Power System Dynamics and Control
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Lecture No. # 44
Stability Improvement Power System Stabilizers

In this the penultimate lecture of this course, I shall describe to you augmentation in the control system of a controllable elements in a power system like, an AVR of a synchronous generator, to improve the relative, small signal relative angular stability of the system. So, today's lecture will be focused on a particular augmentation in a in the controllers, it is also called the power system stabilizer. So, today's lecture will be focused on that. Remember that we have been really discussing in the previous lecture, a possibility, which exist in a power system.

What is that possibility? That you can have small disturbances exciting relative angular motion, which does not damp out with time, this occurs occasionally and in some situations in a power system under certain operating conditions; we do see that the relative angular motion between synchronous machines is not very well damped. And this can be triggered by very small disturbances, so it essentially it is a linear phenomenon, linear it can be studied by the linearis analysis of a power system.

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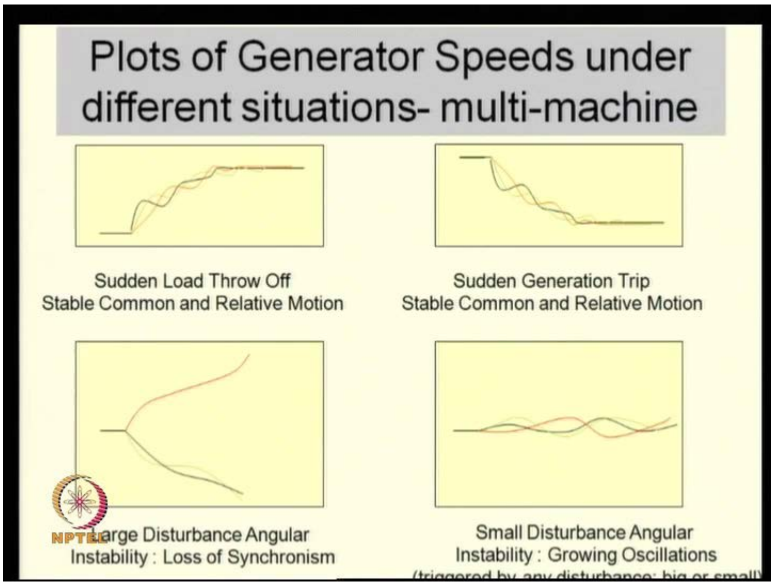

So, if you focus on this slide, what we are really discussing is what is there on the bottom right of this slide? Small disturbance angular instability which results in growing oscillations or very poorly damped oscillations. Now, this of course, has to be distinguished from what we have been discussing so far as stability problems, we are not talking of the overall or aggregate movement of a frequency or you know speeds of generators, we are talking of relative motion and we are talking of small disturbance relative motion.

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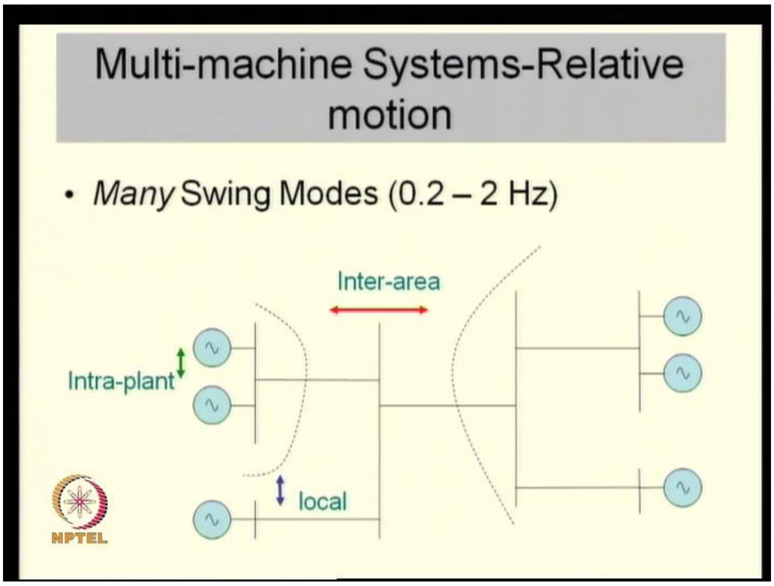

Remember that in a multi-machine system, a relative motion may be a bit more complicated than in a single machine connected to a voltage source situation, you may be having many modes of relative angular oscillations, which are depicted in this figure here.

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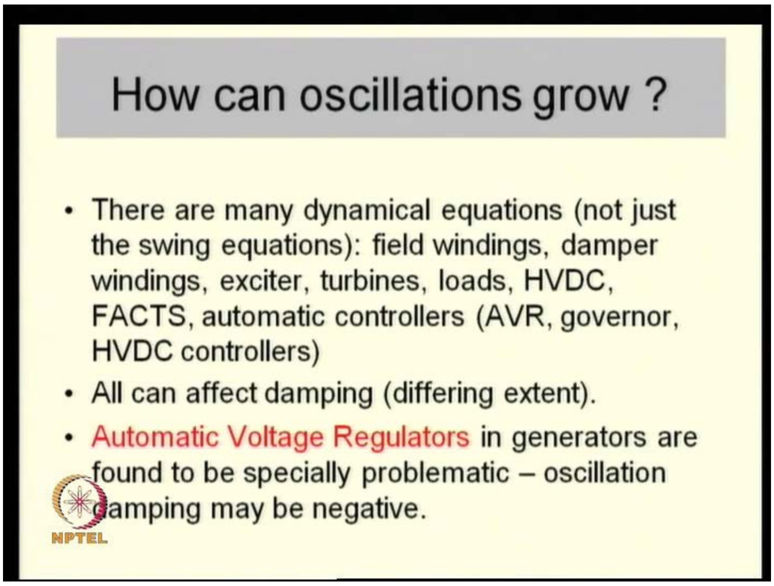

Of course, the question comes that it seems almost counter intuitive that why should oscillations grow with time? Remember that relative angular motion between synchronous machines, I discussed it by you know using a very crude crude and simple analogy of you know synchronous machines connected to each other can be considered as masses connected to each other with springs, like a multi mass, multi spring interconnected multi mass, multi spring system.

So, the question is how can you know the oscillations relative motion, which is excited due to disturbances grow with time, the the important point which you should remember is that unlike the crude analogy which we have we used the spring mass system analogy. In a real power system there are many dynamical coupled equations not just the swing equations of the synchronous machine these.

So, you have got the dynamical equations corresponding to field winding fluxes, damper winding fluxes, the exciter, the turbines, the loads, then the control systems, the AVR, governors, HVDC controllers, flexible AC transmission system controllers, which are of course, power electronic controllers, which are there in in many power systems. One of them we will be discussing in this particular lecture. All of them can affect damping of course, to a different extent, it is found that close loop control systems like the automatic voltage regulator in generators are often the cause you can say it is the, they are the cause of poor oscillation damping. Now, when I say they are the cause, the point is that any control system, which is poorly designed can result in a particular pole or a particular mode or a eigen value becoming unstable.

So, what what is what is the special thing which I have said here, the point is that AVR is of course, are designed it have a very fast response. So, that the terminal voltage of a generator is regulated. And also during disturbances a large gain and low time constants or a fast response, automatic voltage regulation system is useful, because it over comes the natural sluggishness of the filed winding.

So, the point is that if you have designed your AVR to give you a good voltage, you know good transient response as far as voltage regulation is concerned, you may find that you may not of course, have designed it, well enough to operate for all operating conditions. So, what happens is under certain operating conditions, the gains can actually make some dynamics or some modes of your system unstable, so this is essentially what can happen in a real power system.

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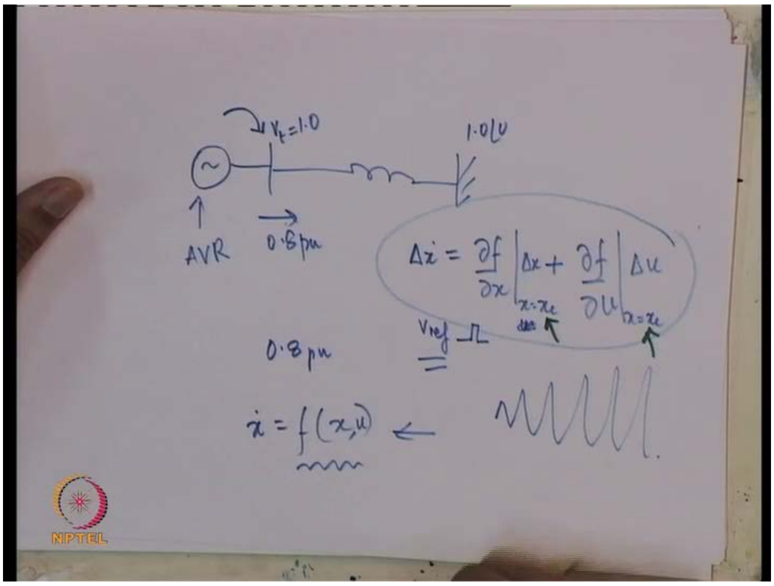

In fact, we are displayed this in the previous lecture by a simple simulation of a single machine connected to an infinite bus via a transmission line, and it had an AVR, which had a relatively large gain and low time constant, it is a fast acting automatic voltage regulator which was regulating the terminal voltage of this generator. We saw that for certain operating points like point per, 0.8 per unit power output of the generator terminal voltage magnitude is 1. For this kind of operating scenario, we found that for a small disturbance around an equilibrium corresponding to this scenario a small pulse change in V ref of the AVR, it excited an oscillation which grew with time, so can we see that once.

