Power System Dynamics, Control and Monitoring

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Lecture - 31
Transient stability (Contd.)

Okay. So, we are back again right. In the previous lecture, we started with this example.

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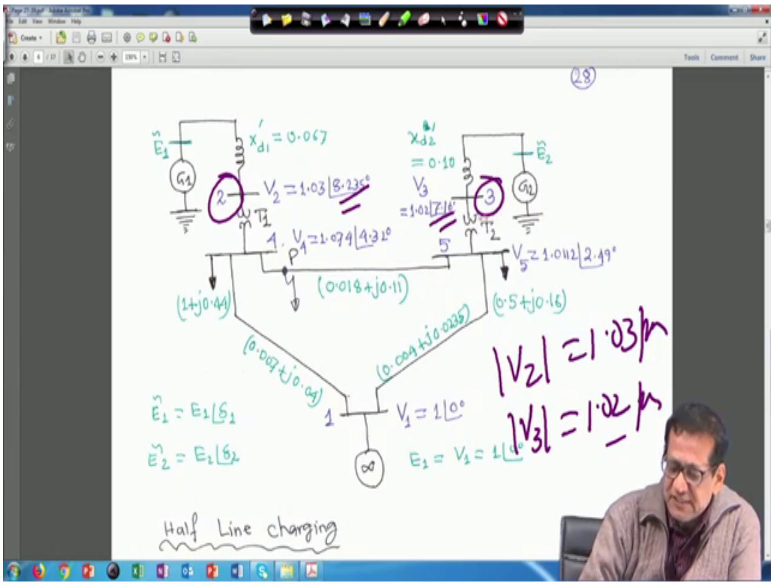

So, this your, what you call this is a pi bus problem and this X d 1 dash for this general, one transformer is there, here and here right, two transformers are there. So, previous examples we have not considered a transformer. If transformers are there, then the transformer reactance will be given in per unit along with that this one you add right. So, we did not make any bus number here actually, there is no need right. So, basically it is a pi bus problem and another thing is for this problem that bus 2 and bus 3 basically they are p v bus. Whatever it is given, that is the load flow solution. These two are p v bus; that means, it is voltage magnitude is 1.03 per unit is defined right. Similarly, for bus 3 that v 3 is equal to 1.02 per unit. It is magnitude is different defined right.

So, whatever angles you was just it is given here, this is the load flow solution from the load flow solution right. So, all I mean load flow solutions all everything is shown here right, v 5, then your your what you call v 4 right everything is shown here and another point is that your the all the load impedances are your sorry load power is given, we have to convert it to admittances right. So, load power is given and at the same time you have to compute E 1 and E 2 right and this is your this is infinite you are what these are slack bus and this is actually shown by your what you call infinite bus right. So, in this case E 1 is equal to V 1 is equal to 1 angle 0. Just to your what you call to simplify the problem because we have to do something which can be solvable in the class and in this case that your r X in per unit for all the three lines are given right, but for the classroom exercise if we take r, it will consume more time

So, we will restrict it to your what you call the reactances, but for this example this r and X will be there right. So, E 1 tilde that is phasor quantities equal to E 1 angle delta 1 and E 2 tilde is equal to E 2 angle delta 2. So, half line charging other data other data are also there right. So, just hold on.

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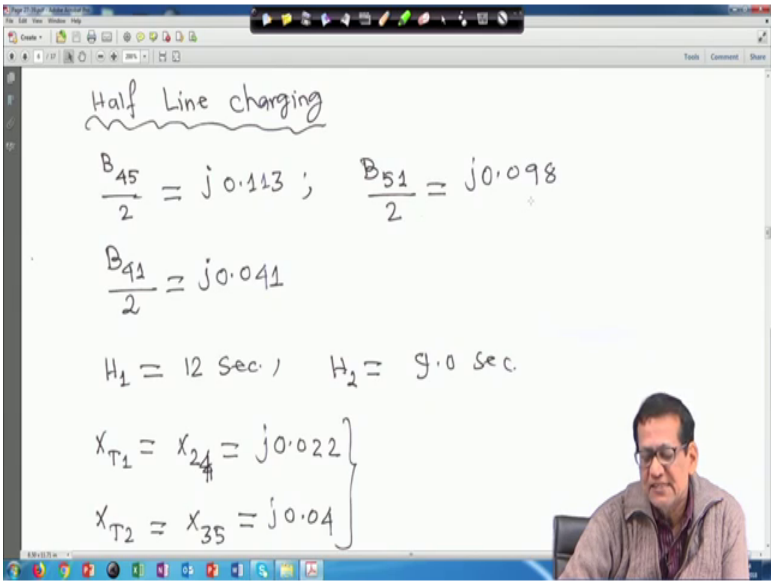

So, if we come back to the other data, just let me make it this thing. So, a half line charging that all the line charging is given. So, B 4 5 by 2 that is your charging susceptance right. It is given j 0.113 and B 5 or I mean B half half half B 5 1 it is j 0.098 and half B 4 1 it is j 0.041 because half half we will take right and then h 1 is 12 second and h 2 is 9 second, the inertia of that two machines right, 1 and 2 and transformer for X T 1 that is nothing but X 2 4 it is j 0.022 that is this one, this one that is X 2 4 that is nothing but X T 1. Similarly, for T 2 transformer T 2 it is X 3 5 right.

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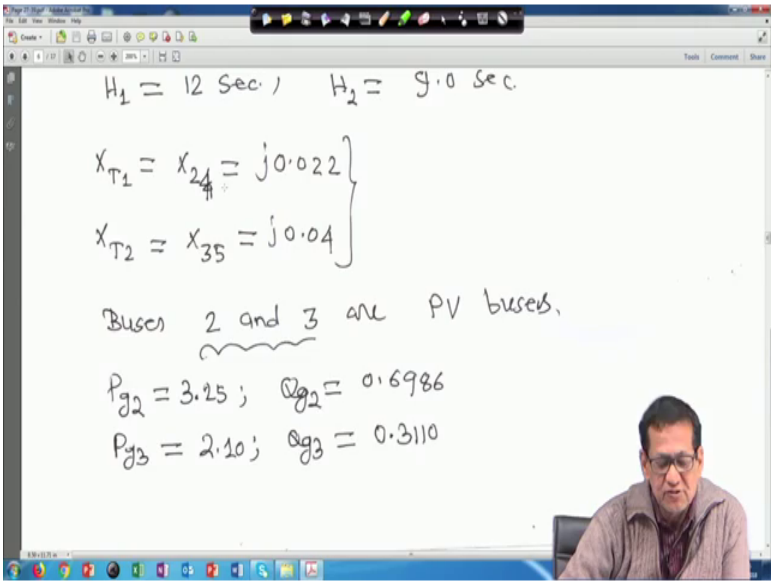

So, these two are given X T 1 is equal to X 2 or your X 2 4 and X T 2 is equal to X 3 5 that is j 0.04 all are in per unit right. So, buses 2 and 3 are p v buses right and p g 2 is given 3.25, p g 3 given 2.10 and as 2 and 3 are p v buses after solving this write that q g 2 is 0.6986 and q g 3.3110 right.

