Power System Dynamics, Control and Monitoring
Prof. Debapriya Das
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 28
Transient stability (Contd.)

Now, we are back again, right.

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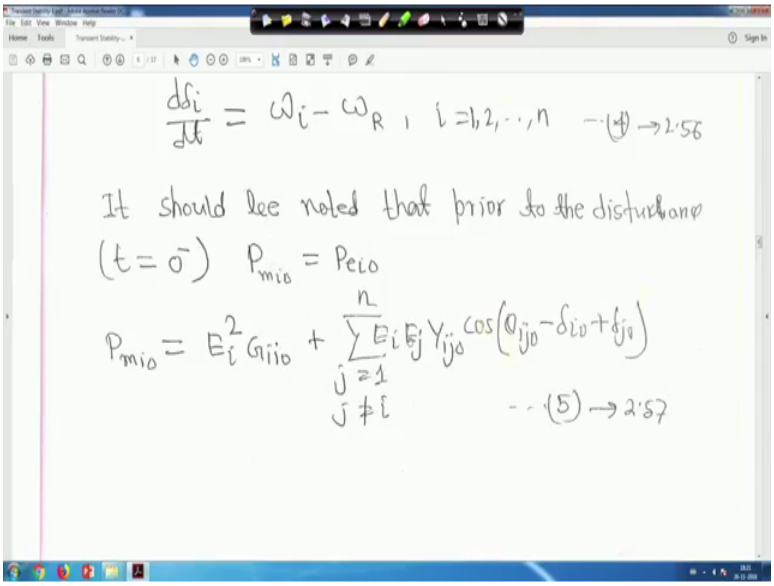

So, up to equation 5 we have seen. Next is your that that subscript I told you 0 is used to indicate the pretransient conditions, right. This applies to all machine rotor angles and also to the network parameters, since the network changes due to switching during the fault, right.

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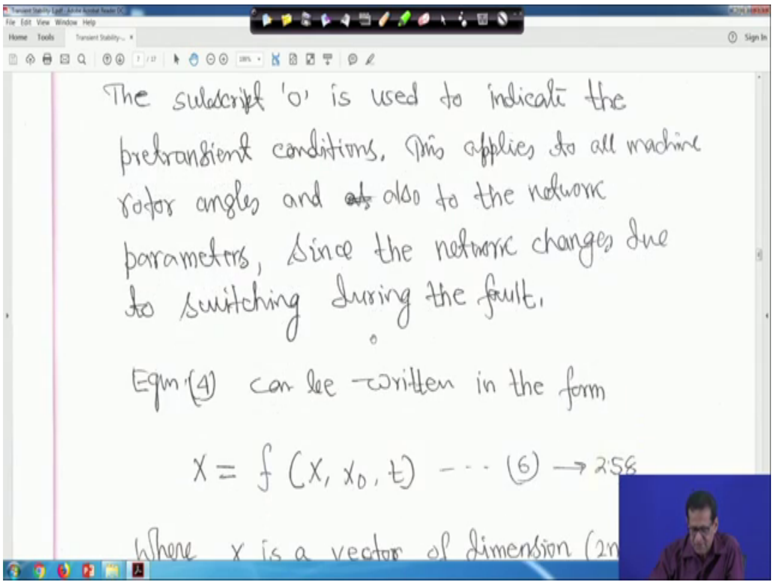

Now, equation 4 can be written in the form x is equal to actually that it will be x dot, right dot is missing.

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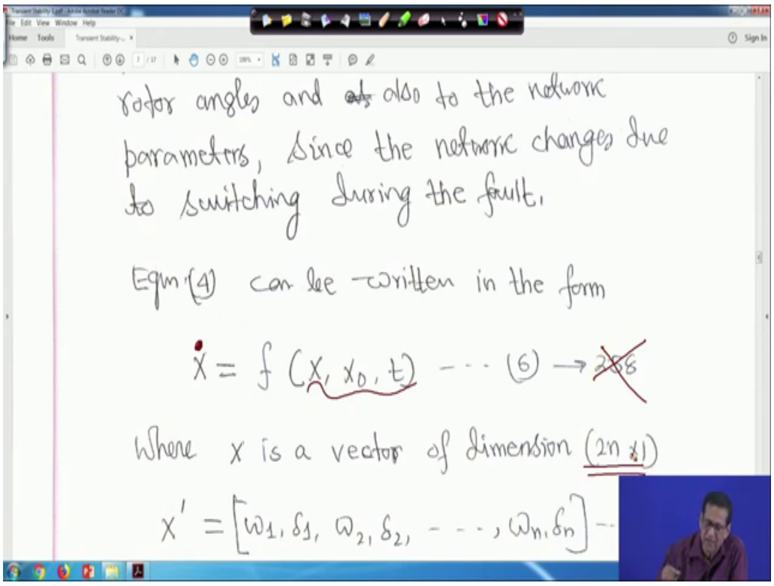

It will be x dot, right; x dot is equal to f x comma x 0 t, I mean this way you can write, right. It is this is for my own reference. So, x dot is equal to f x xo t, right. This way you can write x is a vector of dimension 2 n into 1 because for each machine you have two variables, right.

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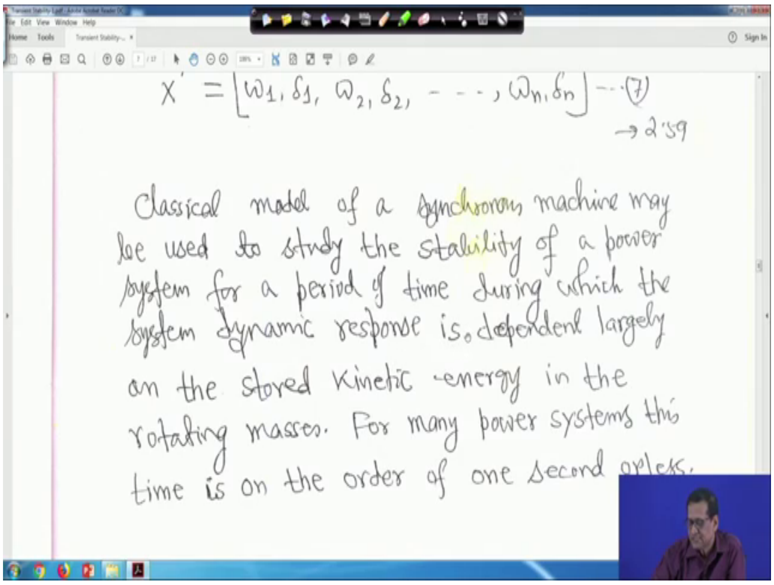

For example, omega 1 delta 1, omega 2 delta 2 up to omega n delta n, this is equation 7, right. So, x dash is equal to transpose, right. And it is, this is actually x dot there should not be any mistake x dot, it is the somehow scanning thing dot is missed, right.

So, now next one is the classical model of a synchronous machine may be used to study the stability of a power system for a period of time during which the system dynamic response is dependent largely on the stored kinetic energy in the rotating masses, right. For many power systems this time is on the order of one second or less.

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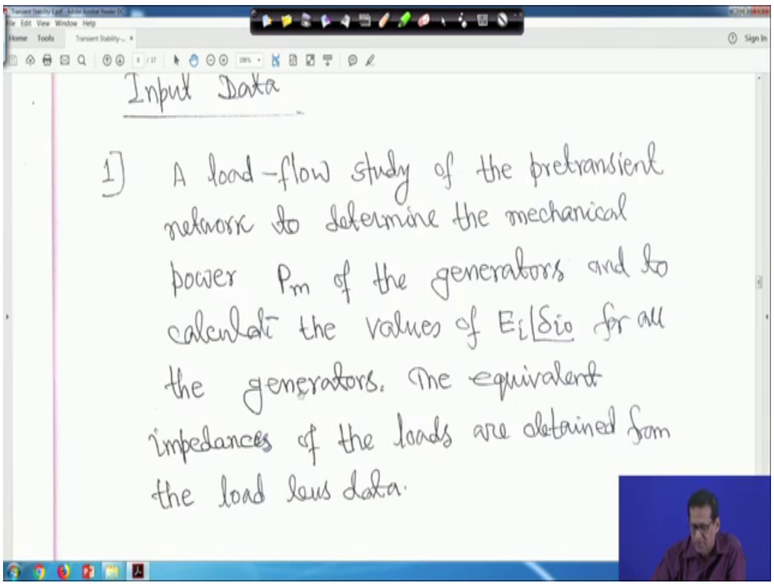

Now, input data, what are the input data are required, right. First thing is a load flow study of the pretransient network to determine the mechanical power P m of the generators and to calculate the values of E i and that angle delta is 0 for all the generators. This is (Refer Time: 02:22) in load flow study is required before fault, right. The equivalent; from that you have to calculate P m angle what you call E i angle delta. Actually, it will be in general that P m 0 equal to P o 0, right. The equivalent impedances of the loads are determined from the load bus data, right. So, that we will see later.

