Flexible AC Transmission Systems (FACTS) Devices
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Lecture – 01
Introduction

Welcome, to the NPTEL online certificate course on Flexible AC Transmission System of FACTS Devices. I am Dr. Avik Bhattacharya, assistant professor of Electrical Engineering Department of IIT, Roorkee. We shall discussed about the FACTS devices in detail.

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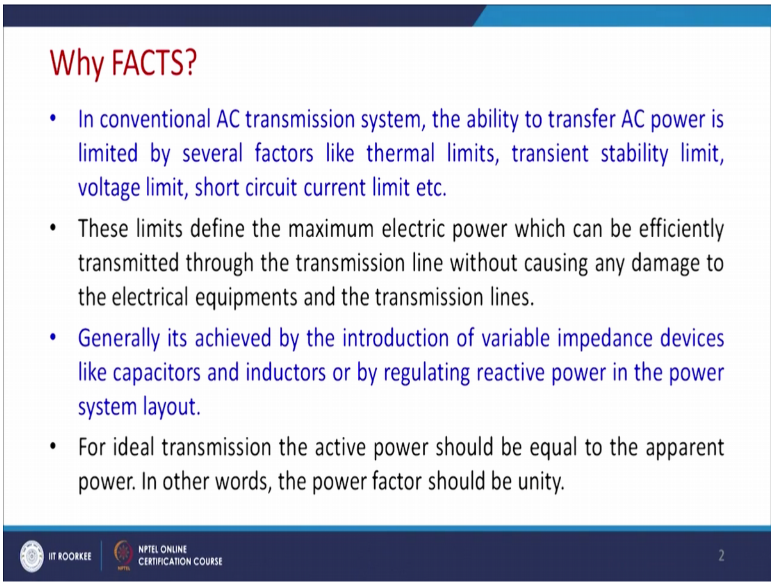

So, first of all we require to discuss what is FACTS? FACTS is a conventional AC transmission system, the ability of the transfer power is limited by the factors like thermal limit transient stability limit of the voltage and the short circuit current. And this limits define the maximum power electric power which can be effectively transmitted through the transmission line without causing any damage to the electrical equipment and the transmission line.

Generally, this is achieved by the introduction of the variable impedance device like capacitor, inductor or regulating the reactive power flow in the system. For ideal transmission the active power should be equal to the apparent power. In other word, power factor should be unity and transmission line is considered to be the loss less.

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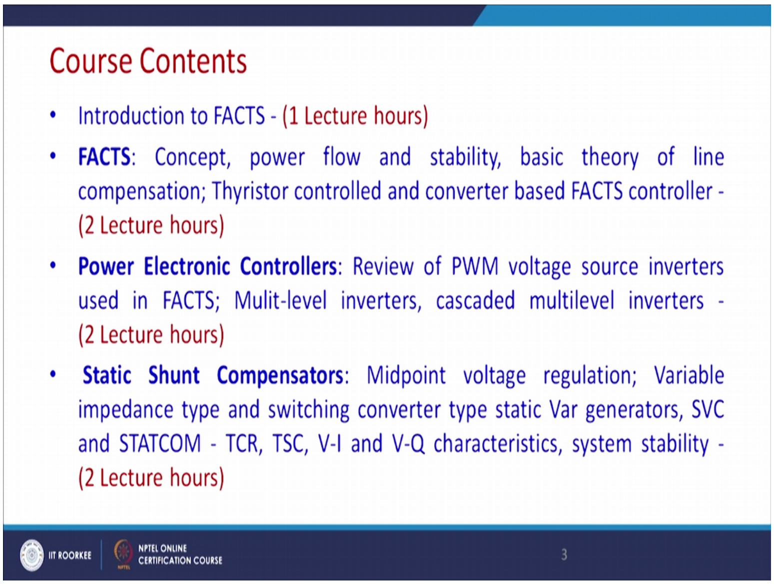

Now, let us focus on the course content introduction to the FACTS, this will be a 1 – hour lecture course, they are up followed by there will be FACTS concept power flow, stability and the basic theory of line compensation, thyristor controlled converter based FACTS controller, this will be 2 – hour lecture courses.

Power electronic controller, we shall review the power electronics different kind of power electronics cont through converters and its control techniques by PWM, different kind of PWM voltage for voltage source inverters, multilevel inverter, cascade multilevel inverter and different kind of topology suitable for the FACTS applications will be discussed.

Thereafter we should discuss shunt static shunt compensator a typical midpoint regulator will be discussed, variable impedance type and the switching converter type static for compensator will be discussed in this course. SVC and the STATCOM and a different type that is TCR, TCSC and it is V-I and the q and the q characteristics V-Q characteristics and the stability of the system will be discussed. Then, we shall discuss about series static series compensator, concept of the static series compensation will be discussed.

