Power System Dynamics, Control and Monitoring
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Lecture - 27
Power System stability, Eigen properties of the state matrix, Transient stability

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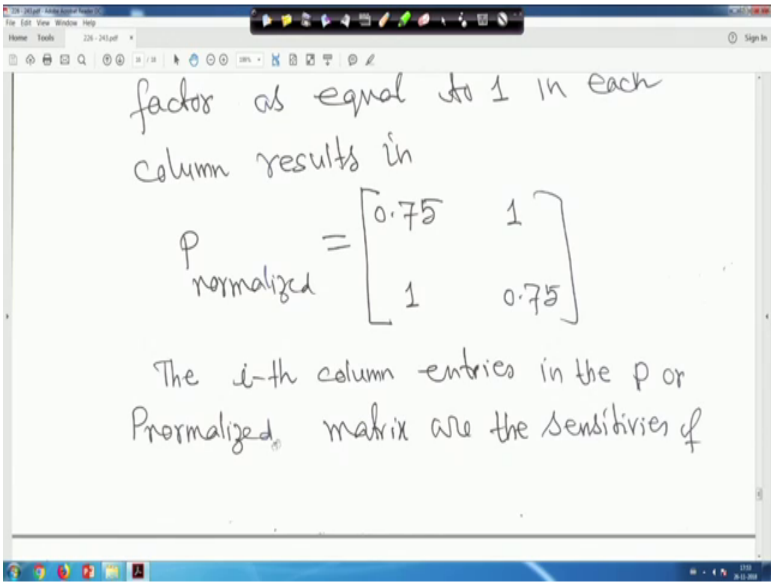

Ok. So, in the previous lecture, we have seen that your normalized one that is just a 2 into 2 matrix right, and this is your what you call that normalize your participation factor right. So, the i-th column entries in the P or P normalized matrix are the sensitivities of the i-th eigen value with respect to the states.

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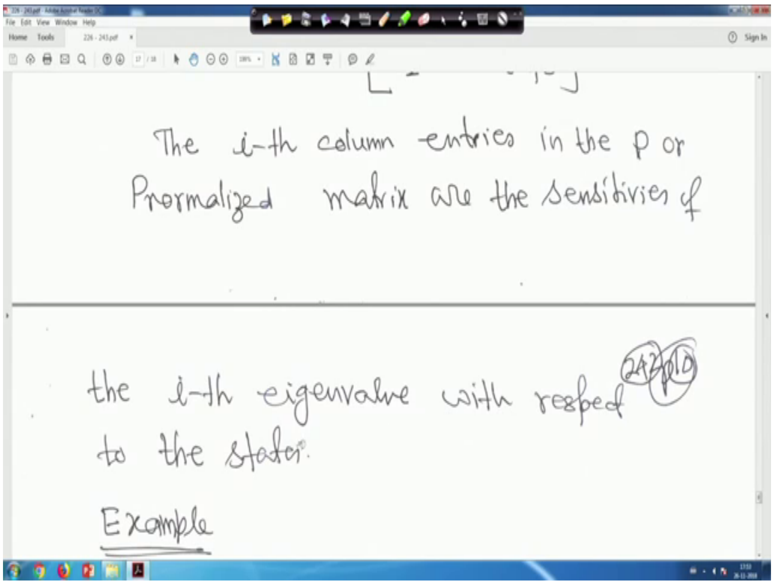

This is the previously we have seen some example, but I again took couple of example just to demonstrate certain things right.

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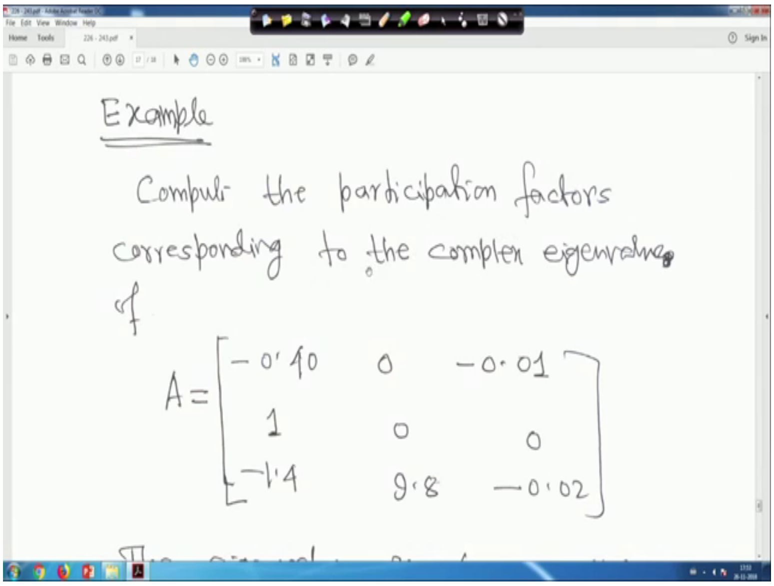

Now, next another example is taken, so compute the participation factors corresponding to the complex eigen values of right. A is equal to this is my a matrix it is a 3 into 3 matrix.

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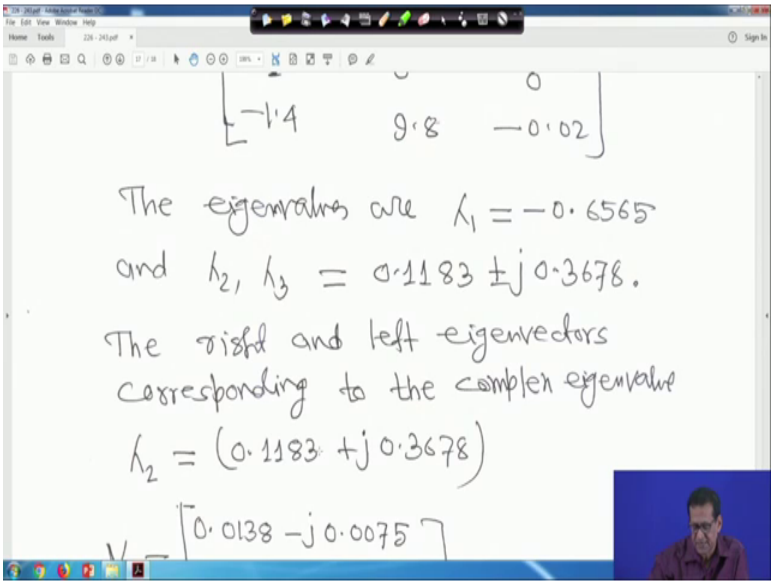

So, minus 0.40, this is 0, this is minus 0.01. This is 1 0 0, and this is minus 1.4, 9.8 and minus 0.02 right. When you find the eigen values of these matrix, so one eigen value will be real that is minus 0.6565. And another two are complex conjugate pairs that is lambda 2, and lambda 3 are 0.1183 plus minus j 0.3678. So, these three are the eigen values right. Here the right and left eigenvectors corresponding to the complex eigen values, you find out right.

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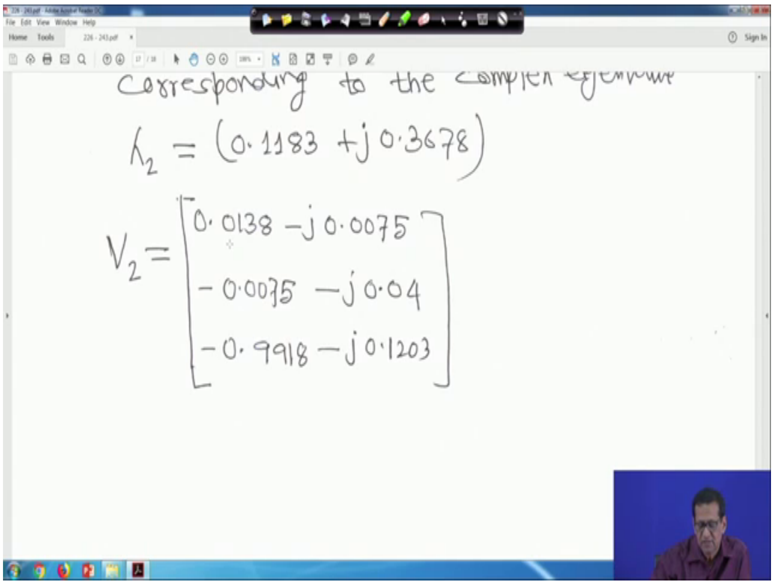

So, only corresponding to these you find out the right and left eigenvectors right. Earlier how to find out right and left eigenvector that everything had been shown. Similar, way you proceed right. Here I am just giving the answer. Similar way you proceed, you will get this is my right eigenvector.

So, it is your this two stands for this is eigen value lambda 2 that is 0.183 plus j 0.3678 that is why, it is written V 2 right eigenvector, this is for lambda 2. It is point 0.138 minus j 0.0075. This is minus 0.0075 minus j 0.04. And this is minus 0.9918 minus j 0.12 zee 3 right 03 right. So, this is right eigenvector.

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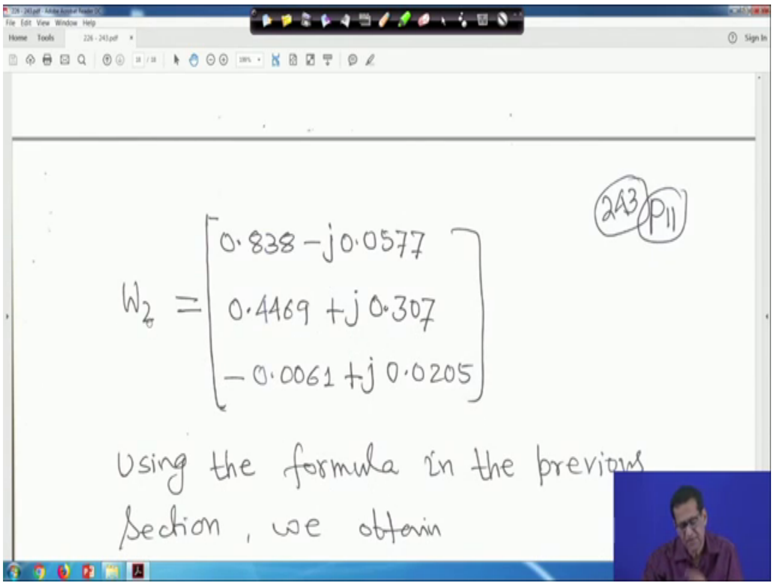

Similarly, left eigenvector corresponding to same eigen value lambda 2, it is 0.835 minus j 0.0577. This is 0.4469 plus j 0.307, and this is minus 0.0061 plus j 0.0205, this you know how to how to find out right. So, just you find out at your basically your what you call you can find out that B matrix, phi matrix, and psi matrix here also B matrix and W matrix. Now, how you have obtained previously same way you follow right.