So, we will what we will do is, I will just show you this oscillation I have already simulated and plotted it, this was done displayed last in the last lecture too. The step change in the AVR excites an oscillation which does not settle down since, it is a pulse change in V ref, and V ref is brought back to its old value. So, we would expect that a system should settle down to the same equilibrium as the before this step, pulse change, so but this does not happen, you find that the oscillation simply does not settle down and we have got essentially what you would call as small signal instability in this system.

Now, why do I call it small signal instability, the point is that this kind of behavior is evoked, even if I make the disturbance very very small, so it is a problem with the equilibrium point. If you do an linearis analysis around the, this particular equilibrium point, its eigen values, the eigen values of the linearis state matrix which you get, would turn out to have a eigen value with a positive real part, so this is what essentially you are seeing here.

Now, of course, it is important to keep in mind that this kind of instability is not seen always, its only seen under certain operating condition, now why is that so the point is that a power system is a non-linear system, so the small signal behavior at various equilibrium points are different, they depend on the equilibrium point itself.

Remember that, the procedure for finding out the small signals stability of a system was you linearis and operating point, linearis the dynamical systems system at the equilibrium point and this involves taking out the partial derivatives of the system differential, the the component of the system differential equation. Suppose, you have got a differential equation x dot is equal to f x which describes x and u, which describes the non-linear dynamical system, you would have to take out the partial derivatives of f at an equilibrium point, in order to get the linearis model.

So, the linearis model would be evaluated at the equilibrium point, which you are studying for small signal stability, so the point is that the behavior of the small signal behavior of the system would depend on the equilibrium point. So, you could have a perfectly normal system at a particular equilibrium point, but you go to another equilibrium point and you see that for any small disturbance also you will not you may find that the system is not the oscillations which are you know which are there may not really die down with time after we disturb.

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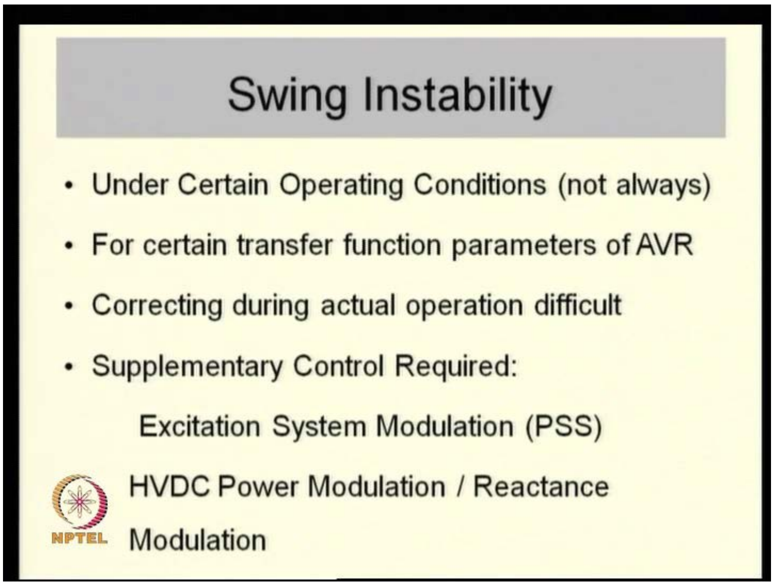

Now, the point is coming back to our discussion, we can try to stabilize these oscillation, we will just summarize what we wish to say here, swing mode instability can occur under certain operating conditions not always, for certain transfer function parameters of an automatic voltage regulator. In fact, automatic voltage regulator was found mainly to be the culprit, if you disabled AVR in many cases, you would not have this swing mode instability, but we do require the AVR to do voltage regulation.

So, there is a we cannot disable an AVR, you cannot correct swing mode instability during actual operation, because the point is if a system operator notices that for a certain operating point, the oscillations which are caused due to random disturbances which are always present in a power system, like load change. If the oscillations are not dyeing down, there is very little he can do in real time operation, because he does not know what exactly he needs to do to get the system, you know get the system to be stable; in fact the only option open to him would be to do a study online and try to find out how to changes the operating point, how to get the system to an operating point in which all these these swing modes are actually stable. So, it is a bit difficult during real time operation to correct this problem, but one can actually in the design or in you know you can actually make augmentations in the control system and improve the damping.

Now, typically you can for example, improve excite improve the damping by modulating the excitation system, what do I mean by that, you have got a automatic voltage regulator do something, augment the controller there, so as to improve the damping. That could include changing the AVR parameters themselves or having supplementary controllers, what do I mean will become clear enough few movements from now.

You can also improve damping, if there is any other controllable element in this system for example, you can modulate the power in an HVDC link or you can modulate the reactance of a controlled the you know controlled reactance device. I will show you one of them in a few moments from now, so these are the things you can try to do in order to improve damping. So, if you look at what exactly would you expect from a damping controller, when I say I will augment my control there of course, certain constrains which I have, you know which should be kept in mind.

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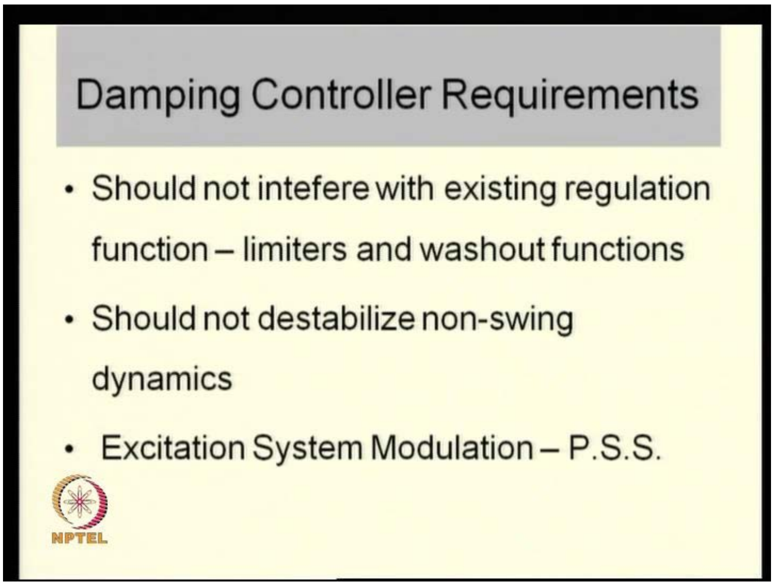

For example, the damping controller should not interfere with the existing regulation function, I mean it should not really you know compromise on the basic regulation functions which are already there for example, if you have got an automatic voltage regulator in a generator excitation system, you would like to still continue with the same function, so if any augmentation is to be done, then we should really limit that augmentation. The second point which is very important is that in steady state the effect of this augmentation should be minimal, that is in case you are making a change in the controller, then the damping controller output should be 0 in steady state, because it has no function in steady state it is just trying to stabilize the system.

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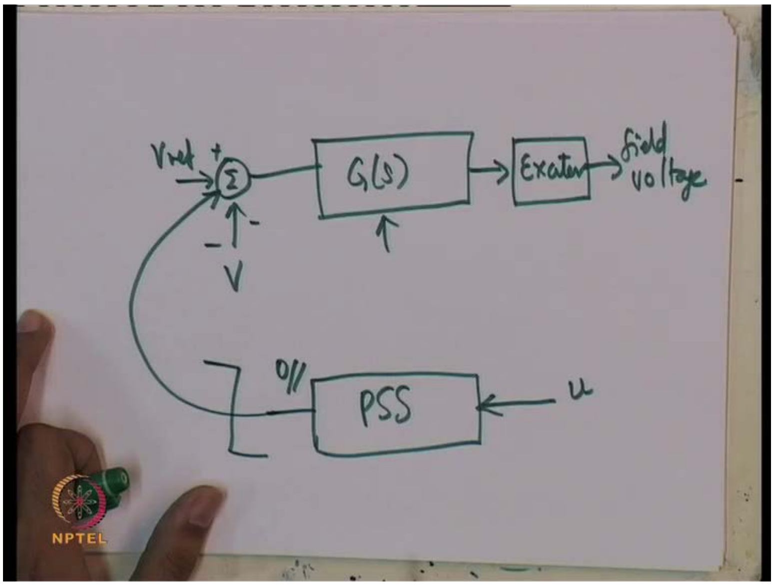

So, a damping controller or in other words a power system stabilizer has to augment the existing controller, when I say augment usually it means that you do not tamper around with the existing control system for example, if you got an AVR, so you have got a AVR, it is a exciter this is the field voltage, one possibility of course, would be try trying to augment this control system out here.

The other possibility of course, is instead of doing that you have a damping controller which augments the voltage reference or a modulates the voltage reference of an AVR, so this is one thing you can try to do, so you know you can have a another controller I will call this the power systems stabilizer this is in fact, how it looks like, which senses a certain quantity in which these swing modes are observable gives appropriate compensation to it and modulates the AVR reference.

Now, the important thing is that the PSS output in steady state should be 0, the output in steady state should be 0, and the second thing is the PSS should not interfere too much with this basic regulation function which is being implemented by an AVR. So, it its output should be limited you do not want it to modulate the V ref to an extent that this regulation function is compromised, so this is one important point which should be kept in mind.