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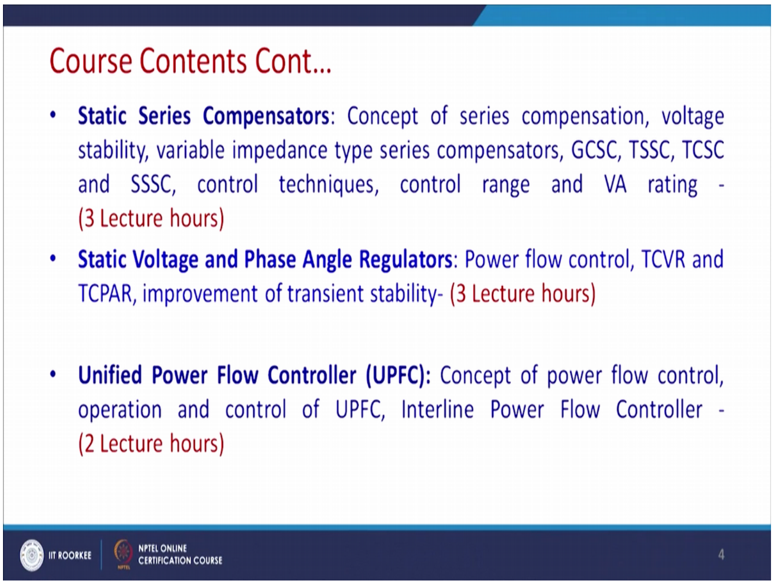

Voltage stability variable impedance type series compensation by different kind of elements like; GCSC, TSSC, TCSC and SSSC and its control technique control range and it is VA rating will be discussed static. Thereafter static voltage and the phase angle regulator will be discussed, its power flow control and TCVR and TCPAR, these are the two element will be discussed thoroughly, improvement of the transient stability by phase angle regulator will be discussed here.

Thereafter we shall discussed unified power flow controller or UPFC, the concept of the power flow control and its operations and its control and thereafter interline power flow controller also will be discussed here.

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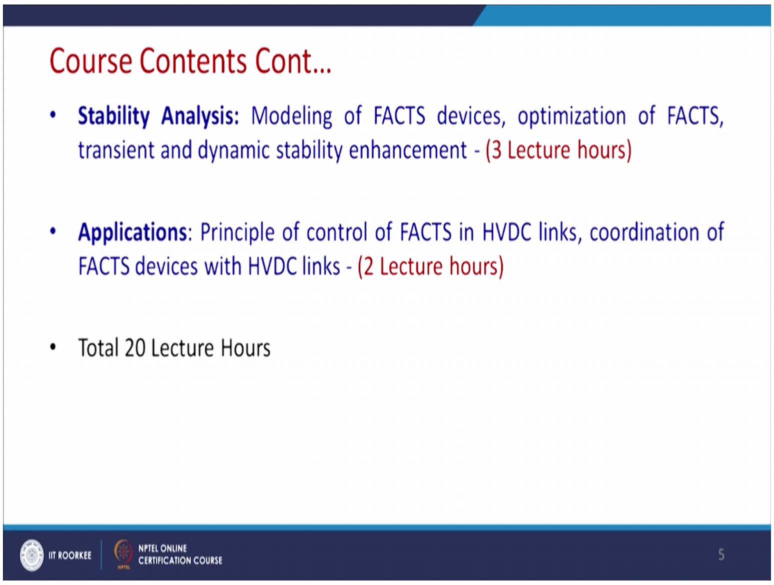

Thereafter we shall discuss the stability of the FACTS devices and modeling of the FACTS devices, its optimizations and its placement transient and a dynamic stability enhanced by the FACTS devices will be covered during this hours. And thereafter, applications of the FACTS devices principle of the control of the FACTS devices with the HVDC link and coordinated control of the FACTS devices with the HVDC links will be discussed total duration of the course will be 20 hours.

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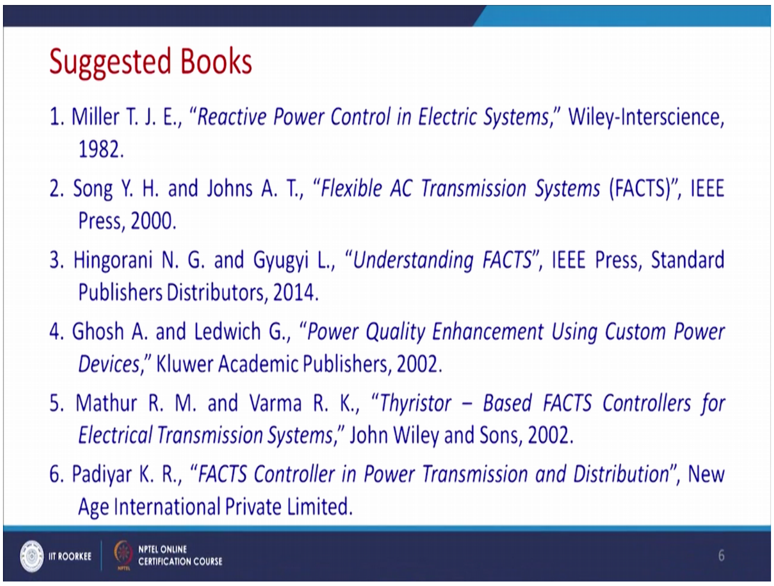

And, now, let us take the next course that is the suggested book. The suggested book is basically Miller Jate Miller T. J. E. that is reactive power control in electric system and Song Y. H. and John A. T. Also, Hingorani and Gyugyi these are all these two books are of I triple E press. Thereafter, Arindam Ghosh and Ledwich G., by Power Quality Enhancement Using Custom Power Devices, Mathur R. M. and R. K. Varma Thyristor – Based FACTS Controller for the Electrical Transmission System by John Wiley, Padiyar K. R. FACTS controller for the transmission and distributions it is by the New Age International Private Limited.