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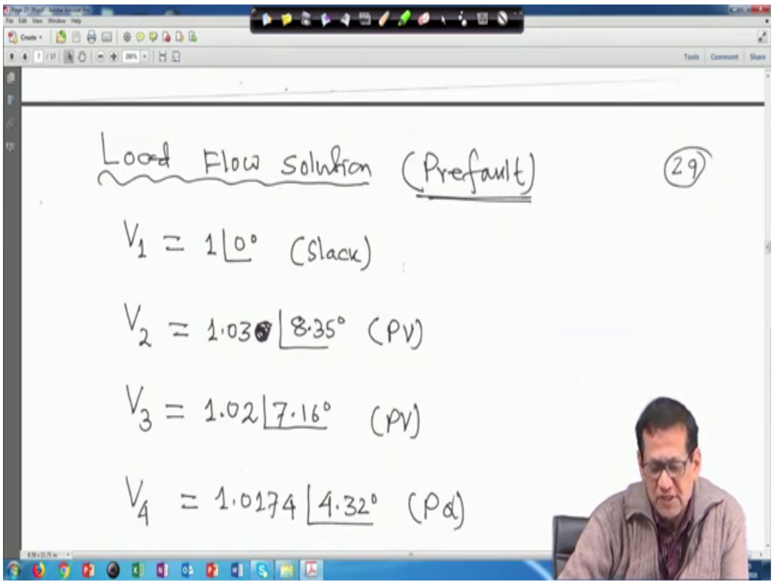

Now, load flow solution. So, these are the load flow solution for the pre fault condition, I mean you have to run the load flow and get. But for the assignment or exam purpose, the solution will be given because you know that that exam it is not possible to solve simulate or this that right. So, this solution will be provided to you. So, B 1 is equal to 1 angle 0 the slack bus B 2 is 1.03, angle 8.35 degree this bus to I told you it is a p v bus. So, voltage magnitudes are specified. Similarly, bus 3 also is a p v bus. So, it is 1.02 angle 7.17 degree p u that is p v bus and v 4 and v 5 that is 1.0174 angle 4.324 and 5 are P Q buses and V 5 1.0112 angle 2.69 degree right, these are the load flow solutions.

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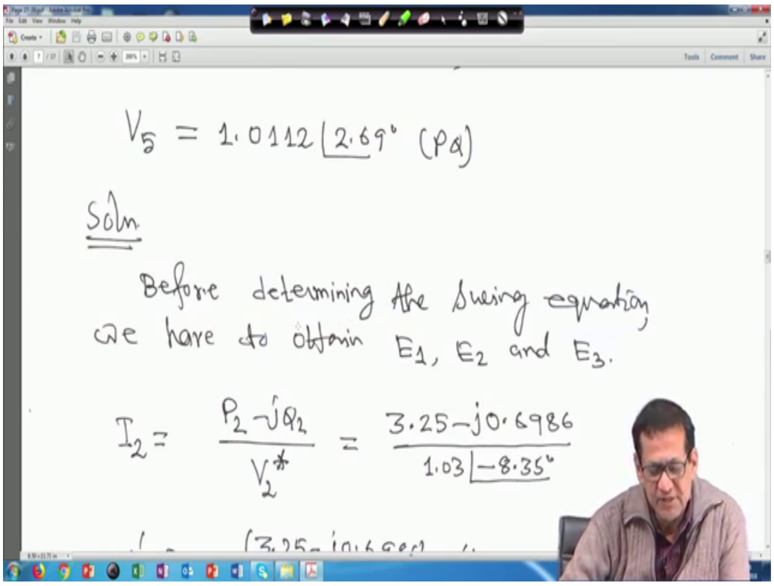

Now, this is given from that we have to find out that before determining the your swing equation, we have to find out the swing equation for those two machines. So, we have to obtain E 1, E 2 and E 3 right.

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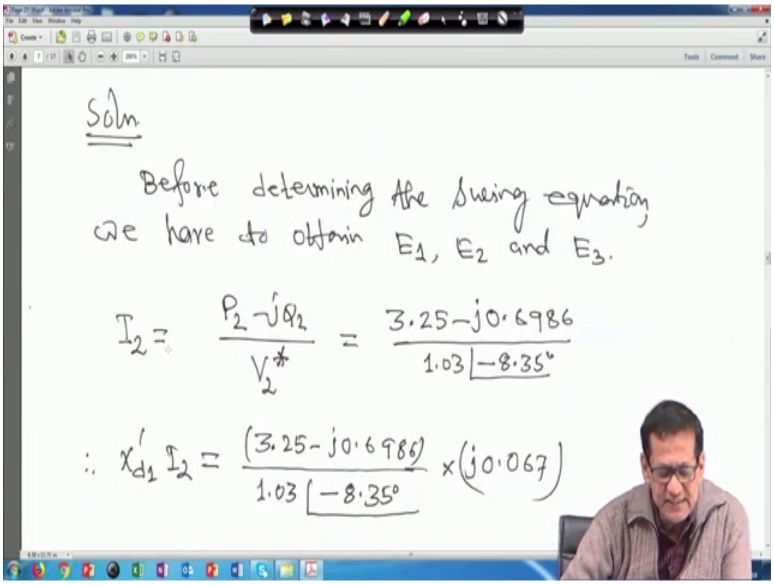

So, we know that a power into that current I 2 will be P 2 minus j Q 2 upon V 2 conjugate right because you have to find out E 1, E 2 as sorry E 2 and E 3 because E 1 is equal to V 1 is known that is 1 angle 0 right and therefore, P 2 and Q 2 you are all are given. So, all you have got from your load flow solution. So, you can find out what is the current I 2 in the current injection that k that is at your current injection right I 2. So, it is P 2 at the from load flow studies, you have got 3.25 minus j 0.6986 upon 1.03 angle minus 8.35 degree, right.

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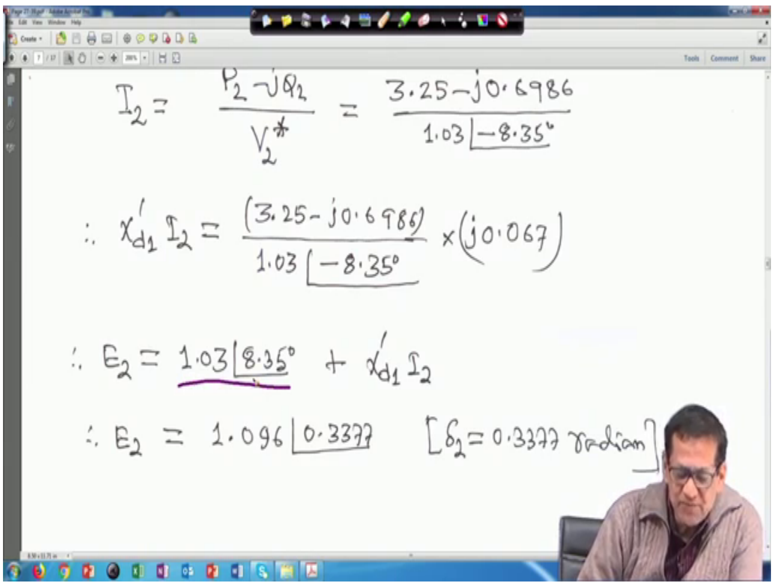

Also multiply both sides by x d 1 dash I 2 because if you go back to the diagram right, we have to complete this. This is actually bus 2 and this is your x d 1 dash right. So, we have to use that equation 9 that is why you are multiplying by x d 1 dash for ah by I 2 right. So, here, your x d 1 I 2 X d 1 dash I 2.

