Power System Operations and Control
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Module-3
Lecture-9

Now, welcome to lecture number 9 of module 3 in this lecture I will discuss about the SVC which is the reactive power control device and also it can improve the dynamic performance of the power system. In the next module that is the module number 4 the FACTS that is the flexible ac transmission system is mentioned, but the fact SVC is mentioned here and this SVC is a device of FACTS family. So, here we can now see what is the FACTS; that is a flexible ac transmission system what are the definitions given by different organizations and what are the device and how we can classify them. Then I will go on the static compensator that is a SVC and also we will see the compression between the stat com that is a static synchronous compensator and SVC.

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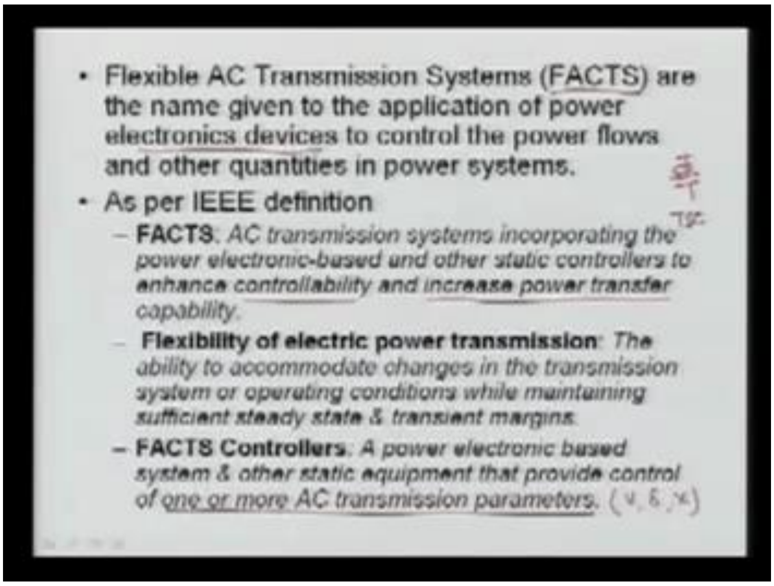

So, to begin with here the flexible ac transmission system that is known as the FACTS and are the name given to the application of power electronics devices to control the power flows and other quantities in power system. There is always question that whether which device is FACTS device or not. So, the term which is used here the power electronic devices for example, if you are using a simple capacitor here with a mechanical switch this is not a FACTS device. But if you are using here some thyristor switch from switching mechanism you are using based on the power electronic device then this device is known as FACTS device; then it is called thyristor switched capacitor that is a TCS.

So, we have it should be a FACTS there should be power electronics device or operators and it should be operated very efficiently in very quick time. So, that is why the FACTS that is a flexible ac transmission system are the name given to the application of power electronic devices to control the power flows that may be real and reactive and other quantity, in the power system other quantities are voltage. We can change the current we can control the reactance we can control the phase angle. So, these are the various power system quantities.

As per IEEE definition to add any confusion IEEE gave a definition that, the FACTS the ac transmission system incorporating the power electronic based and other static controller to enhance the controllability and increase power transfer capability. Means; we can enhance the controllability means we can control some of the power system quantities, it may be your voltage, it may be your reactive power, it may be your real and reactive power flows in the transmission lines or vice versa. And also that, it can increase the power transfer capability of the system by that why we are controlling this why we want to control out this quantity to enhance the power transfer capability are to improve the performance that is a static and as well as dynamic performances of the power system.

The flexibility of electric power transmission is defined as the ability to accommodate the change in the transmission system or operating conditions while maintaining the sufficient steady state and the transient margin. Since the flexibility here is a related to the terms as margin, that is steady state margin as well as the transient margin. Whenever there is a severe disturbance in the system goes in the transient region. And then how much margin do you have that; you can operate your system efficiently. The FACTS controller that, a power electronic based system and other static equipment that provides control of 1 or more of the AC transmission system parameter.

The parameters are normally the voltage angle and x of the transmission line, with the help of these three we can control other that is the real and reactive power flows in the transmission line and also we can. The reactive power control at any bus can be changed accordingly.

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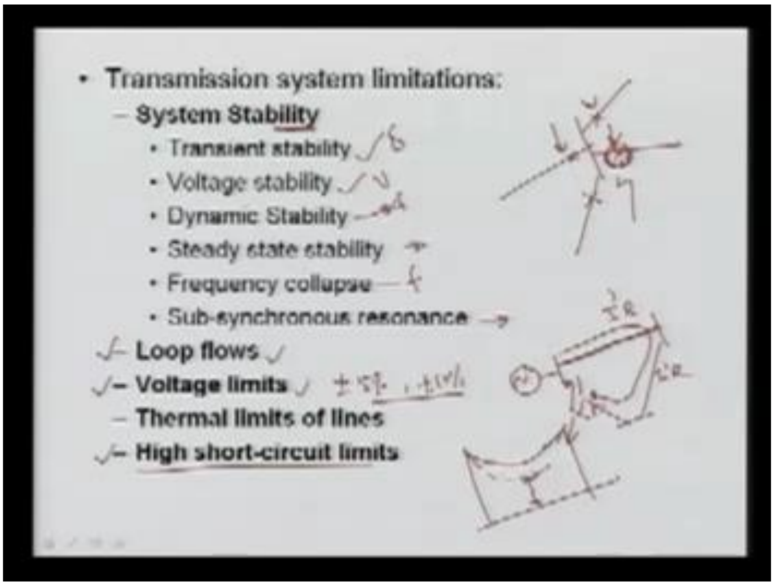

Now, the question why we are going for these entire FACTS device let us go back that what are the limitations of your transmission system. First and the major limitation normally it is called the system stability, because we know that we cannot transmit the maximum power without losing the stability because all the lines are having some stability limits and we have to operate well below that limit. So, the steady system stability limits again can be categorized you know it very well; that is your transient stability here the voltage stability if you are governing here, the voltage here we are talking about angle sometimes it is also called angle stability.

The dynamic stability is also a part of your this angle stability, here the steady state stability the frequency collapse where we are talking about the frequency stability and it may be your sub synchronous resonance problems. So, AC transmission system is limited by the stability limits as I mentioned that where is steady that is stability limits are there and then, we have to improve if we want to enhance the power system performance you have to improve these stability limits. And thereby you can transfer you can transfer more power as well as you can control your power system for the given objective.

Another limitation of AC power system is, the loop flows loop flow is nothing but, the flow suppose a system here you are having a generator here, this is having a line here here again we are having another line. And finally, we are having another load here and now; we can say the power which is flowing here is coming from here rather than here. So, the power which is going all the way from here to here and then finally, coming here that is called your loop flow. And it is nothing but, it is due to the impedance seen by the current we know the current flows in the ac network and it depends upon the impedance seen by that current in it.

So, always the current follows the minimum impedance path. So, here we do not know what the problem with the loop flow is; the problem the major problem with the loop flow is that it will increase the system losses. Now, you can remember here it is I and then, it is I square R again it is going to be added. So, with the more loss. So, to avoid that we have to use we have to control somewhere that, you can use some devices that can control. And that can fact device is 1 of the option another is your voltage limit; we know that we cannot operate our power system satisfactorily beyond a certain limit.