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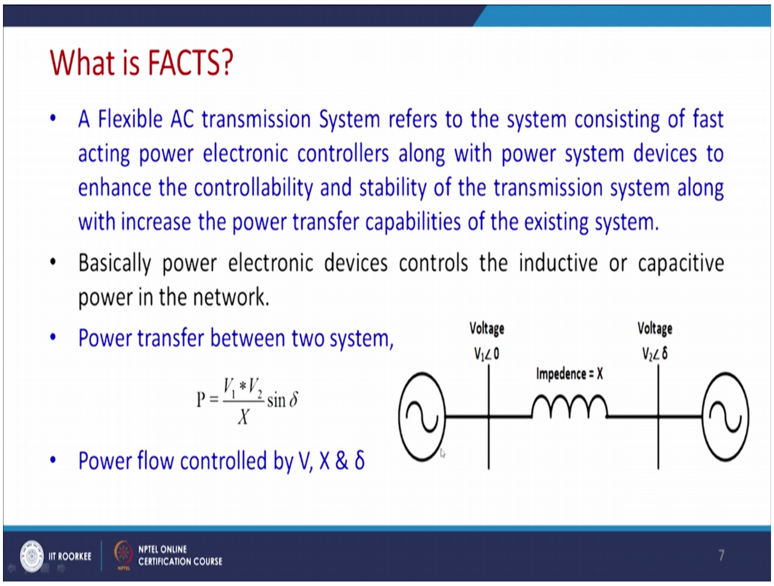

Now, let us come to the point, what is FACTS? So, let us consider the point one, one point here which has a power deficiency and power will be flowed from this point to this point and the power will be transmitted from the V 1 to the from the note voltage which is having marked as V 1 to V 2 will be given by V 1 into V 2 by impedance of the line and the phase difference between these two line. So, how we can enhance the power flow between these two line, is not necessarily the real power also reactive power. So, both can be enhanced by the FACTS devices.

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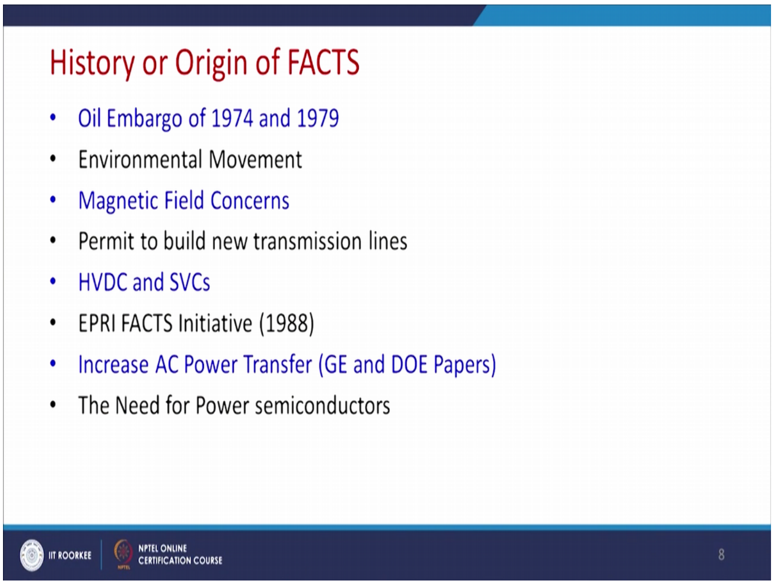

Now, let us go back to the little history of the of the FACTS devices. There was a Oil Embargo in 1947 to 1979. So, due to the huge spikes in rise of the oil then actually putting up the extra power plant became a cross lead the for this recent people think of a solution, where instead of putting extra power plant a power quality power can be transmitted for the long distance one point to another. They have to environment a moment setting up the power plant will actually have updated mostly based on the fossil fuel will have great impact on the environment, for this environmental moment comes into the picture and that forces to actually shut down many of the power plant.

They are term magnetic field concerned and if you have a very high voltage transmission line so, then it will be a hazardous to the inhabitant below it, for this reason there is a magnetic field constant. Permit to build new transmission line. So, since this magnetic hazardous are presents for this reason the locality from where the opponent transmission line go required to take permissions and this permissions due to the environmental and the health related issues getting costlier day by day.

And thereafter, we have come into the technology that is with the HBDC and SVCs; that gives us a scope to revisit the FACTS devices itself and thereafter in 1988, in Westinghouse started actually building up EPRI based FACTS devices and parallelly GE came out with the rotary solutions and then with the advent of the power electronics it is highly feasible to use the FACTS devices nowadays.

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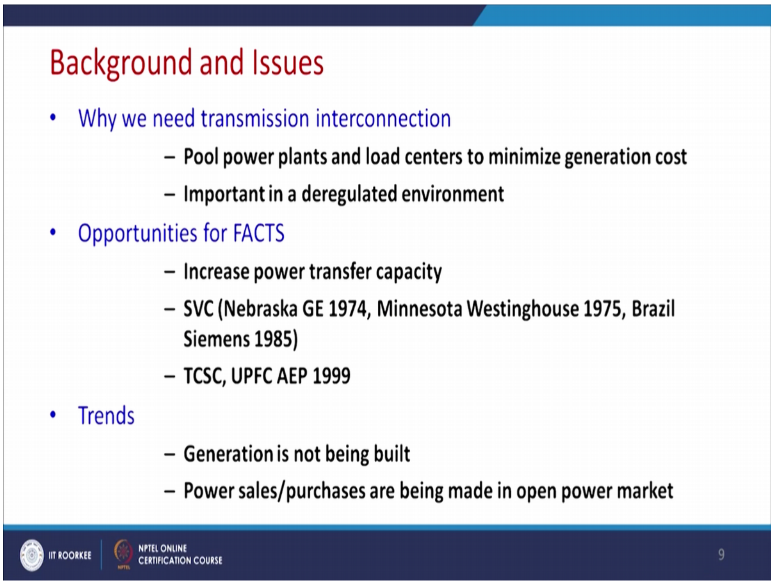

Now, let us understand the background and issues related to the FACTS devices, why we need transmission interconnections. Pool power plant and the load centers to minimize generation cost. For example, let us take an example that for past 20 years the load centers are in the certain part of India and mostly we have a generation based on the fossil fuel that is coarsely available the eastern part of the India. For this reason we required to transmit either coal or the power from the eastern region to the southern region.