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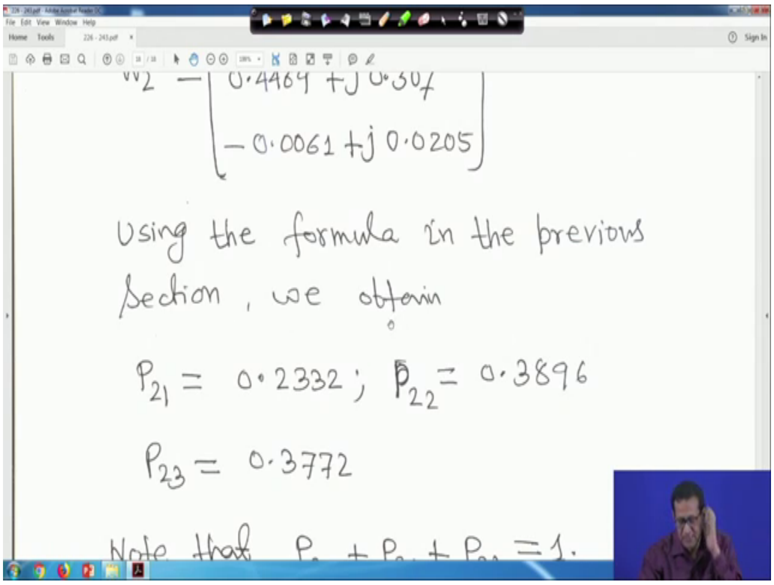

So, using the formula in the previous section, you can obtain that P using the previous formula means this one right, I will go back to this right this one.

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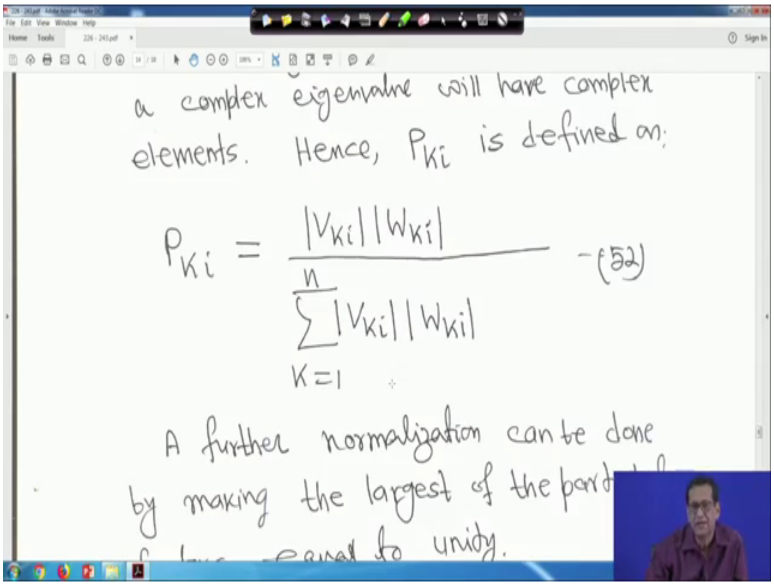

This formula that is equation-52 right. So, follow the same thing equation-52 right, and then you come back to this. So, if you follow this that equation-52, you will get the P 21 0.2332, P 22.3869, and P 2.3772 right.

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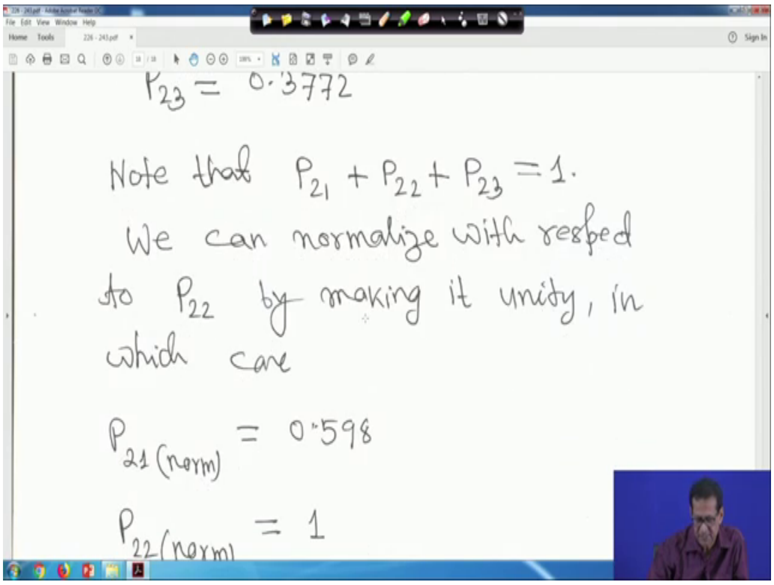

So, note that P 21 because it is normalized, so P 21 plus P 22 plus P 23 is equal to 1. So, we can normalize with respect to P 22 right making it unity in which it can be I mean highest is your what to call that your P 22 P 22 is 0.3896. So, divide everything by 0.3896.

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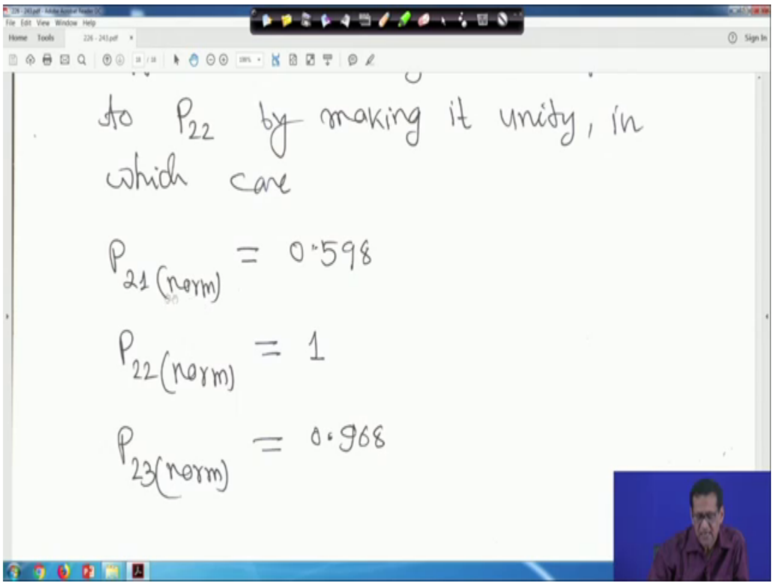

So, in that case P 22 normalise will be 1. And if you divide by P 22 values along P 21 and P 23, it will be P 21 normalize will be 0.598, and P 23 normalize will be 0.968 right, this way one can find out. But, in this case one thing you have noticed that you are it is there is no what to call as it is, what to call that is magnitude is considered right. And it is normalised and you will see that no angle is appearing here right only magnitude.

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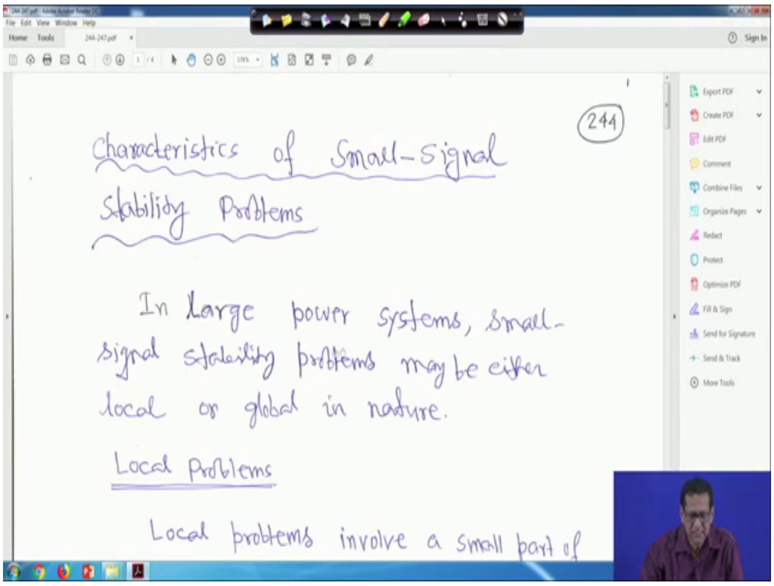

So, after this after this, we will go to some general thing. Now, whatever we have seen so far that regardings your dynamics, basically it dynamics control of what you call small signal stability analysis for synchronize machine. So, only we have restricted to that which is possible for your classroom class room exercise right, so that is why stimulus and other things.

Generally, I have tried my best to avoid those things right. So, now characteristic of small-signal stability problems Now, in large power systems, small-signal stability problems may be either local or global in nature some general ideas right.

