Power System Operations and Control
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Module -3
Lecture -10

Now, welcome to lecture number 10.

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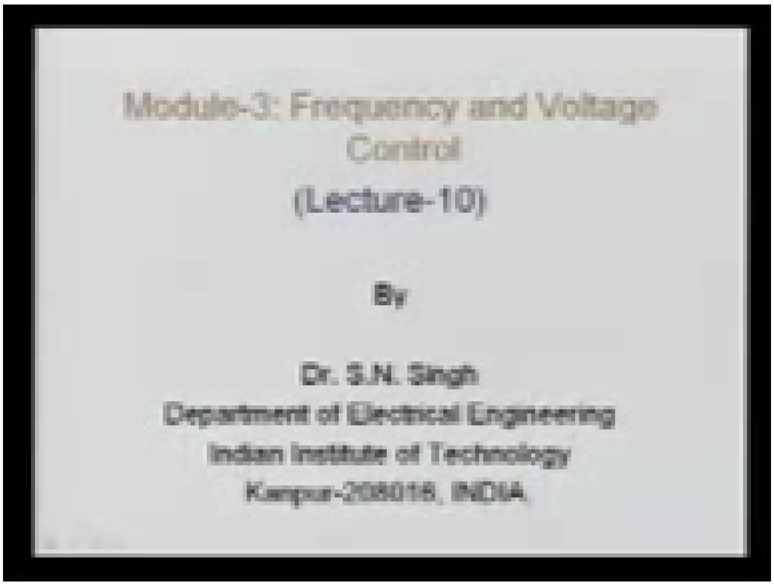

In the previous lecture, we saw the facts controller that is SVC and stat com only, although we will see some more facts controller in the next module. In this lecture number 10, I will be discussing with that which I said in the lecture number 9; that the shunt controller they will improve your steady state limit; that will improve your transient stability limit, that will improve your voltage stability limit and that will also damp out the power system oscillation.

So, all these four advantage with this shunt compensation, that is, shunt facts controller we will do it. We will see how they are going to do means: how they are going to change the limits by controlling these values. To understand this let us start from very basic.

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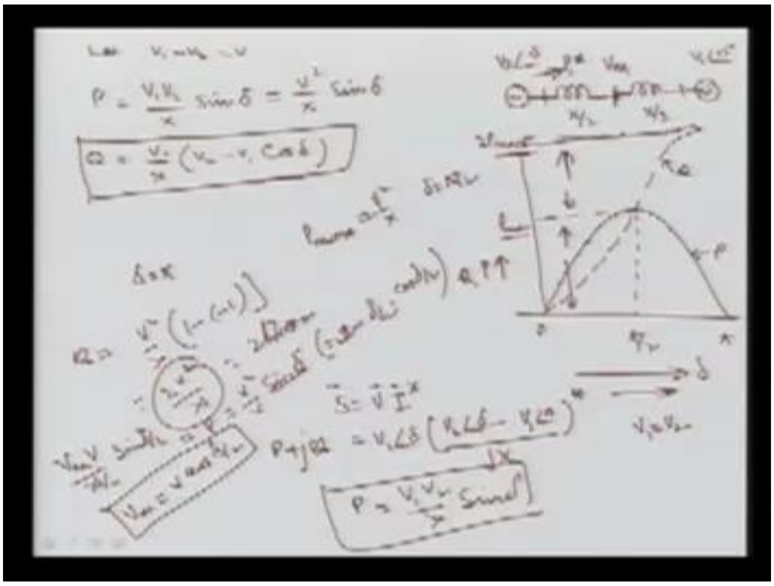

Very basic means you remember here; we are having less force with 2 systems. This you can this is the one system, this is another system and that is connected by a transmission line that is having the reactance x. Now, this reactance is divided into 2 parts, I want to show you. If we are going to put here in the mid of that transmission line so that is why I have put the reactance half half at the both sides of this midpoint Vm. And it is connected by that is a total reactance of the line, I am ignoring their losses, that is, the resistance of the line and this system is angle it is 0 and we are having the angular separation between the 2 is your delta.

Now, if you write the power flow from here, from this that is your P and Q, you will get as we have already derived. Here that P will be V 1 V 2 upon x sin delta that is the angle difference between these 2 buses and x is the total reactance of this line. If, V 1 and V 2 are equal, let us suppose we are maintaining voltages 1 per unit are equal then, it is a V square upon x sin delta. And the corresponding the P delta curve that is here P and this is your delta curve, we will get this curve here that is what I have shown here.

And we know that maximum P max that is the we can get here at the angle pi by 2, that is, 90 degree means: if you are putting the delta is pi by 2, this will become unity and we will get the P max is nothing, but your V square upon x and that we are getting equal to delta is equal to pi by 2, which I have shown here.

For the reactive power here in this expression, you can see again you can put your V 1 V 2 both are equal in magnitude. So, we can get here and then you have the curve for the Q here will be this dash line and you can see here means: at pi we are getting the 2 P max means: you can put here delta is equal to pi in the above equation, you are going to get here V square upon x 1 minus minus 1 means: here 2 V square upon x, it means here 2 P max.

So, you are going here the double of this value here, it is P max here also we are getting P max. Now how we got it, it is very simple means: simply the power here that is the S that flowing from here to here, I can write simply the voltage into the current conjugate that is showing here. And the current curve which you get here, what is the voltage here is the V 2, now I can say angle these are the vectors angle delta, here this I conjugate is the basically the voltage is this minus this means I can write V 2 angle delta minus V 1 angle 0 divided by your jx and this is the conjugate.

So, if you are going for the real reactive power separately for this case, let us put V 1 is equal to your V 2, you will get the previous equation, from here this is nothing, but your P plus j cube. So, you can separate out real and reactive power here from this expression we will get of course, your P will be your V 1 V 2 upon x sine delta like the previous case and Q we will get here this expression. So, it is very simple, there is no need to remember you can derive also and we can have these characteristic now.

Now, let us see; what is the voltage at this point means: if you keep on increasing the loading means if delta is increasing here, what will be the midpoint voltage here. To see this, the midpoint voltage it is nothing, but can be calculated here. Now the power which flowing over this section will be equal to this section means: I can write here this is your Vm V upon x by 2 sine delta by 2 will be equal to that is equal to your P. Or this P which is flowing here I can say V square upon x sine delta, means: I can write this Vm will be nothing, but your V cos delta by 2 means: you can just obtain from this equation. Hence your V V will cancel x will be cancelled here sine delta I can break into the 2 term, that is, a sine delta by 2 here twice into cos delta by 2. So, sine delta will be cancelled and here 2 will be all also cancelled 2 will get here this expression.