FACTS enable us basically to pool power plant and to transmit power from this actually look to the to the load centers instead of actually putting extra power plant, an important to in a deregulatory environment. An opportunity for the FACTS it increases the power transfer capability of the line and thereafter, these are the few case studies as we see in they have it must be in place by GE in 1974 and Westinghouse actually placed another FACTS devices SVC west.

We shall discuss what is SVC in detail in 1975 and Siemens placed this FACTS devices as early as 1985 in Brazil and TCSC, UPFC based FACTS devices came into the pictures in 1999 and this present trend is generations is not being built. Then, nowadays you can sell and purchase power like a trading market. So, for this you say there is a huge amount of economical benefit is involved using the FACTS devices.

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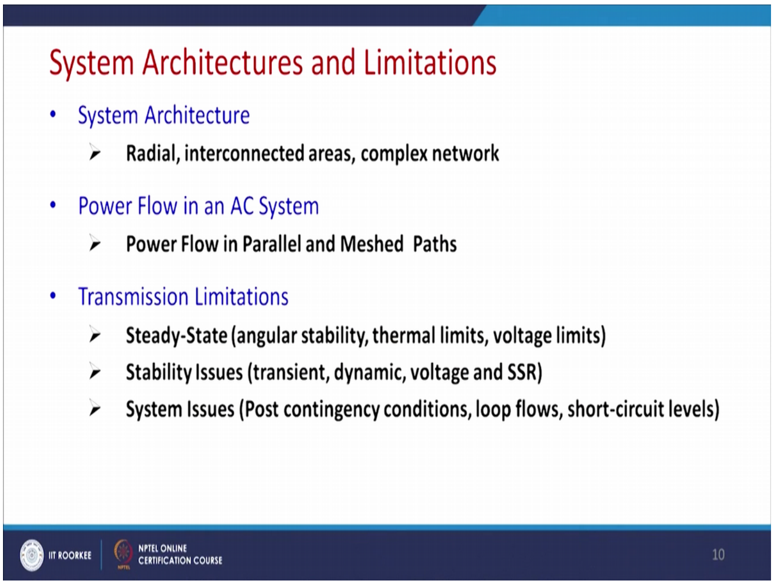

Now, let us understand the system architectures. So, generally transmission line have a different kind of architectures and that is radial, interconnected and the complex network; Power flow in the AC system, power flow in the parallel and the mesh paths. Transmission line limitations; the steady state limitations are angular stability, thermal limits and the voltage limits. What are these? Angular stability you we of course, as we have explained in the previous slide actually V 1 the power it is transmitted it is given by V 1 into V 2 by x sine delta. For this reason there is a angular stability that delta cannot be more than 90 degree.

And, thereafter, the thermal limits and thermal limit is basically we have estimated little bit of conservative way. What is the actually the worst case conditions of the thermal limit? Once actually the amount of the current flows through the flows through the transmission line increases then it may touch the thermal limit. But, it is possible to actually actively monitor the health of the line and the temperature and thus we can also disperse extra power dynamically controlling the temperature, that a voltage limit it is related to basically the insulation limit.

Generally, we should allow the allow the voltage to be go around 10 percent higher since it is also designed based on the worst case conditions that mean may be the actually why I am actually they have insulations is low. So, we can also considering the environmental conditions we can increase the dynamically using the FACTS devices the voltage limits.

There are stability issues. Stability issues are transient all of a sudden huge change of the loads or the throwing of the any power plant will leads to the transient stability that a dynamic stability. Dynamic stability also as an issue when load changes occurs thereafter voltage. And, sub transient reactance. Sub transient reactance is a is a great demerit in case of the power system we shall discuss about the sub transient reactance with the greater details in later slide. System issues, post contingency conditions and a la loop flows and a short-circuit levels. These are also keep in mind while designing the FACTS devices.

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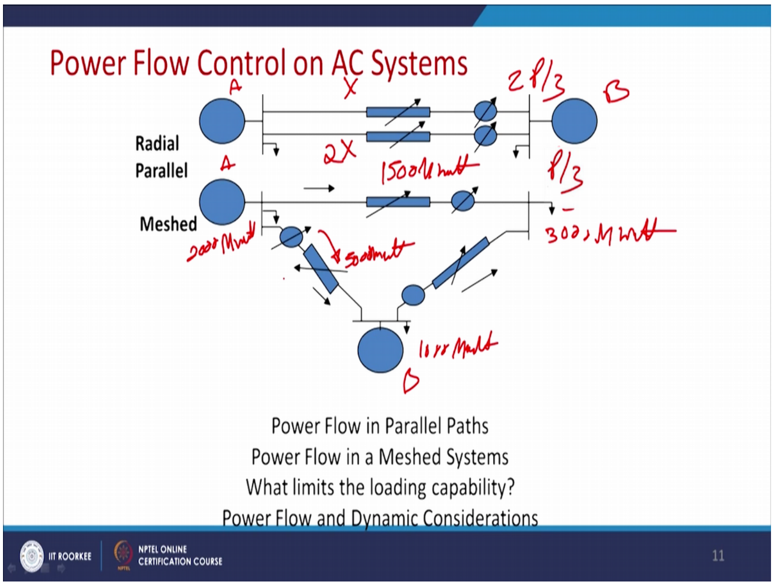

Now, let us consider what is we understand by the FACTS devices, that is the radial parallel line. Here we can we can see that the power can be sent to one point to another point and by the two parallel line, but in this case generally which line will have a less impedance will carry more power. Let us consider this is a generating point A and this is the generating point B and these having impedance X and this having impedance 2X, then you will find that you know this line will carry power P by 3 and this line will carry power 2P by 3.