Normally thus we say that for EHV line the plus minus 5 percent is the limit; however, for this other it may be plus minus 10 percent limit and beyond that we may face several problems. Suppose, the voltage is more there will be lot of flash over an insulator, flash over insulation breakdown etcetera. So, that will cause another problem. So, if it is under voltage then there will be huge reactive power generation of the induction machine loads etcetera, and that will gain require more reactive power. So, we have to restrict that with a certain band thermal limit of the line we know this limit the lines of the limit lines are limited by the thermal limit

Means we cannot flow the power in a particular line beyond its thermal limit because, if thermal limits is the limit if you extend that power in the line that beyond that limit the line will sag and there will be another problem. What will happen, normally if you’re current exceed here this is your normal cathode ray that is formed on the transmission line. If the temperature of this wire increases there is a possibility that, it will again more sagging. And then there is a possibility here that we may lose the ground clearance and there may be flash over there may be danger of the life and so, many problems will occur. And again if the current will increase load will increase there will be, that this line will melt and this will be broken because tension will be less.

So, that is extreme case, but even though there is a small increase on temperature only this sagging will be more and then, the flash over and the further problem will occur in the transmission line. So, we have to do in such a way that we can utilize those lines that they are not heating the thermal limit we can transfer the power from 1 line to another line and then we can achieve how are the performance of more power transferred over the carried our subset of networks. Another problem is your high short circuit limits we know that, if you are keep on adding several transmission line let suppose at this bus we have several lines going and coming.

This bus here we are having and we are having the circuit breakers in the each line; now, the rating of this circuit breakers are decided by the fault level that is a three phase fault at this bus and that is we have decided. Now, if you connecting more line here again let us suppose, what will happen the fault level of this bus will increase because we are adding another parallel path here this earlier three parallel now 4 parallel. So, impedance will be reduced and the fault level will be increased and there will be possibility that, we have to replace these circuit breaker ratings as well means we have to go for higher current rating circuit breakers and get the cause will be more.

So, once you are keep on connecting the ac network the fault high short circuit current is going to increase and that, will 1 time it will limit that, we cannot get the circuit breakers of that rating. Because we have some standard practice of the circuit breakers rating like 63 mba may be it is eighty mba. So, we know this what the current limit is and what is the power limit of this and based on that we decide it. So, these are the various limitations already other limitations that you know, the Ferranti effect and more coronal aspects those those are the minor loss problems in the ac transmission system.

So, to avoid the FACTS controller can do much in this directions it can no doubt here the FACTS devices will not elevate these problems completely, but they will improve the performance of the system. For example: the transient stability or you can say stability of a system; using the FACTS controller we can improve the stability of the system. Means, we can have the more margin and then we can operate our process satisfactorily. So, it can stability we cannot say that, there is no stability problem, but we can say we are enhancing the stability limit by using some extra devices and that is FACTS that is we are talking. We can avoid the loop flow, we can go for the voltage control as well we can load the line up to thermal limit, and we can reduce the short circuit limits of the buses etcetera.

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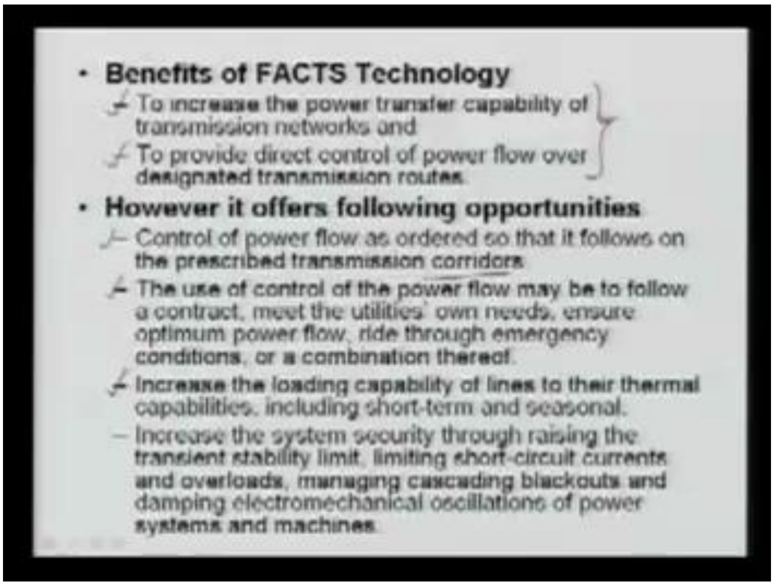

Now, let us see what are the various advantages means benefits of the FACTS technology. There is a basically 2 major advantages of FACTS technology FACTS devices or you can say FACTS controllers to increase, the power transfer capability of transmission network, means, it will increase the power transfer capability of transmission network and it will provide, direct control of power flow over designated transmission routes. It is not necessary that wherever, you are putting that device it will control power flow or power system quantity of that line only it can control the quantity of the other line, other designated route or other designated corridors.

It can control and we therefore, what will happen we can improve the power system performance accordingly. So, with the help of these 2 various major benefits; means that will increase the power transfer capability of the network. And it will provide direct control means you can control the power flow over the any designated route based on that we can have the various opportunities and those opportunities can be, again written as first-one that it can control the power flow as ordered.

So, that it follows on the prescribed transmission corridor means we can control the power in the some lines that it will meet the requirement of the specified power flow in certain corridors; means, set of the lines may be 1 line 2 line and so on. So, in the transmission corridors we can fix the amount of power, another is here the use of control of the power flow may be to follow the contract meet the utilities own needs ensure your optimal power flow, right through emergency condition or a combination there of.

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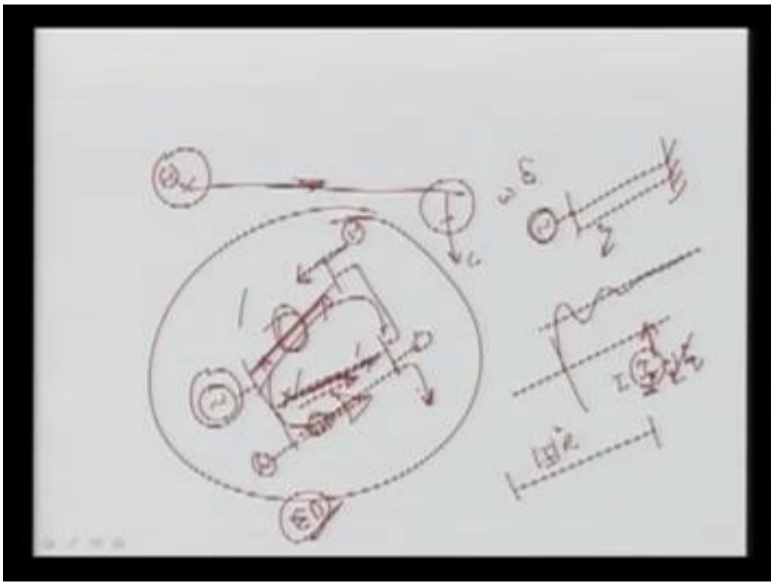

So, use of control of power flow may do several objectives for example, I can tell you let us suppose, we have here 1 utility and another here is consumer is here in this utility this is a consumer here 1 generator in this utility and we want the power and then, here from transmission line we want the power here. So, the power which is agreement between these 2 can be controlled that, how much power they are having in this line.

We know suppose your generators are here 1 generator the 2 buses are here; now, here another load is there. And let us suppose here that, we have another generator and the load it is not necessary that, the power which is taken by this generator is directly coming here, it may be we cannot identify the power flow because the electrons are not having any color. So, the current here which is flowing that is basically in which line what is the contribution of these powers or the contribution of this load can be obtained and normally this is known as the power tracing.