So, if you multiply by x d 1 dash I 2, it will be like this and if you simplify all these things you will get your E 2 is equal to, your E 2 is equal to that voltage is known 1.803 angle 8.35 degree that is your this voltage your just for a hold on this voltage that is your V 2 right, just hold on this is your V 2. If you come back to this diagram, if you come back to this diagram, this E 1 tilde this one.

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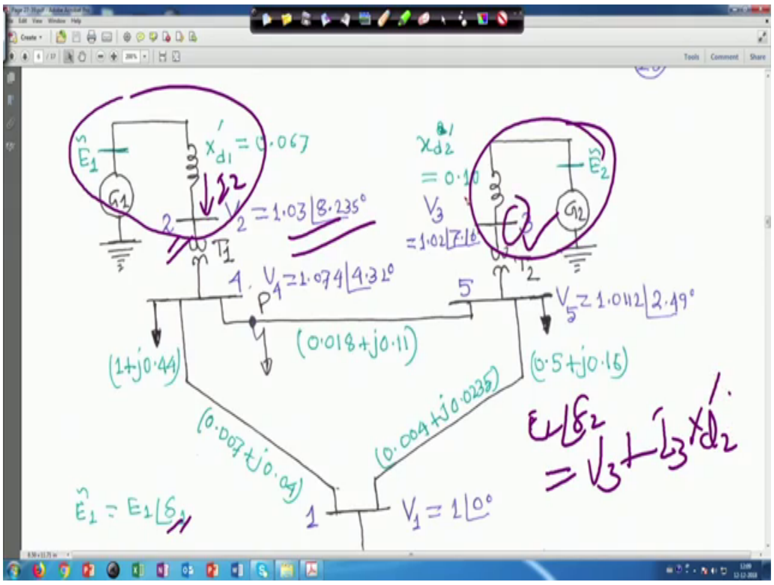

This one you see that, if you come back to this portion right. So, E 1 angle delta 1 right is equal to your this current injection here is I 2. So, your I 2 into X d I 2 into X d 1 dash plus this V 2 right V 2 is equal to 1.03 angle 8.235 degree. Similarly, if you come to this one actually here also, it will be E 2 angle delta 2 is equal to this, voltage V 3 this one plus here the current injection is I 3 into X d 2 dash because this is bus 3 right.

So, that same philosophy is applied here for computing that. So, here you will get if you simplify this one, you will get E 2 is equal to this much right. So, it will come 1.096, 0.3377 it is actually in radian not in degree I have written delta 2 in radian right.

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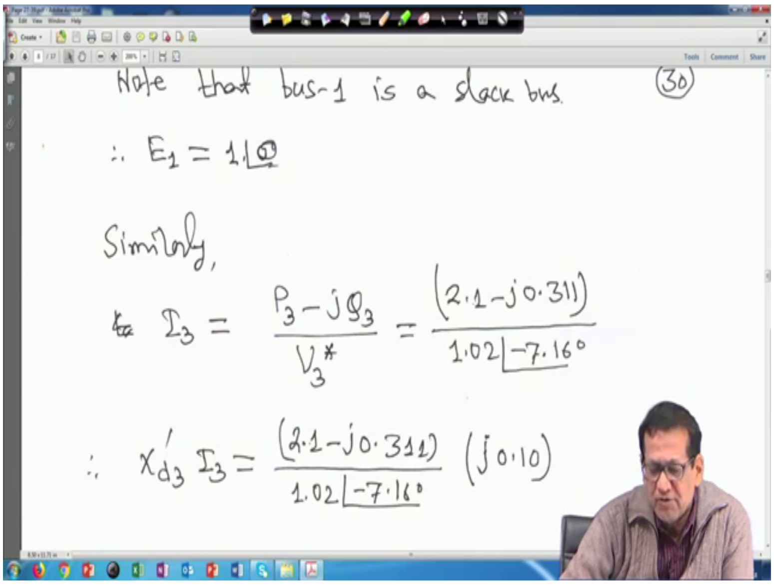

Note that, your E 1 is equal to 1 angle 0 degree because bus 1 is a slack bus and it is shown infinite bus no X d 1, X d 2 or X d 1, I do not know X d 1 dash there. So, it is E 1 is equal to simply 1 angle 0 degree right or radian, whatever it is

Similarly, for I 3 if you calculate it will be P 3 minus j Q 3 upon V 3 conjugate right. So, it is 2.1. So, minus j 0.311. So, it is 1.02 angle minus 7.16 degree that is your I 3 right. So, here also I repeat that E 1 is 1 angle 0 because bus 1 is a slack bus right and similarly you multiply X d 3 dash your I 3 right. So, if you come back to this bus 3 right, bus 3 same thing here that your this one this one will be make X d 3 just this bus 3.

So, that so I make it X d 3 not X d 2 right such that symmetry or what you call this with bus number this X d 3 dash this the number 3 will be maintained right. So, it is by mistake I have made an X d 2 you make X d 3 dash right.

So, otherwise you calculate X 2 also does not matter, only calculation should be correct.

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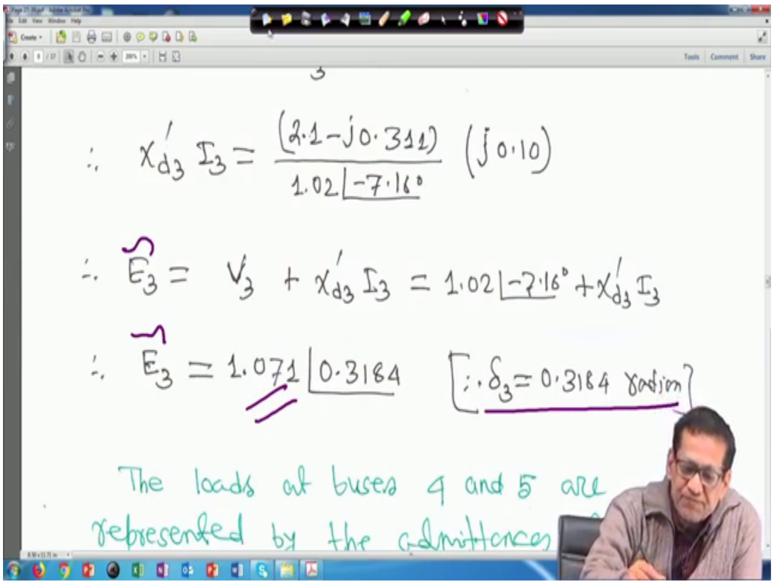

So, this one this one a when you do that you are E 3, that E 3 is equal to your V 3 plus X d 3 I think generally if we put like this right. So, basically it will be your what you call that you are whatever it comes say E 3 tilde I can put like this E 3 tilde. It is basically it is a pressure quantity. So, it is 1.071. After simply by applying this angle 0.318 for radian because delta 3 we have given it is a radian. So, this E 1, E 2 and E 3 easily you can compute if you know the current injection, if you know other parameters and of course, that pre fault case the load flow solution must be known to you then only you can compute all this right.

