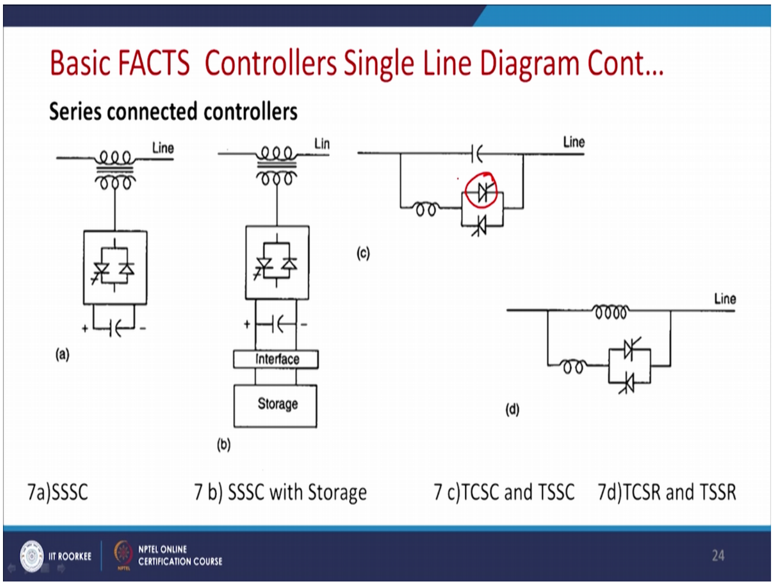

Now, let us consider the FACTS devices which is basically it SSC, it is a series controller. So, again in it is same as a STATCOM, but it is it requires a series injection and ultimately it is also it can also have a current source converter topology, but it is not very popular, for this is an here voltage source converter topology has been shown. And, same way this SSC can come with the storage devices, so, it can inject the voltage and current in phase and quadrature and it is quite versatile device as far as series compensation is concerned.

TCSC essentially deals with the variable impedance part component of it. By changing the triggering angle of the thyristor the changing of the change the impedance can be controlled and thus you can control the impedance of the line by this transmission system. Same way if you have a TCR and we will have a we will have a this kind of system. Please note that thyristor should be connected in the line, where actually inductor is connected we cannot connect thyristor in series with the capacitor. Why it is so, I left this question to the student.

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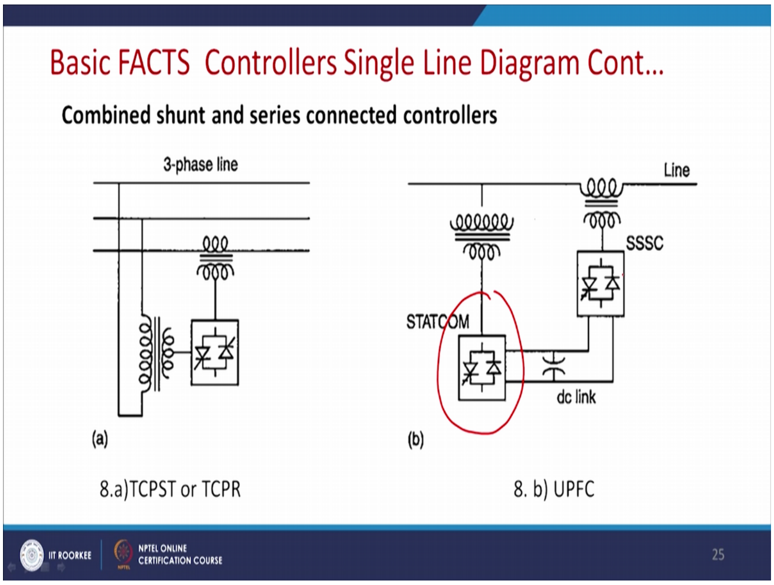

Now, let us come to the combinations of the FACTS devices. This is combined shunt and series compensated controller and this is called TCPSTS, this is essentially a phase angle regulator. And, this is a and this is a UPQC or UPFC, this is a series shunt combination. This part acts as a STATCOM and this part acts as a SSSC or the series compensation. So, altogether advantage of the series and shunt both are captured here.

So, both we shall capture in the next class. One of the advantage of different kind of shunt and the series network and we shall in detail we shall talk about this what are the application of the different kind of FACTS controller in next class.

Thank you.