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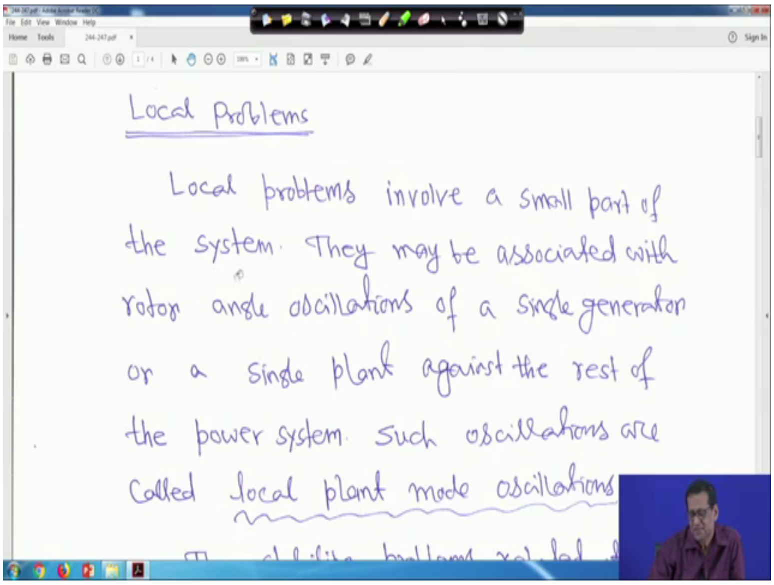

Now, local problems. Now, local problem involves small part of the system right. They may be associated with rotor angle oscillations of a single generator or a single plant against the rest of the power system right, such oscillations are called local plant mode oscillations.

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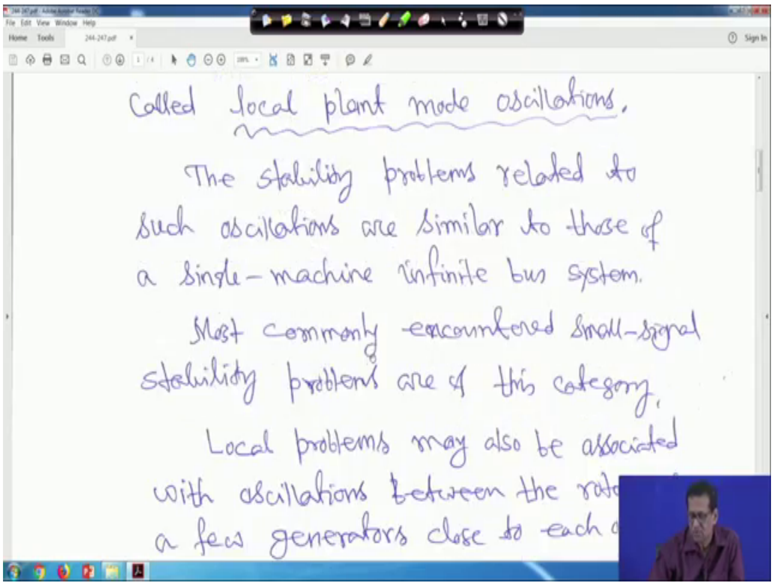

So, certain terminology you should keep it in your mind, so that your this is called local plant mode oscillations right. Now, next is the stability problems related to such oscillations are similar to those of a single machine infinite bus system. Most commonly encountered your small-signal stability problems are of this category right.

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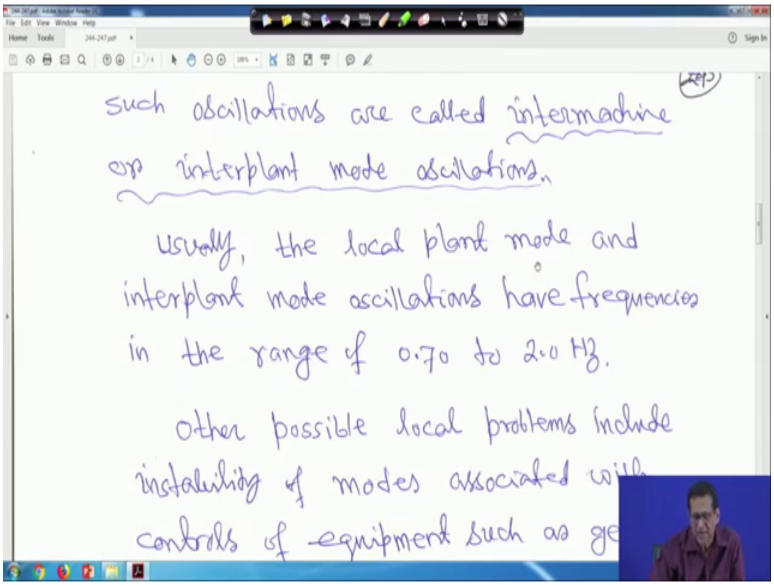

Local problems may also be associated with oscillations between the rotors of few generators close to each other; such oscillations are called inter-machine or inter plant mode oscillations. This terminology you should keep it in your mind, because this is underlined also right. Usually, the local plant mode and inter plant mode oscillations have frequencies in the range of 0.7 to 2.0 hertz right.

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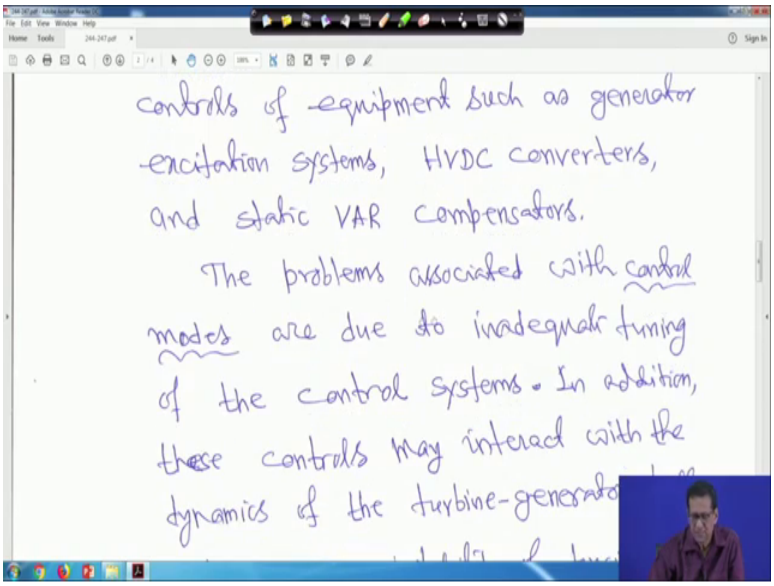

Other possible local problems include instability of modes associated with controls of equipment such as generator excitation systems, HVDC converters, and static VAR compensators right that is the SBC. The problem associated with control modes are due to inadequate tuning of the control system that the parameters are optimized or proper tuning is necessary that control parameters.

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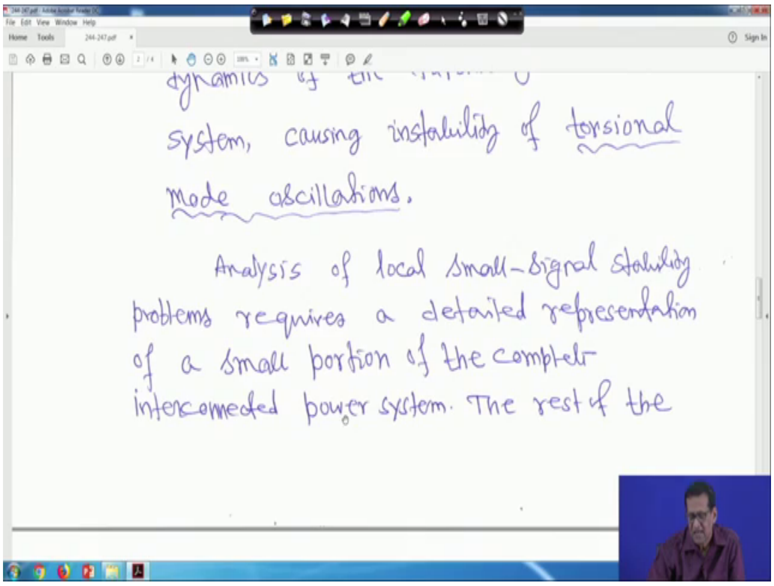

In addition, right these controls may interact with the dynamics of the turbine-generator shaff system, causing instability of torsional mode oscillations. This one this torsional mode oscillations I thought I will cover little bit, but later I decided I should skip it. By chance if I get some time at the end, I will see that right, it will take few equations and how it is done. So, this is actual instability of torsional mode oscillations right. Analysis of local small-signal stability power systems require a detailed representation of a small portion of the complete interconnected power system right.

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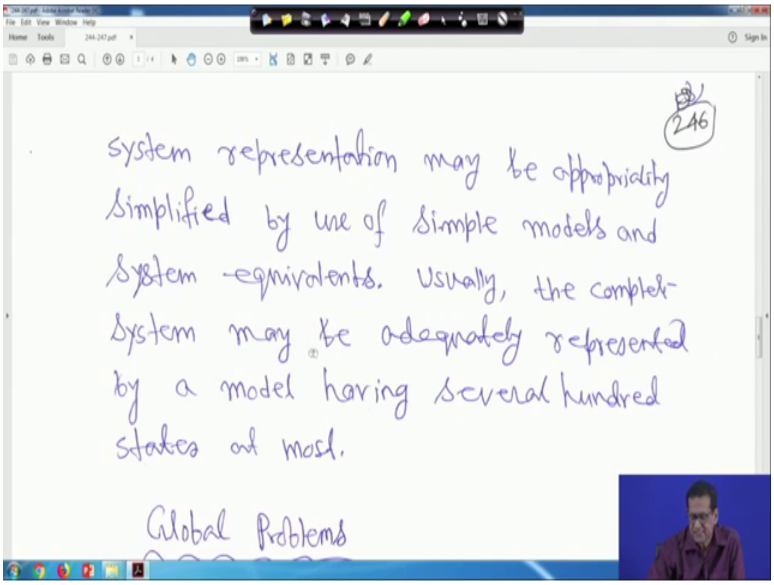

The rest of the system representation may be appropriately simplified by use of simple modes and system equivalents, simple models and your system equivalents right. Usually, the complete system may be adequately represented by a model having several hundred states and states that is (Refer Time: 08:01) If you consider that interconnected system so many machines are there, so you will have several hundreds of states variable right.