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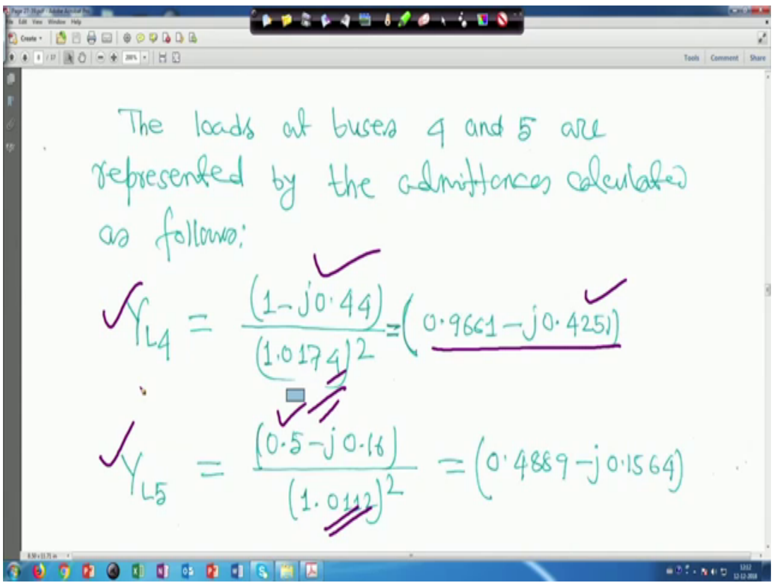

So, the loads at buses 4 and 5 are represented by the admittances calculated as follows. This one we have your what you call we have seen it before that at bus 4 the load is given 1 minus j 0.44 divided by the magnitude of your p 4 square. This already we have seen for the previous example and this is your load if you simplify that load admittance will become 0.9661 minus j 0.4251 right. Similarly, for bus 5 load is given 0.5 minus j 0.16 divided by this V 5 square V 5 magnitude. So, 10.0112 square right. If you do so, it will be 0.4889 minus j 0.1564. These two load admittances are known.

Now, you have to compute the y bus matrix per pre fault, fault and post fault condition right.

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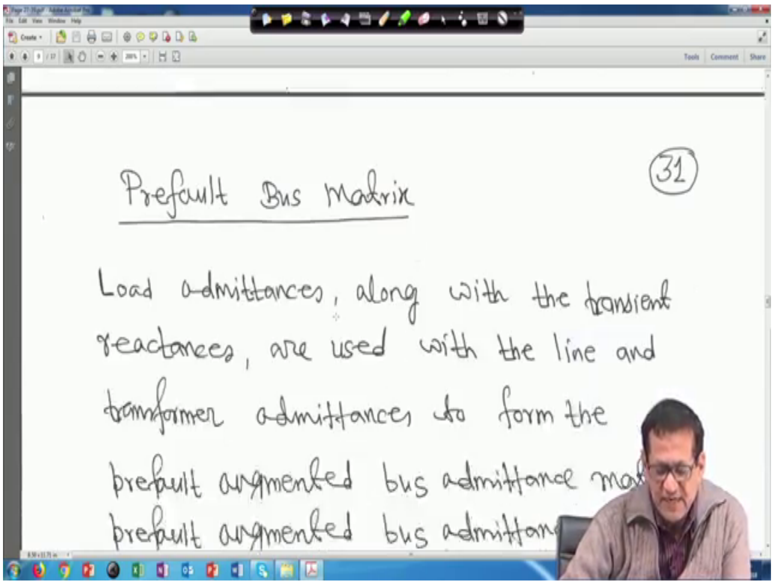

So, now prefault bus matrix right. So, load admittances along with the transient reactances are used with the tie line and transform admittances to form the prefault augmented bus admittance matrix right which contains that transient reactances of the machine.

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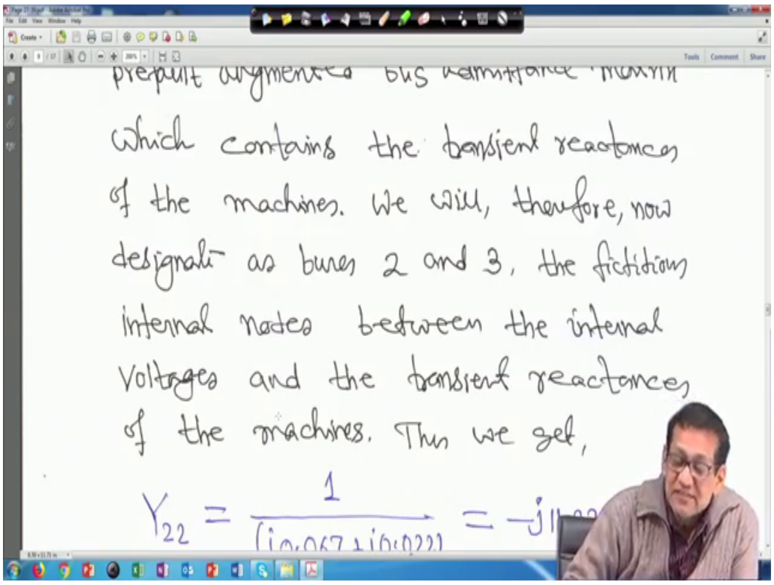

We will therefore, now designate as bus 2 and 3, the fictitious that is why 1 and 2 that internal machine things, we have not considered a term we are actually making it together.

So, we will therefore, now designate as bus 2 and 3, the fictitious internal nodes between the internal voltages and the transient reactances of the machine right.

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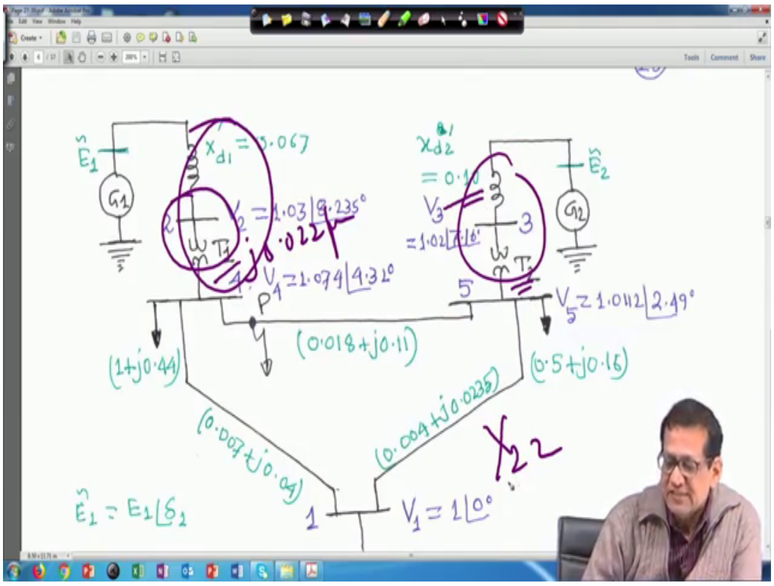

This will do; that means, that means, if we go back to the diagram if you go back to the diagram right, here, if you go back to the diagram that y 2 2, the transformer is actually j 0.022 right per unit.