Now, of course, whenever you design stabilizer of this kind we should ensure that if you have stabilized one particular eigen value or one you know the swing mode you should not go and destabilize something else, so that is a important requirement of any damping controller, so when you are designing this damping controller, one has to keep that in mind. Now, the excitation system modulation is see whenever people use the word power system stabilizer they usually refer to the auxiliary controller which is present in an excitation system of a synchronous generator.

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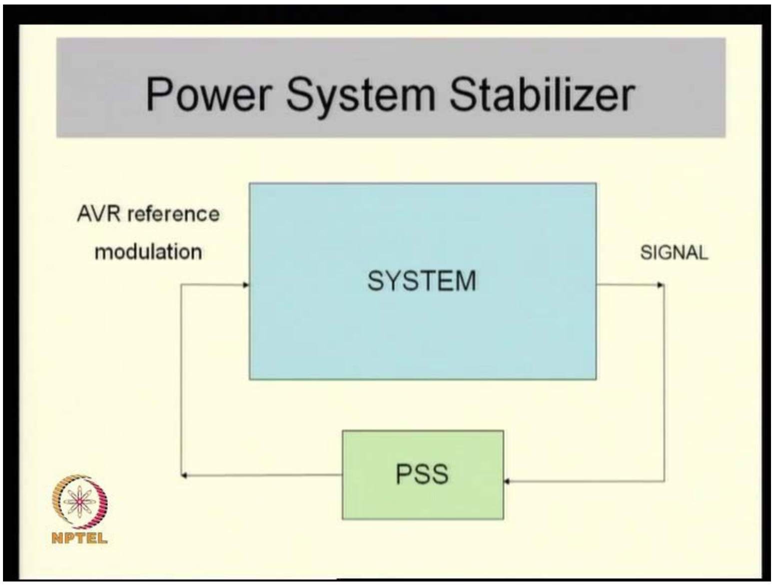

So, if you look at how a typical, if you just look at how the typical block diagram would look, you have got a power system, the input to the power system is the reference voltage which you give to an AVR, you sense a certain signal at the from the swing system. Power system it could be for example, generator speed, it could be generator output power, you feed it to the controller which is called a power system stabilizer, the power system stabilizer augments or modulates the reference voltage of the AVR, so this is how the power system stabilizer does or looks like.

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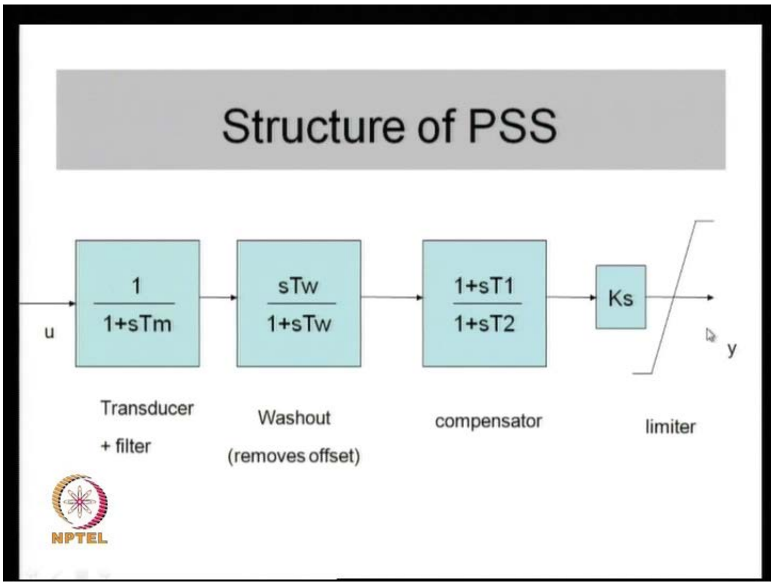

The structure of a stabilizer as mentioned before has got several important components one is of course, the limiter which ensures that the output of the PSS or the power system stabilizer does not affect the steady state regulation functions of say an excitation system. If the power system stabilizer is connected to an excitation system control like the AVR, then the power system stabilizer should not modulate the reference voltage of the AVR beyond a certain value.

So, you have to have a limiter, so a limiter essentially ensures that a power system stabilizer essentially improves the small signal stability of the system without interfering with the large disturbance or the regulation function, basic regulation function of the AVR. You also have a compensator and a wash out block, the signal which you use is usually obtained via some transducer, which is also usually filtered, so often a PSS input stage that is the measurement stage is modeled by simple first order transfer function, which really represents the transducer and filter delays.

But, this wash out circuit here is very very important; the point is that a power system stabilizer should give 0 outputs under steady state condition. So, adding this block in cascade with the other blocks of a PSS ensure that the output here is 0 in steady state, a compensator block gives a phase shift, it has got a frequency response which is such that it gives a variable phase shift. If the input signal is sinusoidal varying or if a signal is varying this compensator kind of changes it to some other wave shape, if it is sinusoidal input it will give a magnitude as well as a phase change, phase change to the signal.

So, these are the basic components of a power system stabilizer, these are in fact necessary, so that the output of the PSS modulates, the controllable element appropriately, so that you get damping you know. If you take a control signal you cannot just feed the control system with a gain, this may be possible under some very special situations, but normally you need to have a offset removal block as well as a compensator block you may have one or more stages of this compensator, this is just one shown here, you may have to have a gain and then modulate the controllable element.

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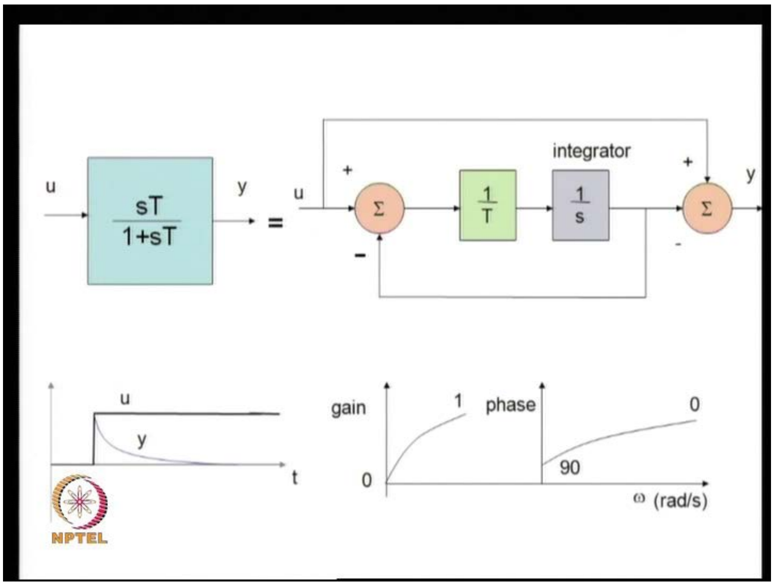

So, what is the function of this offset block, this offset removal block remember that a transfer function s T upon 1 plus s T in a stabilizer or any other control system is such this transfer function has got a 0 gain for low frequencies, and a gain of 1 for high frequencies. So, this particular block is called a washout block it lets in transients, but blocks any steady state offset, so any steady state d c value will give a 0 value in steady state here. So, this ensures that the signal which you have here modulates the controllable element, the power system stabilizer modulates the controllable element only when they are transients in u, but not when u has got some d c value or some steady state value.

So, for example, if there is a step change in u, the output of this block will be a kind of a, has a response something like this, it has got some response initially a gain of 1 during transients, but it eventually kills out the response in steady state. So, remember that in any stabilizer you will find that there is a washout block of this kind to remove any offsets in the signal view, so that our stabilizer does not you know you know actuate the controllable element under steady state conditions at all, so it does not interfere with the regulation function in steady state.

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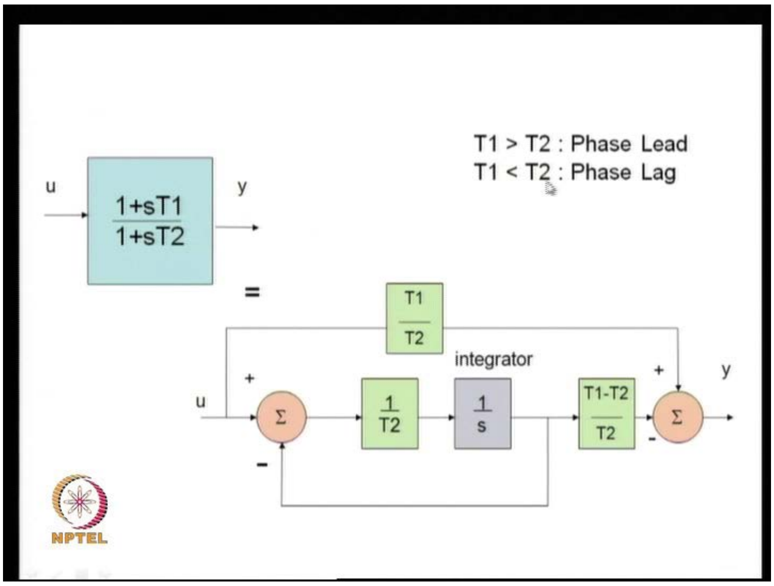

If use in conjunction with a automatic voltage regulator, on the other hand a phase lead or a phase lag block can give appropriate phase shifts and even magnitude shifts or magnitude a a gain, appropriate gain which is frequency dependent. So, this is a also a usual component in any stabilizer power system, stabilizer it is called a lead or a lag block depending on when T 1 is greater than T 2 or T 1 is less than T 2, in fact by appropriately choosing T 1 and T 2 you can get the required phase shifts.