If you are just going draw the graph for this; what we are going to get.

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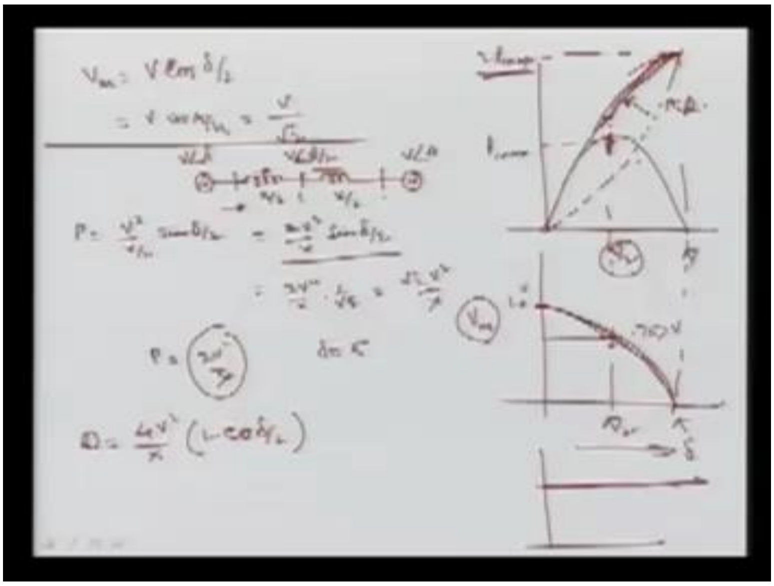

We will get this V cos delta by 2 means: here if you are going to draw this, I am drawing here your midpoint voltage Vm, this is your angle delta. Now, and I am going to draw this Vm it is nothing, but your V cos delta by 2. When delta is 0, V is your the value that is 1 per unit here. That I can say this is a 1 or you can say V here simply when delta is 0. When delta is your pi by 2, what will happen; this will be value means pi by 2 means; it is a pi by 4 means it is is your V into cos pi upon 4 means, you can say v upon under root 2 means you are getting some voltage here. And when delta is pi here this is the pi. So, this is 0 and we are getting 0 we are going to just get this voltage profile and this voltage is nothing, but your 0.707 V.

So, it is saying; when you are achieving here the voltage of midpoint is going to be 0 and this is declined in the voltage of this line. Now if we can maintain the midpoint voltage to its 1 per unit limit, then we can see we can transfer huge amount of power. So, this is the limitation. So, once you are showing more power means: more power means more delta separate 1. So, you can see the voltage angle here the voltage magnitude of your this bus the midpoint is decreasing.

Now, what I am going to do; if let us we are maintaining that voltage here which I said this voltage if you are maintaining to V by any device here means: I want to put some device here and that is your facts controller, it may be your SVC or stat com, with that we can maintain this voltage by varying this xc or injecting some reactive power to the system means we are maintaining Vm voltage to the V. And let us see what is the improvement what next we are going to achieve. To see this; what we are going to have now.

In the midpoint voltage is your no doubt V. Now, I can again write here this is your generator, this is your transmission line, this is your midpoint voltage, here this is another transmission line and here we are having another voltage source, here V angle 0. Here we are having V angle delta, this voltage we are going have a V angle delta by 2, this is a midpoint. So, the delta will be shared half of that. So, this midpoint voltage magnitude as we are shifting to V, but angle will be half. And this value is nothing, but x by 2, this is also x by 2 and now we want to derive the power.

So, the power which will be flowing here; it will be the P, your V any section. The power here will be equal to the power here. So, either you can write for this section or this section in material. Let us write the power for this section, that is, between this voltage and this voltage. So, I can write this here the V square upon x by 2 this section into sine delta by 2. Or I can write here 2 V square upon x sine delta by 2. So, now, this is the power flow which is flowing this expression. And this expression if we will draw the characteristics what is happening if delta is 0, this p is 0 we are here.

If delta is pi by 2, then this is your what is happening; this value is your pi by 2 you can put 2 V square upon x here pi by 4 1 upon under root 2. So, we are getting under root 2 V square upon x and we are getting some values here, that is, 1.4 times here and this value. When it is pi, this value is unity and then your this P will be your twice V square upon x, it is at delta upon delta is equal to pi. So, this shows that now, this is a twice P max and we are going to here and we are now this is the characteristic if we can maintain the midpoint voltage now, for this happening. You can see here there was some stability problem here means: it was not possible to load the power system the system more than this 90 angle, that is, pi by 2. Even though always we load below this because, there is some sort of transient system will lead it into the unstable zone.

So, we can go maximum in steady state up to this and now we can go the twice of that. And here all the region is stable here, it was not stable beyond the beyond this. So, we can see we can have increase the steady state voltage, steady state limit power transfer limit of the system to the twice of the P max value, so it is increased. Now you can see the reactive power this Q what will be this under this condition, it will be nothing, but that is your 4 V square you can derive it x and it is your 1 minus cos delta by 2. And now what you can do; you can draw the equation here and it will be like and this is you will appearing like this.

So, here I want to tell you that, by this maintaining the voltage, now what will be the mid time voltage, that is we are maintaining to the V the constant. So, if you are maintaining the voltages in the transmission line at the equal intervals, what will happen; we can transmit more power. So, this is the beauty of your facts controller. And then, I can see here your steady state limit is improved.

Now other just I can again explain you that, how the voltage stability that can be improved. Let us see that.