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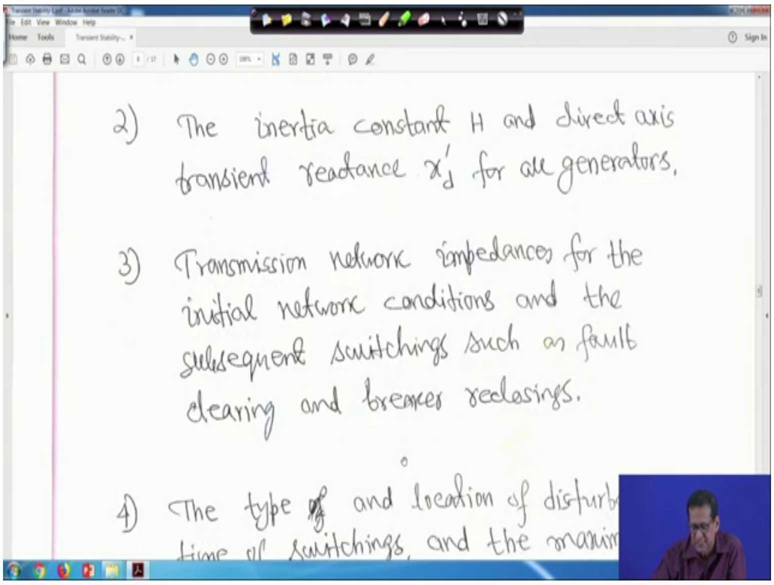

The inertia constant H and direct axis transient reactance x d dash for all generators. This data required one is inertia constant H and the x d dash this is required an r is very small, so neglected, right. Now, that is for generator.

Transmission network impedances for the initial network conditions and the subsequent switching, such as fault clearing and breaker reclosing, right. So, I mean all these impedances transmission network impedances are known because you have to compute that Y matrix that is before fault that is pretransient condition during fault also you have to calculate and post fault also, right.

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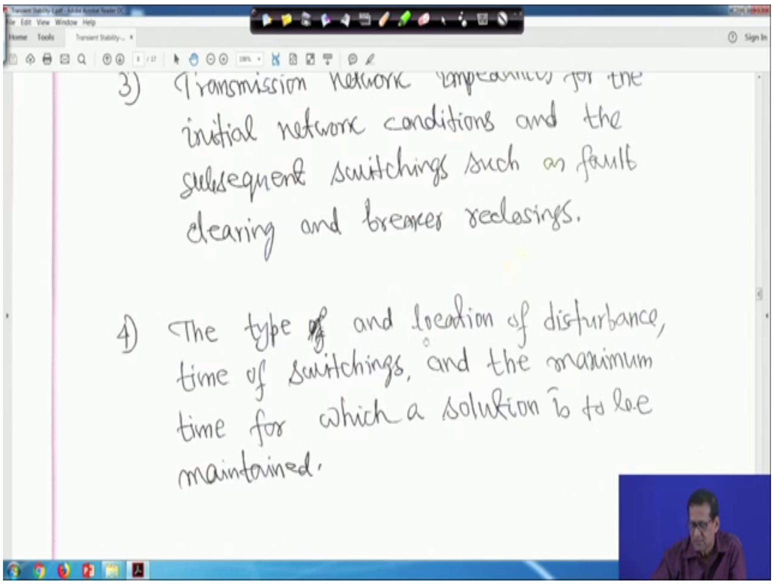

Now, number 4, the type of location of disturbance, time of switchings and the maximum time for which a solution is to be maintained, these are the input data before writing the code, although we not learn code here, right.

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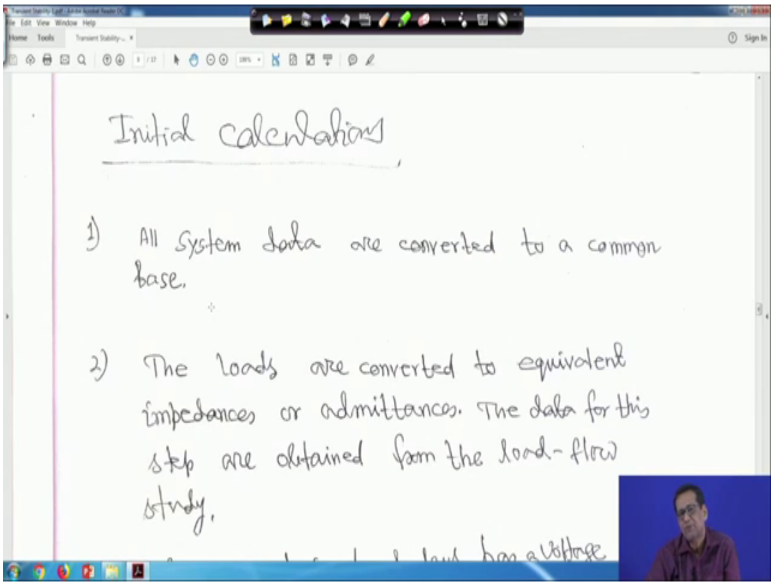

Now, initial calculations, what are the initial calculation requires for transient stability studies? All system data first converted to a common base; that means, convert to a common base; that means, per unit system, right. Loads are converted to equivalent impedances or admittances, the data for this type are obtained from the load flow study that we will see later, right.

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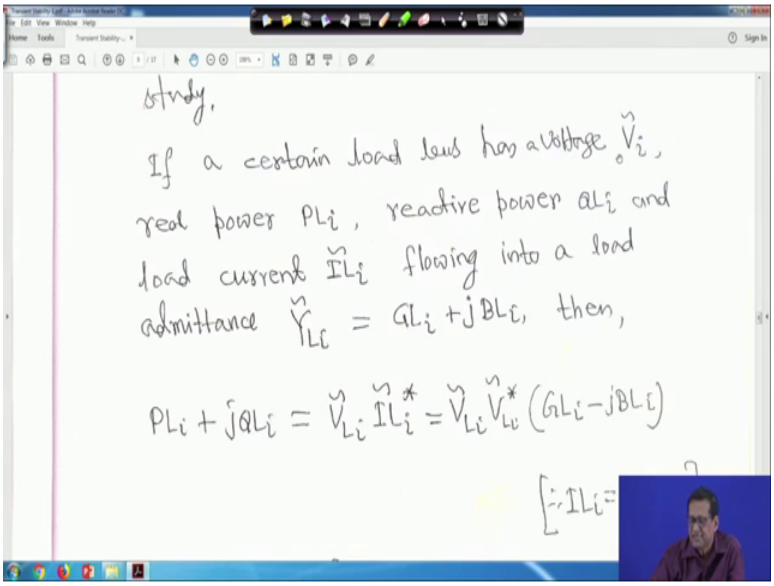

If a certain load bus has a voltage V i tilde, suppose now if a certain load has a voltage V i tilde the complex pressure quantity. Real power P Li, reactive power Q L i, a load current I L i tilde, flowing into a load admittance say Y L i is equal to tilde is equal to G L i plus j B L i then we can write P L i plus this you know from your load flow studies then we write P L i plus j Q L i is equal to V L i tilde then I L i tilde conjugate, right. Or if your write P L i minus j Q L i then it will be V L i tilde conjugate then I L i, right.

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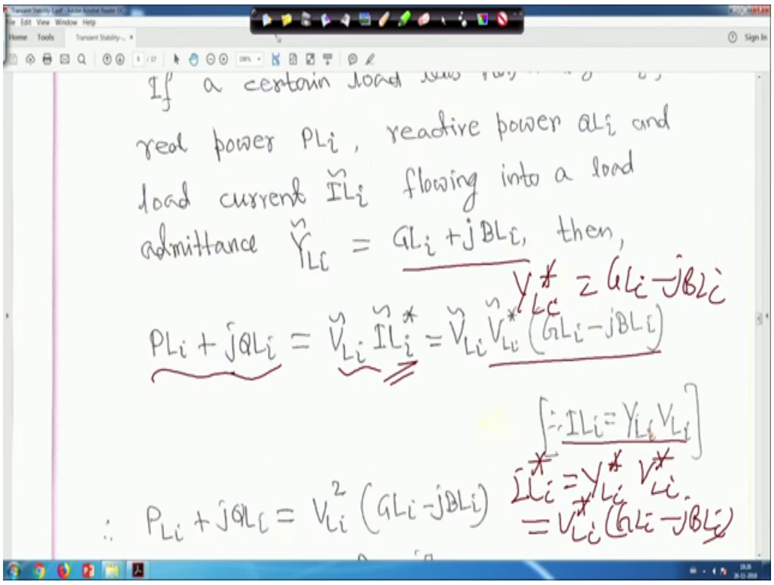

So, now, this one your what you call that, the I L i is equal to your Y L i V L i, right and Y L i is equal to j L i plus your j B L i. Therefore, your I L i conjugate, right because here we need I L i conjugate is equal to your Y L i conjugate then V L i conjugate, right. Or we can write this one that V L i conjugate, right and Y L i conjugate means it is Y L i and Y L i conjugate means it is G L i minus j B Li, right. So, if you made it, it will be G L i minus j B li, right.