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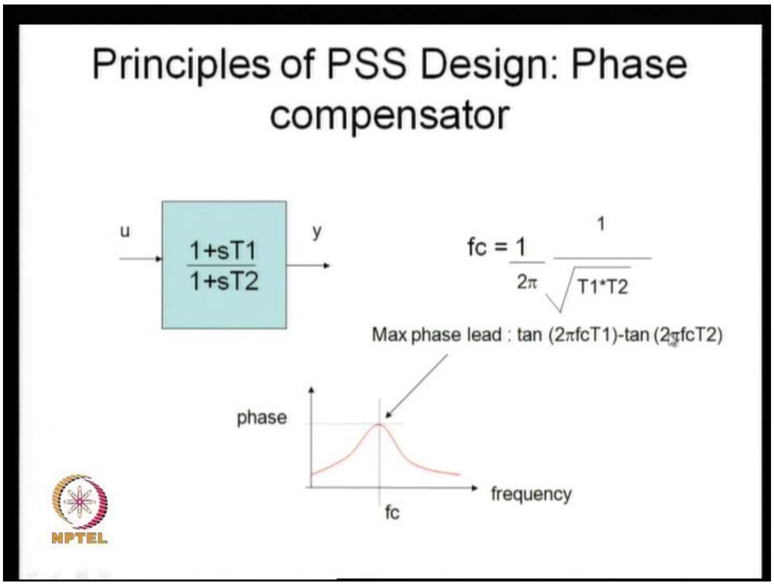

For example, if I choose T 1 greater than T 2 then I can get a lead compensator and which has got a maximum phase lead at what is known as a center frequency which is defined by this equation. So, by tuning T 1 and T 2 you can change the center frequency, you can also give appropriate phase lead or phase lag, so you can choose from these two equations T 1 and T 2, so that they satisfy your center frequency as well as maximum phase lead requirements, so these are the essential components of any typical power system stabilizer.

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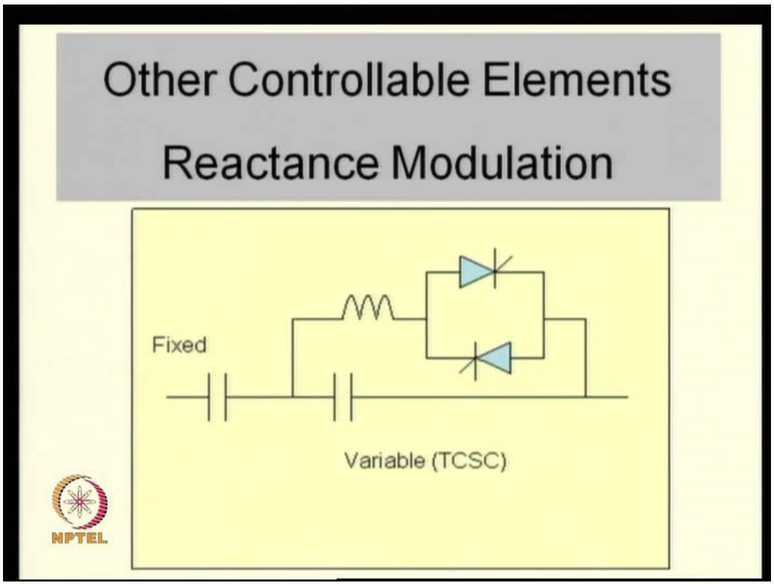

You can also you know excitation system is a simple and economic way of implementing a power system stabilizer, but you can also do other things for example, if you have got a controllable element in the system for example, this is called the thirstier controlled series compensator, essentially it is just a reactance series reactance modulation device.

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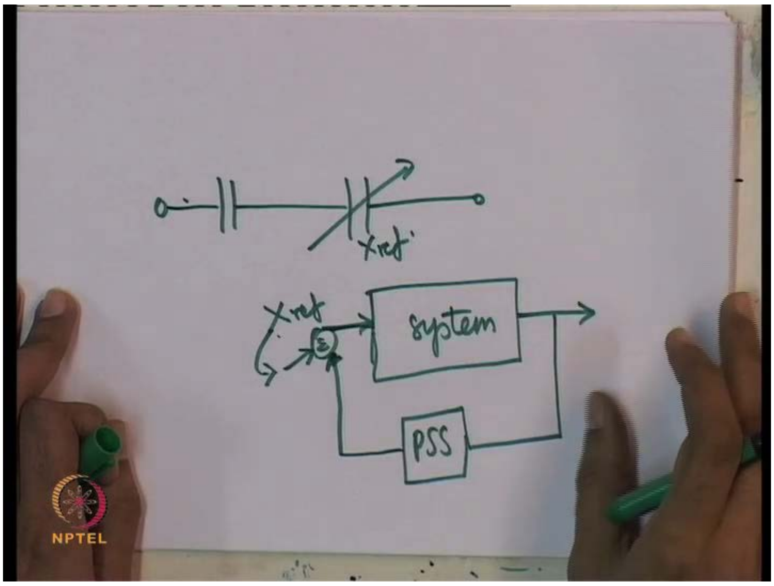

So, if you have got a series reactance modulation device, what you can do is modulate this in such a way, that it causes damping, so if you you know look at the block diagram of this it will look like this, so this is your power system stabilizer, this is your power system. This is the reactance reference of this device you sense certain signal have another, we will also call this a power system stabilizer and modulate this x ref.

So, instead of giving x ref directly, x ref is given here and a modulation signal is added here, so you can modulate this reactance to get damping is well, so this is basically what you can do to improve stability there is another possibility.

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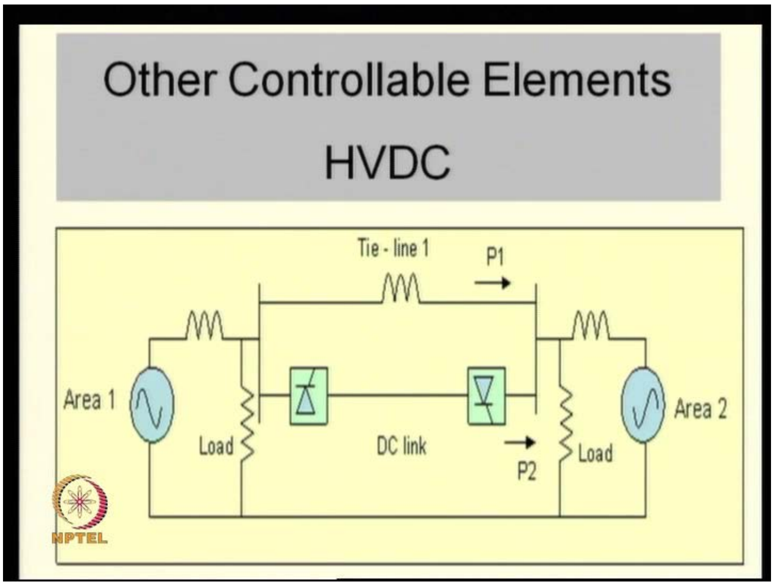

So, you will have a look at this slide, suppose you have got a two machine, two area or two machine, two area power system which looks like this, its connected by an AC line, AC tie line, it is called tie-line 1 here in this figure, and you have got a DC link in parallel as well. a DC link remembers is another controllable element in the system, you can by controlling the firing angle of the thirstier used in the convertors of an HVDC link modulate the power in a DC link.

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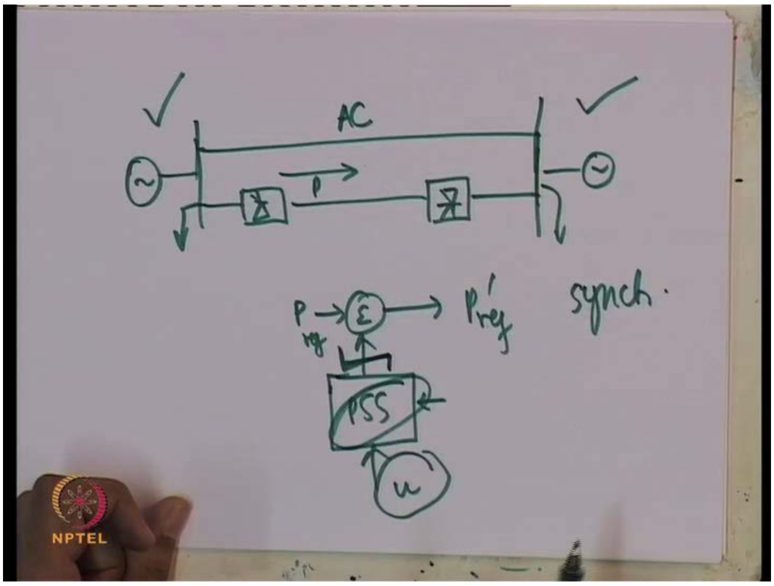

So, if you have got a two machine, two or two area system with its local load which is connected by an AC line and a parallel DC link. In that case by modulating the power in this, so you know instead of having a constant power flowing from the rectifier to the inverter, what you do is the power is modulated by another power system stabilizer, so this is P ref dash.

So, you can take a signal which has got you know the swing mode observable in it and modulate the power here, so as to get damping of course, most important question is how do you get damping, you have to design this power system stabilizer to modulate this power, so that it induces damping, so actually this this involves some design again. Again here remember that the power system stabilizer has to have its output is limited, so that it does not affect the power regulation function in a significant way it only improves the small signal, small disturbance behavior.