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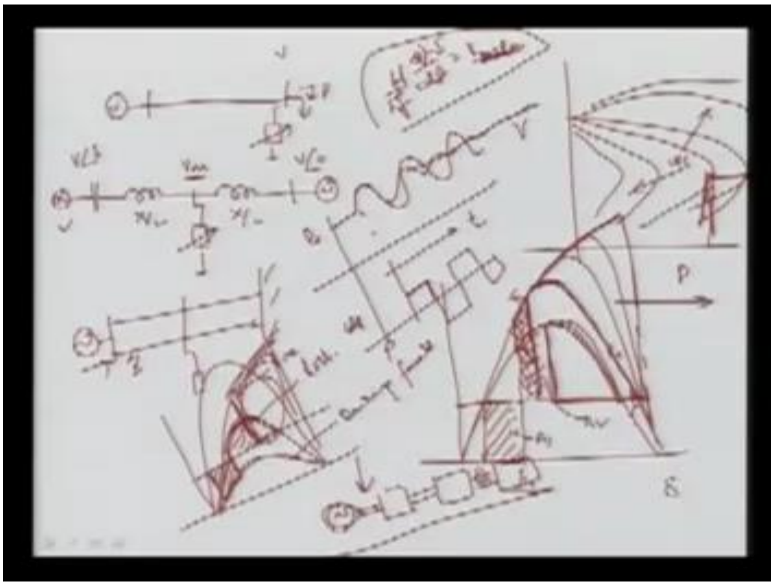

To see that, now I can draw here the PV curve; that is very widely used. We use the p delta curve to see this steady state limit. Now I am using the P power which we are showing and this is your voltage of that load. Now, what we are doing. Now you are very well aware that PV curve is this much and the maximum you can go up to this loading of the system and this is called your nose point, already I have explained in the voltage stability.

Now, if we are going to use the compensator means; for you let us suppose you are having a generator, here your transmission line this is your load if you are using some compensators here that is the shunt compensator, again it may be your SVC or stat com that is variable. So, we can here that is the P that we are drawing here and the voltage at the bus can we maintain it. So, here with the help of let us suppose you are just going for the leading here, if you are injecting the power, your this value will be like this and it may be sometimes like this, it may be going like this.

So, this is leading power factor, if your lagging power factor you may be observing, then you can go for more less loading. So, here it is lagging and this side it is upf, I can say unity power factor and then we can improve we can say; by providing the reactive power support we can go for more loading here in the system and then we go for the voltage more voltage stability limit of the system. So, here with the help of shunt compensator, we can improve the voltages stability limit as well, which I explained you in shunt compensator.

Now, another just I am going to discuss about the transient stability limit. And let us see how it is going to improve the transient stability limit. Again we will consider the same system, that is, we are having here that is your line that is the parts partition in the 2 part. Here the voltage that is the source, here another source and we are having here the midpoint voltage that is your x by 2 here x by 2 and this voltage is angle delta; here this is your angle 0. Here we are putting some compensator in the mid of the line. Note down this compensator can be put anywhere, but if you are putting the mid just I will explain the whole theory behind that. You can put somewhere and again there will be improvement of course, but it may be the better exp improvement if you are putting in the mid of the line.

Now what will happen for this case, now let us draw here again the P, for the transient stability always this is the angle here it is your power angle normally we discussed. So, this is your P delta curve let us suppose in the normal case. Now, I said that, it is if we are going for the midpoint compensator, here our characteristic is going to be your double of this. So, this is your when we are putting the compensator and we are trying to maintain the midpoint voltage to the ending in voltage and the fix voltage.

Now, if there is faults here at the bus, let us suppose your system was operating here and there was a fault and the power injected to this system is 0, this machine will accelerate, the machine will accelerate. And then here what happen, this was your Pm your now your fault is less it was operating at 0 not and the fault is clear here at this point, that is, delta 1; suddenly what will happen once fault is cleared, this will follow at this curve and it will see as your mechanical power which is flowing here is more than your electrical power and machine will decelerate. And then it will try to decelerate up to certain extent and here it will be this area.

So, area here is called accelerating area A 1. This is your area that is called decelerating area A 2. So, this will go up to that point when it will be equal to this and then if this area is equal now, we have this margin up to this value, means: this machine can decelerate up to this point otherwise at this point will again start accelerating because, here the P mechanical is at this point P mechanical will be more and the machine will more accelerating. Here P e this curve P electrical this delta at the P electrical curve this delta is basically the P delta which I am trying, it is the electrical power which I am trying. So, this is basically the margin Vi.

Now you can see if you are having the compensator. This I explained without the compensator. Now if you are again operating here, there are some fault here 3 phase fault, system was clear let us suppose the delta. Now here you can say we are going to up to this point and now this area we require only this much and this is your decelerating area because, this area must be equal.

Now, the margin you can say we had the margin here up to this point, this is your margin. Now you cans see huge margin we are having, earlier we had this margin you would see this, this margin we had, now, we have the huge margin. So, it shows that your transient’s stability limit is improved, means: you are having your larger margin. Normally this characteristic is very ideal, means: it is assumed that this compensator is having infinite power which is not true.

So, if you are adding some sort of let us suppose we are having some limitation on this injective power, it may be going up to the portion and again it is coming here. It may come here again for the different value of axis, means: if it is not infinite, so once it would be hitting limit it will go to the 0. In that case also you can see now this margin is now changed here and still it is more than previous 1 which was here. So, we can say our the system the transient stability improvement is tremendous, if you are putting some shunt compensator. And I showed if the margin is more means more you are stable even you can for the more fault here. And even the fault is persistent for the longer period your system will be not unstable.

If, the margin is less there will be chances, your system will be unstable because you will not have enough margin and the system will keep on accelerating and delta will keep on accelerating from other machines. So, similarly we can also explain let us suppose our system here is generator which is feeding and connected with the 2 lines. Let us suppose we are putting here compensator and here is infinite bus.

And again we can, now so for the other conditions other system here it was single line, now we are having the 2 line and the fault occurs here, we can show again your transient stability limit will be improved significantly, means: here what will happen now this is again your P delta curve that is called post disturbance fault. In the pre disturbance; before that let us we had this much. During the fault we can say this 1. So, this is your during fault, this 1 is your post disturbance fault and this is your pre disturbance fault, while pre disturbance condition because, the system was in healthy. Here when there was a fault, this machine was just accelerating and we had these characteristics. Then this line is dripped impedance of this line is more than the previous 1. And then we are having this line.

Now let us suppose we are operating here; what happens during this when system came here, it was going up to this period and again this was during the transmission line is dripped and machine is oscillating here. So, you can see this area here will be should be equal to the area here and we are having this margin. Now if you are using the midpoint compensator, this is the case when there is no compensator. If, you are using the midpoint compensator what will happen; in this case also here now this will be improved, this condition we can go for larger value and now you can say we can have larger margin here, even though outage of this we can improve this.