So, we can do the power tracing and then we can see the switch is contributing how much. So, here that is use of control of power flow may follow a contract means; we can meet that and check contract what is over that line. Means some we are having line and then, we are having contract that will flow hundred mega watt powers over that line. So, we can meet that, requirement by controlling the FACTS controller.

So, it can meet the utility needs and it will ensure that optimal power flow means, we can optimally flow the power. So, that we can cheap our object as may be our minimum cost or minimum cost and other objective that, we can achieve with these FACTS controller. In emergency condition; suppose 1 line gets 1 line drips what will happen other lines may be overloaded. So, in that even too it may elevate that emergency condition by redoing the power flow in other lines.

Third is your increasing in the loading capability of lines to these thermal capabilities including short term and seasonal; means here, we can increase the line loading through their thermal limits by controlling the FACTS controller parameter. What will happen means; we can in the short term as well as in the seasonal means for long term we can control and then, we can load the lines up to their thermal limits increase. The system security through raising the transient stability limit. Limiting short circuit currents and overloads and managing the cascade blackouts and damping electromechanical oscillations of the power systems and machines by controlling we will see later on.

So, Even by using SVC we can see we can damp out the oscillations; we can improve the transient stability of the system, we can limit the short circuit currents and we can manage the cascade dripping as well. What happens normally I'll tell you an example: let suppose here, this is a line the load is here and this system is this system is running smoothly. If this line is dripped what will happen, this complete power will be followed through this. And there may be possibility this line will be getting overloaded there will some protection system, that is your overtime protection or distance protection what will happen this will be also dripped and there will be cascade dripping and whole system will blank out.

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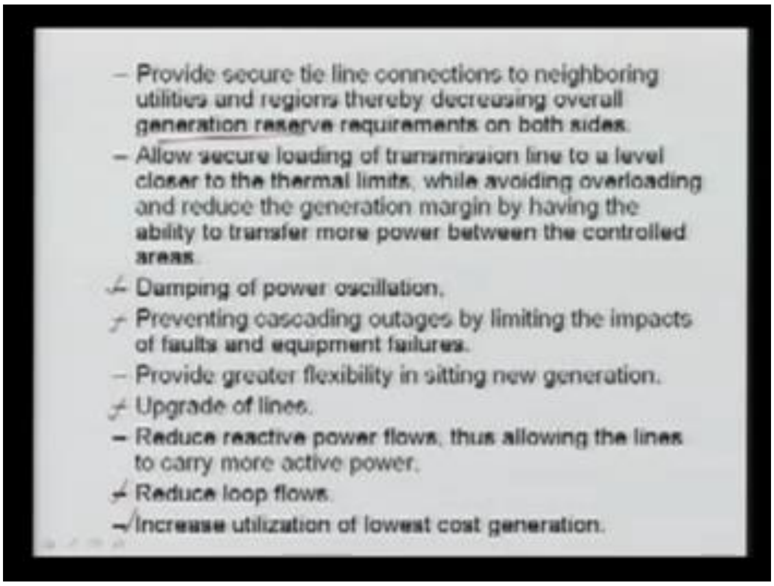

So, with the help of controlling if there are other lines we can control easily and then, we can control the block outs means we can avoid the block outs in the system. The FACTS controllers can also provide the secured tie line connections to the neighboring utilities and the regions; thereby, decreasing overall generation reserves requirement on both the sides. Already I have explained in the previous lectures that connecting 2 tie lines means connecting 2 system with the tie line can reduce the reserve margins and then, we can have sometimes very secure tie line can provide, the emergency support of 1 area from the another area.

So, it can do very good duty during the emergency even and of course, it will decrease your generation reserve and therefore, we can run the power system at higher plf. It also allows the secure loading or the transmission lines to the level closer to the thermal limit. While avoiding overloading and the reduce the generation margin by having the ability to transfer, more power between the control areas. Means we can again go up to the secure loading; means, we can go up to its limiting value and then this will again improve the power transfer capability between the 2 areas.

So, another opportunity that we can achieve with our power FACTS controller that, it can damp our power system oscillations while the power system oscillates. In the power system, there are various types of faults and that faults here for example, having generator let say a single machine is infinite bus; here we are having 2 lines this is infinite bus if there is a 1 fault in the transmission line what will happen.

This machine will accelerate and de accelerates; so, there will some oscillations in the rotor angle delta and also the speed. So, this machine will keep on oscillating and then it will be going at a certain value. So, this oscillations can be done out quickly with the help of the power system FACTS controllers. It can again, thus prevents it can prevent the cascade outages by limiting impact of fault and the equipment failures. It provides greater flexibility, in see to in new generation what does it mean? I want to say that here let us suppose in a power system; now, this lines are loaded there is a possibility we have another line here that is under load .

So, we can put it even though generator here and then, by putting some device here we can control the power over this line and then, we can put here or we can put anywhere and then we can utilize them properly. So, FACTS controller may allow that proper fitting of the generator with the help of, controlling the power flow in the lines another is upgrading of the lines. Means at the same time you can go for the upgrading of the lines means from 1 conductor to you can go for other size of conductors and then, you can load up to that limit by using the FACTS controller. It also reduces the reactive power flows, thus allowing the line to carry more active power.

So, it can reduce the reactive power in the transmission line. So, that we can go for the more active power what does happen you can see thus you are having a transmission line here between the 2 buses. Here this current which is flowing here that is the magnitude and here this is I square r losses there. So, this line has these limitations that, I is the real and reactive component are here. Means I is nothing but, your IR plus JI here, you can say real part and q part; now, if you are going for this is less then you can go for more reactive real power current and then you can transform more real power than active power.

So, if you are having this then this will be reduced because this I square R , I square is the limiting value of the transmission line, because I square r is the last and then it is you can say limiting value that thermal limits. So, with the help of if you can control this you can imagine this, we can go for more real power again I said it can reduce the loop flows again we can control the power thus we can redirect the power in the different fashion according to our requirement.

So, loop flows can be reduced; it will increase the utilization of the least cost generation means, we can have the different generating stations and then we can go for the economic dispatch. For example: you are having several generators here then, you can run this economic dispatch without any problem. Normally, what happens here there are some possibilities some transmission lines are getting congested then we have to reduce the loading of the cheap generator some time with the help of your FACTS controller we can redirect and then we can load.

We can utilize the cheap generations first followed by the next cheap next expensive generator. So, the economic dispatch here that is a optimal power flow or economic generation, least cost operation can be achieved very efficiently compared to that without FACTS controller.