Another important point is the power system stabilizer here, again has to have a 0 output in steady state, so these are the two requirements which are usually will be present in any power system stabilizer. Now, importantly it is important to remember here, that you can have relative motion between the machines in this area and this area, the important thing to be remembered here is that this is a synchronous link, because it has got an AC line in parallel with the DC link. So, the machines here and here have to remain in synchronism and if you give a disturbance you usually have oscillations between these machines, because this is a synchronous link.

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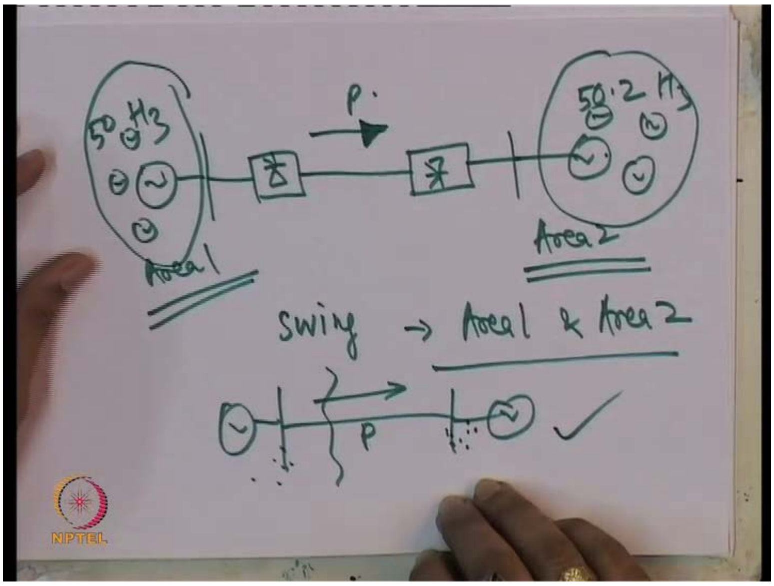

If somebody asks you the question, how do I improve the relative angular stability in a system between the machines in area 1 and area 2 using the HDVC link of this kind, so if somebody asks you the question how do I improve the relative angular stability between machines in this area and this area, what would be your answer be what would your answer be, the thing is that if this area 1 and area 2 are connected by DC link, the frequency and rotor angle here could be absolutely independent of each other, the power flow could be regulated by this HVDC link in spite of the you know you can have for example, the frequency here is 50 hertz and here is 50.2 hertz.

But, you can happily operate, because the power out here, the power flow between this region and this region can be strictly regulated by the HVDC link and the power flow is not a function of the phase angular difference between these two busses. So, in fact power swings in you know you cannot, there is no you know there is no relevance to trying to improve relative angular motion in this situation, because this system and this this area and this area can happily have distinct frequencies.

And absolutely arbitrary angles with respect to each other without having any problem, because the power flow here is not dependent on the phase angle, difference between this end and this end. So, swing phenomena between area 1 and area 2 does not occur in the same sense as in a synchronous system, in a synchronous system the relative angles between these two points are related to the power flow, so if angular differences are oscillating and power flow also will oscillate. And if the two machines lose synchronism due to large disturbance, you cannot operate and you will have to separate out the system this is not the problem in an asynchronous link.

So, the problem is not applicable or power system stabilizer are not applicable when you want to, you know is not applicable in this scenario, there is no issue or there is no problem, if these two areas are operating absolutely a distinct frequencies and the phase angular difference the swings which you see when you have got an AC interconnection, I am not seeing here because, power flow is absolutely regulated.

Of course, within a synchronous grid you know these there are many machines here, there could be oscillations between these machines, there could be swings between these machines in any case the HVDC link here will not be able to easily or its not really very you know obvious that the HVDC link can control the swing modes here, they could, the HVDC link could, but it is not very obvious.

The point which I want to make here is that you can have oscillations between machines within an area, but if you have got an asynchronous link the problem is kind of irrelevant as far as relative motion between the machines in one area again swinging against the machines in this area, is that yeah, so swings can occur, if synchronous machines are connected via an AC transmission line.

The problem of power power swings is between area 1 and area 2 can occur even in this case, because you have got an asynchronous connection and this is effectively a synchronous grid, but the problem of power swings between area 1 and area 2 is irrelevant in this situation is that ok, this is an asynchronous link.

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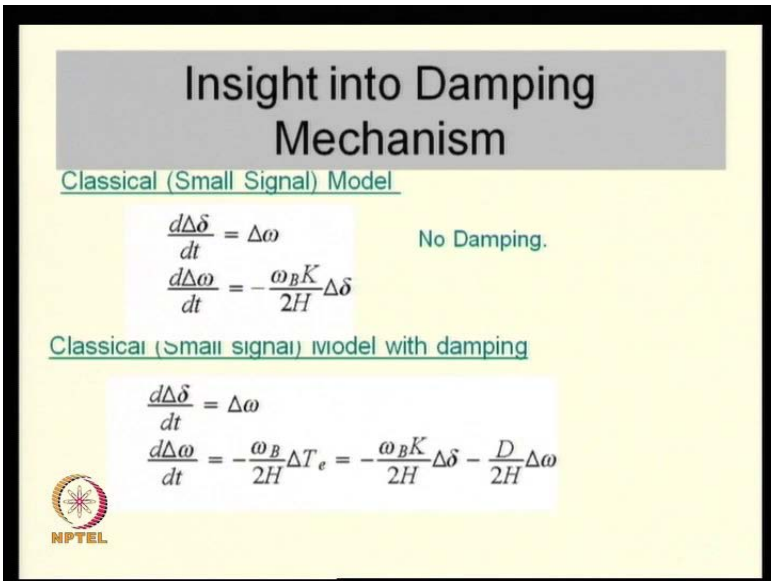

I have told you that you have to make augmentations in the control system, so that you get damping, now of course, this involves actually some kind of control system design.

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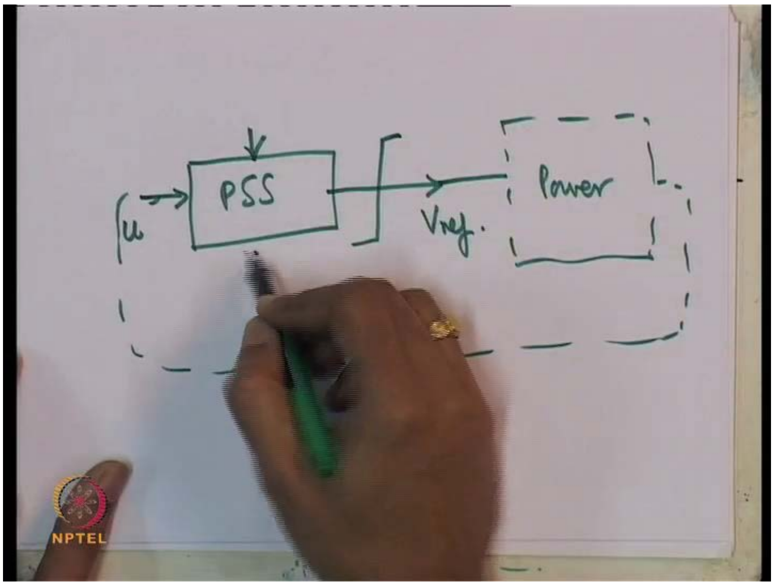

After all what you have here is an input signal and the PSS modulates something in the system for example, V ref in an automatic voltage regulator of an excitation system and this is your plant which is nothing but a power system and you got a signal which is fed back from the plant. So, this is basically a classical problem of control system design, the only catch of course, here is that the structure of the PSS has to be in some sense rather the structure of the PSS has some constraints, first thing it is limited and the second thing is the PSS transfer function or the PSS structure should be such, that the output of the PSS is 0 in steady state. Now, the point is now, how to design this controller you can use classical control system design techniques, but in this lecture I will not really try to show you how to design a PSS, but try to give some insight into how you could, in fact change the damping in a power system.

(Refer Slide Time: 32:52) Pay attention to what I have shown you in this slide here, if you look at the small signal model with a classical model of a synchronous machine, a classical model of a synchronous machine has got just two states, delta and omega. We had discussed simplified machine models several lectures back, somewhere around the 23 or 24th lecture of this course, we had talked about simplified model and most simple model of a synchronous machine, which can actually show you this phenomena of swings is the classical model.

Now, if you look at a classical model which is linearis around an equilibrium point the equations are as given here d delta d delta delta by d t is equal to delta omega and d delta omega by d t is equal to minus omega b by 2 H into k into delta delta. Now, k here is operating point dependent, because you have obtained it by linearising the system and that is evaluating partial derivatives and you know plugging in the values at the equilibrium point.

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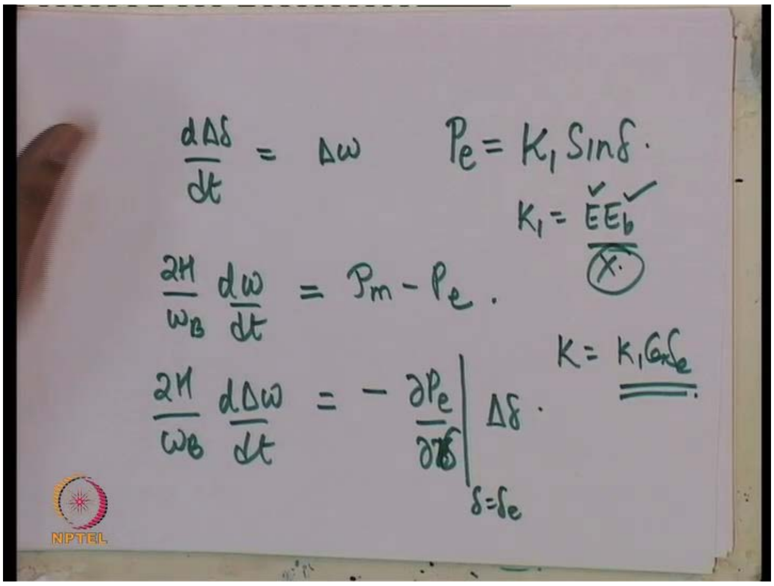

So, if you recall for the single machine infinite bus system this is true and 2 H by omega B d omega by d t is equal to in per unit P m minus P e, which if you linearis with the assumption that mechanical power is a constant then you will get (No audio from 34:28 to 34:37) if.