So, the margin here again that is a increase. Now another I said advantage of shunt compensator are: here I can say this, the power oscillation damping. In under damped power system, any minor disturbance here small disturbance can cause machine to oscillate around its steady state value at the natural frequency of the total electromechanical system. And that is called your power oscillation. The lack of sufficient damping is a major problem, means: if you are having less damping in the system, then this is the major concern, means: oscillation will persist, even though sometimes if your damping is negative your oscillation will keep on increasing and that will lead to your power system chaos and that will give you other problem.

So, the shunt compensator can be applied to countered counted at the oscillating and de oscillating of disturbed machine. When machine will be decelerating, as I said here you remember that is your H d square delta upon dt, here it is your Pm minus Pe, basically it was your pi f and then we can write this machine. So, this is your accelerating power, machine will accelerate if you Pm is more than P, if Pm is less than P, then machine will decelerate.

So, what happens the power swing here normally of this characteristic; this is let us suppose your power is oscillating, this is lets through the power and it started oscillating here. This was your P not and this is your with respect to time. So, this is oscillating. Now what we can do if we can do any some mechanics that reactive power support, we can provide from this point, means: here if the oscillating we can inject more reactive power in the system, then it will be and if it is under damped then we can go for this. What will happen; this machine will be here and just slowly and this will be stabilized.

So, with help of reactive power injections when it is accelerating and decelerating, its power is more or less, then this machine will be stabilized and this will improve the power system damping and then we can damp out this. Another which I said the natural frequency of this, you know here we are having the generator; this generator is rotated by the turbines separate stages. So, we are having several natural frequencies of these systems. So, there may be possibility these oscillations will in fact, with the natural frequency of the system and the huge oscillation will occur and sometimes it may give chaos and you can say the damage of the equipments as well.

So, the swings of the disturbed machine, we can put some reactive power compensation in this way, we can damp out the power system oscillation and this is another advantage of your shunt compensation. So, that can be done by both SVC and stat com. Only the characteristic will be changing and therefore, they are having some advantage and disadvantage accordingly. So, let us see how this, the current that will flow in the SVC as I said the only bearable part.

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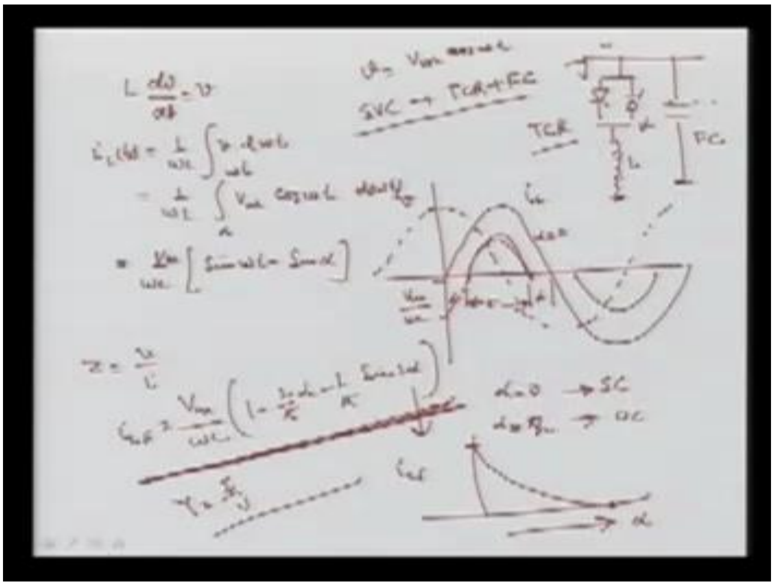

We are having here thyristor, that is, anti parallel thyristor and as again I have to draw here. And then we have 1 conductor and then we are having other component that is a capacitor. Now I want to draw the characteristic, if you are changing firing angle delay angle that is the alpha here, then this l how this L is going to be changed. So, let us take if the firing angle is 0 and then what I am going to draw let us draw the sinusoidal curves here, means, here your i L that is flowing here, this is your i L current. Now, the voltage will be as I said here it will be the current will be lagging here and voltage will be leading. So, I can draw here the 90 degree. So, this is your I can draw the voltage curve here, again the magnitude will be different of course and this is your voltage with the dotted line that is your V.

Now when this alpha is 0, then we will get the i L curve completely because, the pure this l is appearing at this bus and this alpha is 0, means: they are just behaving as the short circuiting the both cycles. Now, if you are delaying what will happen; after that delay here let us suppose this alpha is delayed here, the current which will be flowing that is the conducting here for half of the period and your current here will be this much and this both side this alpha will be there and this value is your sigma.

So, this is the case when we are just going to have. And what happen now, this value here which is appearing, that is, your Vm over omega L. Now this I can write this expression here. As we know this L di by dt it is nothing, but you're the V and this i L is inductive current in the time, I can say 1 over omega L, I can put here the differentiation of V d omega t, now just I have changed the dt here. Now here, again let us suppose we have the V as the Vm cos theta means: V just we are applying your Vm cos omega t. So, we can write 1 over omega L integration from alpha to omega t this we are firing that is your Vm. Here cos omega t d omega t.

And finally, here we can get 1 upon now Vm will be coming out omega L and now here we can say sine omega t minus sine alpha. So, this is here the current that is flowing here. We can just there is some phase shift here and it is coming here, means: when alpha is 0 means here the switches are closed or you can say it is a short circuit condition, when alpha is pi by 2 then what will happen; then it is open and then at that case you can put this alpha is equal to pi by 2, we will find it is open circuit and I think OC will be there.

So, change in firing angle means changing the impedance and thus the z here I can say it is nothing, but V upon I. And since V is the constant and I is changing by alpha. So, again I can say this ILf will be nothing, but your Vm over omega L, here 1 minus twice pi upon alpha minus 1 upon pi sine twice alpha. Why this is a big expression because, we are now talking about the fundamental component of this type of frequency here current. So, this is a some repeated curve. So, we can go for the fundamental component and then we will get this Lf will be this value. So, we can get the impedance that is dependent on alpha.

So, once you are changing alpha, your impedance is changing. So, again we can put your this impedance E is your I upon V and then we can get the expression here. And now you can see this ILf, this is the fundamental component how it is changing. If it is alpha this is your ILf this is fundamental component of this current inductor current, this current just we have taken fundamental component, harmonic let us suppose we are ignoring, where you can see it is starting from some value if it is a alpha is 0 from higher value and then it is going to be some z at pi by 2 it is your 0 and this is your this value.