So, most of the power will basically go through the point upper point upper impedance line which has a lower impedance if it is a fixed impedance, but if you can control, if you can control the power through this line then you can change the different kind of situation. Let us consider the mesh kind of network and let us consider that power demand by this point C is basically 3000 megawatt and let us assume that it can it can handle only 1500 megawatt of power and you know generating capacity of it is 2000 megawatt then what will happen and varying capacity of this point, let us mark it A and mark it B and C and is 1000 megawatt.

Then in normal cases without FACTS devices then extra power of this much amount of 500 500 megawatt will flow through this line. So, for this reason this will be a detrimental, but this can be changed by the FACTS devices and these are the two kind of one is radial net radial parallel network and the mesh network.

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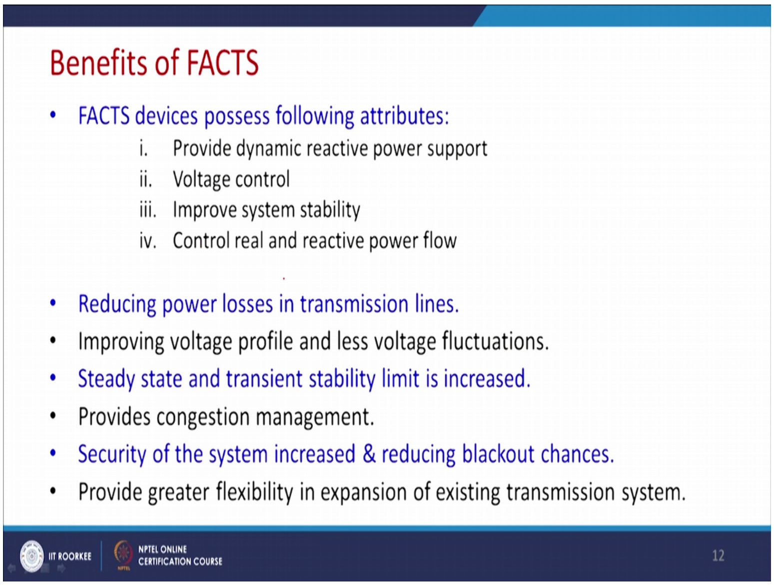

Now, let us see that how it will be changed. FACTS devices actually FACTS devices possesses the following attributes and these are the advantage of it. It can provide dynamic reactive power flow; we will be discussing in detail, what is it and thereafter voltage control we can we can control the voltage of the any of the bars. Generally, it is being done by the shunt active power shunt compensators and it can improve the stability of the system and control the real and reactive power simultaneously.

And, thus in that way we can reduce the power losses in the transmission line because we can control the power flow of the line, improving the voltage profile and the less voltage fluctuations. Since we can introduce a voltage control by the FACTS, steady state and a transient stability rebate will also be enhanced by the FACTS devices and it provide congestions of the management of the power. We can actually take out power from the over congestion line to the less congested line by the FACTS devices, security of the system can be enhanced and chance of the blackouts will be reduced and it provides a be better flexibility in expansion of the existing transmission line.

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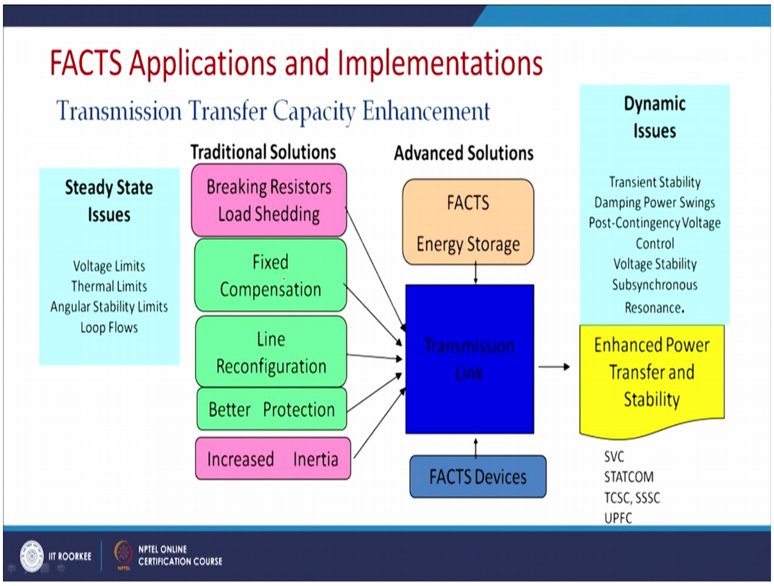

Now, let us see that applications and the implementations. Now, when we have a state, there are steady state issues there are dynamics issues. So, steady state issues are the voltage limits thermal limits, angular stability and a loop flow. So, traditional limit is basically traditional solution at the breaking resistors and the load shedding when you have a greater amount of load you require to shed a part of the load. You got a fixed compensations so, you cannot do much about it and you got a line re regulations and a better protections and increased inertia, these are the basically the solution you can think of.