Now, typically P is only a function of delta, so that is why I have only shown the partial derivative with respect to delta, it typically for the very simplified model of a power system P is proportional to, so I will call this K 1 into sin delta. Now, this K 1 is for a single machine finite bus will be E E b by x where E is the internal voltage of the synchronous machine behind the transient reactance, E b is the infinite bus voltage, x is the cumulative reactance which includes a transient reactance of the generator.

So, this is a very simplified model and if you look at the basic equations, so if you evaluate this, you will get this capital K, so K is in fact, K 1 into cos delta E, so this is what a we get for this. Now, if you look at the equations of a of the classical model of a synchronous machine, linearis classical model of a synchronous machine you will notice that they are like spring mass equations, of a equations of a spring mass system.

And if electrical power is only a function of delta, the important thing is that there is no damping, so the first two equations tell you of a situation where there is no damping, in fact you can introduce damping, if you have an additional term which is proportional to speed it is called viscous friction term. So, if you look at this classical spring mass system there is no damping, but in case there is a component of electrical torque which is proportional to the speed, one could really get some kind of damping.

So, this is what is indicated here, in fact you can show this that if K and d are greater than 0 the eigen values of this system are going to be having a negative real part which indicates, if the oscillations will die out with time. Where as in the first case there is no damping you will have eigen values which are purely, which are a complex purely imaginary complex conjugate pair.

Now, the thing is that what I have tried to show you is that you can actually introduce damping of the swing modes, but trying to have electrical torque components which are proportional to speed, this is a kind of a very (()) and a crude kind of explanation of how one could actually achieve damping.

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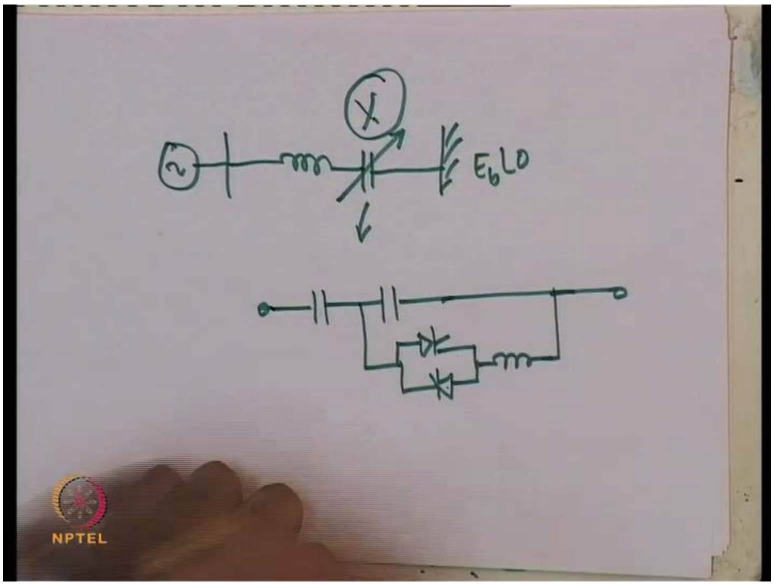

So, if for example, let me give you an example, how you could have a power system stabilizer, suppose you have got a synchronous machine connected to an infinite bus, this is an infinite bus E b angle 0 and this via transmission line which has got a controllable reactance, how do you implement this controller controllable reactance I had shown you a slide some time ago.

This is one way; one can implement a controllable reactance in this system you know if this variable reactance is actually this by controlling the firing angle of these thirstier you can actually get a variable reactance. Now, we do not go very much into the details of the workings of this, but let me just, let us just take it that by you can have a variable x by changing the firing angle of these thirstier, now what does it imply as far as the electrical power is concerned so if you have for example.

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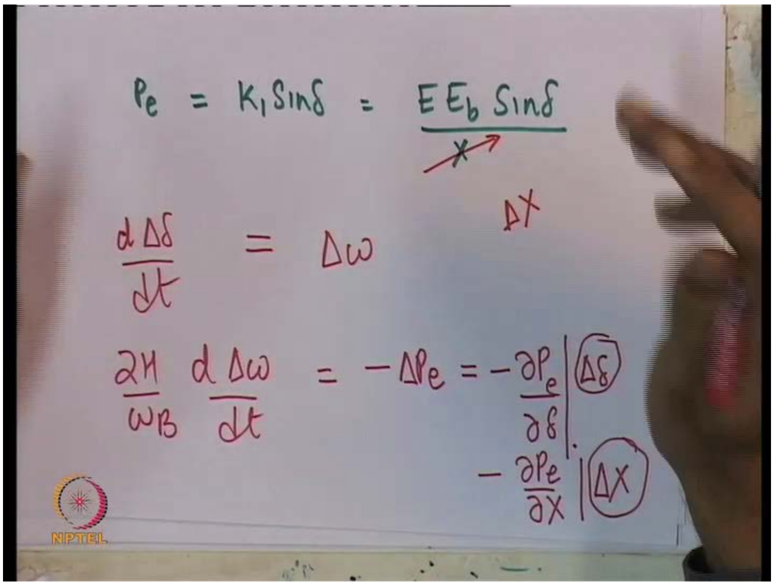

P e is equal to K 1 sin delta which is nothing but E E b sin delta by x for the most simple model, the classical model of a machine, what we have now is of course, that this x is variable. Now, so if I am writing down my linearis equations d delta by d t is equal to delta omega and 2 H by omega B d delta omega by d t is equal to minus delta P e assuming delta P m is equal to 0, which is nothing but minus of d P e by d delta, delta delta as the straight line indicates that we have to evaluate, you have to evaluate this partial derivative at the equilibrium point, minus d P e by d x into delta x.

So, now you, your electrical power is not only a function of delta delta, but also delta x, so delta x is a change in the overall reactance of the transmission line which includes the transient reactance and this variable capacitive reactance.

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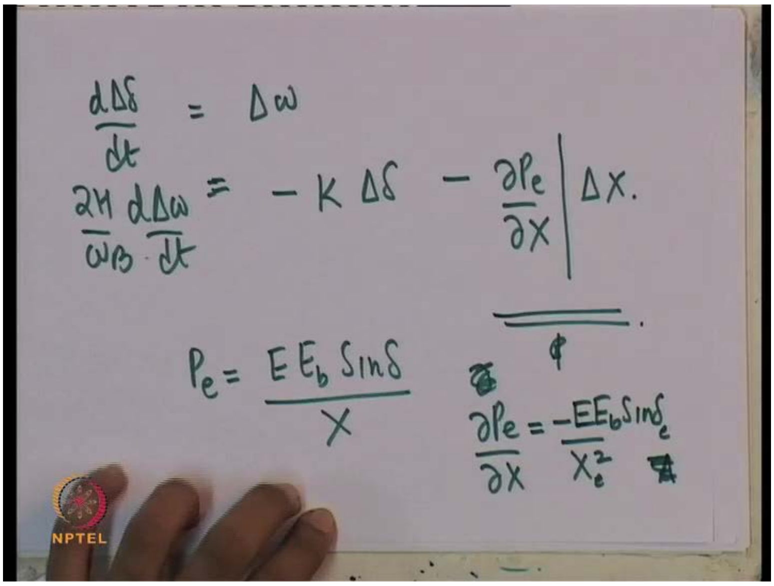

So, the point is that, what we have here is you know we can see that d delta by d t is equal to delta omega and 2 H by omega B d delta omega by d t is equal to you will have minus K delta delta minus d P e by evaluated at the equilibrium point into delta x. Now, the thing is that a nice idea would be, that you modulate your x in such a way, that you create a torque component which is proportional to the speed, that would be nice torque or power component, remember torque and power are almost equivalent in per unit, if is the speeds are not too far away from the rated speed.

If for example, what is minus dou P by dou x, so you have P e is equal to E 1 E E b sin delta by x, so if you take the partial derivatives with respect to x this will be (No audio from 41:37 to 41:49) evaluated at the equilibrium point into yeah, so this how it looks like.