So, that is why this I L i conjugate is actually V L i conjugate into G L i minus j B L i and here it is written I L i is equal to Y L i V L i, right. So, I L i conjugate is this one, right. Therefore, your V L i tilde into V L i conjugate will be simply V L i square because it will magnitude, right. So, therefore, P L i plus j Q L i is equal to V L i square into GL i minus j V li, right.

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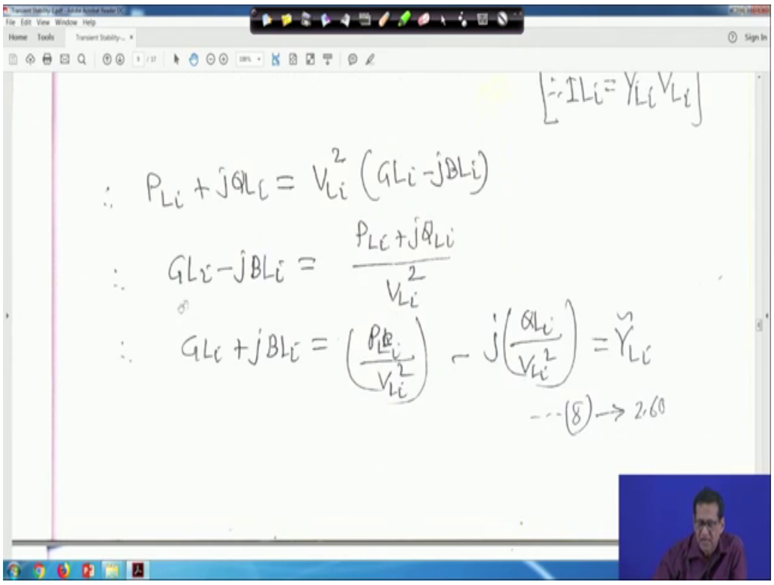

So, that means, I can we can write G L i minus j B L i is equal to P L i plus j Q L i upon V L i square, right. Or if you take your what you call that conjugate on both side, so that why it is writing G L i plus j B L i and this side we are writing P L i upon V L i square this plus because of conjugate, right hand side will be become minus so minus j Q L i upon V L i square is equal to say Y L i conjugate. This is the equation 8. In both side you take the conjugate, right therefore, your; that means, from here you will get G L i actual is nothing, but P L i upon V L i square and V L i will be minus Q L i upon V L i square, right.

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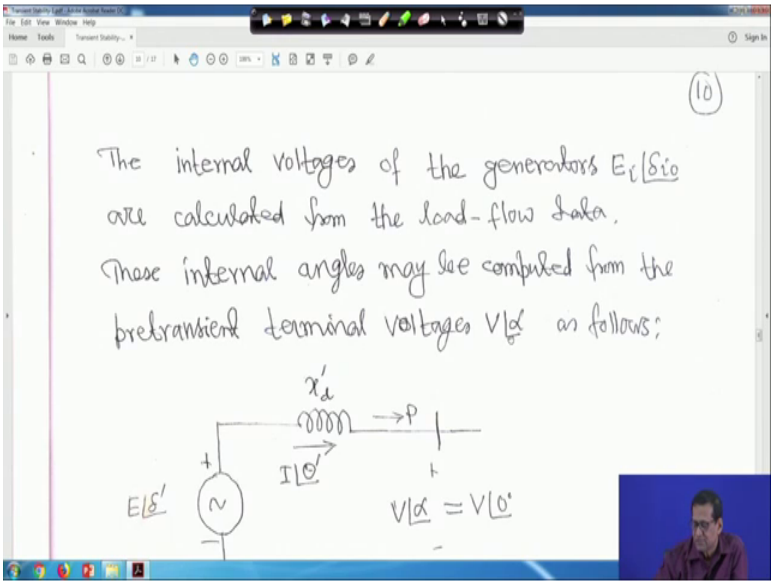

So, the internal voltages of the generator say E i angle delta I 0 are calculated from the load flow data. These internal angles may be computed from the pretangient terminal voltage V angle delta as follows, right.

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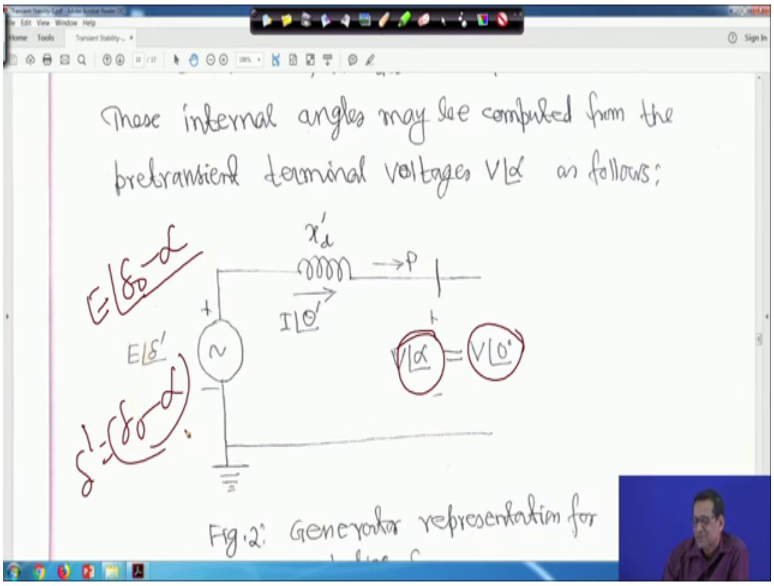

Suppose it is E angle delta dash, right and this is your x d dash r is neglected this is I angle theta dash, and this voltage V angle alpha is equal to V angle G. Earlier we have, earlier we have seen that this if you change that if I if you change this thing for example, if this side is this side is my suppose it is E by angle was say delta 0, right. Now, as this side if you make it as a reference instead of V angle alpha if you make V angle 0, so naturally this side will be delta 0 minus alpha, right that means, if I make it like this; that means, by delta dash will be delta 0 minus alpha, right. So, earlier also we have seen for the synchronisation studies, right.

So, that is why the meaning is that when I write V angle delta is equal to V angle 0 means it is not like alpha is equal to 0, we are changing the reference. If this is V angle 0 degree then this side angle will change, right. So, that is why we will take this terminal voltage V as a reference, right. Therefore, so this is generator representation, for computing delta 0 later it is given, right.

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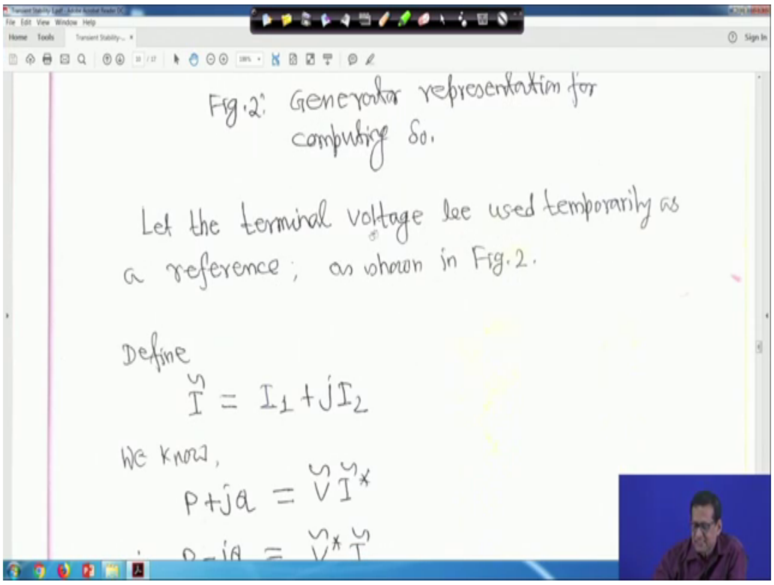

Now, let the terminal voltage use temporarily as a reference, I told you V angle 0 as shown in figure 2; this V angle 0.