Now what we are going to do in this 1; you want to this is very important characteristic and we will see with the change of alpha we will and other components here because, we are adding some capacitor, we will have the different zone, there will be 1 portion where this x will be canceling out the other x and then it will have some resonance or we can say margin where we should skip from inductive operation to your capacitive operation, means in this stat com, we are going to add here this capacitor.

So, this is called this is nothing, but your thyristor control reactor this unit because, reactor here L value is controlled by thyristor. So, it is a TCR. And here it is your fix capacitor Fc. So, this SVC is nothing, but your TCR; thyristor control reactor plus your fix capacitor unit and then we have to see the characteristic of this whole system. Now, we have to now go for the various characteristic using this Ic and the Vc. What we are going to do; now if you are connecting some here some current is flowing I. And then we will see with the help of voltage and current, we can have the different characteristic.

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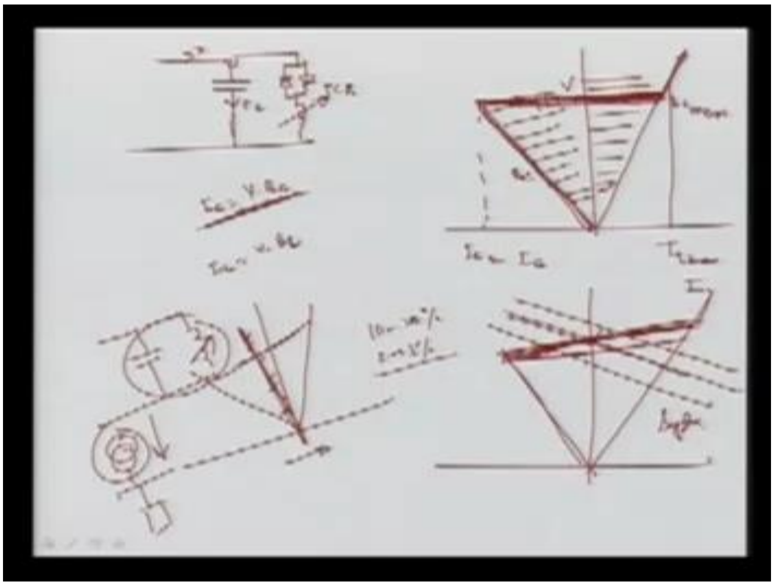

Means let us a characteristic of this circuit we want to draw, then it will more clear. So, this is your thyristor unit, this is your inductor and we have this, this is your I can say this is the Fc, this is your TCR and some current here is flowing here I. In this if it is Ic here, so, Ic is nothing, but the voltage multiplied by the Bc in this 1. Here what we are getting; so, for this characteristic you can say if the Bc is changing, the voltage here is a linear characteristic. So, I can draw here in 1 zone, this is your let us suppose say current I. So, this characteristic is the voltage that the Vc is inductive that is the linear curve and then we are getting here and this is your capacitor that is the Ic. So, in this zone and we can go up to certain value that is maximum Ic maximum max value and this is your slope is Bc.

Similarly, here in your inductive zone in this 1, we can also write what is the here bear and we can say this IL is your v that is a VL here and this we can say now we are having another component here that is your VL, so this is inductive. Now with the varying your this VL value. Now if you are having the fixed reactor, let us suppose this is your C, this is your inductor what will happen; we have to have a combined 1. Then characteristic this and this characteristic will combine, we will get some characteristic and this is the point at this line characteristic.

But with this variability of this, we can have the zone control value, means: if you are adding this, what will happen; now this no variable will have some characteristic either positive or negative means either this zone means suppose here resultant may be somewhere here in between. So, your operating point will be the least with the different value of the means different value of characteristic of … voltage you are changing the current will be changing. But here since this is variable, so this is the zone.

So, between this to this we will see this value is 0 we can go we can achieve here up to this point. If this value is more, then we can go this side and then this is your characteristic. So, we are just getting a characteristic of inductive zone here and the capacitive zone here this, we are getting. So, this is value of maximum VL max VL here and the current here we are this is your VL max at this maximum value we can achieve, this is slope the boundary of them because this is variable, means: like this the total we can get. And the current which is we are getting here, that is, IL max, that is the maximum current that can flow in the inductor.

Now what we do; there is possibility here, this is a characteristic here, we can achieve and normally we can say this is the characteristic here we operate normally in the capacitive zone. When the voltage is less, we must operate in the capacitive zone that we require the reactive power and we must supply it. So, our characteristic power here normally moves here and then slightly going here and then at this point, means: when the voltage here difference value is less, we have to operate in this zone because, we have to provide this less.

If voltage is more, then we have to go for this. Here this is very if it is a straight line, what will happen; it is oscillating. So, it will be moving means; what will be the current, whether here here here or which point if it is a floor, what we will do normally we provide some characteristics and this is normally we have to go for some regulating slope we provide. This is your inductive power and we provide normally this slope here.

So, the characteristic is not here the 100 percent this horizontal, we provide some slope and this is basically called the natural regulation and it into the transformer which we connect. If you remember here it was the transformer, then we have your SVC here. So, this impedance is there, so the current which is flowing here that will be a again some drop will be there and there will be some slope here. But sometimes we have to go for another characteristic, means we have to intensely provide more slope for another characteristic means: we have intensely provide more slope and the loading of the line.

So, the regulation slope, the terminal voltage is allowed to be less in the capacitive zone and more in the as I said; here we require the voltage less and more here because, we require a voltage is more then we have to go for this. The perfect regulation may result in the oscillation as I said. If the perfect regulation here and then it will be oscillating, due to the poor defined operating point there is a 0 regulation. So, here the operating point is not defined, regulation, that is, the drop or flow tends to in force, the automatic load steering between the static compensator and other voltage regulators.

Due to the coupling reactance, the voltage drop is normally 10 to 20 percent, but the slope reactance typically between 2 to 5. So, we do not want much slope. So, what will happen; this slope is not much desirable. So, we try to go for the minimum slope that is required so that, we should not have hunting, at the same time we can have the stable operation. To understand this it is very easy that, we can have the different load lines here, if the voltage here load is your increase or decrease voltage less, then we have to operating characteristic with here, otherwise will be here.