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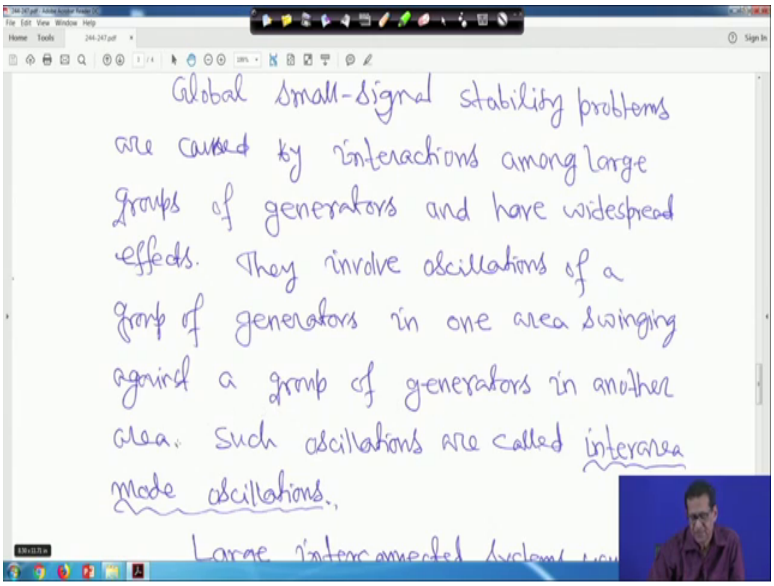

Another thing is that global problems. Global small-signal stability problems are caused by interaction among large groups of generators, and have wide spread effects right. They involve oscillations of a group of generators in one area swinging against a group of generators in another area right. This is actually this kind of stability problem that is I mean multi machine system right. So, it is beyond the scope of this core (Refer Time: 08:37) as per as classroom exercise is concerned right.

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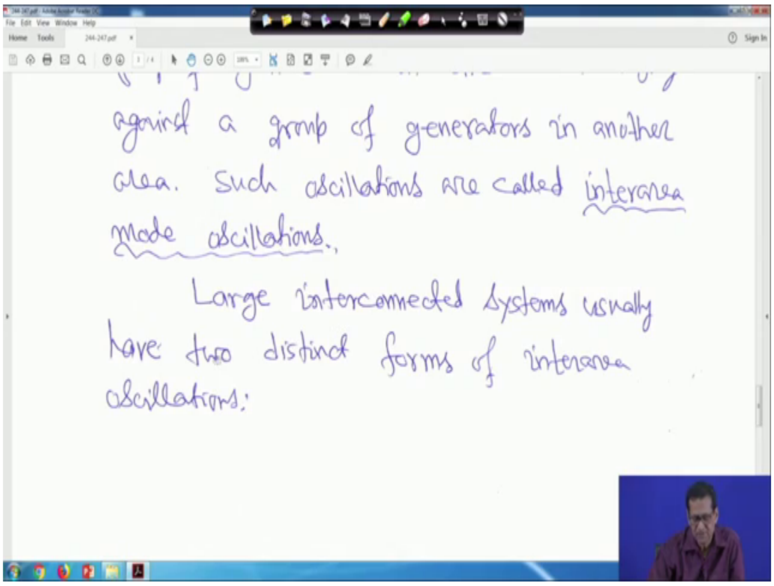

Such oscillations are called inter area mode oscillations. Large interconnected systems usually have two distinct forms of Inter area oscillations.

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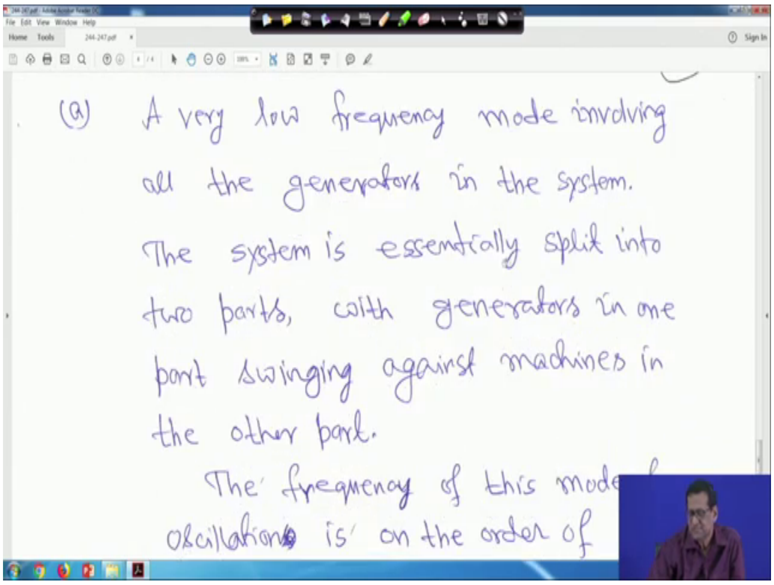

First one is a very very low frequency mode involving all the generators in the system right. So, system is essentially split into two parts with generators in one part swinging against machines in the other part right.

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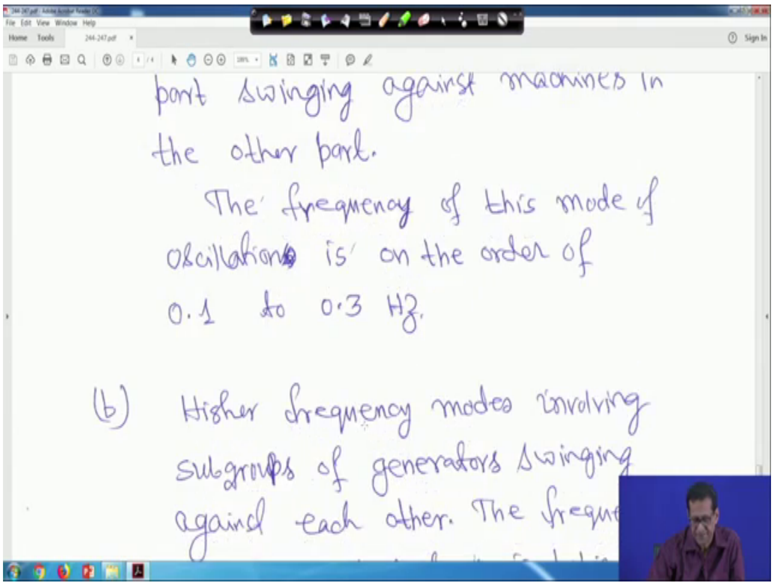

Then we group of generators right swinging together swinging against that your what to call group of machines in another area something like this right. The frequency of this mode of oscillation is on the order of 0.1 to 0.3 hertz right.

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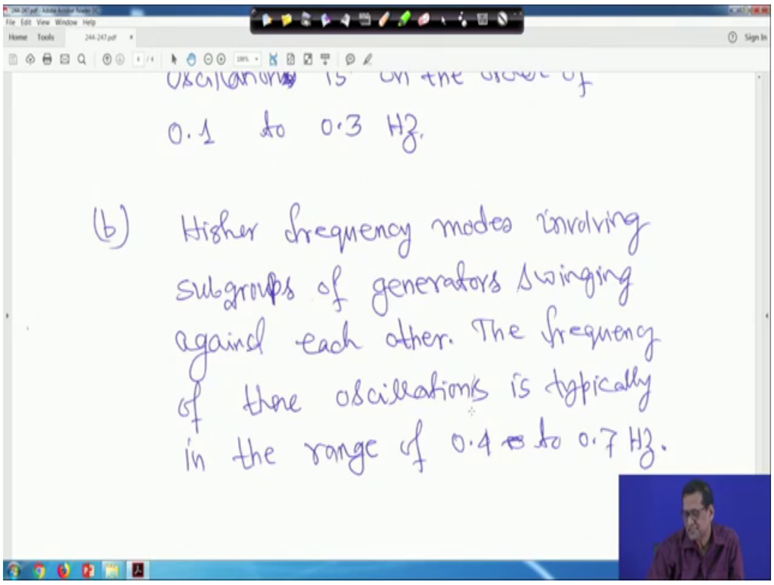

Number second one is at higher frequency modes involving subgroups of generators swinging against each other. The frequency of the your frequency of this oscillations is typically in the range of 0.4 to 0.7 hertz right. So, with this that your synchronized machine part we call this it is almost over. Only thing is that if time permits, I will see of distributary exiting system of synchronized machine that is if time permits right. Now, next what we will do after this, we will move to the transient stability analysis particularly for multi machine system right.

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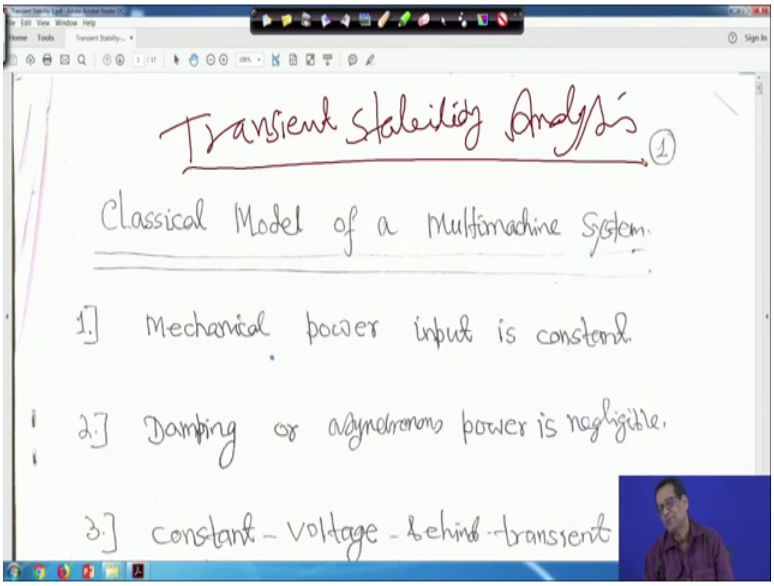

Next one will be that your transient stability analysis for multi machine system. So, here I forgot to write that headline, it is transient stability analysis transient stability analysis right. So, basically your in power system analysis codes that single machine infinite was we have seen it.