So, all these two things will be added together right. So, you add 2 and take the reciprocal of this then you will get your y 2 2 right. So, same philosophy will be here also that whatever T 2 reactance is there, transformer T 2 will add this one and we will take the reciprocal of that such that we will get say y 3 3 right. So, we will come back to this thing, right

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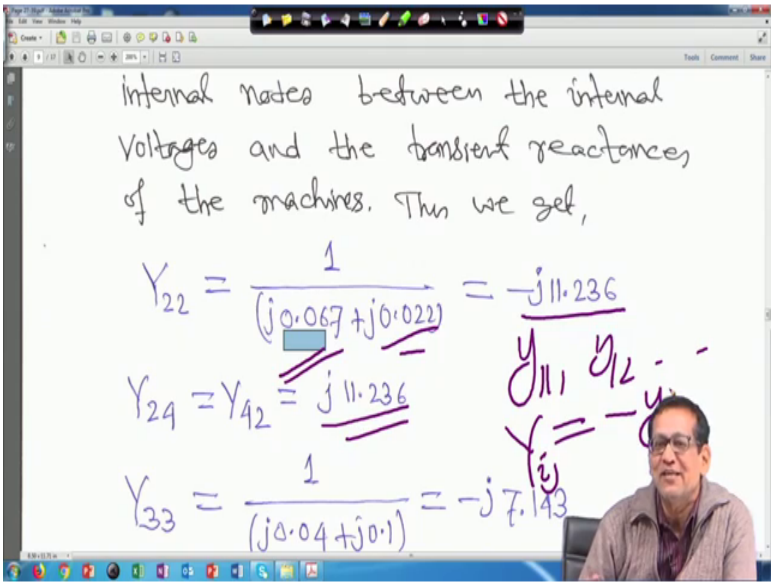

So, therefore, y 2 2 will be 1 upon your 0 j j 0.06 j 0.067 plus the transformer 1, it is coming actually minus j 11.236 right. And y 2 4 will be y 4 2 it will be plus j 111.236. So, we know that we calculate no small y 1 1 small y 1 2 like this and capital Y whatever it is i j is equal to your minus small y i j, this we know right and in diagonal 1, we just add all the small ones.

So, diagonal will be always with a negative sign right and your half diagonal 1 will be minus of small y y is minus. So, it will be positive sign right.

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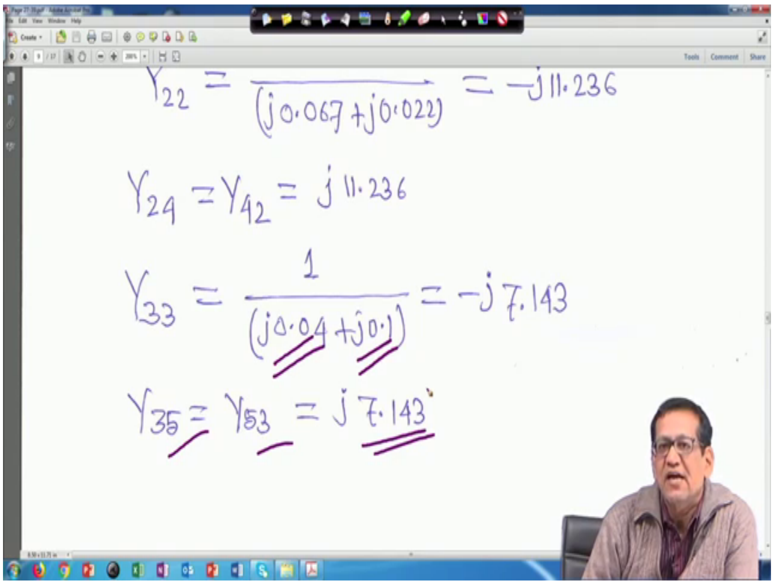

So, y 2 4 is equal to y 4 2 you will get j 11.236. Similarly, y 3 3 will come that your this is your j 0.04 that is a transformer thing plus that your that X d 3 dash right. So, it is coming minus j 7.143. So, y 3 5 is equal to y 5 3 5 3 will be j 7.143 right. This you know from the load flow study is how to construct that admittance matrix.

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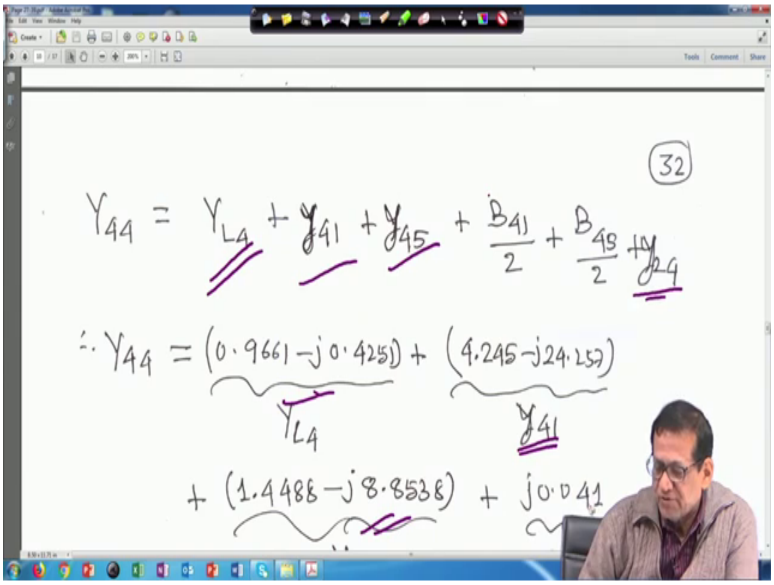

So, now when you calculate y 4 4 all should be added right. So, this is that load admittance then y 4 1, small y 4 1, small y 4 5, then half B 4 1, half B 4 5 by 2 then plus small y 2 4. If you do so, if you do so, so it will be your this is your y 1 4 it is marked here, this is y 4 1, this is y 4 5 and this is half B 4 1 other things just let me move little bit up right.