If you are loading is decreased, then we can go for another and then reactive power support is required. So, these are called the system voltage or load line and these are called the natural characteristic. So, we can have the natural characteristic here, that is, the intersection are less.

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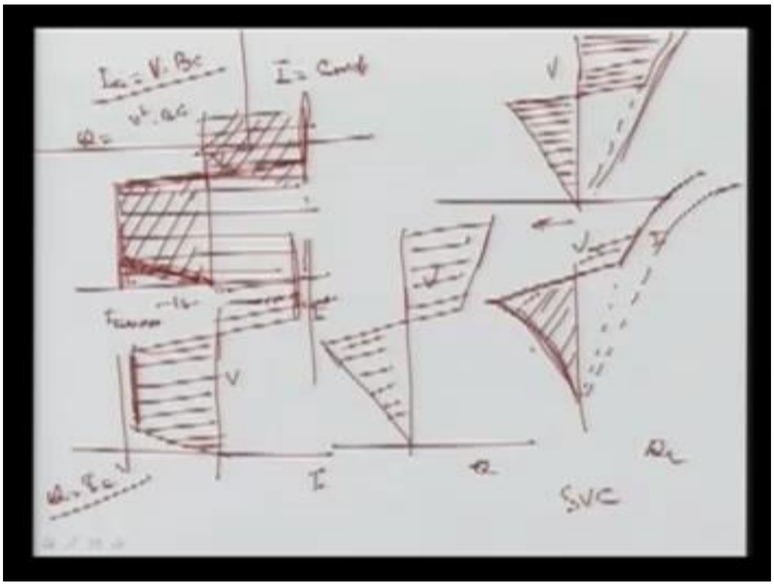

So, the natural characteristic of svc, normally the operating this zone; this is this. And then we have the slope and then this 1. So, here this is operating zone, here we have to operate our SVC is; when voltage is more than reference point then we only we have to go for in this inductive zone, this is your capacitive zone and this capacitive zone, if voltage is less then we have to provide this 1. So, this is your called your current-voltage, that is, VI characteristics of the svc.

Now, let us go for the VQ characteristic of the SVC means: I want to draw this Q here and the voltage line here. Already we defined this IC it is nothing, but your V into your Bc. So, it was a linear curve. Now if I go for the Q it is nothing, but your V square into Vc. It shows that it is a square of the voltage now, the reactive power it was current was near, so which were getting linear here; now it will be the quadratic and then we are just going to have here this characteristic like this. And then for this zone here we can again go for this type of characteristic. So, here this is your this and otherwise this.

So, here this quadratic if not linear, but this zone this is also quadratic and we are also going to get this characteristic and this is your operating zone. So, this is your VQ characteristic of this svc. Now here another problem that, the over rating because, we are having the inductor, what is the value that we can go for the over rating, that is, transiently that we can go for this zone as well as this zone can increase. So, this is that margin can go for here from there. Now let us see the stat com characteristic. This we saw this is your svc. In the stat com, what relation we are getting; this I is the constant in the both side. Means: we can maintain this Ic value constant, so I can say the V and here this is your current, this is your V. Now we can go for here this is Ic max, we can go up to the maximum means we can vary current in the both side and we can go for here that is your IL max value.

So, this is your operating zone in the between here we can go for this. But again as I said the voltage is less, we have to operate in this capacitive zone; here this capacitive, this is your inductive. So, the actual characteristics is normally; it will operating here in this zone when the voltage is less and when it is voltage higher, it will be operating in this zone. So, this hash line area will be now this is your operating zone, this is again we have to provide the slope and this is here.

So, now we can say it has the wider range, as I said in the very beginning when I was comparing in the previous lecture, the SVC and the stat com. Here you can say this zone is very small, here we can have wider range, especially the low voltage you can say here the voltage is low we have this much, here we have this wider range. To add the practicality, here if the voltage is 0 we cannot go for the Ic maximum. Normally we have another characteristic here at this end, it is not possible to maintain the IC if, the voltage of the system is 0.

So, in that case here we go for the this characteristic and normally we can get the characteristic like this here, upto this very small voltage this, we can go here, here, we have slope here and this is your that is VI characteristic of and this is your zone of operation. This is your stat com. So, it is better, that is why this device is better than that device. Now if you are going for the reactive power, as I said we can see the reactive power here and now I can draw here the reactive power here; this is your Q, this is your V.

Now, this value this horizontal line, that is, I said the Q will be your Ic into your this voltage. So, it is a linear. Now we can have this characteristic here and now this zone also we can have this and this 1. So, you can see this is better here, this value is very less, this is more this is reactive power support and this is characteristic are static. So, this stat com is better in terms of dynamic range has a wide dynamic range, it is better operating range and also it has a more overload capability, means: we can go for this current is more and in both side. Here only this side we can go for the more current and normally we require in this capacitive zone. So, this is basically the difference between the SVC and stat com.

Now, let us see another that is the major difference that, when I was saying that if you are going for the P delta curve.

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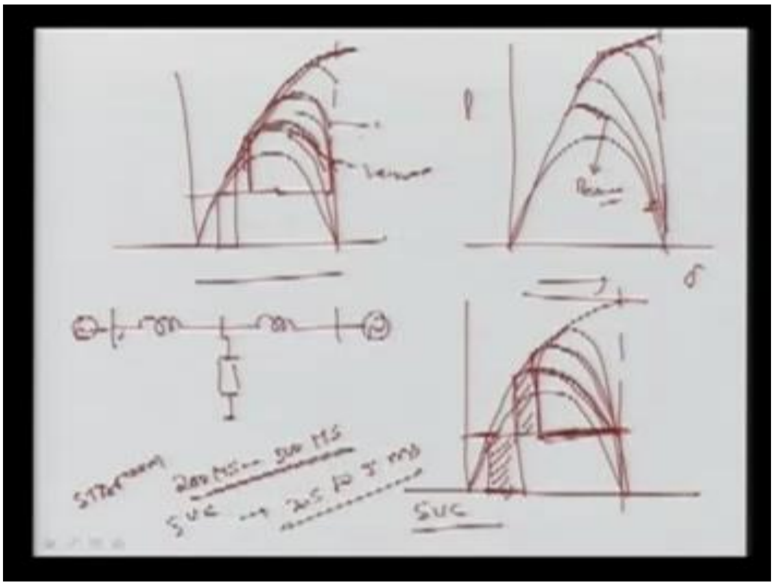

If I was telling you, do you remember this is your delta and I said you it is a without compensator. If you are going to compensate, ideally here we are going to the double this. When there is no limit in the midpoint compensator, then we will achieve the P delta here this curve. This is without compensator, this is with compensator. Now, if the limiting value is hitting, means: if your value for SVC is hitting, then what will happen; this your pi by 2 as I said here it will be like this. The characteristic will be here finally.