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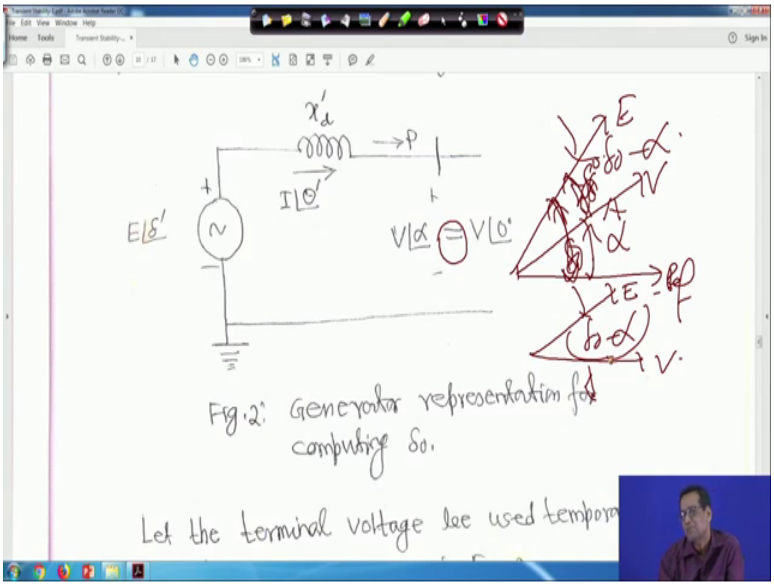

But let me tell you that it is a reference if you shift the reference from V angle to that means, this alpha here this side has to be subtracted. Meaning is very simple for example, suppose this is your reference line this is your reference line, right. Now, suppose it is your for example, suppose this is your alpha, right and this is your V and suppose this is your E, this is your E, right and this angle say for example, this angle is your say I can make it say your what you call delta 0, right. So, this your what you call that is this angle, this is my reference, this is V and this angle is your what you call delta 0, right. So, with better you take with respect to reference delta 0, right. So, these angle, these angle will be delta 0 minus alpha, right this angle will be delta 0 minus alpha.

So, that means, with respect to B with respect to reference this angle is alpha and with respect to this one this angle was delta 0; that means, this complete angle was delta 0 this is nothing, right. So, that means, the angle between E and V will be your what you call delta 0 minus alpha. Therefore, if you take now your V as a reference same thing and if it is your E then angle between this two should be delta 0 minus alpha this is what I wrote earlier, right. If it is alpha it means delta 0 if it is angle 0 it will be delta 0 minus alpha, right. So, that is why.

So, now define now I tilde is equal to I 1 plus j I 2. So, this is actually say real part and this is imaginary part, right. Now, we know P plus j Q is equal to V tilde I tilde conjugate or P minus j Q is equal to V tilde conjugate into I tilde. So, I tilde is equal to P minus jQ upon V tilde conjugate, right or I is equal to we have assume I 1 plus j I 2; that means, I 1 plus j I 2 is equal to P minus jQ upon V, but we know that we have V tilde angle V tilde conjugate is equal to V angle 0 is equal to V. That is why this one directly we have written as a V. This is that this is actually V as a reference if you take it makes our computation easier, right. So, it will be P minus jQ upon V, right.

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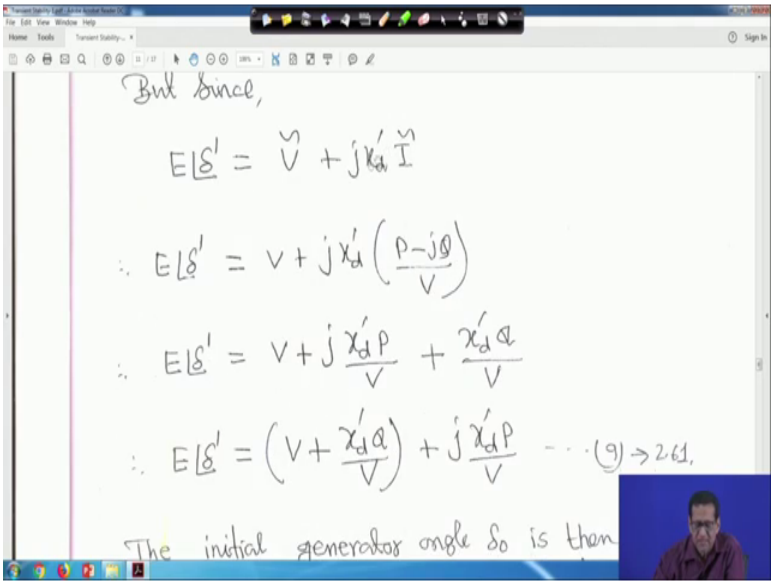

Now, since that E angle delta dash is equal to V tilde plus j x d dash I tilde; that means, if you come to this if you come to this it is E angled your delta dash is equal to I tilde G x d dash, right plus V. So, here also we are writing the same thing that E angle delta dash is equal to V tilde plus j x d dash I tilde, right or E angle delta dash is equal to V plus j x d dash and substitute whatever we have got just now that I tilde is equal to P minus j Q upon V, right.

Now, you just multiply then you will get E angle delta dash is equal to V plus j x d dash P upon V plus x d dash Q upon V, right or E angle delta dash, right is equal to V plus x d dash Q upon V plus j x d dash P upon V. This formula we need for computing the E value. Later you will see then we will take that your what you call that some problem. So, this is my equation, this is our equation 9, right.

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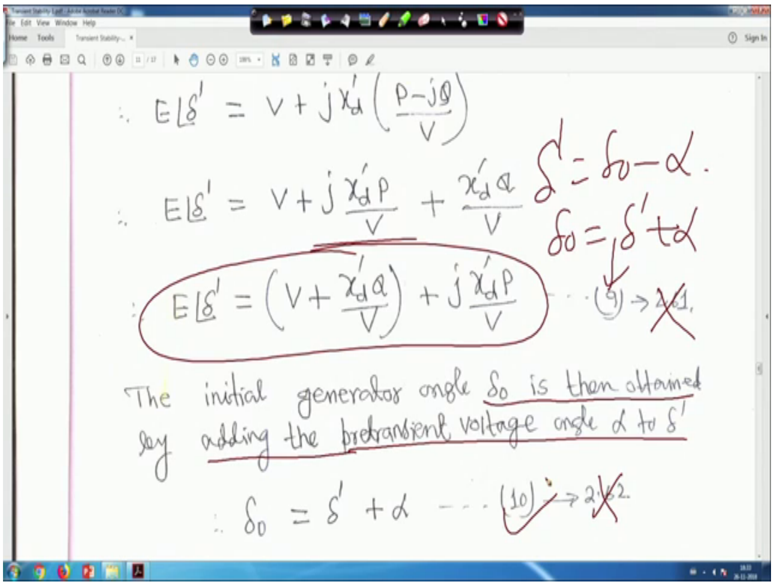

And either I told you that delta dash will be is equal to delta 0 minus alpha; that means, my delta 0 will be delta dash plus alpha. Now, the initial generator angle as delta 0 is then obtained by adding the pretransient voltage angle alpha to delta dash. So, delta 0 will be your delta dash plus alpha this is equation 10, right. So, this is how I told you earlier.

So, this equation 9 will be required for some computation of E and angle delta dash, right.

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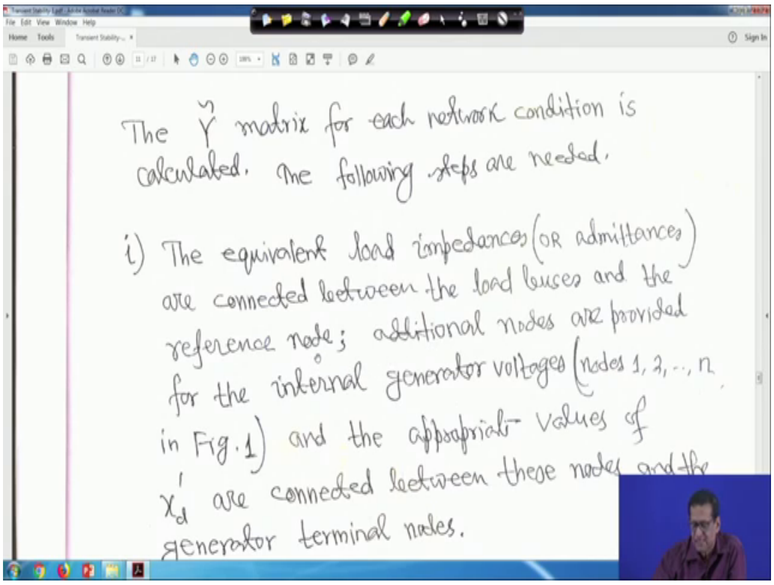

Now, the Y tilde matrix, for each network condition is calculated. The following steps are needed. The equivalent load impedances or admittances are connected between the load buses and the reference node. Additional nodes are provided for the internal generator voltages that is node 1, 2, n we have seen in the figure 1, right that general equivalent on transmission system node and the machines, right. And the appropriate values of x d dash are connected between these nodes and the generate terminal your what you call nodes, right.