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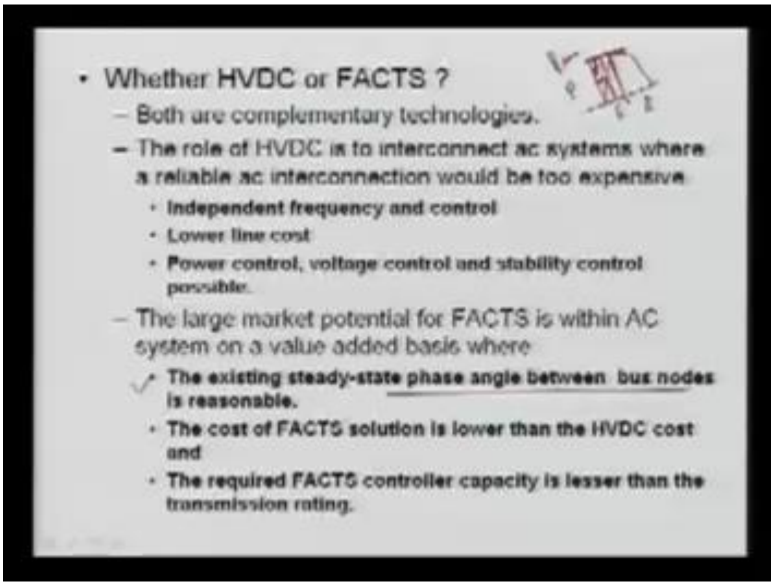

So, these are the major advantages of FACTS controller; now, in the remember in the very beginning I discussed about, the FACTS as the HVDC and again in the next module I'll discuss about the salient features of the HVDC control. Now, always the question arises that, whether we are going for HVDC system or FACTS controller because the HVDC system here it's we are talking the transmission is the DC we are generating ac utilizing AC, but the intermediate part we are transferring the power over the DC lines.

So, the here both are using the power electronics devices in HVDC also, we use the converters we will see in the next lecture next module of the lectures. And the FACTS controller also uses power electronic devices. So, these 2 FACTS as well as HVDC are the complemented technologies role of HVDC is to interconnect AC system, where our reliable AC interconnection would be too expensive or if you want to transmit power over a long distance more than 600, 700 kilometer AC is not particularly feasible and its very expensive because we have to go for the several stages of compensation.

So, you can use the DC system and already in India in UP itself we are having HVDC long HVDC line that is coming from the Rihand and it is going to Dadri near Delhi and this line length is approximately 900 kilometers. And we are flowing 1500 megawatts in a steady state condition and the voltage is operating plus minus 5 volt. So, it is a bipolar operation again I'll discuss HVDC in the next module.

So, the advantage of HVDC that is the independent frequency and the voltage control means here, the 2 independent frequency systems can be connected and the power can be controlled independently after system frequency of the 2 areas. The we require only 2 wires maximum or 1 wire we can use the ground as return. So, the lower line cost of course, in the three phase system if the power control is possible voltage control we can do very well and stability control is also possible.

However; in the DC there is no stability concern at all because p delta angle is not a existing there. For the FACTS the large the market potential for the FACTS is within the AC system itself and on value added basis where; means, FACTS technology is incorporated in the ac system itself you are having a ac transmission system if you are having AC transmission system. If you are going for the DC then, you have the built a new transmission line dc and you have to put the converters etcetera .

But here what we are doing that, we are not going to change the transmission line we are not going to change anything else only we are putting some devices in the AC system itself. And the what, should be the base is that existing steady state angle between the buses should be reasonable. Why it is so, because we know that this value is this is your delta this is p, I am talking this 1 from very beginning. Now, if you are loading the power system here, your delta is this much this delta is the angle difference between the 2 buses; now, you have the margin up to this 1 this is the p max.

So, if you already operating here; whatever the device you are using you are very close to p max and the margin is very less with u. So, the point is just noted here; it means that if you are having the more the margin. If the delta difference is less then you can load more from here you can go up to this margin and this very high. So, this is a value added region. So, the existing steady state phase angle between the bus nodes that is 2 ends should be reasonable should be small.

The cost of FACTS solution is lower than HVDC cost of course, we will see the cost of FACTS devices are always lower than, the HVDC cost and the required FACTS controller capacity is lesser than the transmission rating. Because the transmission rating is this much. So, it is always this rating is less than capacity of the transmission line. So, these are the 3 point where we have to decide.

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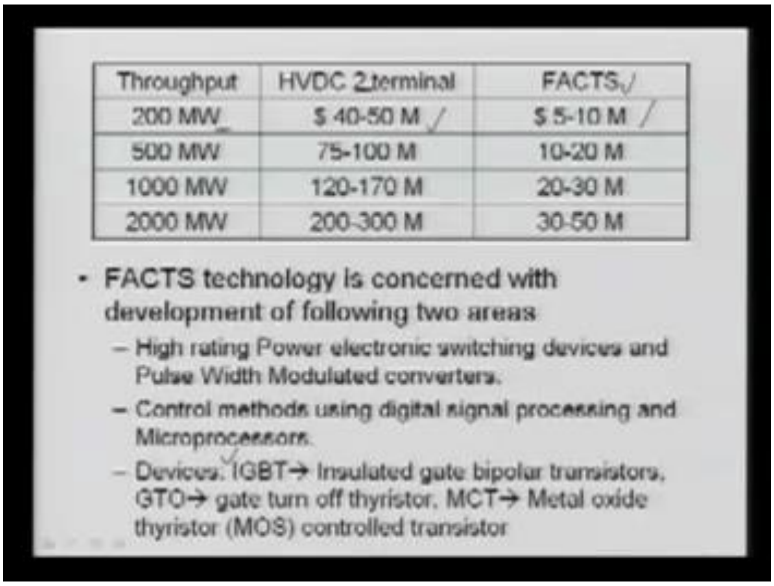

Now, if you go for the compression for HVDC to terminal the cost for the 200 megawatt through put means that is the power which is we are going to transfer here it will require this 40 to 50 million dollar. However the FACTS is the 5 to 10 million dollar. So, you can see this is almost 8 to 10 times lesser compared to your HVDC. So, this device is cheaper economical hazard. Now, the FACTS technology is concerned with the development of the following 2 area; now, why this FACTS technology is so, much becoming popular and popular. The reason behind that, the high rating power electronic switching device and the pulse with modulated converters are existing; means, earlier the line come get converted where thyristors were there and they were creating lot of problem, but now we can use the pulse with modulations for the converter circuit and then we can maintain the even the power factor unary .

And also we are right now we are having the power electronics devices with the more voltage as well as the current ratings and that is, making feasible and also the cost is reducing. Another reason that is the control methods using the digital signal processing that is called dsp and the microprocessor and microcontroller are feasible nowadays and based on that we can control very efficiently and smoothly, various devices normally in the power electronics. We know, it vary with simple thyristors we had the IGBT that is a transistor based technology that is insulated gate bipolar transistor, we are having GTO gate turn of thyristors; MCT that is metal oxide thyristor MOS controlled transistor.

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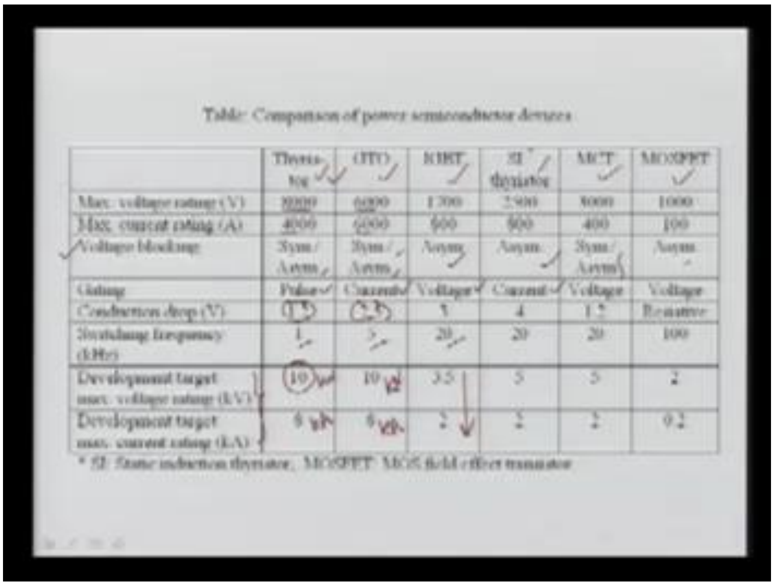

So, we will see what the compression of the power semi conductor devices is. I have just compared the thyristors GTO’s IGBT’s SI that is the static induction thyristors; here MCT and we are having the MOSFET that is a MOS field effect transistors. Presently we are having approximately 8 kv voltage rating and 4 kilo ampere current rating of single unit of thyristor. Whereas the GTO’s we are having 6 kv and 6 kilo ampere IGBT’s of course, we are having 1.7 kv and 0.8 kilo ampere current and others are also, lesser than your thyristor and the GTO’s.