So, where it is hitting depends, means: here the Vc max I can say this is nothing, but this is your Vc max, the total Vc max how this you are achieving and then you are getting this characteristic. However in this stat com what we are going to get; again I will compare this, this is without I mean infinite limit. If your system lets say hitting that is a system current limit is hit, what we are going to get here we are going to get here. It is not going to 0 mind it, only the difference here is always going to 0 because, now we are having simple inductance, where inductance is fixed variable part is 0 and finally, we have to come here.

Here we are injecting this is your this value is Ic, Ic 1, max, here Ic 2 max and it depends Ic 2 max is more and then we are getting this characteristic. Now here also we can say that, this device is better that this device when improving the transient stability of the system, how come? Now you can see again for 1 case previous case which I was using the fault simple 1, lets show this midpoint; this is here, this is your, this is generators this is we are putting here our SVC or a stat com.

If you remember here, now again I can draw this P angle here, this is without compensator, if we are using compensator what is happening, now you can go for this much. Now, our system it was operating, the mechanical power here it was there and now this value is shown 0. After certain time of the fault which occurs here at this bus, it is clear and your system will be coming here and then this value, this area here must be equal and this area here it is you're A 2.

Now, for the different value of the limiting value or we can see let us it is a SVC. In SVC I said if your there is a hitting we are getting this or we are getting this. Now how much margin you are getting; this margin if your, this is your characteristic which is this value you are hitting, then you have this margin, or you are having this margin, or you are having this margin; these are the margins.

Now, the same if you see here what we are going to do; now you can see this, now this and this value is now hitting, now you can see now this value is not 0 here; it is now we are getting this characteristic more, now if it is more; now it is this. So, this is not going to be 0, earlier it was going to be 0 here. So, we are having more margin. So, we can say the stat coms are better in terms of the dynamic performance than your SVC, but the stat coms are expensive compared to your SVC and that is why this device is very popular and very simple also. And very simple to control very simple to manage and already we are having all these things.

If you see the time response here; the stat com basically time response is from 200 microsecond to 500 microsecond, this is for stat com. However, for SVC, it is from 2.5 to 5 millisecond. So, this is very fast compared to the SVC as well because, we are having the control, we are adding the converter based technology. Here we are the inductors because, switching here you require some time. So, here this time is millisecond. So, it is also very fast as well.

So, let us see the impact; how this SVC or stat com can improve the voltage and the system performance by improving the voltage.

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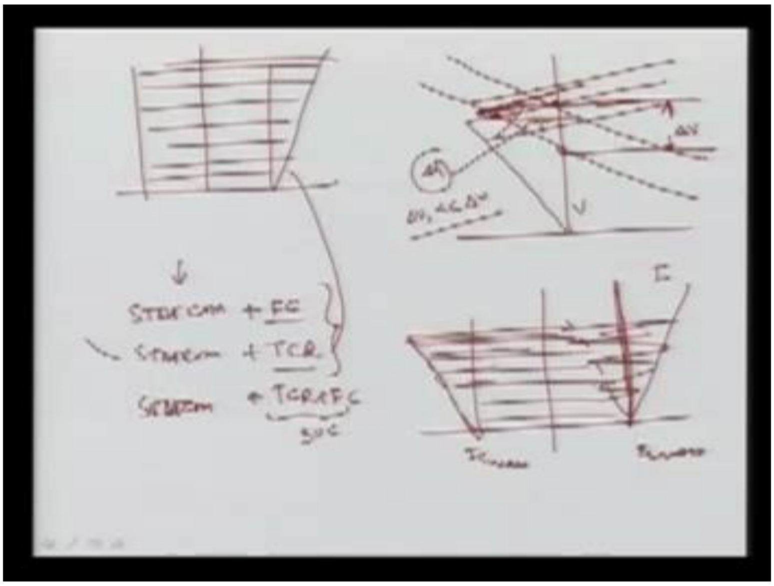

As I said let us take the characteristic of any device, that is, SVC or stat com. We are having some slopes here, that is, as I said the natural slope or it is the non natural slope means: the natural slope means already we are having the transformer impedance is there and that drop is just related with VI characteristic, this is I, this is the voltage. Now if you are having this let us suppose your system load line is this, now if your voltage here the system line is reduced if more load is increased, what will happen; if there is no compensator it was operating here at this point, now it is coming here and your voltage drop is your in the system, that is, this 1 that is the delta V.

But if you are having the characteristic, you are having some compensator and you can have this characteristic what will happen; now this is your operating point that is a operating point will be the intersection of this curve, that is, characteristic of this device plus this load line or system line. Now, what will happen; only the difference here in these 2 is now I can say this is your delta V.

So, this delta V 1 is always very very less than delta V and we can say our system voltage variation is very well and then we can you can say that is improvement in your voltage profile. Same time even we can change this characteristic on here and there by firing the angle and then even though we can maintain with this load line voltage and we can get this characteristic and then a voltage can be also fixed at to the terminal voltage.

So, whenever this load and voltage variation takes place, there is a possibility by changing the firing angle, we can change the characteristic and then we can maintain the terminal voltage to its rated value. Now, let us see the various combination, various combination of our stat com. Let us suppose we have the stat com characteristic as I said, means: we have the stat com plus we can have some fixed capacitor, means: we can have the minimum rating, this margin is less, but we can add the fixed capacitor they are very cheap. Another we can have this stat com stat com plus I can say thyristor control reactors. We can have another several combination of this, even though we can have stat com as well as you're here TCR plus fixed capacitor we can put and then this is plus your stat com, stat com that is nothing, but here it is your SVC.

So, we can see the characteristic means the characteristic that we can change and we can say how it is going to be this. Now the stat com characteristic as I said; this is your stat com characteristic which is shown. Here it is your Ic max maximum current that is in capacitive zone, here your IL max. Now if you are adding the Fc what happens; now you are adding this characteristic that is a slope here and so this is a fix value, so this curve will be suspected here, this will be added here this will be added here. Now our operating zone will be this much. What is the advantage we are getting?