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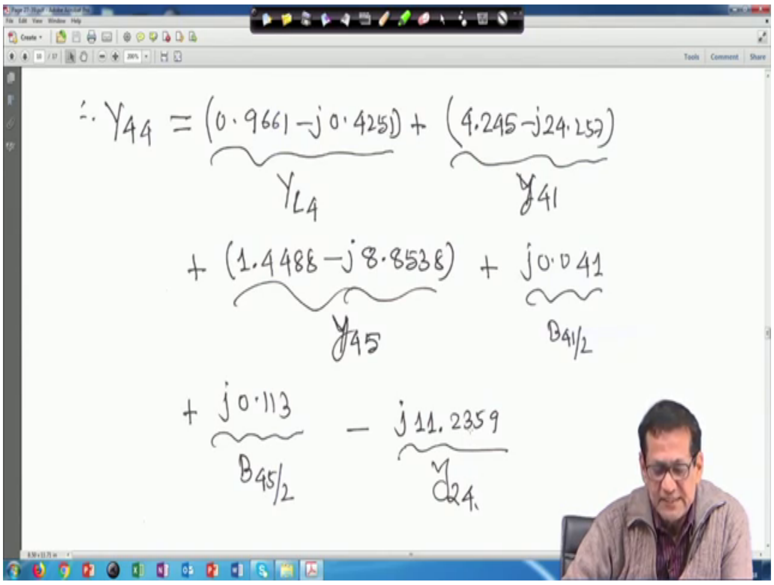

And this is your half B 4 5 that is j 0.113 and this is your minus j 11.2359, there small y 2 4 right. So, if you I mean whatever it comes if you add together you will get, y 4 4 will be 6.6598 minus j for 44.617, right.

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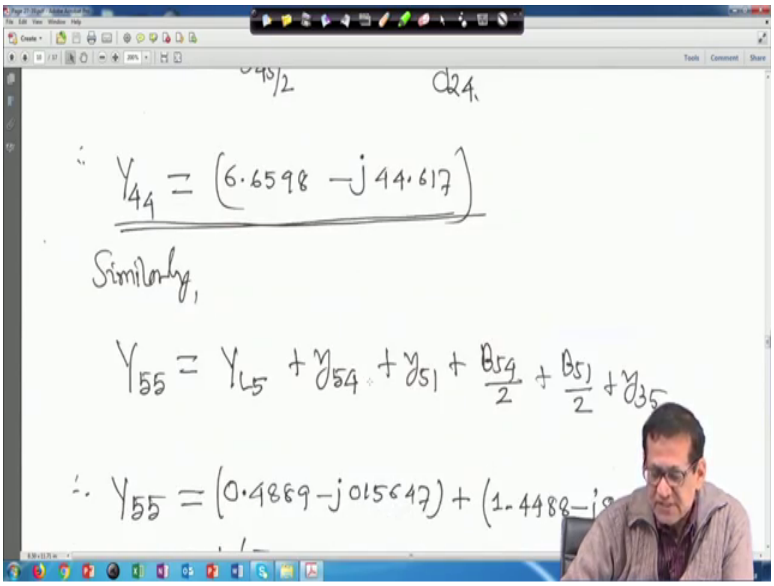

Similarly, similarly y 5 5 you calculate you know how the only thing is that that your load admittance that is how we take as a shunt admittance right that has to be added. That is why it is y l 5 it is there we have already computed.

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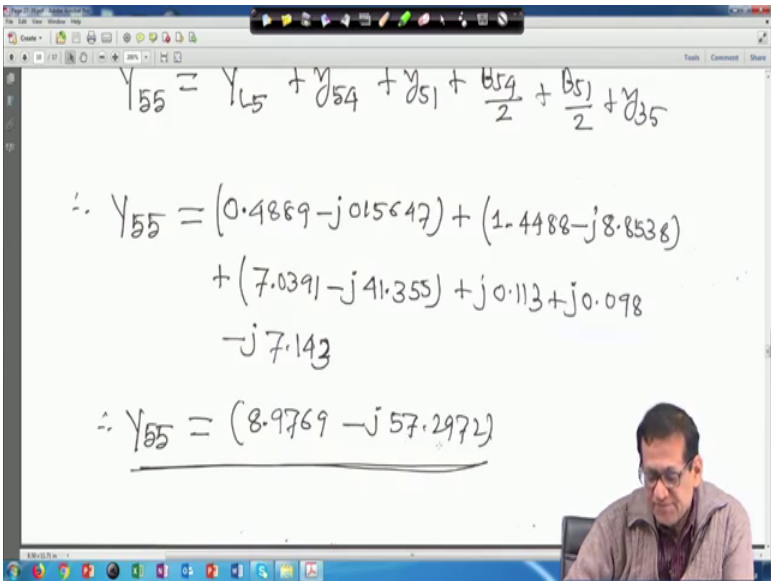

If you add all, you will get y 5 5 will be your 8.9769 minus j 507.2972 this is y 5 5 right.

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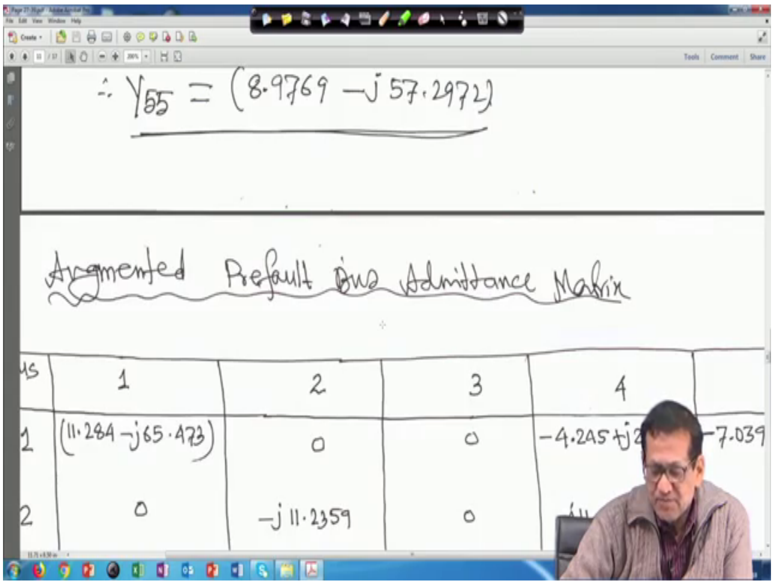

And augmented prefault bus admittance matrix, right.

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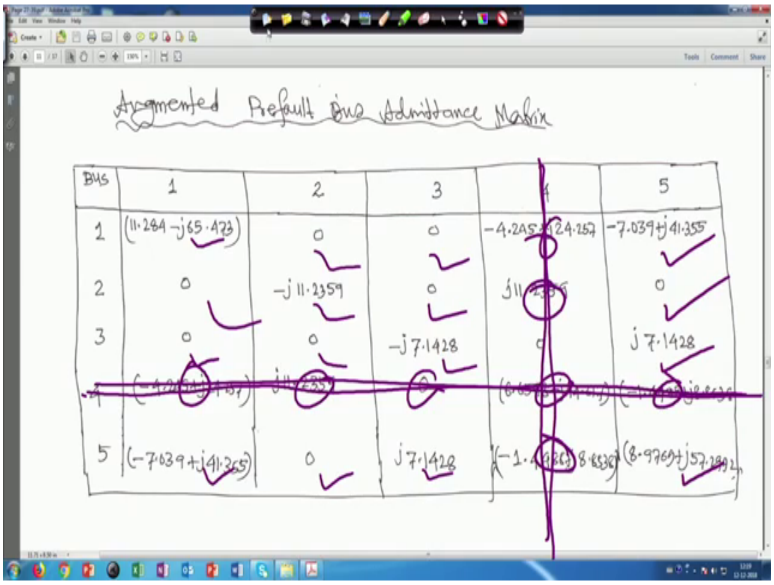

That is, that is your it is a 5 into 5 matrix.