So, here we will see that multi machine system, but let me tell you one thing that the what you call that your stimulus and other thing right. And those techniques we will skip, because in the classroom we cannot do that right. So, only I will think from the point of your classroom exercise. So, in the case of this transient stability analysis this first we have to see the classical model of a multi machine system.

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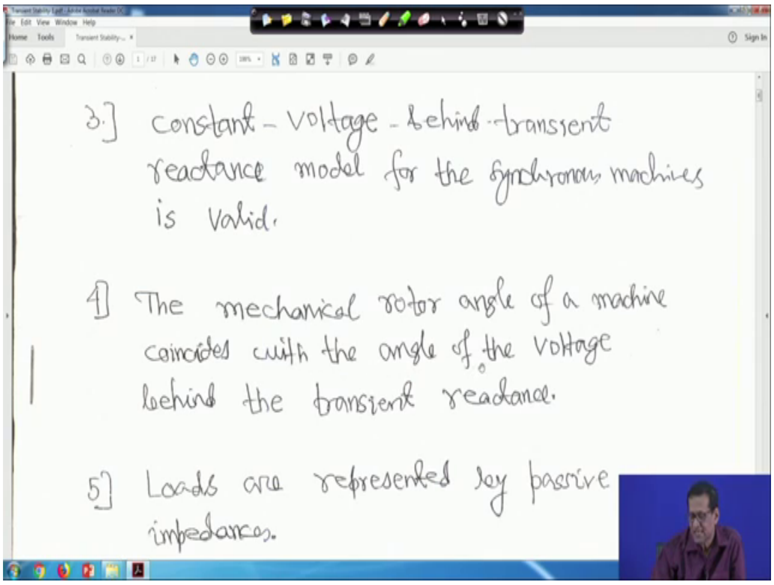

So, number-1 mechanical power input we assume that it is a constant; we have to make some assumption. Number-2 damping or asynchronous power is negligible right, it is based on certain assumptions we will move. Number-3 constant voltage behind transient reactance model for the synchronous machines is valid right. Number-4 the mechanical rotor angle of a machine coincides with the angle of the voltage behind the transient reactance. Number-5 loads are represented by passive impedances or admittances right. Here admittances not written either passive impedances or admittances.

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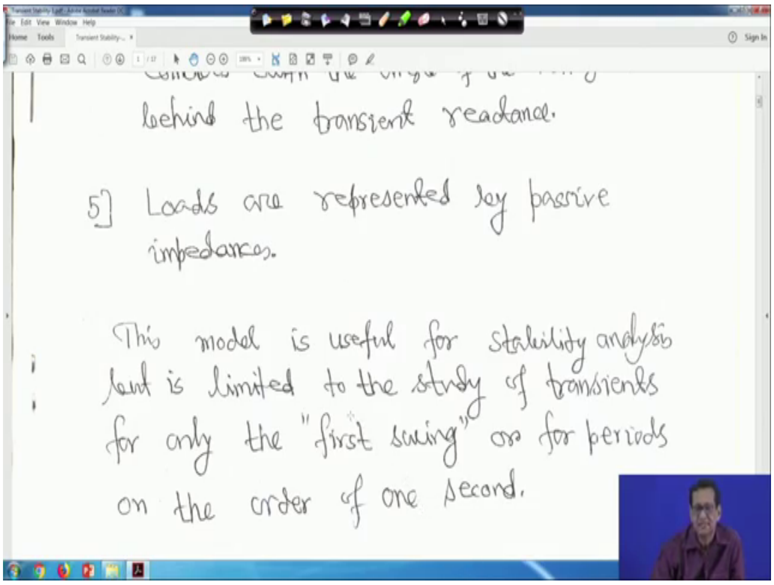

This model is useful for stability analysis, but is limited to the study of transients for only the first swing or for periods on the order of one second right maximum.

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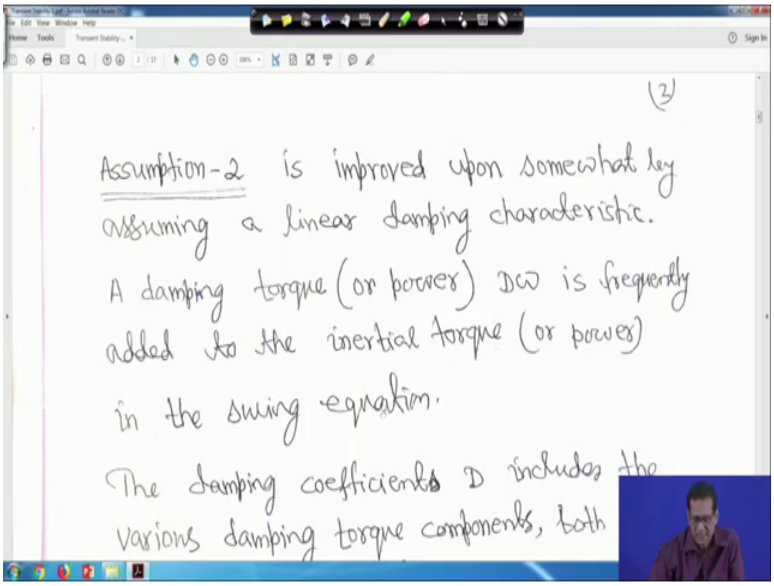

Now assumption-2 is this one that damping or asynchronous power is negligible right. So, assumption-2 is improved upon somewhat by assuming a linear damping characteristic. A damping torque or power the D omega that we have seen previously right is frequently added to the inertial torque or power in the swing equation.

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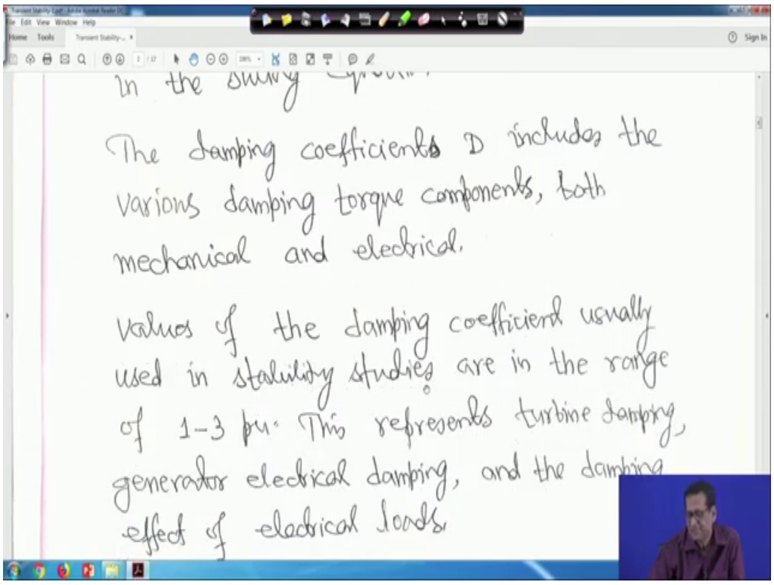

The damping coefficients D includes the various damping torque components, both mechanical and electrical right. Values of the damping coefficient usually used in stability studies are in the range of 1 to 3 per unit right. This represents turbine damping, generator electrical damping, and the damping effect of electrical loads right. So, this is the range of the value of the your damping coefficient in between 1 to 3 per unit right.

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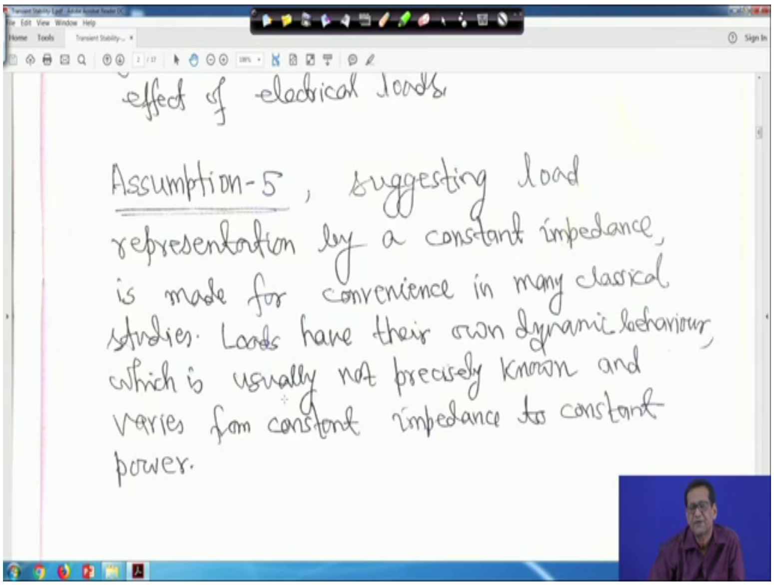

Now, assumption-5 assumption-5 is this one that loads are represented by passive impedances right or admittances. So, assumption-5 suggesting load representation by a constant impedance is made for convenience in many classical studies right. Loads have their own dynamic behaviour, which is usually not precisely known and varies from constant impedance to constant power right. So, we will take here constant impedance right.