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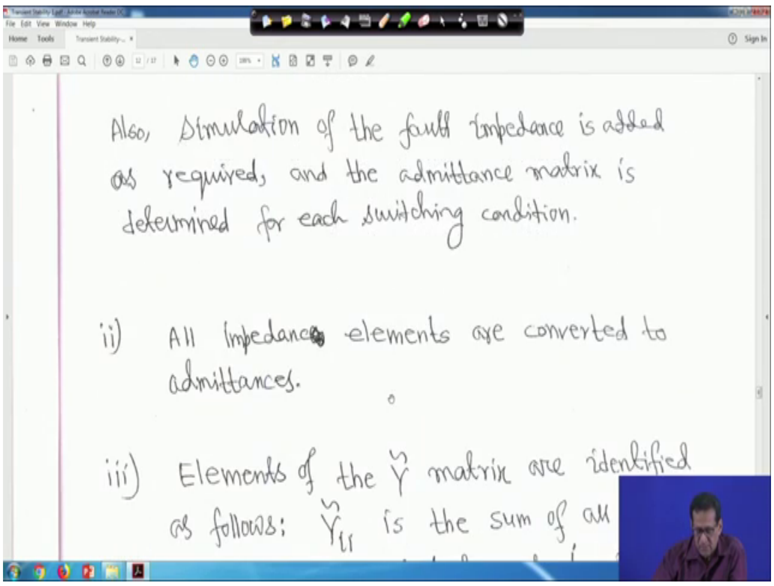

Now, also simulation of the fault impedance is added as required and the admittance matrix is determined for each switching condition, right. Now, number 2 is that all impedance elements are converted to admittances, because we have to consider we have to compute Y matrix no, that is why we have to make it in terms of admittances, right.

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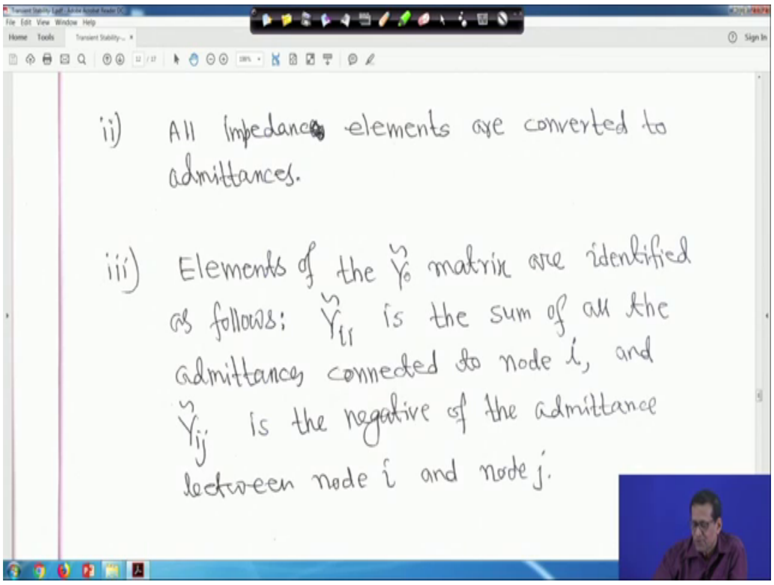

Now, number 3, elements of the Y tilde matrix are identified as follows. Y ii tilde is the sum of all the admittances connected to a node i. This you know from your load flow studies and Y I j tilde is the negative of the admittance between node i and node j. That is why in the load flow studies that your what you call in that Y matrix that we use capital Y 11, Y 12 like this, but when we find out the admittances diagonal admittances all y small y are added and all your off diagonal events capital Y i j is equal to your minus of small y i j it is negative of that, right. So, that you have studied from the load flow studies, that you know.

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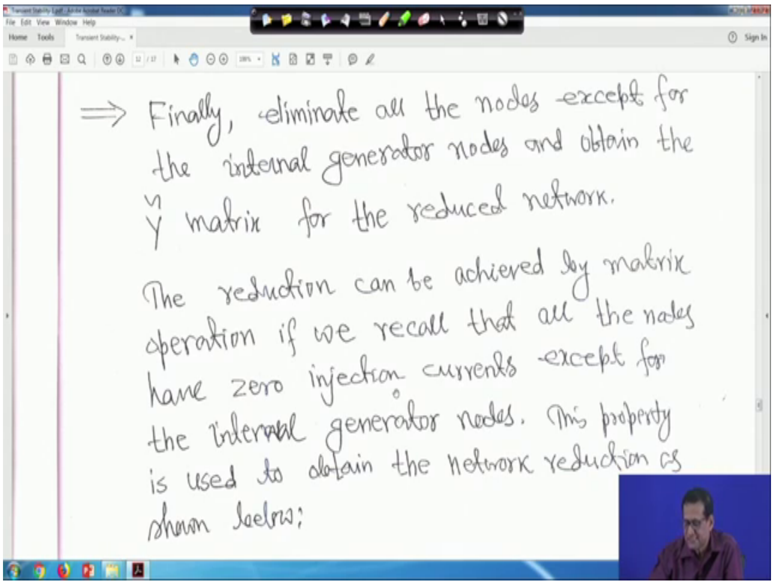

Now, finally, eliminate all the nodes except for the internal general nodes and obtain the Y tilde matrix for the reduce matrix. Ultimately, what will happen that you have to you have to reduce the Y matrix that is order should be if you have n number of generators then it will be n into n matrix, right. So, that you have to reduce, so we have to reduce by some technique that we will see.

The reduction can be achieved by matrix operation. If we recall that all the your what you call nodes have 0 injection current except for the internal generator nodes. We will assume in all the nodes there are current no current I mean zero injection of the current, right. That means, 1 2 n generators current injection is there, but rest of the nodes for generator as a not there the current injection will assume it to 0, right this property is used to obtain the network reduction as shown below, right.

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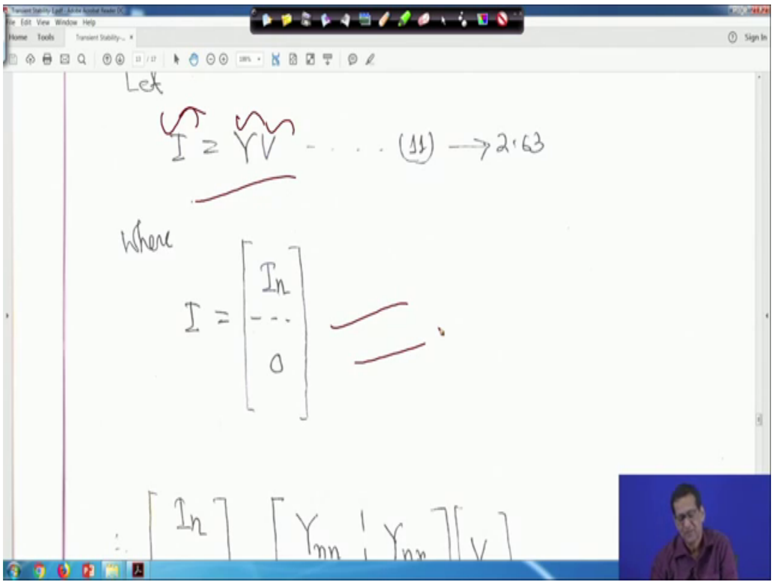

Now, we know that in general I is equal to YV, right. So, look it is pressure quantity, but again and again, again and again I had not made it tilde, but understandable is all these are pressure quantity, right. So, all these are pressure quantity.