The other difference between these all 6 power semiconductor devices are voltage blocking that is here, it is a symmetrical and asymmetrical is possible here symmetrical and asymmetrical both are possible. Here only asymmetrical a symmetrical here symmetrical and asymmetrical; means, gating here we get the pulse in the thyristors GTO we get the current, IGBT we get the voltage and SI we get the current and the voltage and so on so forth. If you see the voltage drop the thyristor are having the minimum drop that is 1.2; however, your GTO's are 2.5 switching frequency you can say here is 1 kilo hertz here the GTO's are 5 IGBT's even have 20 kilohertz.

Now, the targeted value it is expected in the future; we can achieve the thyristors of rating 10 kilo volt and here we can get the 10, 8 kilo ampere. We are also expecting the GTO's they will be available here in the 10 kilo volt rating of single unit and here 8 kilo ampere. Similarly, the IGBT's also we are expecting more development and then again the cost also it may keep on reducing.

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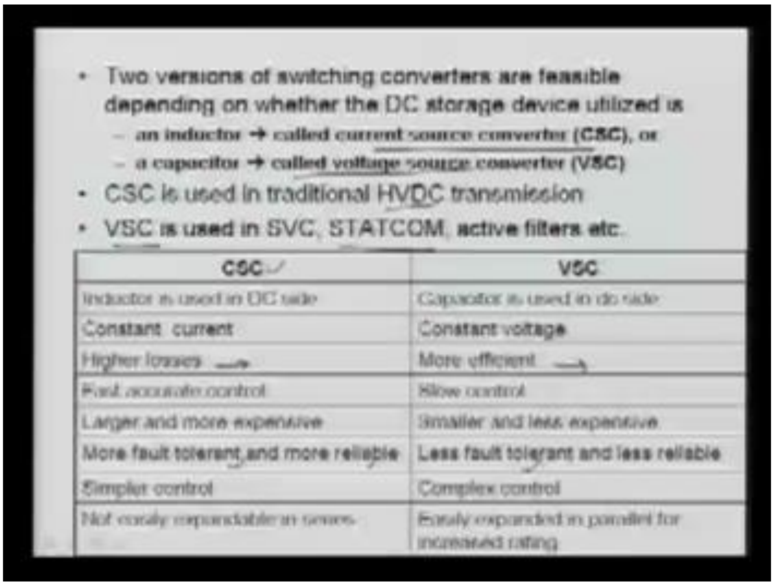

So, the 2 versions of switching converters in the power applications that is the FACTS controllers we can categorize the devices into 2 categories, 1 they are using the converters. So, it is called converter based FACTS controller and others are simple without the converter FACTS controllers. So, the 2 versions of switching converters are feasible depending upon, whether the DC storage device utilizes it means if you are talking about the converter based technology. So, if you are using the power storage device as a inductor then, it is called current source converter if you are using capacitor then it is called voltage source converter.

So, HVDC basically use the current source; however, this VSC is used in the stat com and other active power filters. The compression you want to see that CSC and the VSC; in the current source converters inductor is used in DC side; however, in the voltage source converter capacitor are used. In the CSC the current constant current is achieved; however, in the voltage source converters constant voltage is achieved. The CSC are having more losses whereas, this VSC is less or also so, more efficient. CSC we can have the fast control and accurate as well; however, this is slow control CSC requires larger and the more expensive, area require is more and it is more expensive.

However; the VSC are smaller in size and they are less expensive; the CSC there is a current source converter more fault tolerant and more reliable; however, the VSC they are less fault tolerant and less reliable. In CSC the control is very simple; however, the VSC control is very complex; CSC not easily is expandable in series; however, the VSC that we can easily go further adding the expanded adding the parallel to increase the rating.

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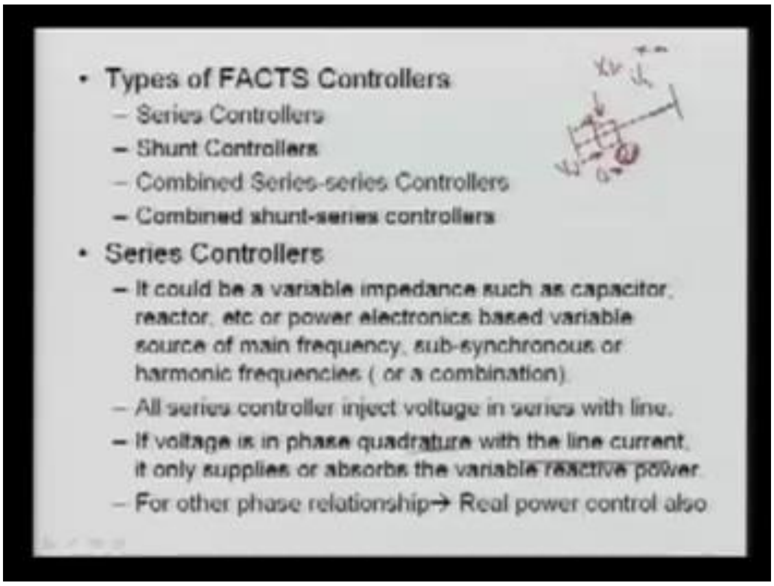

Now, let us come to the various devices and how we can categorize. So, the types of FACTS controller; now, we can categorize the first category I just I made based on the converter or non converter. Now, here again we are going for the different means how they are connected in the system and then we can classify the FACTS controllers. First 1 is your the series controller means; they are connected in the series as it name. Shunt controller, they are connected to the bus combined series series controller means they are place in the series of a 2 lines combined shunt and series controller means, there will be a shunt shunt is always connected in the bus and then, to the ground and then the series inside the line.

So, the series controller it could be variable impedance such as capacitor, reactor etcetera or power electronics based variable source main of main frequency, sub synchronous or harmonic frequency.

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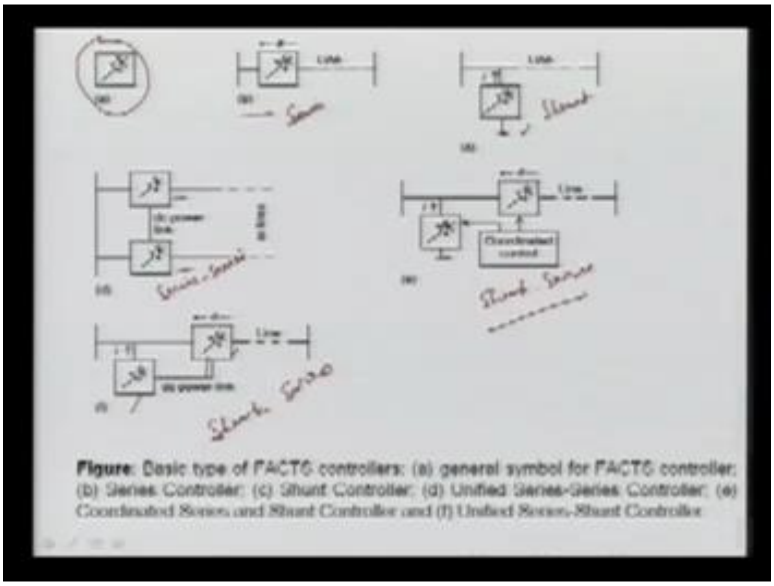

You can see here first; this is let us suppose a notation of FACTS controller then, what I am going to do here just I am putting here. In the series of this line this is line we have put this FACTS controller then it is called your series FACTS controller. If you are putting in the shunt here you can say it is shunted at the bus or in the lines end, here it is called shunt FACTS controller. Now, if we are using the series here and the series here and again if you are connecting with DC link then it is called, your series and series FACTS controller, there is a possibility you can have 1 shunt and then 1 series and then we can have, the coordinated control then it is your shunt and series FACTS controller and this is a coordinated.