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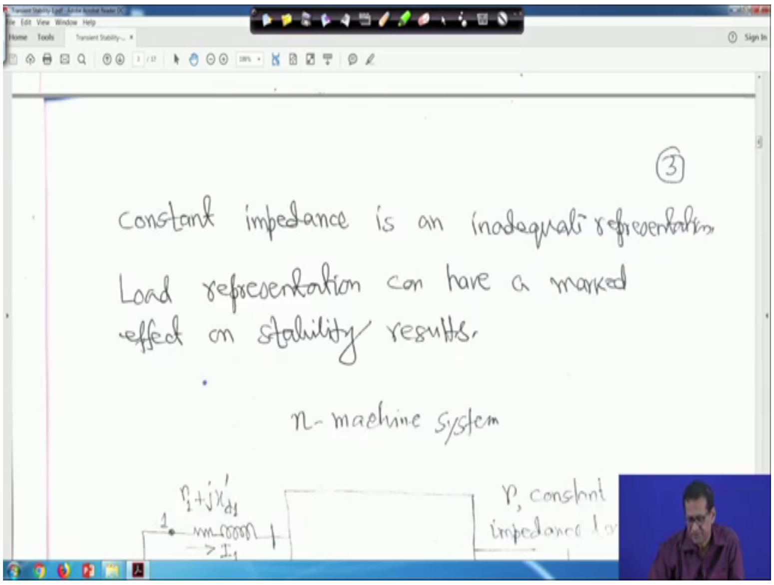

So, now constant impedance is an inadequate representation. Load representation can have a marked effect on stability results right.

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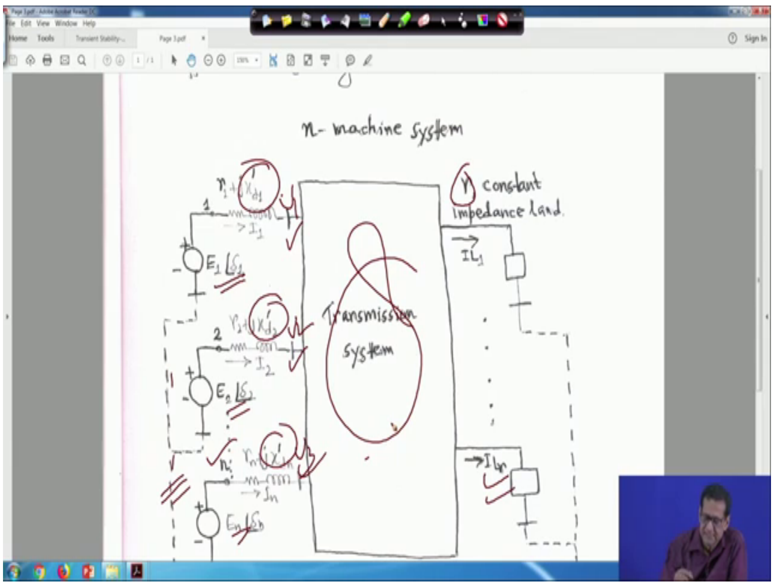

So, this figure it will be faint right, so I will be bring a good figure just hold on right. So, same page I mean just I have redrawn this. So, constant impedance is an inadequate representation load representation can have a marked your what to call an stability results.

Now, suppose the you are a machine system right. And this one this one this is my this is my transmission network right. So, generators are there suppose you have n number of generators right. So, voltage behind this transient reactance it is given by E 1 angled delta 1, then E 2 angled delta 2 upto n right upto n n angled delta n. Then the impedance set is given r 1 plus j x d 1 dash, r 2 plus j x d 2 dash upto r n plus j x dn dash, but usually that r 1 r 2 upto r n right this is negligible.

So, in our studies we will only consider this x d dash in general right x d 1 dash, x d 2 dash, x d n dash. And this E 1, E 2 your what you call this (Refer Time: 14:44) up to E n. So, these are generator voltage behind your transient reactance that is E 1 angle delta 1 E 2 angle delta 2 like this. And these are the bus bars.

Say for example, say this is bus voltage V 1 V 2 like this or may be any bus numbers, these are the buses these are the buses right. So, this and this dash line this is basically a reference node or common node that will that I will move later. So, and this side that you have a load you have constant impedance loads, we have r number of buses right. So, it is say current here is I L 1, here next one will be I L 2, ultimate it will come to I L r right. And this is my transmission network, and this is my generators n number of generators, and there you have r number of your load buses right.

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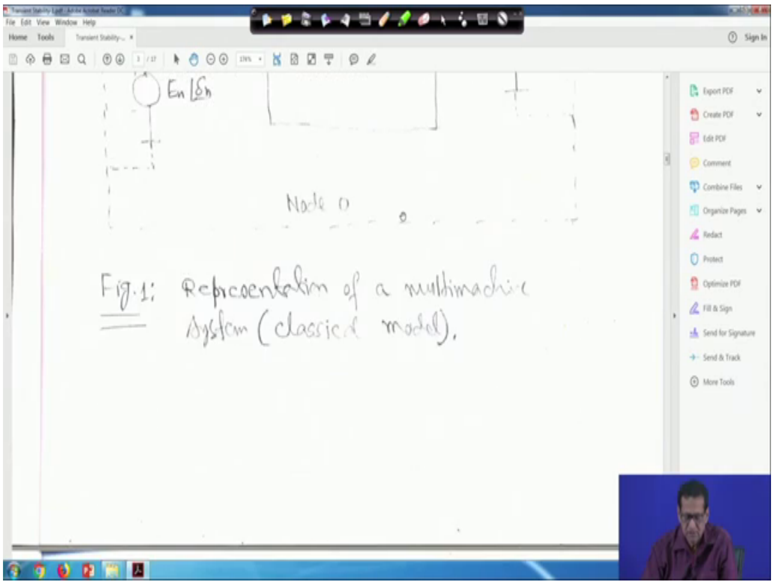

And this is node 0; actually you call as reference node right. And this actually figure-1 representation of a multi machine system classical model. So, this way we can represent your what you call that in machine system right. So, this is shown actually this figure was faint that is why I showed the other one.

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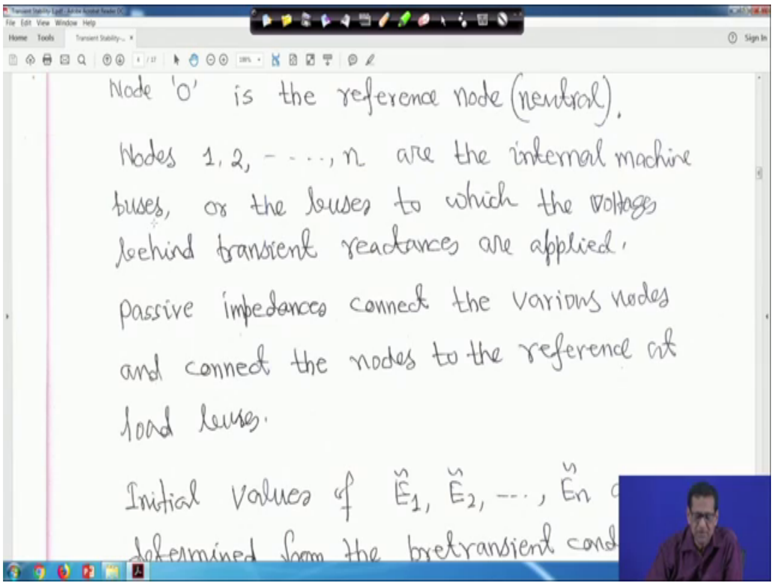

Now, node 0 actually is the reference node that is neutral right. So, nodes 1, 2, n I told you are the internal machine buses right or the buses to which the voltage behind transient reactances are applied right. So, passive impedances connect the various nodes and connect the nodes to the reference at load buses right.

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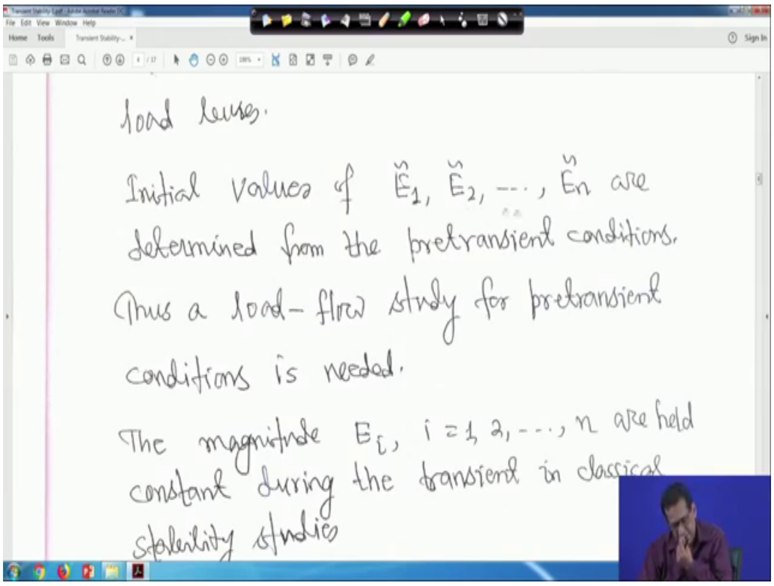

So, initial values of E 1 tilde E 2 tilde up to E n tilde are determined from the pre transient conditions right. Thus a load-flow study for pretransient condition is needed right. So, this figure is actually better figure I shown, so I have shown you, this voltage E 1 delta 1, E 2 delta 2 right. So, once load-flow is known, then E 1, E 2, E n and delta 1, delta 2, up to delta n all can be computed that we will see later right.

And the current flowing here I 1, I 2 up to I n right and these are the internal your what you call this is marked actually this is internal 1, this is 1, this is 2 internal machine buses up to this n right. So, let me clear it. So, initial value of E 1 tilde, E 2 tilde up to E n tilde these are quantities that is why tilde are used are determined from the pre transient, what you call conditions thus a load-flow study for pre transient condition is needed.