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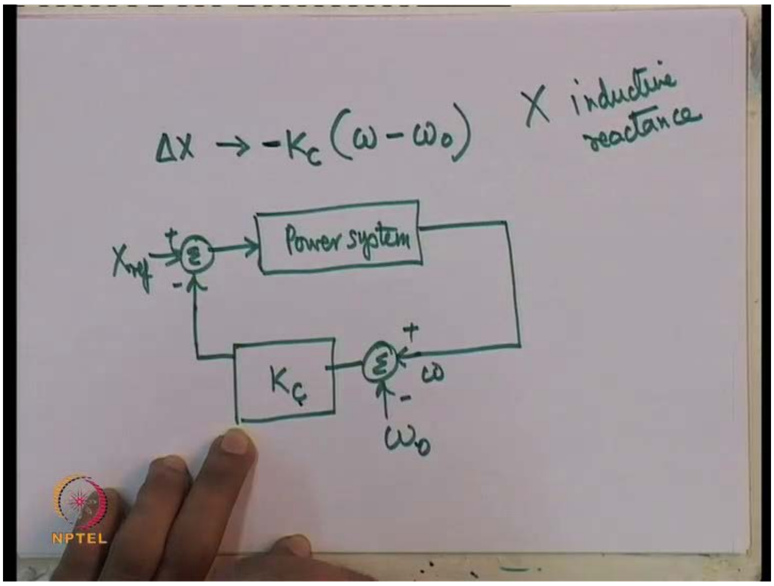

Now, the thing is that, now we have suppose delta x is modulated in proportional to I will call this some gain of the controller omega minus omega naught, so what am doing is this is your system power system, I measure the speed omega, I modulate the reactance of the transmission line by changing this, the overall reactance of the line can be changed by the react, changing the reactance of this.

So, what I have done is taken this reactance and simply have a gain K c, so what I am doing is delta x i sorry, delta x is changed according to this, so the point is of course, that x is the inductive reactance in the formula which you used for power x is the inductive reactance, so the thing is that omega minus omega 0 into K c is used to change the reactance in this fashion.

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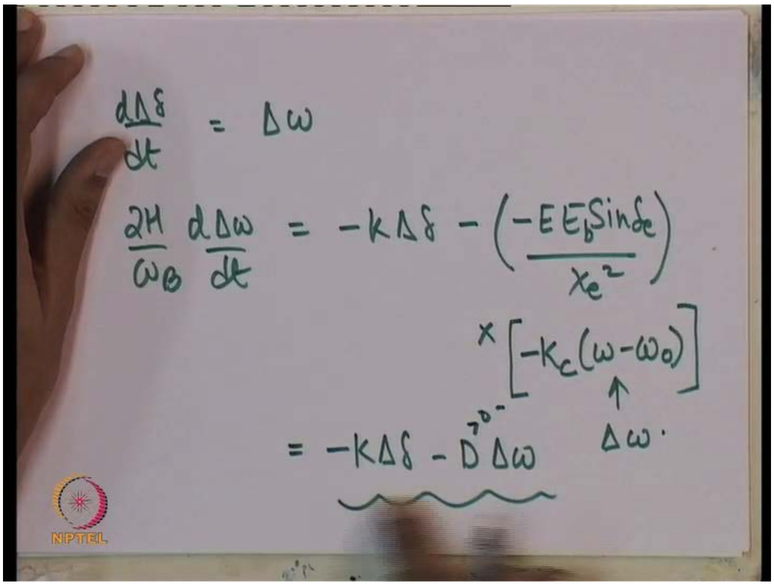

If you do that the resulting equations will be, if you look at these equations, you will have d delta by d t is equal to delta omega 2 H by omega B d delta omega by d t minus you have minus of E E b sin delta e by x e square into delta x, delta x nothing but minus K c into omega minus omega naught.

So, what you have here is omega minus omega naught is nothing but delta omega is that so the thing is that you have got, now a term which is proportional to, so if you look at you can look at this like this, you have got a term which is proportional to delta delta. In a second order system of this kind will have D is positive second order system of this this kind will have eigen values in negative real part, K greater than 0 and D greater than 0.

So, this is the basic idea you can actually introduce damping by having a control system of this kind, now one or two important points here, I have not shown a limiter, so this will if this K c is large it could cause a very large modulation in x, this is normally not permitted, so normally there will be a limiter here, as I mentioned sometime back.

This is a single machine infinite bus system, so omega will be equal to omega not in steady state, because it is connected to a synchronous, because it is connected to a infinite bus with a fixed frequency, so the other condition which is get satisfied is that in steady state the output of this will be 0.

So, in this particular system, if I use the signal omega and subtract it from omega naught for a single machine infinite bus system, if I subtract it from omega naught, in that case I do not have to make any special provisions for ensuring that the output is 0, it will become zero in steady state. If omega naught is the frequency of the infinite bus and it is constant, in that case the output of this particular stabilizer will become 0 in steady state.

So, you can actually design this kind of control systems, this is a very crude design just to give you some insight into how you can get damping by having a control system which modulates some controllable element in a power system, this is how you do it, in a general situation whether is no infinite bus, if you take omega you there is no infinite bus. So, we do not know this omega could not necessarily become a you know let me repeat this, in this particular system we do not have to make any special provisions for ensuring that the output of the stabilizer is 0, this may not be true if you use other signals, and in other situations where there is no infinite bus.

So, just remember that important point, so the the thing is that can we demonstrate this, can we try to show that you can actually get damping by modulating the reactance of a transmission line, the answer is I will just demonstrate this to you by just modulating the reactance in our simulation. Remember that a more economical way of getting damping would be probably modulating the voltage reference of an existing automatic voltage regulator of an excitation system of a generator, but it turns out that at least to illustrate this concept of introducing damping by control systems, it is easier to show it on a system with a variable reactance, because the the relationship between power and reactance is relatively simple.

Whereas, if you look at the relationship between the voltage reference of an AVR and the power output of a synchronous machine it is much more complicated, because there are many many sub systems, the field winding dynamical equations, the excitation system dynamical equations. Which kind of make the relationship between V ref and the electrical torque a bit complicated, out here electrical power and reactance were related in a, relatively is very simple algebraic relationship is it ok.

So, what I will do is to illustrate damping I will take the simple case of reactance modulation in a transmission line, so what all that I have to do, to demonstrate this to you is take our simulation program, this is our simulation program I will just go through it slowly.

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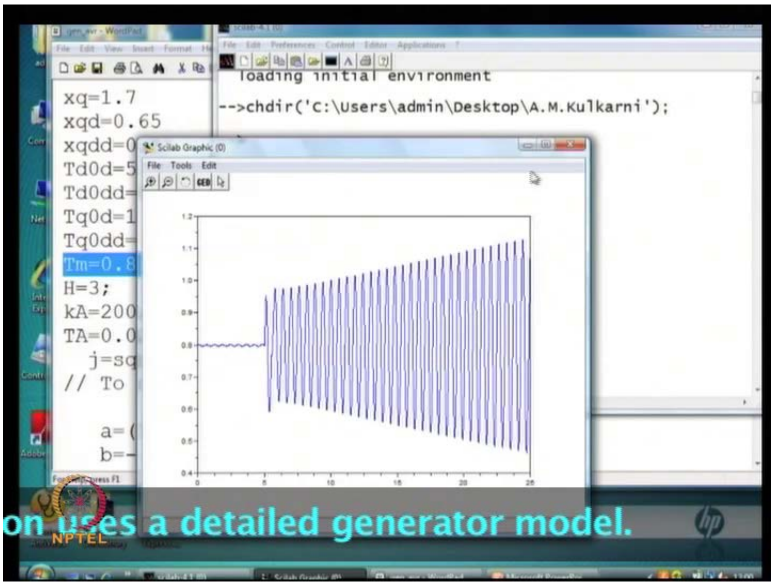

We had seen that for T m is equal to 0.8, if you give a small disturbance in V ref at time T is equal to 5 seconds a small pulse change, the system was not stable; so in fact, if you recall I had plotted the time verses power plot for this for this equilibrium condition, if I give a disturbance this system does not settle and this oscillations grows on growing with time.

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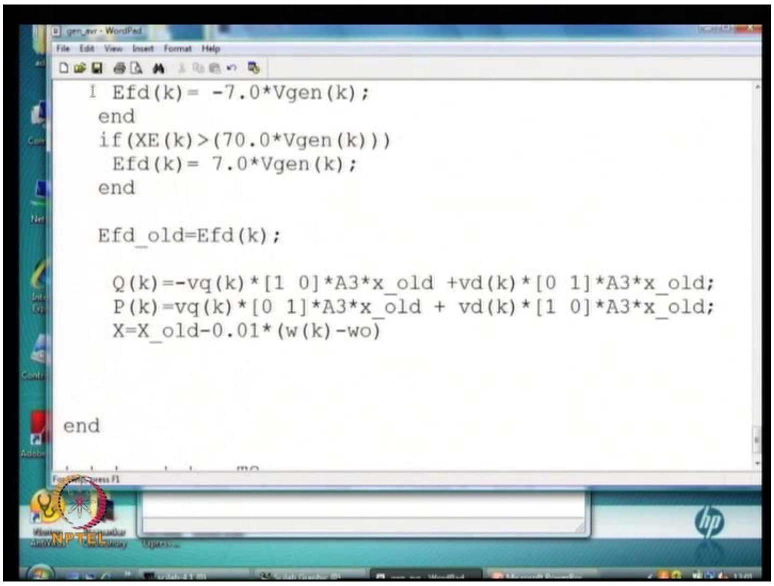

Now, what I do is I keep the same disturbance and checkout the stability when, so this is the point at which I introduce a disturbance at T greater than 5 there is a pulse change in V ref, between T is equal to 5 and 0.5, there is a small pulse given in V ref which induces the disturbances. What I do here is, I will uncomment this I will not keep x of the line fixed, what I will do is, I will change x for example, I change x using this rule this K c I give a value of 0.01.

So, I am sensing the speed of the machine and modulating x of the transmission line by a controllable device of course, the controllable device model I have assumed to be very simple, one thing which you should note is, in actual practice you would have implemented a variable reactance by using what is known as a thirstier controlled series compensator.