So, this is your just hold on let me reduce the size right. So, this is your bus admittance matrix. So, it is a it is a 5 into 5 matrix right and all and their are all elements are sold right. This is your pre fault admittance matrix, right.

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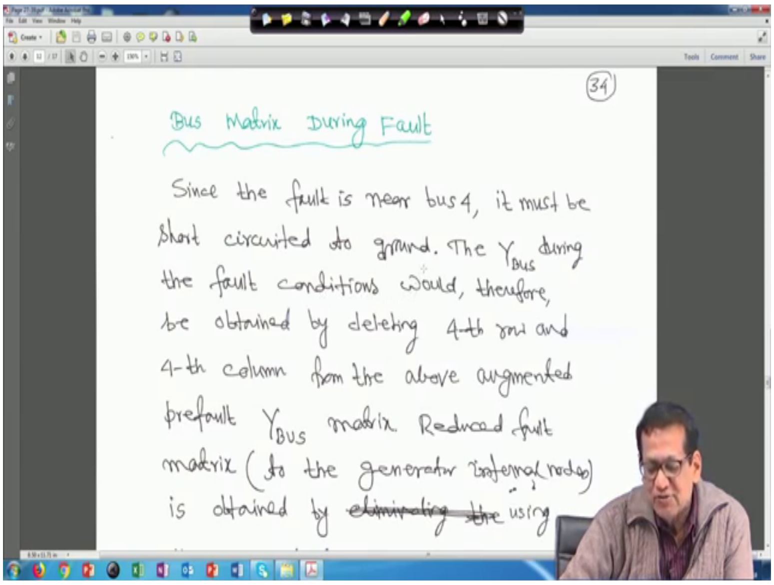

Next is that bus matrix during fault right. Since, the fault is near bus 4. So, it must be sorry, it must be short circuited to ground right it is a 3 phase fault the y bus during the fault condition would therefore, be obtained by deleting the fourth row and fourth column from the above augmented prefault y bus matrix. So, bus as occurred 3 phase fault has occurred at bus four. So, what we will do is that 3 phase bus. So, this row should be eliminated and this column should be eliminated, right.

So, finally, it will come down to a your what you call 4 into 4 matrix. So, this element, this element, this element will be retained right, this one, this one, this one and this one will be retained. This one, this one, this one will be retained and this one, this one, this one and this one will be retained. So, this will go all will be 0 0 0, all will be 0 0 0 during fault right; that means, in general if you want to make say we want to make it as 5 into 5 that in that case this will be 0, this will be 0 0 0, this will be 0 0 and 0, right.

So, all these things you have to what you call fourth row and fourth column, you have to eliminate.

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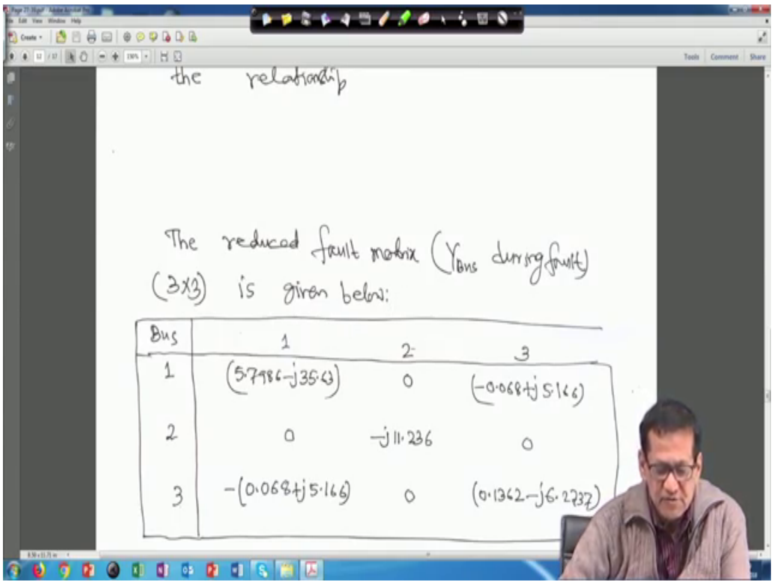

So, if we do so, then the reduced fault matrix that during fault right. So, it will be it is actually what happened that, it is a reduced fault matrix reduced fault matrix means that just just I am making it here because all these calculations are not shown, then it will be too lengthy right.

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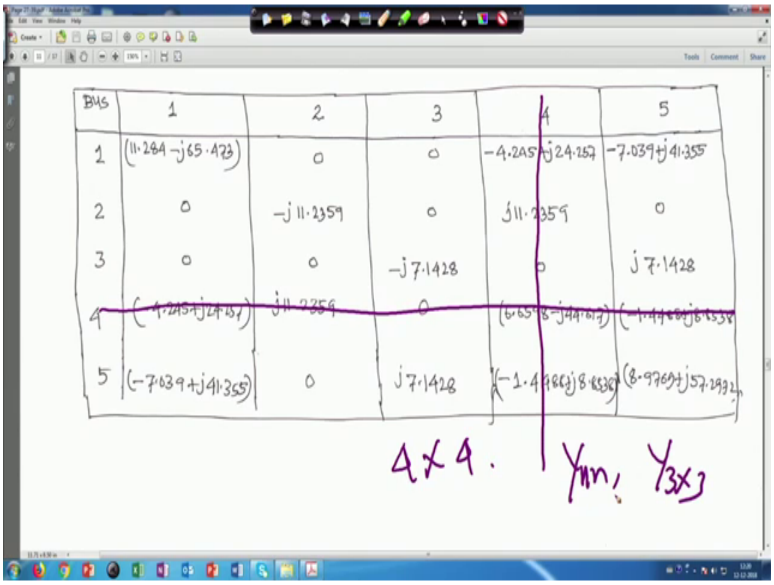

So, only thing is that you will make this will eliminate, this will eliminate right. So, this will not be there. So, ultimately it will be a 4 into 4 matrix right, it will be a 4 into 4 matrix right, but you have a 3 machines right. So, in that case you what we will do. So, this will be 4 into 4 matrix. So, Y n n right it will be actually, Y 3 into 3 right Y n n, Y n r, Y r n, Y r r right after that same philosophy that to the Y matrix reduction that has been done.

So, that is why this this your what you call that Y reduced matrix will be 3 into 3 during fault because 3 machines are there. So, we have reduced this one to your 3 into 3 actually during fault it is 4 into 4 right, but Y n n, n is 3 because number of machine is 3. So, it is 3 into 3 Y n n, then n r r is 1 right. So, that your 3 into 1, then 1 into 3 then y r r right only one element.