So, because here the control are HVDC are coordinating such that it can operate smoothly, another is your here is it is also shunt and series FACTS controller because 1 shunt here series, but they are connected with the DC here power link. And it is that is why it is called unified; here there is no control it is a unified control automatically it is taking care of and then, it is called unified series shunt controller here it is called coordinated shunt series FACTS controller. So, in series controllers I can say, here it could be variable impedance; means, as I put here in transmission line what is this it can be a variable x or it can be x or l whatever you can say, and or it can be a voltage source.

Means it can be simply x l it can be your xe it can be a voltage source and this voltage source, may be of the same frequency component of the operating system or it may be sub frequency or super frequency or the combination of all these is possible in series controllers. All series controllers inject a voltage in series with a line; no doubt these controllers will inject voltage whatever will be the current flowing here. If it is a VSC of course, it is injecting if it is a x scalar xe some I into xe is injected.

So, all the series controllers injects voltage in series with line, if the voltage is in the phase with the quadrature if this is the voltage which is injected is in phase coordinator of this VI no phase with the line current. Here which is flowing, line current if it is in the quadrature then it only supplies or absorbs the reactive power and then, it is working as a variable reactive power flow. For other phase relationship, the real power is also controlled and then it is called your series controller.

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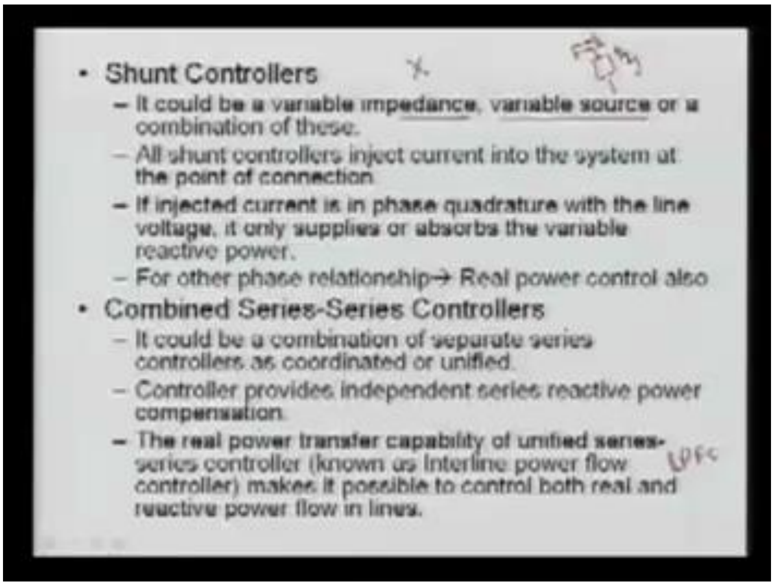

Now, let us see this other controllers that is a your shunt controller it could be again the variable impedance as I said this impedance here x; it may be a variable source or combination of these. So, this is you shunt controller all shunt controllers inject current into the system, at the point of interconnection as we shown here. This is connected here with the FACTS device this will inject, the current again it may be leading or lining current. It will inject into the system where, it is connected if injected current is in phase quadrature with the line current here this line I and this is your I injected if they are in the quadrature then, it only supplies or absorbs the reactive power.

For other possible relations here the real power will be also controlled; in the combined this series and series controllers it could be combination of separate series controllers, as coordinate or unified already I showed you. Controllers provide independent series reactive power compensation means; they can control the independent reactive power as well control real power transfer capability of unified series series controller, is known as inter line power flow controller makes it possible to control both real and reactive power flows.

Means we can change the power from 1 line to other line and this is a interline power flow that is called IPFL means; IPFC is 1 device that is a interline power flow controller that, is a example of series series controllers.

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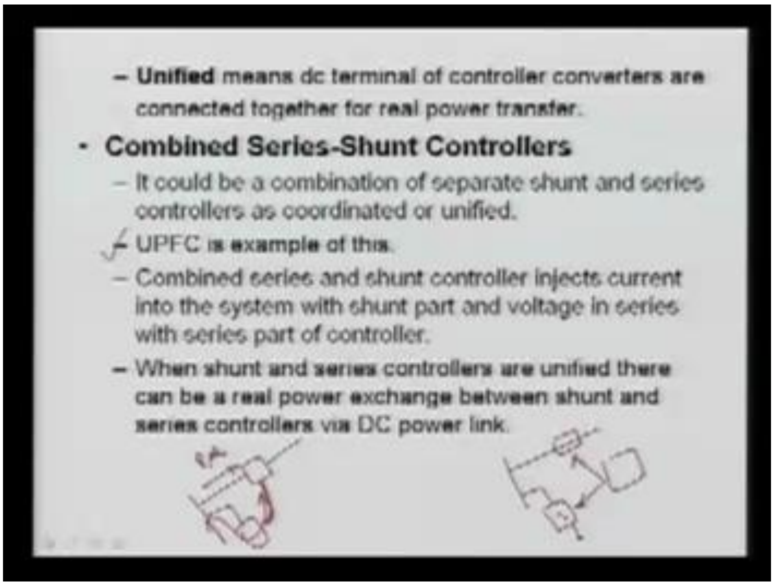

Unified means that DC terminal of controller converters are connected together for real power exchange. So, here this is a DC if they are 2 converter are connected by DC link. The combined series and shunt controllers or shunt series controller you can say, it could be a combination of separate shunt and the series controllers as coordinated or unified. The example: of this is UPFC that is very versatile device and it is called unified power flow controller. Here it is called unified because the series and shunt controller's converters are connected by the DC link.

If it is not by direct DC link you are controlling separately then, it is called coordinated combined series and shunt controllers injects current into the system with shunt part and voltage in series with series part of the controller. When shunt and series controller are unified, there can be a real power exchange between the shunt and series controller via the DC link I want to say that; for example, let us suppose here this is your line here we are having the shunt FACTS.

Here we are having series; what we are doing if you are controlling here separately by coordinated controls here then, we cannot transfer exchange the power between the shunt and the series, but if you are removing this and we are having this type of arrangement this is a FACTS controller series part here your shunt and if you are connecting by the DC line here, then there is a possibility the power will be exchanged through this DC link. And then, we can control the active and reactive power independently and the

UPFC is example of this which is very versatile it can control the bus voltage here, it can control the power flow here p and q independently. All these three quantity can be controlled independently from the UPFC.