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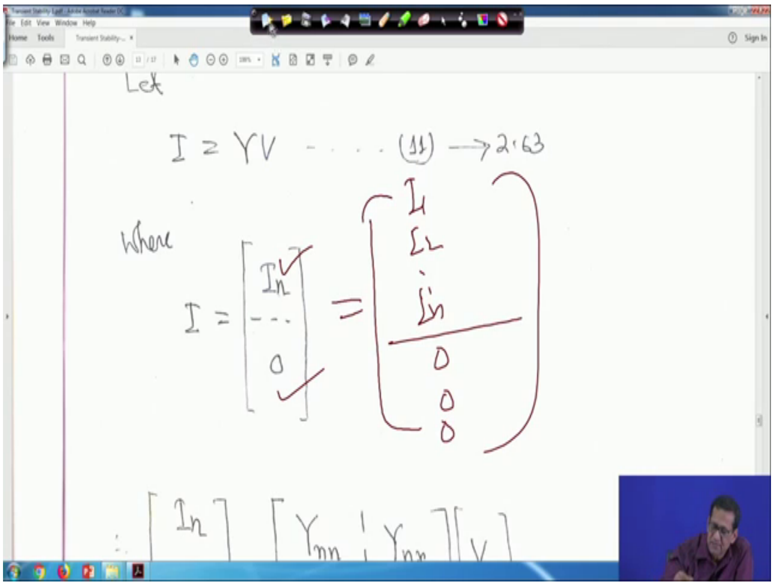

Now, that your I is equal to, it can be written I n 0; that means, suppose you have, suppose you have n number of generators. So, all the generator buses you have that your current injection I n, right and all other buses load buses all current injection is 0 that is why in general this I n and 0, right. So, I n means I 1, I 2, I n. If you have 3 generators then n will be 3, right.

Therefore, this Y matrix, right, so that means, we know this I is equal to Y V and I is equal to I n 0 then this can be left-hand side I can be replaced by I n and this 0, and this Y matrix can be partitioned.

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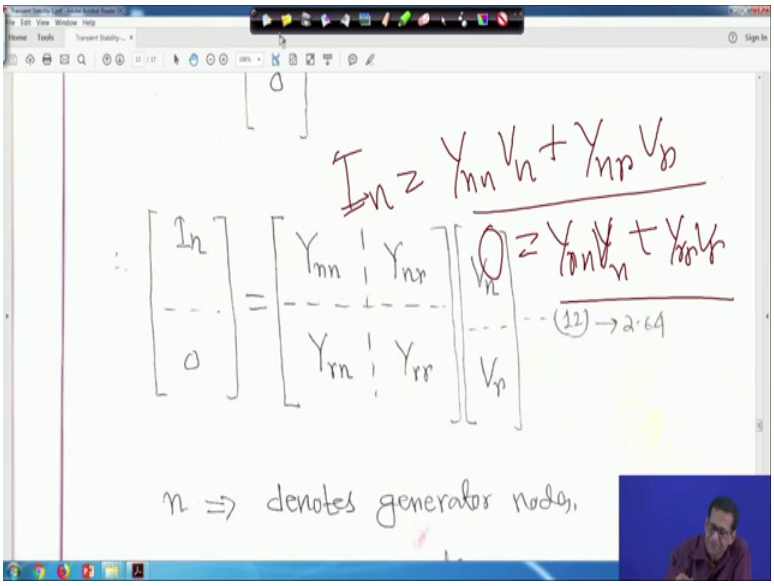

That is, you can make it partition like this Y nn, then Y nr, then Y rn, Y rr then V n is that I told you that V n is that we have n number of generators V 1, V 2, V n and rest are all the load buses, right. So, it is up to V r then the dai figure 1, we took no 1, 2 up to r buses, the load buses. So, this is equation 12.

So, this one we can write this equation partition Y nn, Y nr, then Y rn, Y rr this way you partition the Y matrix, right and this is V n, this is V r; while you take few examples at that time you will find things are very easy, right. Now, n denote the generating nodes and the remaining nodes, right. So, now from this equation from this equation you can write I nn, I mean you can write two equation from this equation you can write in matrix form of course, I am just writing like this I n is equal to Y nn V n, plus Y nr V r this is one equation, I mean I n is equal to. Another equation will be 0 is equal to, I mean this side is equal to Y rn Y Y rn then V n plus Y rr V r, 0 is equal to this is one equation this is another equation, right.

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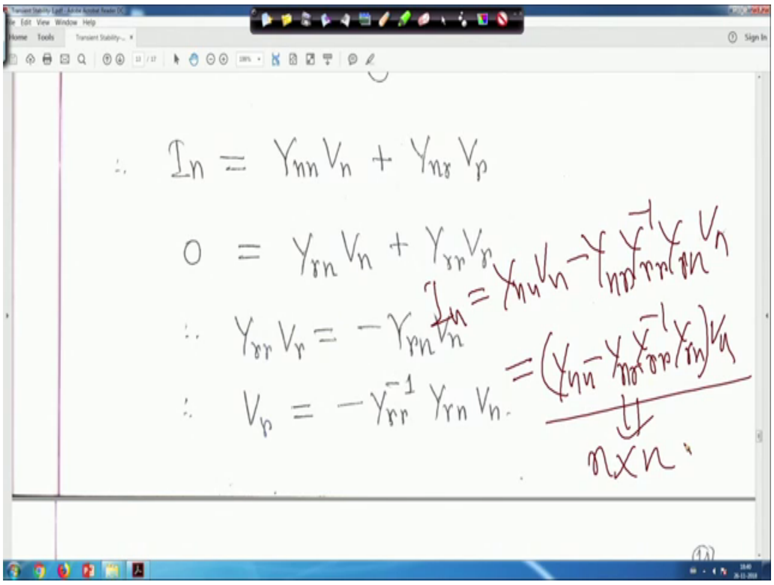

So, from this, this is the first equation, this is the second equation from this equation you can write Y rr V r is equal to minus Y rn into V n or V r is equal to minus that Y rr inverse Y rn V n, right. So, this V r you got, this V r is equal to minus Y rr inverse V n you got and this V r you, V r is this one you substitute here you substitute here, right. Then, what you will get if you substitute? You will get I n is equal to Y n and V n minus Y nr Y rr inverse Y rn into V n, right.

If you substitute here, if you substitute here then what you will get, I am just over writing that I n is equal to Y nn V n. Now, you substitute here. So, it will because of minus it will be minus then Y nr then Y rr inverse then Y rn is V n, right. If you take your V n common, right then it will be Y nn minus your Y n r, right then Y rr inverse then Y rn then V n, right. So, it will matches, this matrix actually reduction to your n into n, right. If you I mean it will be an intended matrix; that means, the number of generators are n, so it will be a n matrix. So, that is why here we are writing.

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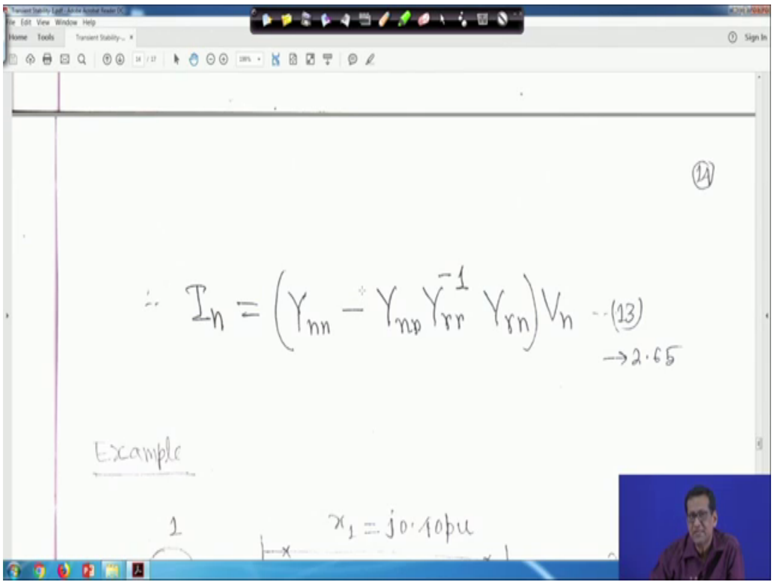

If you substitute you will get I n is equal to Y nn whatever I showed minus Y nr Y rr inverse Y rn into V n, right this is equation 13. Now, this is actually reduction. So, all these things have been done. We will take a small example, right.