But, with the FACTS devices with the storage and the transmission link we can increase the transient stability, we can instead of a load shedding we can have a app, we can have a actively damp out the power swing curve and the post contingency voltage control. We can stabi we can introduce the stability of the voltage, we can mitigate the subsynchronous resonance and thus we can actually as a output. We can give the enhanced power transfers and the stability to the network. and, this has been done by the few power element is basically is a series element, series compensator, STATCOM is a actually parallel compensator, UPFC is a combination of series and parallel combinations.

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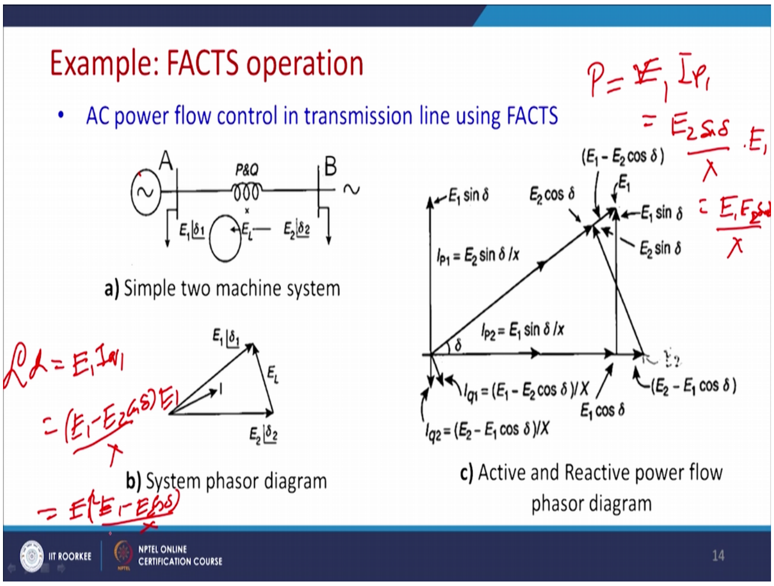

Now, let us understand how does facts works for that two machine model. Now, let us consider the point A and point B, and assume that point A is a generator or has a power surplus and point B has got power deficient. So, power will be transferred the point A to point B. Now, we can calculate what is the amount of the power it can transmit. So, for this is you know you can refer to the phasor and E 1 and E 2 an angle between they were delta. So, real power flow it can be read it in as P is basically V is basically E 1 into I p 1. So, E 1 into I p 1 can be rewritten as so, it is E 2 sine delta by X into E 1. Thus value of power transmitted between the point E 1, between 1 and 2 is given by E 1, E 2 by sine delta.

Similarly, the value of the q will be given by it is v into I q 1. So, we can see that what is the value of I q 1. I q 1 and I q 2, I q 1 is basically here it is E 1 minus E 2 cos delta by X into E 1 that gives you the power. So, that values comes out to be E 1s square or you can take in a bracket E 1 minus E 2 cos delta by X. So, this is the active and the reactive power and this is the phasor of particular active and reactive power. When this lines too close and thus the delta is very less then power can be hen power can be increased by this loop by increasing the value increasing or decreasing the value of the impedance.

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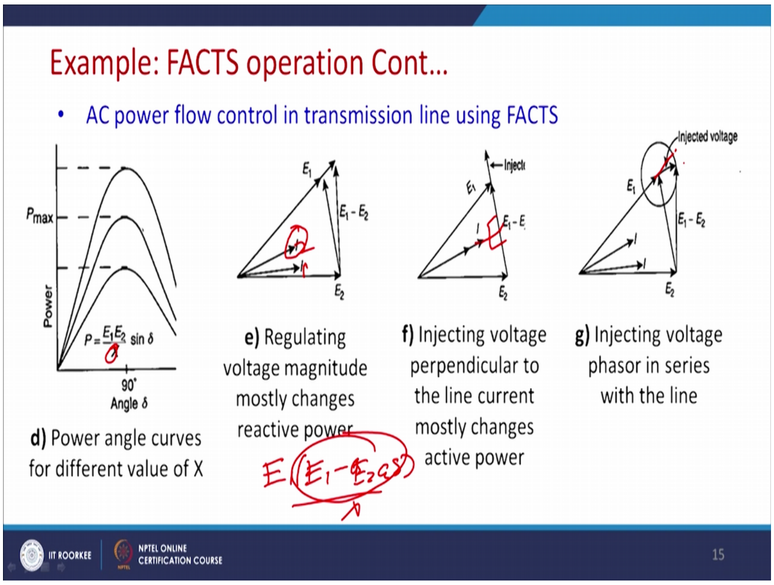

So, thus if you change the value of X so, we can have the this lines parallelly. So, thus what happen if you can increase the value of X or decrease the value of X, accordingly as the maximum power handling capability of the line will change. So, this is the this is the constraint, but what will happen here if we increase the value or increase or decrease the value of X then accordingly it may touch the thermal limit. Since the voltage between these point A and B is same what you were essentially doing basically the value of the current flowing through this A and B is changing and thus we have to consider dynamically what should be the thermal limit accordingly the value of the power can be change in this consideration.

And, let us consider the figure – e, what happen here you know; it is a deregulating voltage magnitude and it will mostly change the reactive power. So, what essentially we do previously let us assume that the I 1 was the currents between it and if by injecting some amount of current resultant current becomes the I 2, then thus you know the angle between then what will happen then what will happen then the actually the reactive power element this actually we know that electric power is given by E 1 E cos E 2 cos delta by X. If these value changes then reactive power changes so, this can be done by injection shunt injections.