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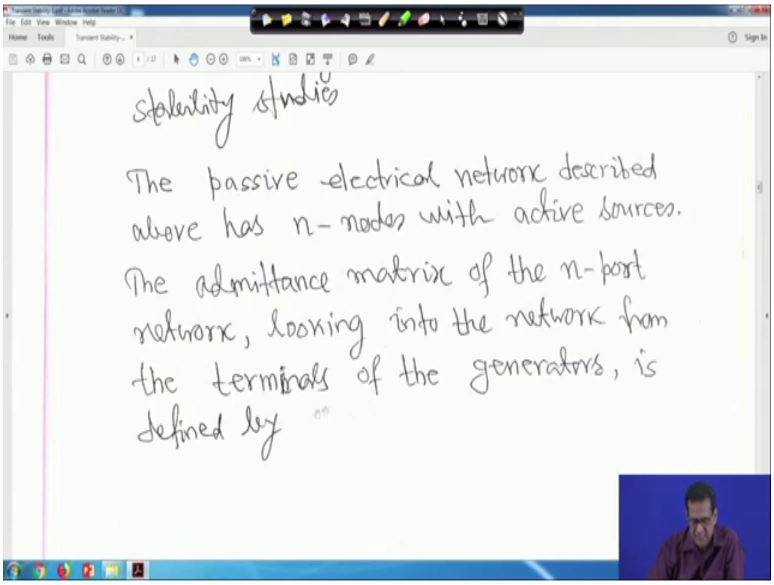

Now, the magnitude of E i for i is equal to 1 to n are held constant during the transient in classical stability studies. Once that E 1, E 2 upto E n's are computed, then it will remain constant right during transient this is an assumption. The passive electrical network described above has n-nodes with active sources right. The admittance matrix of the n port network, looking into the network from the terminals of the generator is defined by.

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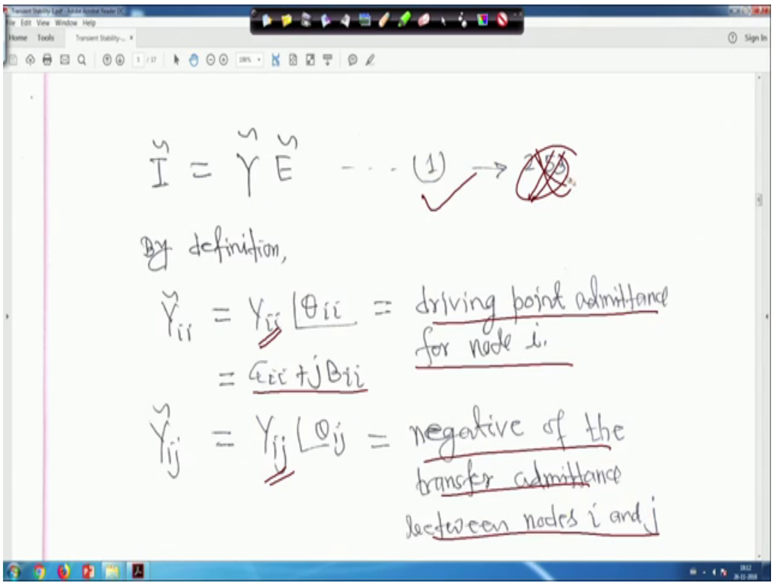

I mean we know that I is equal to Y E. And here it is E, so generate terminal voltage. So, I tilde is equal to Y tilde E tilde right. This is not for you this is for my own reference right. So, by definition that Y i i tilde from a load flows studies you know it is Y i i angled theta i i. Theta Y i i means this is the magnitude right, and theta ii is the angle and this is called driving point admittance for node i. This already you know from the load-flow studies is equal to we can write G i i plus j B i i.

And Y i j tilde is equal to Y i j angled theta i j. So, Y i j is the magnitude and theta is its angle, it is negative of the transfer admittance between nodes i and j, this also you know from your load flows studies right. So, this is the equation-1, and this is nothing this is for my own reference.

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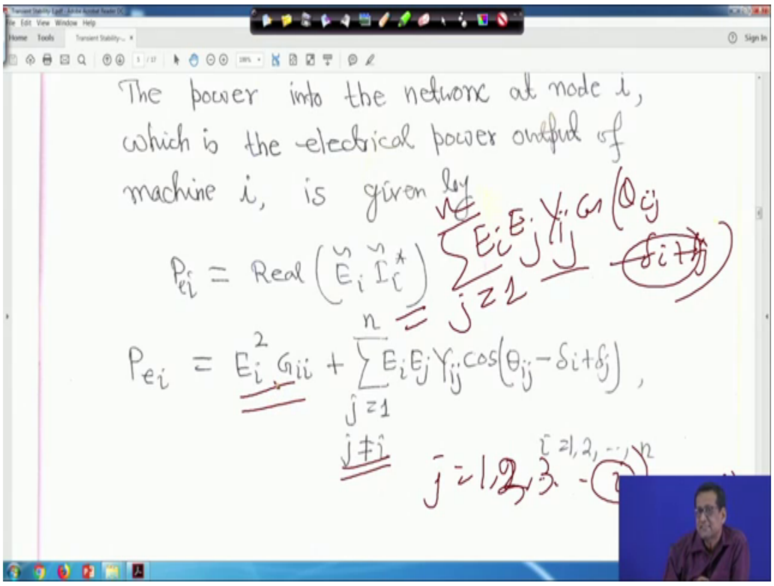

So, next one is that so Y i j also we can write that G i j plus j B i j, this is equation-2 right. Now, the power into the network at node i, which is the electrical power output of the machine i is given by that P e i we can write real of E i tilde into I conjugate tilde, this is the real part of this one.

If you make real from your load-flows studies, you know how to do this right. So, we can write p e i is equal to E i square G i i plus sigma j is equal to 1 to n, j not is equal to i E i E j Y i j cosine theta i j minus delta i plus delta j that that from load-flow studies you know when you have taken i-th term out from this 1 one, it is E i square G i i that's i why here it is written j not is equal to here. Load-flow studies also you know pi is equal to j is equal to 1 to n your b i b j y i j cosine theta is a minus delta plus delta j this way right now.

So, this equation when you write like this say j is equal to 1 to n right, then you can write E i, then you can write E j, then you can write Y i j, then you can write cosine theta i j minus delta i plus delta j. This is you know valued from load flow studies.

Now, from this expression when you are taking your i-th term out, now from this expression when you are taking j your i-th term out right, then when I mean when j is equal to say 1, 2 this way 2, 3 this way when I will come it will come to n right.

So, when i-th term is out from this sigma, so it will be when j is equal to i, so it will be basically your what will happen that it will be your E i into E i e i square it is Y i i. And this i is equal to they mean this term will vanish, it will be theta Y i i cos theta i i. So, basically E i square G i i that is why it is written like this right.

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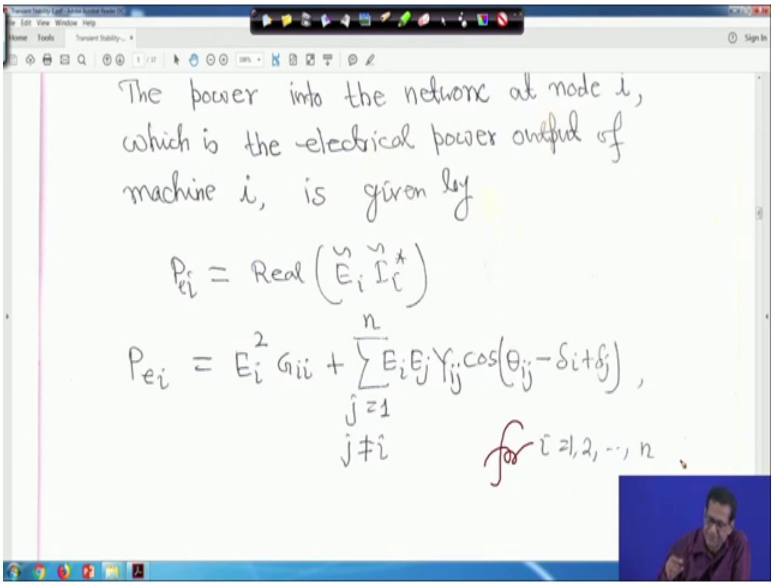

So, that is why the P i is equal to E square G i i j is equal to 1 to n, j not is equal to i right your what you call E i E j Y is equal to X cosine theta i j minus delta i plus delta j for i is equal to 1 to n right.

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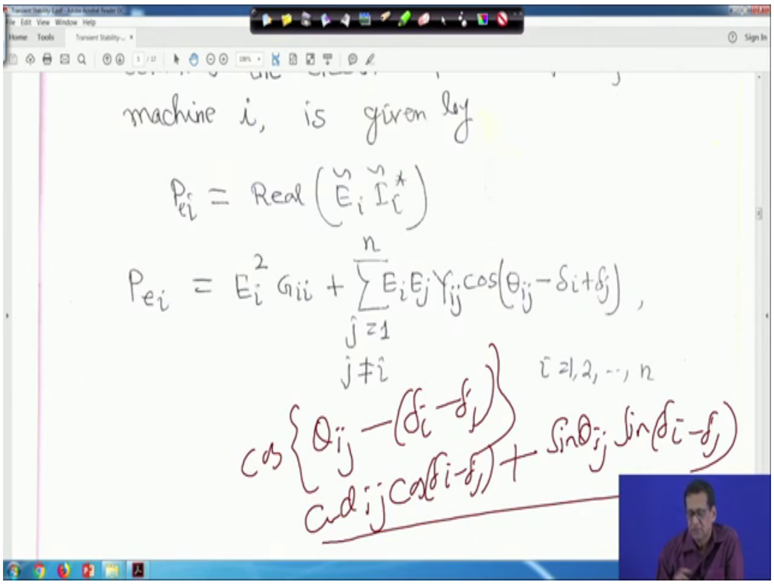

Next is that P i mean this term this term you can I mean before going to that right this term this cosine your theta i j minus delta i minus delta j right, this one you can write now. Cosine theta i j cos a cos b plus sin a sin b, so cos delta i minus delta j right plus your sin theta i j, then sin delta i minus delta j right this term, so that is what we have done here.