Now, this is also dynamically acting device, so it is not certainly true that if I give a change in firing angle immediately it gets implemented, and you get a variable change in x, there is a dynamical model of this. But remember that a power electronic device like this has got a very fast response time for the slow transients, which we are studying here, you can assume that this is an instantaneously acting device, that is if I tell it to change the effective reactance it is instantaneously implemented.

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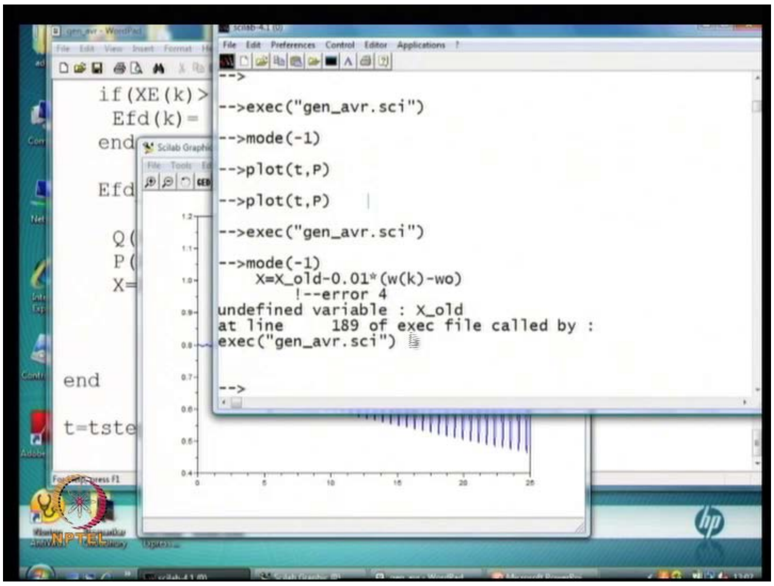

So, this is the assumption which I make here, which is quite reasonable, because the transients we are studying are quite slow, now if you look at this program and I run it just takes a little bit of while to run. So, I have changed changed the program by introducing this change, introducing this damping I run it again, we will have to just (()), so the variable just a movement (Refer Slide Time: 51:42).

I have uncommented some part which I had commented, we run this again, so since we are simulating for 25 seconds with oiler method this takes quite a bit of time, I would encourage you not to use oiler method, but use RK four forth-order method an explicit method, but with better which will have a better accuracy, so we just wait for a while for this to simulate.

One thing I would like to clarify here, would like to caution you here is what I am trying to show you is here, just to just to give you an insight into how you can make a, you can get damping by modulating you know a controllable element in the system. This is not a rigorous design; this is something which you should keep in mind, so this is just for to illustrate this concept.

Now, what I have done is, because of this look at the red curve (Refer Slide Time: 52:58), you see that it damps out the equilibrium point also does not change, because remember that the output of the power system stabilizer in in steady state is 0. So, this particular stabilizer will introduce damping into the system and prevent this kind of instability, small disturbance instability is that ok.

Remember of course, that we have actually tried to improve the small signal stability of the power system, not the large disturbance stability, what we have ensured is that for small disturbances around an equilibrium point we are going to be stable. So, this is an example of how you could improve damping using a controllable element, let me remind you that there are other controllable elements as well, which may be cheaper to use because they already exist in a typical power system.

For example, a modulating the V ref of an automatic voltage regulator, modulating the power in an HVDC link, these are also examples of how you can modulate in order to get damping. Of course, you may ask can we also try to modify the governor characteristics, the governor characteristic, and the governor acts on the steam or hydro turbine in a power system.

But, the responses are relatively slower of these mechanical systems, so it would not be appropriate to try to modulate them, in fact since, the responses are very slow changing for example or modulating you know a reference in a governor will not give you the same kind of responses, much more it will practically be impossible to try to design power swing stabilizer using a governing system, because the basic idea is that the turbine is relatively a slow subsystem.

Similarly, by changing taps in a, tap changing transformer you cannot improve a power system damping, swing damping, because the movement of taps is very very slow, so you cannot get that kind of modulation, In effect we are using power electronic devices in the system to improve damping, like modulating the power in a HVDC link, the HVDC link has a power electronic device it is very fast acting.

So, actuators in in which use power electronics are much much faster, so we can design these things effectively for phenomena like swings, so trying to modulate turbine output or tap changing transformers seems to be impossible, it does not seem to be right to thing to do; to get damping of power swings which are relatively faster than the kind of responses you can expect out of these actuators.

Now, you in real life also you can actually you know, these are the things the kind of power system stabilizers which you have studied you know the for example, reactance modulation damping or V ref modulation in an automatic voltage regulator of an excitation system are actually carried out in practice. And the only important point which I should bring to your notice is that what we showed here was a very simplistic kind of situation, single machine infinite bus, there is only a one swing mode.

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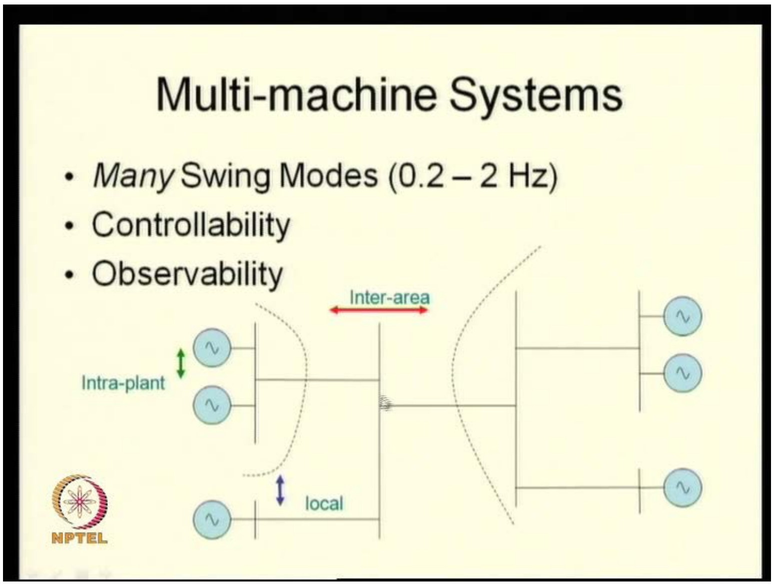

In a real life situation you may actually have many many modes, let us look at a typical multi-machine system you can have many many swing modes and one or more of these could be poorly damped or unstable. So, what you would need to do in a when designing a stabilizer of this kind would be to worry about two things, these are the two important things, which are which are important sorry, with the these are the two important things.

The point here is that they are may swing modes, so your design should ensure that you damp out all the swing modes, the second thing is your controllable elements suppose it is you know for example, if you have got a controller element here you know in this line here, suppose you have got a variable reactance device in this line. When you are trying to use this variable reactance device, the question may come arise, can I use this variable reactance device to damp out or improve damping of the intra plant modes.

Very unlikely the point is you have to worry about the classical concepts in control systems; the intra plant mode is very unlikely to be controllable by reactance modulation present on this line here. So, there is an issue of controllability all swing modes may not be controllable by using a single controllable device which is present at a certain geographical location that is an important point which you should remember.

The second point is observability, by taking you know local measurements for example, another problem you may face here, when when trying to damp out swings say in a remote location within the transmission system is that the signals you are going to use should have observability of the swing modes which you intend to damp. So, both controllability of a particular swing mode by a element at a particular location should be there also the feedback signals which are using to induce damping in the system, in those signals the critical or unstable or poorly damp swing model should be observable, is that ok?

So, this is basically, these are the two important things which you have to consider, when you are actually going to design, stabilizer, power system stabilizer to improve swing mode damping. It is quite well understood that in a very large system, it is unlikely that a single controllable element can control all the swing modes that is very very very unlikely, so the pragmatic approach would be to go on trying to design or having a large number of decentralized modulation controllers or power system stabilizers.

So, each synchronous generator for example, at least the (()) larger synchronous generator in the power system, you could choose and ensure that you modulate, your voltage regulator reference, so that you get damping. So, you do that in many many many many synchronous machines excitation systems of synchronous machine, so you actually, if you want to have good stability of most or all synchronous swing modes you would need to tune or need to you know deploy power system stabilizers at several places in the power system.

So, that these are the important points you should keep in mind when you are talking of a power system stabilizer or swing damping in a large power system, one thing which you know we should keep in mind is, what I have discussed today in this lecture was pertaining only to small disturbance stability.

So, what we really discussed here was that you give a small disturbance; if the damping is inadequate you try to induce it by making auxiliary controllers, which introduce some more damping into the power system, so this is what we discussed. The more difficult and the more worrisome problem I would say more worrisome, but a worrisome problem which occurs, which is also related to relative motion in a power system is that of large disturbance stability.

Large disturbance stability is something which occurs following a large disturbance, so if you look at the bottom left figure it shows a particular situation which may occur in a power system where in lot of machines are connected to each other, lot of synchronous machines are connected together by AC lines. And there is a large disturbance which causes the machines to lose synchronism, that is the machines speeds do not come to the same value, they in fact diverge away, while the machines are still connected, this is a instability problem which is a large disturbance problem.

So, I am reiterating this because it is often we have had a large amount of phenomena or large amount of a discussion which have been which we have done in this course and it may you may lose sight of the basic problem. So, in the next lecture, what we will do is discuss these large disturbance phenomena, and the ways we can improve the stability of large disturbances; what we did today was see, how by augmenting control systems you can improve damping of power swings. So, this is the phenomena in the next lecture is large disturbance phenomena, what are the ways we can improve stability; with that we will be concluding the course.