Here, in this case what happen you know we inject the voltage perpendicular to the current. So, this angle is 90 degree. So, you inject a voltage perpendicular to 90 degree and this will essentially will change the reactive active power of the line. So, reactive power can be enhanced by inject power perpendicular to the current and same way injecting voltage we can injecting voltage in series with the line. So, in this case we can inject a voltage in series in this case both E 1 and E 2 both will increase and thus what will happen effectively both P and Q both will increase an apparent part in engine. This circle is called the sphere of influence and based on that we with the different kind of injection different kind of objecting can be achieved.

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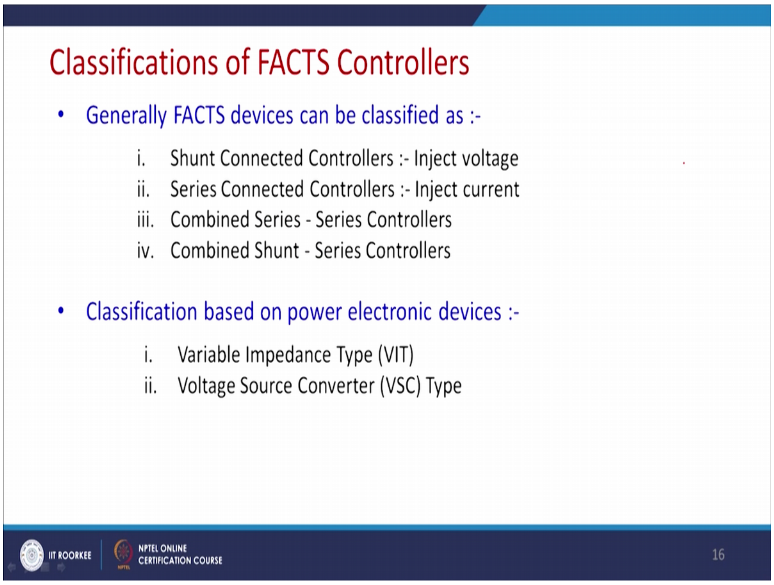

Now, let us talk about a general devices. So, we can talk about the shunt connected fact devices, that is, shunt connected controller and to inject voltage; series connected controllers, inject current; combined series, series controllers; combined shunt and that is series controller. Classification based on the power electronic devices will have a two kind of power electronic devices; one is variable impedance type VIT and the voltage source converter type, it is basically VST type we shall discuss in VST type and all those things in subsequent classes.

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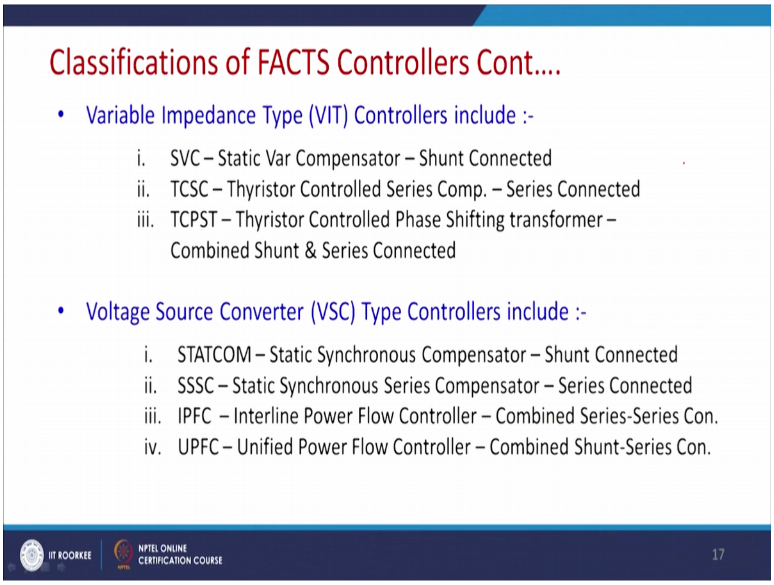

Now, variable impedance type controller are the following, that is static word compensation that is used in the shunt com shunt connected system. TCSC it is a thyristor controlled series compensator is series connected and TCPST thyristor controlled phase shifting transformer and that is also VIT type.

And also we have a voltage source converter VCSC type controller, that is STATCOM, static synchronous compensator, it is shunt connected, it is SSSC. SSSC that is static synchronous series compensator. It is series connected compensator intermittent or interlined power flow controller it is combined series combinations and UPFC, it is a unified power flow controller or this is combined series shunt combinations.

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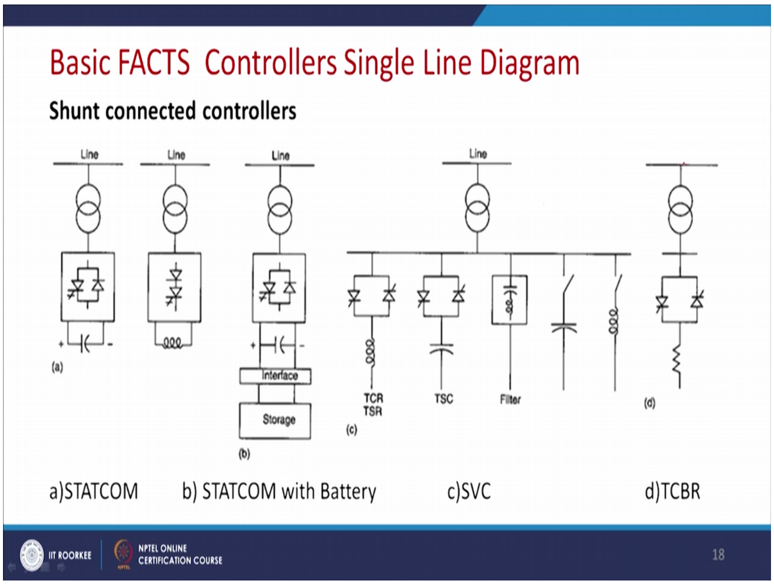