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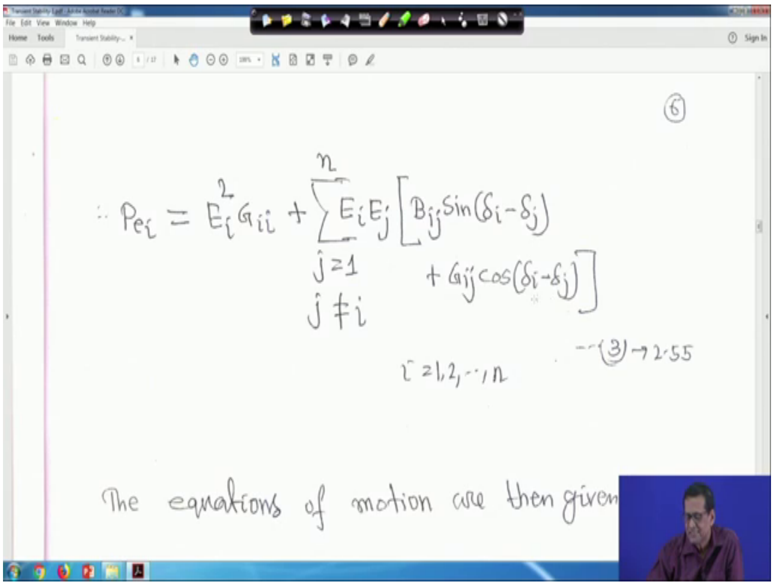

This one we can write E i E j B i j sin delta i minus delta j plus G i j cosine delta i minus delta j right.

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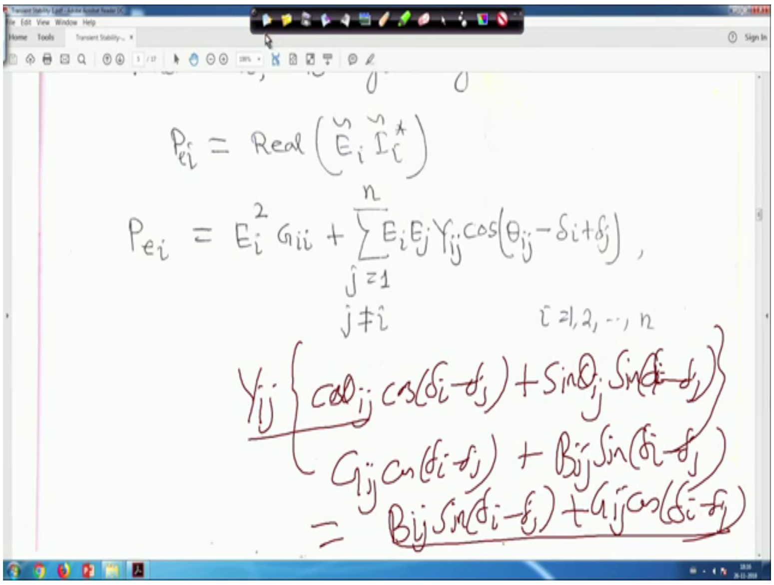

I mean if you when you are expressing this one, when you are expressing this one, so this is say Y i j and this term just I wrote now cosine theta i j cosine delta i minus delta j plus sin theta i j, then sin delta i minus delta j right, so that Y i j cos theta i j, it will be your G i j into cos delta i minus delta j.

And this one Y i j into sin theta i j, so B i j sin delta i minus delta j or this time we have written plus. So, B i j sin delta i minus delta j plus G i j cosine delta i minus delta j right that is this term we have written there, so that is why this we are writing that E i square G i i plus j is equal to 1 to n E i E j, it is B i j sin delta i minus delta j plus G i j cos delta i minus delta j i showed you that this is the thing. And this is also for i is equal to 1 to n, this is equation-3 right.

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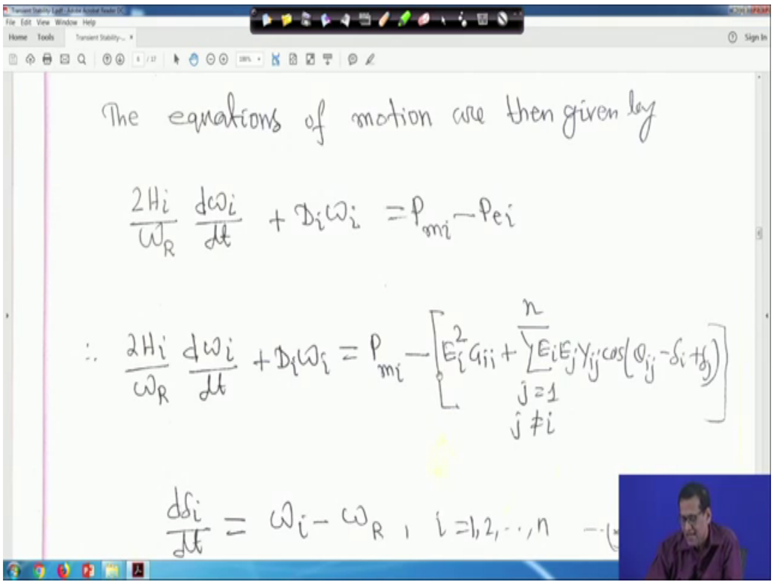

Now, the equation of motion are then given by this swing equations, so that should differ for synchronisation analysis this same thing we can write 2 H i upon W r right over some other omega r over the reference speed right into D omega i dt plus D i the damping term damping co efficient omega i is equal to in general P m minus P i, this is for i-th machine this is for i-th machine right. And that means, that 2 H i upon omega r into D omega i upon dt plus D i omega i is equal to P m i. And this P i P e i this is the expression for P e i you substitute here you substitute here, that is minus in bracket E i square G i i plus j is equal to 1 to n, j not is equal to i E i is Y i j cos cosine theta i j minus delta i plus delta j right this is your equation for omega.

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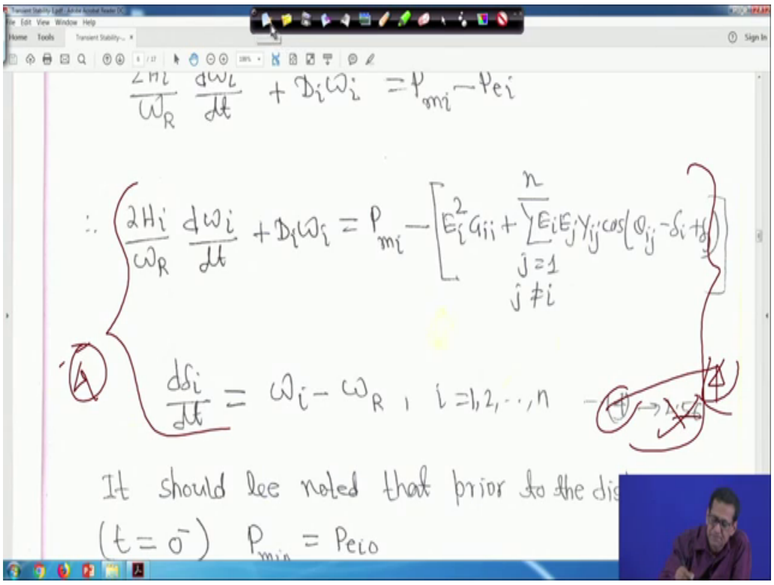

Another thing is di upon dt delta upon dt, this also we have seen that omega i minus omega is the reference speed and omega i is the speed for the i-th motion omega i minus omega R. This is for i is equal to 1 to n; actually, these two equations are equation-4 right, this is nothing. These two equations actually equation-4 together right I written here is 4 is a basically these two equation together, it is equation-4 right.

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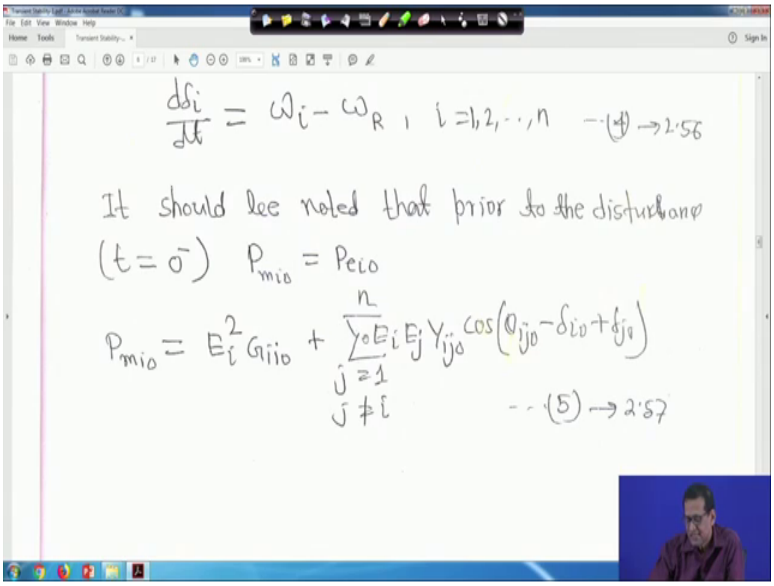

So, it should be noted that prior to the disturbance at t is equal to at 0 minus I mean just before disturbance P m i 0 actually equal to p i. Actually, it had balanced right, P m i 0 mechanical power input is equal to electrical power output P i 0 so right, so that means just before disturbance P m i 0 is equal to then we can write same equation, but using one suffix 0 that E i square G i i 0 plus sigma j is equal to 1 into n, j not is equal to i E i E j Y i j 0 cosine theta i j 0 minus delta i 0 plus delta j 0, this is equation-5 right.

So, this is nothing this is actually before disturbance right, before disturbance these thing we will get it because I what you call load-flow studies are carried out. Later we will see on, I will take the example that from that load-flow studies your voltages. The internal machine bus voltages E 1, E 2, E 3 up to E n are all will be computed all the angles will be known. So, at that time you can easily find out what is your P i j 0, and pi 0 is equal to nothing but the that your P m i 0 right.

So, thank you, we will be back again.