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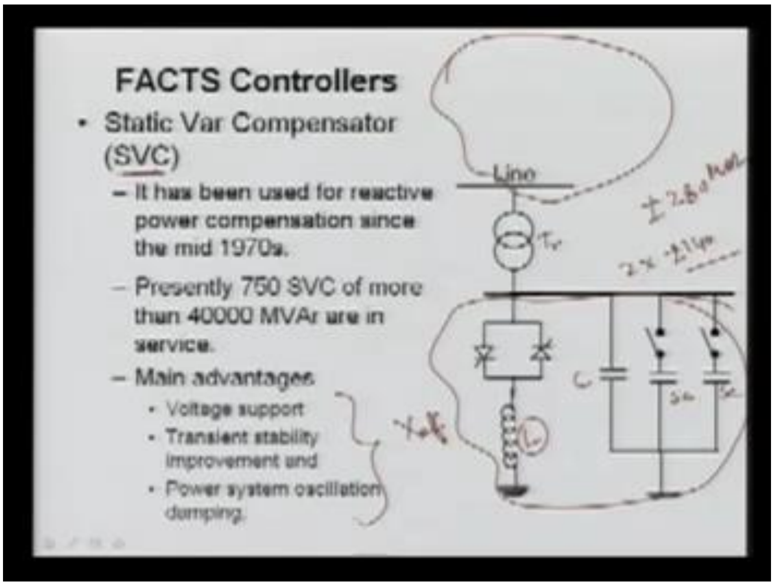

Now, the basic FACTS controller that is the shunt controller that I want to explain because in this module only this SVC is mentioned. So, I'll be discussing SVC more and again, another advanced technology is there that is called static static synchronous compensator here it is static VAR compensator we normally call it SVC. Now, you can see the, construction of HVDC how it is connected; this is your system here we are having, it is connected by your transformer because we are connecting at the lower voltage.

Here this is your reactor we are using anti parallel thyristors and these thyristors are controlled in such a fashion that, value of l can be controlled thereby we are controlling the impedance of this complete system. This is your fixed capacitor this is your switched capacitors here and they can be added. So, that you can say here this total effective x of the system is changed and by that, we can inject or we can absorb the reactive power.

If whole this x effective is capacity then, we can inject the reactive power we can improve the voltage profile. We can do other purpose as well; however, if it total is inductive then we can absorb the reactive power and we can reduce the voltage. So, static VAR compensator has been used for the reactive power compensation since mid of 1970s it is more than 36 years old device and till today it is more than seven fifty location are SVC device are in the system and they are basically providing 40000.

Now, so, many locations in India also here in that is the power building station of near Guwahati and Kanpur; we are having the SVC that is the rating here is the plus minus 280MVR; basically we are having 2 device and that is here plus minus 140 and that is doing the purpose from the very beginning from the early of 90s if you notice from 88 or 99 onwards. So, it has a several advantages advantage that it can provide the voltage support it will improve the transient stability we will see later all these things and it also damp out the power system oscillations. And we will see these 3 advantage by analyzing by taking a simple example;

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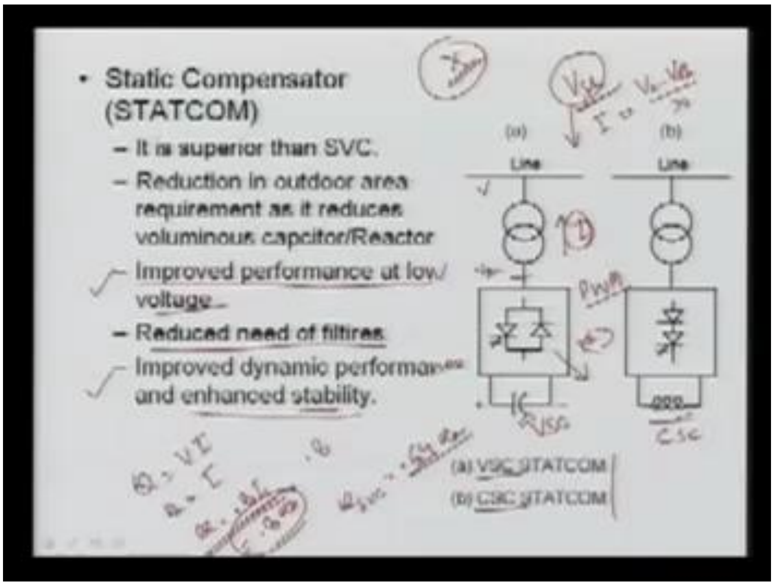

However, another shunt device is your stat com that is called static synchronous compensator or stat com simply. It is superior than SVC the reason that, it is here the converter based technology. If you see in the previous one it was here your thyristor simple anti parallel thyristor it is not a converter. So, it is superior because we are using the converters here, the reduction in the outdoor area requirement it requires less space it reduces the, voluminous capacitor and reactor there are. So, many inductors and capacitors were used here we require only 1 capacitor or inductor that will solve your purpose.

So, that is why we require less space as well; here its performance is better in the low voltage system, thus in earlier cases the thyristors once you are firing if you are changing the inductance what will happen. You are just delaying your firing angle or you are advancing the firing angle thereby, we are generating the harmonies in the system here; however, it reduce the harmonics very well and therefore, there is no need of the filters those can be filtered out.

So, the dynamic performance also and the stability limit enhancement with the stat com is better. Now, the question here why the voltage performance is better for the stat com compared to SVC. To understand this, in the previous case here you saw here the reactive power provided by this whole system. This q it is nothing but, V square upon that is the x effective voltage here is the voltage of the system. Here this is the V; if voltage falls what happen this q generated is less again we just take a new page here, in SVC I can say let us take SVC example: here I am talking about stat com and then we see the difference for the reactive power support under the low voltage.

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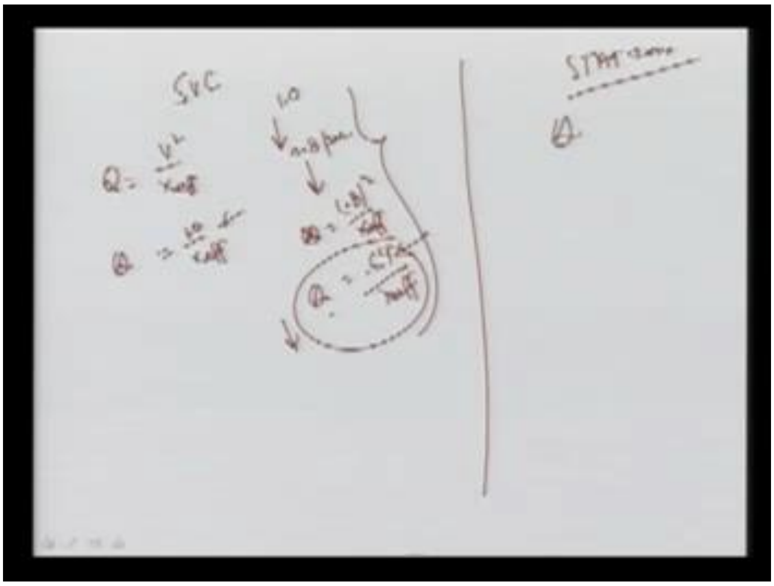

So, the reactive power provided by your SVC it is the v square divided by whatever can say xe or x effective which I am using. Now, you can see if your voltage falls down from 1 per unit to let us suppose 0.8 per unit, when it was 1 per unit it was giving the reactive power at 1 per unit this 1 over x effective. Now, I have this value this x cube will be your 0.8 square divided by x effective and it is 0.6 4 upon x effective what does it mean.