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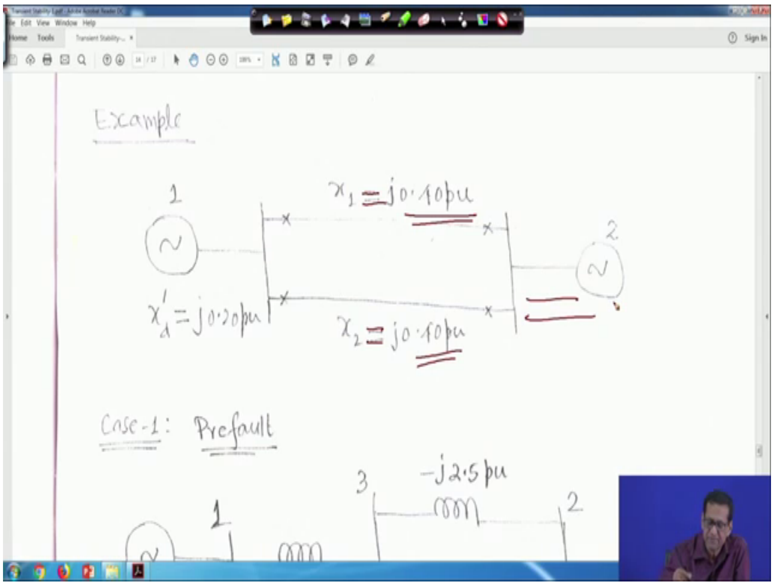

I hope everything is readable. This is scanned copy of my notes. So, x 1 is equal to line impedance is given j reactance rather r is neglected j 0.40 per unit, right and it is double circuit line and x 2 is equal to j 0.40 per unit both are same, right. And this is actually x d dash is equal to j 0.20 per unit and this side nothing is given, right.

So, we have to find out that your I mean pre-fault your what you call then fault and post fault Y matrix, right. First, we will see the first we will see how we are doing it. Now, first what you do is, that this where fault actually for this problem not shown I will tell you.

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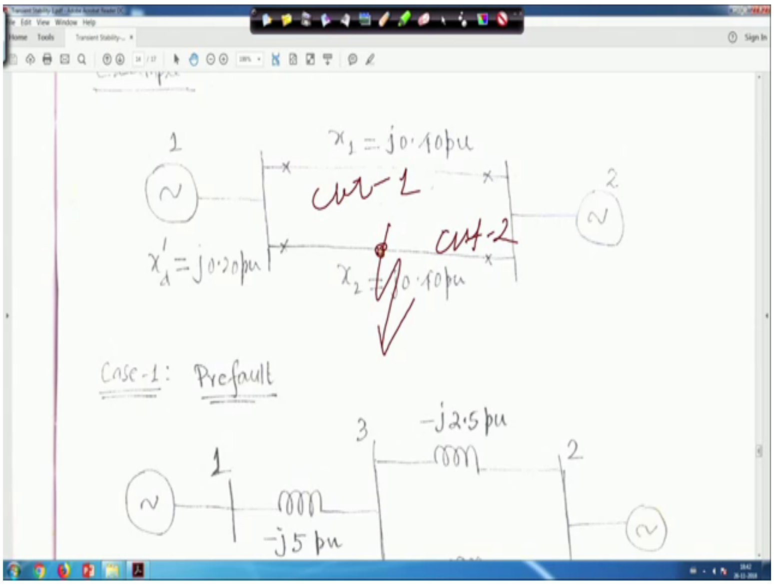

Fault actually thickest fault has happened in the middle of the line second line, that circuit 1, this is my circuit 1 and this is my circuit 2, right. So, in the middle of the line fault has occurred, right.

Now, that we will see later, now that when you represent this and x d dash is given j 0.20 per unit, right. Now, when we made it in terms of your admittances, so it will be 1 upon x d dash. So, it will be minus j 5 per unit, right. Similarly, if you put in admittance it will be 1 upon j 0.4. So, it will be minus j 2.5 per unit everything is per unit and this one also minus j 2.5 per unit, right.

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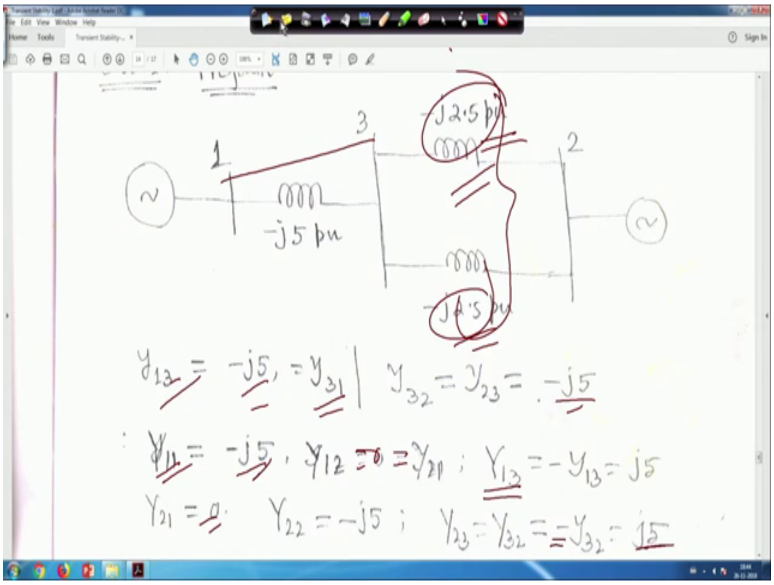

So, in this case pre-fault if you first you represent by small y tit will work from load flow studies. So, Y 13 that is your Y 13 that is 1 2 3, it is minus j 5 is equal to y 31, right. Now Y 32, right Y 32 is equal to y 23 it is your what you call it is a double circuit line, so Y 32 minus j 5 because this two will be added, this two, this two will be added, right it is a admittance one, so that is why it is minus j 5, right because we have converted that reactance to your what you call acceptance or in general we call that it is your admittance, right.

Similarly, then your Y 11 then will be only minus j 5 that your what you call Y 11. Similarly, Y 12, no connection between Y 12 is equal to y 21 is equal to 0, because no connection between 1 and 2 no direct connection, right. And Y 13 is equal to, capital Y 13 will be minus y 13, right minus Y 13 that is your j 5. And only diagonal element or smaller I will be added or capital element will be minus, right and Y 21 also no connection is 0, and Y 22 that is your Y 22 that will be minus j 5 because this one minus j 2.5 this is minus j will be added because it is admittance, right. And Y 23 is equal to Y 32, so Y 23 is equal to Y 23 is equal to minus small y 32 that will be j 5 this is my your what you call pre-fault Y matrix, right, this is pre-fault Y matrix.

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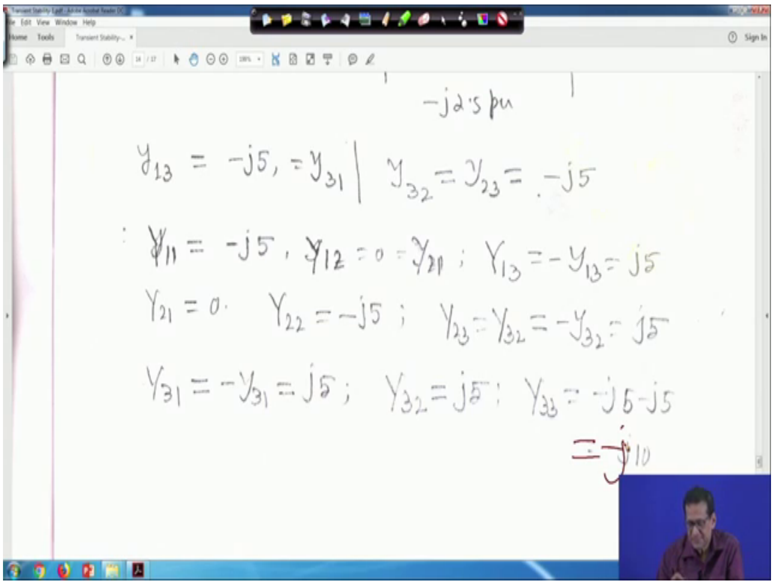

Now, this matrix I will show later, but in the terms of this thing, similarly, Y 3 11 thing is left similarly Y 31 is equal to minus capital Y 31 is equal to minus small y 31 is equal to j 5; that means, we know that they are Y 13 is equal to Y 3 minus j 5.

So, when we like off diagonal elements capital Y 31 will be minus small y 31 is equal to j 5 and capital Y 32 will be also j 5, right because 3 22 and this will be added and it will be minus small y 32. So, it will be j 5 and Y 33 will be minus j 5 minus j 5 is equal to minus j 10, is equal to minus j 10, right. So, this one this matrix form I will show later, right. So, this is all Y matrix, this you know how to calculate, right.