Most of the time if, the voltage is less we want the reactive power support and here you can say this area is shown, now we are having this final 1 and this is more and this system is better compared to complete stat com. Now, if you are having this stat com for stat com plus TCR, the characteristic again here we are having this, now this TCR is nothing, but this characteristic. So, what we are doing this is a variable 1. So, we can go from here 0 to here. So, we are adding this region only. So, we are having this characteristic completely. So, this is your this characteristic. Or we can add the stat com SVC and that will solve the purpose of your whole wide range in that area. And then we can have the fixed capacitor here, we can have the TCR as well here, what will happen; there is a possibility that, we can maintain this 1 value with this variable.

So, we can go for this zone even though like this and we can have the very wide range zone of stat com and then we can operate our system very smoothly. So, basically this is the stat com of precision devices of very very popular to improve the power system performance, again in terms of static as well as dynamic performance.

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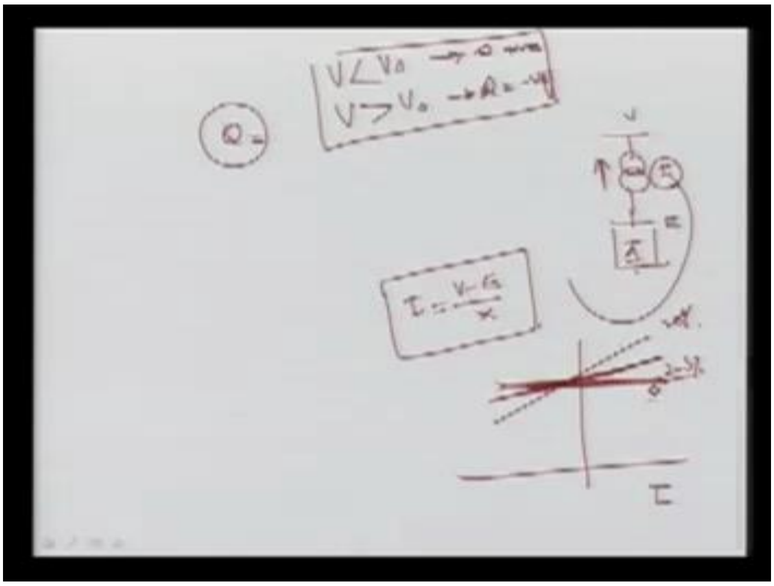

Here again I want to show you that, this reactive power here the supply is 1 objective, means; whenever they are connected, they normally feed reactive power or they can absorb whenever required, means: the stat com or the SVC; they will inject the reactive power at the system, when the voltage is less, when the voltage is less for example, stat com configuration as I showed you here; this is your converter.

Now this is voltage e, this is voltage V here I. So, I can say this V minus e upon x is I. If this voltage is more, then we can say it is just providing the current to this system and therefore, the leading and lagging current is decided by this, whether this current is injected or that 1, we will get from here. Now, the reactive power they will be providing the reactive power to the system, when voltage this voltage V is less than V not, then they will be providing the reactive power; that is called positive generation. When this V is less greater than V not; they will absorb reactive power and normally it is you will get from the system to maintain the voltage.

So, these devices in the steady state will work like a simple reactive power support device, but their supplementary controllers can be used to improve the dynamic performance, as I saw that using these devices that we can change the transient stability limit and the same time, we have to model their dynamics as well, if you want to see the impact together along with the system dynamics. So, the modeling of these devices in the dynamic is also very equally important.

And normally they are modeled by the simple singular equations and it is the current which is your giving, in that, it is Bc Sc that is a capacitive, impedance is variable and then we can go for the different time fractions. Already we saw they are very very fast and their dynamics can be also included in the transient in the simulation of the SVC or stat com, with the other system that is the dynamic already we have defined earlier.

In the total, we can suppose we are having other devices, then control coordination problem is also 1 of the major challenge, means: we are having the let us suppose HVDC, we are having the controller that is a your exciter controller, you are having the real power controller that is LFc loops, you are having the controller corresponding to the facts controller. So, there may be possibility that, these controller will interact with each other and they may oscillate and system may go somewhere else, even though instead of improving the dynamic performance.

So, the controller design of the controller and their tuning is equally important and we have to take care there in a very sophisticated and efficient way. So, I can now recap with this, now lecture number your 9 and 10. Here I just discussed the facts controller those are only the shunt type because, the shunt type here is very simple and it is used for reactive power support, along with the that they will dynamic performance.

So, here we saw that, some characteristic that as I said the slope characteristic. Now again sometimes some people ask that, why this characteristic here this is the VI characteristic of the stat com or you can say SVC, we not going for the 0 here slope, always you go for some slope here and it is very minimum that we go for 5 to 2 to 5 percent. As I again said if it is 0 percent slope, then there will be the operating point is not possible if this is shown. For a same voltage if it oscillates hunting. So, we intensely we go for the 5 percent, we do not want to 2 percent. This 2 to 2 for 5 percent we can maintain, 0 percent is not desirable; however, we can go for that. But in the natural characteristic, this slope is 20 percent because; the reactance of the transfer is very high.

So, I or the V characteristic is related with the reactance of the transformer. So, we normally go for such type of compensators that is having the slopes of 2 to 5. We saw the performance of both stat com and SVC and we found that, stat com are better than SVC in several aspects that, they will improve the transient stability better than SVC if, the limits are available. They can damp out the power system oscillation if you strictly compared to SVC. They can also provide more reactive power that is dynamic range compared to the SVC. Only the limitations of stat com is that, it is a expensive device compared to your SVC that is very simple and reliable that is why it is existing in the system from very long period.

So, this whole module now, I can recap this whole module. We just discussed about the load frequency control in the very basic few lectures. Then we modeled the power system and after that we went for the AVR load that we can we in AVR load that is automatic voltage regulation of the alternators. We also saw some other devices for the reactive power sources and since that is a transmission line, transformers, cables boosting transformers etcetera because, they can provide some reactive power support to the system and of course, the capacitor are 1. And we also that saw this facts controller; those are the 1 in the nature that is the SVC and stat coms.

Here in the whole voltage and the frequency we saw that, we can improve the power system and that is very very important to run the smooth, reliable and the secure power system.

Thank you.