Now, the reactive power provided when the voltage is less the reactive power provided by the system is less. It means that, when we need more reactive power it is providing less here it is providing more it is 1 per unit. So, therefore, here you can say the reactive power reduction is the square term and therefore, when we need more it provides less. So, this is not. So, superior here now, come to the stat com in the stat com what we are doing we can see in stat com here we are just injecting the current this is your voltage.

So, the reactive power here this q will be nothing but, your V into I. And we can fix the current limit the limit limiting value here is your I. So, let us suppose it is at the limiting value and your voltage is reduced. So, earlier it was 1 per unit. So, your q was I and now once it is voltage is 0.t 8 now, q here is 0.8 I. Now, this is also reducing no doubt, but what happens earlier in SVC was your q SVC was 0.64 times of your q original. So, it was more reduction than this it is 0.8 times of the original value I can say, 0.8 q not and here 0.64. So, this is giving more reactive power when you require compared to SVC although this is also reducing.

So, that is why it is said the improved performance at here low voltage another here that, your reduce need of filters as I said, the requirement of filters are minimized because here we are can use the pulse width modulated converters firing circuit. By that we can eliminate the harmonics generated by these converters and even though, sometimes we can improve the power factor of this very effectively compared to your SVC. So, SVC is nothing but, a variable impedance source variable impedance device; however, this stat com is variable voltage source because this is a different between the stat com. So, SVC is your variable x that is, the shunt. Here it is your variable voltage and then we can change the voltage and thereby we can change the current. So, here if this is your voltage vss. So, I can write V minus VSS divided by the transformer impedance is your I.

So, this is your I want to say this is voltage source device this is your variable impedance device. So, here we can generate this voltage source with the fundamental frequency. So, there will be no harmonics. So, the reduced need of filters wherever, there we require some filters, but another advantage of that SVC here if you are putting the filters here add the fundamental frequency those filters here they are used they provide the reactive power at the fundamental load.

So, there is a this filters sometimes very advantageous that, they will inject the reactive power at the fundamental; however, harmonic frequency they will work as a filter and it will be going to the ground. So, this, but again the cost will be more you are putting another extra device and the dynamic performance, it is better and enhancement of stability will be also better and then only we can understand this part only based on if you go the characteristics of these devices.

So, then we are just before that again we have to go for the basic fundamental about the stability that, how it is going to improve and we will see that this stat com is better than SVC. But the SVC is the voltage device in the FACTS family and that is why still it is cheap also, but this device is very expensive and the main disadvantage of this 1 is it is expensive because here we are using converters.

So, may thyristor are used wherever there we using 2 thyristor. So, that device is cheaper this device is expensive; now, another difference here the 2 type of stat com's are available that is your voltage source and the current source as I said the CSC are the current source you have to use inductor here we are using inductors. So, this is yourCSC here you are using capacitor it is your voltage source. Now, this stat com's are now people are planning to put in the earlier people, were using simple capacitors now with the help of that can improve the static as well as the dynamic performance of the system.

Because now, the cost of this devices is keep on going down and we can enhance the power system dynamics or you can say performance both static as well as dynamic with the help of these compensator and that is the shunt controllers .

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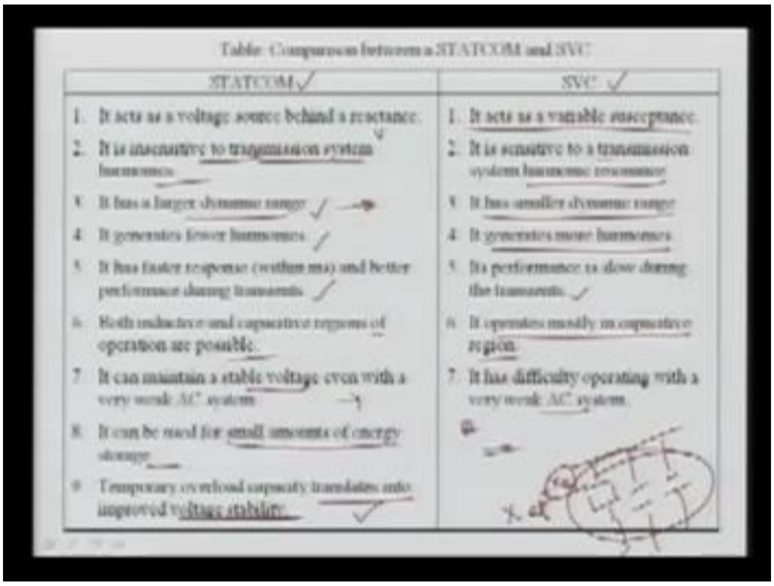

So, let us see the compression of a stat com and SVC whatever I told in the initial now we can go in the detail that we here, I have written the stat com here this is your SVC. First we will see the compression that this stat com acts as a voltage source behind the reactance, as I said it is your voltage source here it is just acting like a variable susceptance or impedance. The stat com is insensitive to transmission system harmonics because, we are injecting the voltage source and that voltage source is independent of the system harmonic; however, this is the very much sensitive to the system harmonic.

So, then there may be some resonant because we are using some parallel capacitor and inductors and there may be some other harmonics component may resonant and this may give your outage or you can say damage of that equipment and the other elements of the SVC. The stat com is having higher dynamic range again this compression I'll come later, but you should know here right now; this here it has the larger dynamic range means it can operate in range very very wide compared to your this SVC. SVC is having smaller dynamic range of course, this stat com generates less harmonics fewer harmonics; however, it generates more harmonics compared to the stat com.

A stat com has faster response within milli seconds and better performance during transient its performance that is, SVC performance is slow during the transient stat com both inductive and capacitive region of the operations are possible here you can operate both the region that is the inductive as well as the capacitive this SVC are mostly operating in the capacitive region means whatever just you are connecting here your this thyristors and here your inductors here you are using capacitors barrier. So, total here normally your x effective will be your xe; means, we are using in the capacitive region most of the time 1 stat com that is we are having in the power building substation Guhwati Kanpur it is operating your xe mode always; stat com can maintain or even stable voltage even with a very weak AC means; your system is weak it can maintain the voltage compared to your AC weak system as I said the reactive power generation here the q is once voltage keep on down then reactive power generation is also reducing.But at that time we need more here that reduction is less.

So, it is better it can maintain voltage stability with even though very weak AC system. A stat com can be used for the small amount of energy storage device as I said here we can use the static com for storing some energy because we are using capacitors here as I see here, in this capacitor or this inductor. They can store the energy for little amount no doubt though this is not huge amount. If you are going for the huge storage then the cost will be going very high, but that energy can given during the emergency condition. And that, it will be better when you need some power in the emergency condition and it can provide.

So, it can handle a small amount of energy as well, but here there is no scope of storing the energy. The temporary overload capacity translate into the improved voltage stability here, we can go for the over means; we can go for the temporary overload capacity and therefore, we can again improve the voltage stability of the system whereas, SVC it is not possible. So, in this lecture just we saw that the importance of the FACTS controller we also just compare your stat com and your SVC's devices and we saw that, static com is better than SVC.

But the main problem with the stat com it is expensive than SVC and due to that, here the SVC's are very popular and it is already located in more than 75 locations all over the world and it is feeding 40000 almost more than that MVAR power to the system. So, the SVC's are very popular and then here now, I am going to just these 2 sent I'll show you later that how they are, who is better again based on that I mentioned here we will compare in the next lecture .

Thank you