Now, these are the few circuit diagrams. So, that is basically this is example of the STATCOM. So, this is basically a shunt compensation. Shunt compensation will have a two variant; one is actually it can be controlled it can have a DC link and followed by a bold followed by a current control voltage source inverter and it can be by it can have a inductor linked, it is followed by a current source inverter. So, both can be used and both will inject the current into the system. So, these are the shunt com compensation.

Same way we can have a STATCOM with the battery that will actually inject the real power to the system and it will it can also where control the real power flow and in a line generally we will have a different kind of system that is that is actually the SBC will have a TCSC, TCSR there are TCSC. Thereafter, we will for mitigate the harmonics, we will have a filters, thereafter we may have a inductors to improve the power factor capacitor improve the power factor and thereafter it is TCBR it is essentially control the power flow between these two line.

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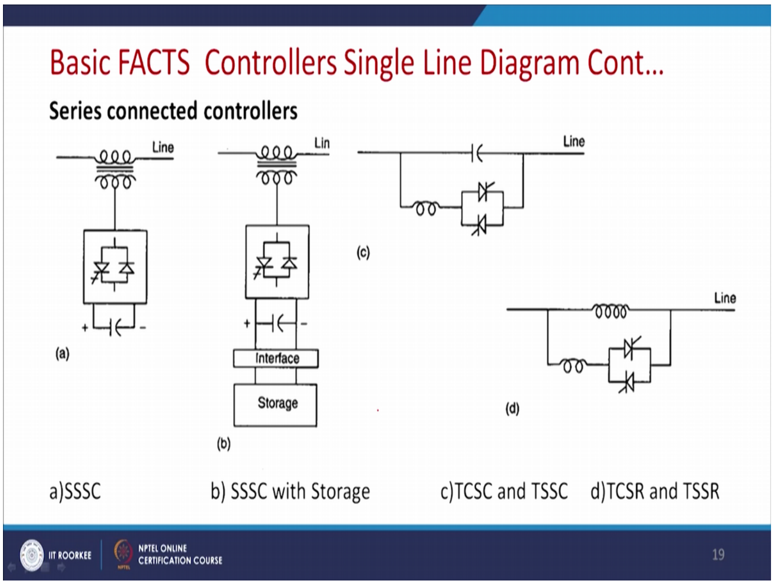

So, now let us see that different series connected controller this is essentially SSC. So, and so, it can it can inject voltage in phase or quadrature and thereafter it is SSC with a storage, it can also inject the voltage in phase. So, thus it has a advantage one it can it can mitigate the sac and it can enhance the power flow in the line and in SSC with the storage. It can actually inject as well as absorb sac and soil both the conditions and another is TCSC essentially these are the this is basically injects a voltage in series this is controls the impedance of the system.

So, what does it do you know this TCSC is essentially controlled the impedance of the line and line accordingly will be changed by the by the firing angle of the system and thereafter we have a d that is TCSC are it is all the same. So, this is this will be a dynamic inductor will be placed into the system to reduce the power handling capability of the line. It is generally it is a definition and this is generally a enhancer or the power handling capability of the line.

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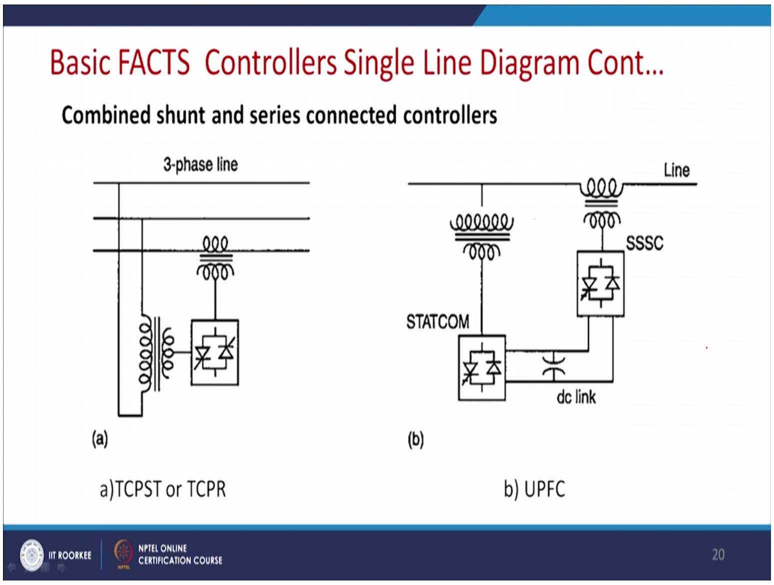

Next it is basic FACTS controller of the single line diagram we can show that is basically a controller called TPSTC or TCPR. So, it has both series and shunt controller. It can control both series and shunt and thus it can control voltage and current together.

Same way another version is by the voltage source inverter or the STATCOM and the SSC that forms UPFC, it is more versatile devices and it can have a features like power flow control, harmonic mitigation if it can mitigate the harmony then it is said to be the power quality condition. That is all for the today's lectures.

Thank you.