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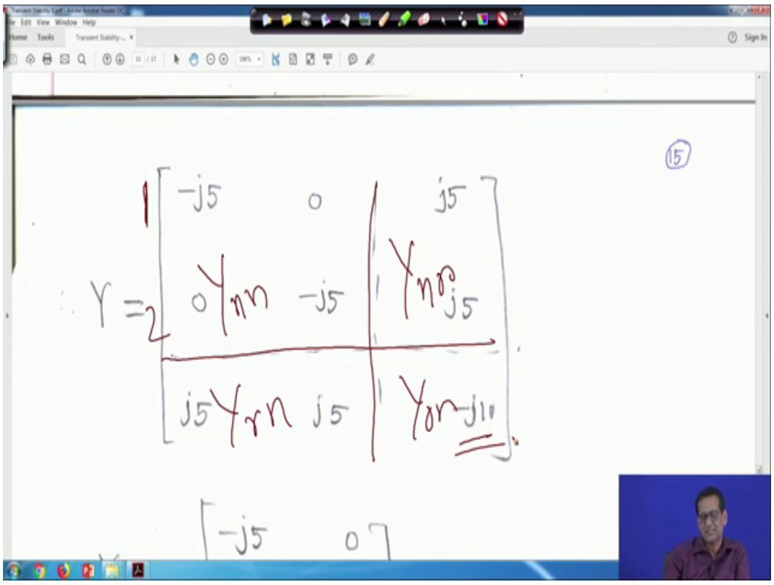

Now, now this Y actually it is your what you call minus j 5, then 0, then j 5, then 0, minus j 5, j 5, j 5, j 5 and minus j 10, right. So, now in this case what you do is, so if you look into this that Y 11 is minus j 5, so minus j 5. Now, Y 12 capital Y 12, right is equal to Y 21, 21 is equal to Y 12 is equal to 0 then Y 13 capital Y 13 is equal to your what you call 31 is equal to j 5. So, it is j 5. So, Y your 21 is equal to Y 12 is equal to 0. So, Y 21 here it is 0, right then Y 22 is equal to minus j 5, right. So, Y 22 you have given that is your what you call that Y 22 means here right, Y 22 means only these two minus j 2.5 minus j 2.5, right. So, that is actually here you see minus j 5, so minus j 5.

And Y 23 is equal to Y your 32 capital Y this one is equal to minus small y 32 is equal to j 5. So, this is j 5, right. And last one Y 31 is equal to minus small y 31 j 5, right. Similarly, Y 32 is equal to same as j 5 and Y 33 minus j 5 minus j 5 this is minus j 10, right.

So, now, you have in this in this example you have two machines you have two machines that is why this is 1, this is 1 and this is 2. So, its partition should be like this, right. So, this is actually your Y nn 2 into 2, n is equal to 2, right Y nn Y nr this is Y nr, right; and this is Y rn and this is your Y rr only single element only single element here in this case because in the classroom we cannot take the examples, but certain thing will be shown, right.

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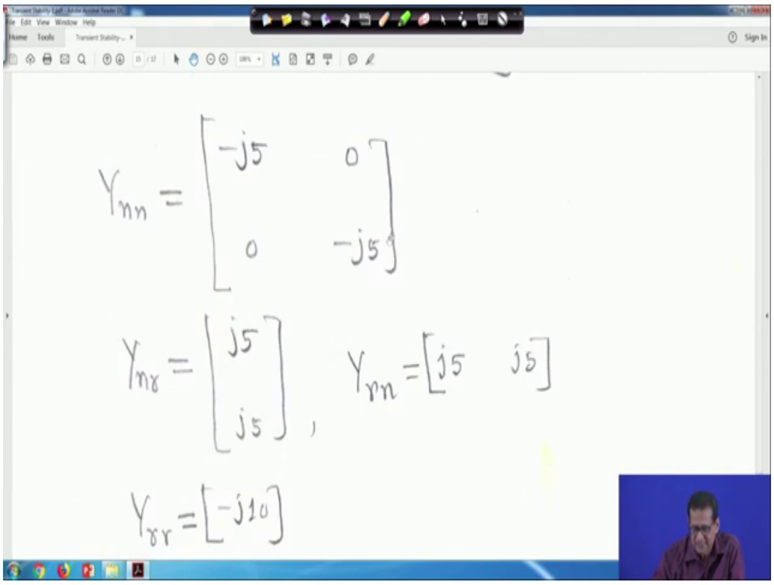

So, this is Y nn, this is Y nr, right this one I told you and this is Y rn I told you, and Y rr is a single element minus j 10, its inverse will be just one upon minus j 10, right.

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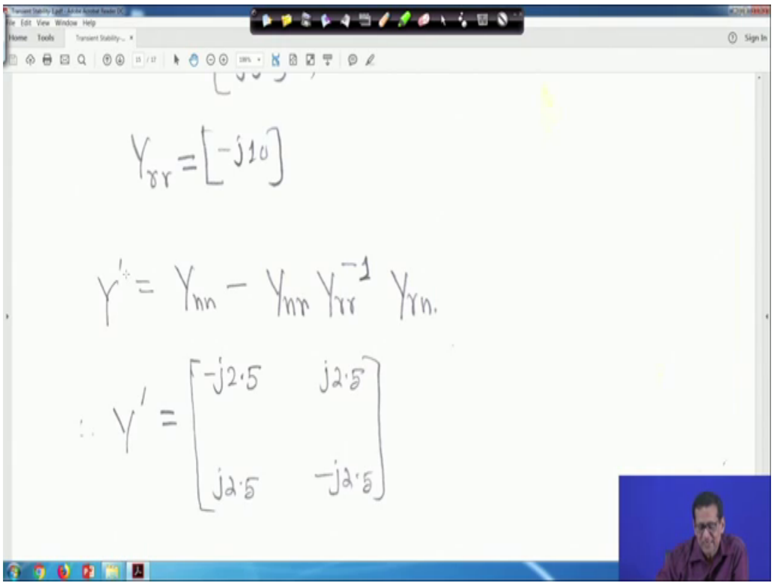

Now, we know this I put Y dash is equal to Y nn minus Y nr Y rr inverse Y rn, right. If you substitute I mean if you substitute all these value and if you simplify you will get Y dash is equal to minus j 2.5 and j 2.5, and j 2.5 minus j 2.5 this is actually that your what you call that your pre-fault matrix, but reduced to 2 into 2 because you have two machines, right you have two machines, right. So, this is your what you call that your pre-fault 2 into 2 matrix.

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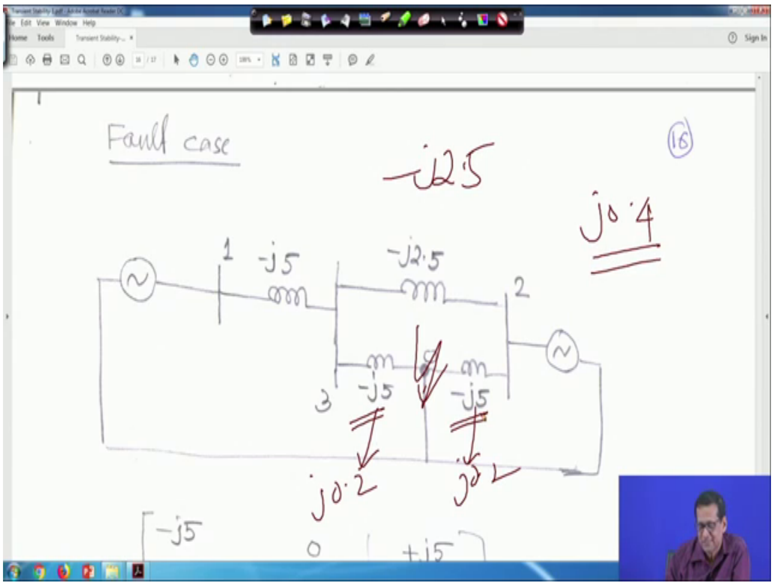

Now, for fault case, a fault has 3 phase fault has occurred here in the middle of the, in the middle of the your line this second line. In the middle of the line 3 phase ground 3 phase ground fault has happened that is why at this is admittance that whole line admittance was minus j 2.5, right. But now it will be minus j 5, minus j 5 because it was j 0 0.4 that your reactance.

Now, if it is in the middle of the line, so this side reactance will be j 0.2 and this side will be j 0.2. So, it is 1 upon 0.2 will be minus j 5 and this side also will be minus j 5, right. So, based on this one, right we have to find out that your first 3 into 3 your matrix during the fault case then again will reduce into 2 into 2 because we have two machines, right.

So, thank you very much. We will be back again to solve this.