So, if they after that you reduce it, that using that formula y n n minus your what you call Y n r then Y r r inverse into y your what you call r n right. So, after this reducing this we are getting this one, but it has to be a symmetric your so, what you call symmetric matrix, it is a symmetric matrix right. So, it is a symmetric matrix a 1 3 3 1, 1 2 2 1 and your 1 2 3, 1 3 2 right it is a symmetric matrix. If you do not get a symmetric matrix, then somewhere something has gone wrong in the calculation right

So, this is actually reduced fault matrix that is 3 into 3.

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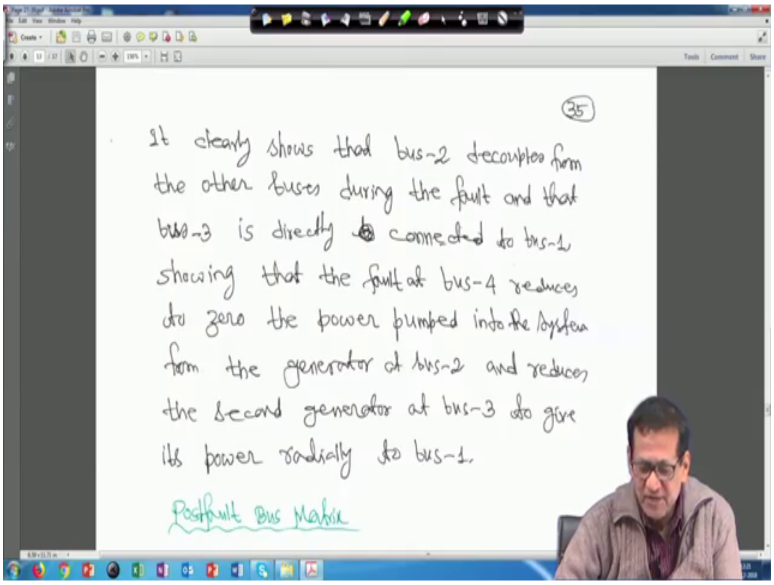

Now, when fault was cleared that line 4 and 5 that your what you call that post fault bus matrix that that is removed.

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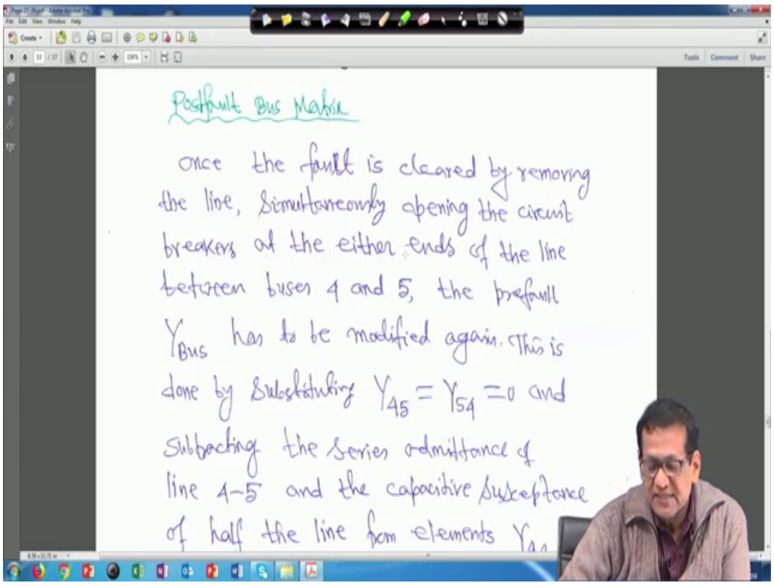

Now, once the fault is cleared by removing the line simultaneously opening the circuit breakers at the either ends of the line between buses 4 and 5; that means, you have to reconstruct the y matrix.

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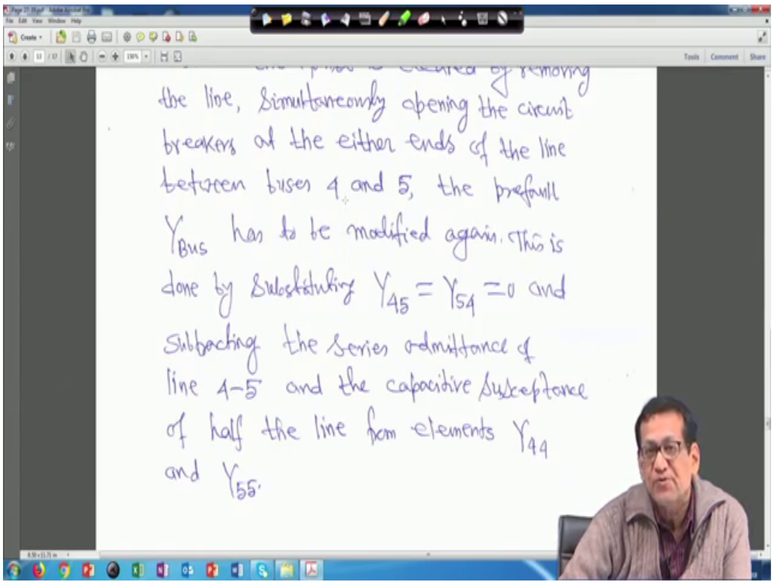

So, if 4, 5 is open, then y 4 5 will be y 5 4 will be is equal to 0 and accordingly you have to modify the y bus matrix right.

So that means, that your you are subtracting the series admittance of line 4 5 and the capacitive susceptance half of the line from elements y 4 4 and y 5 5. So, this will be change first thing is y 4 5 is equal to y 5 4 will be 0 and second thing diagonal element y 4 4 and y 5 5 we have to change.

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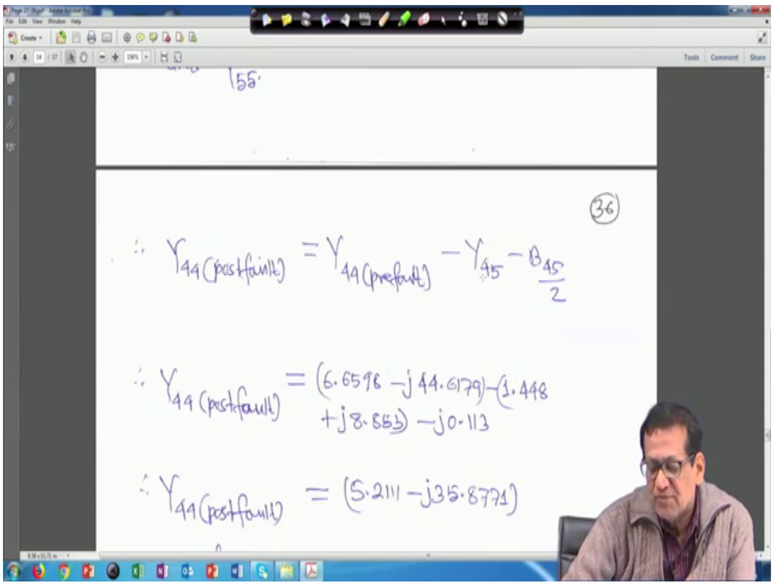

So, that is y 4 4 post fault will be y 4 4 prefault minus y 4 5 minus B 4 5 by 2.

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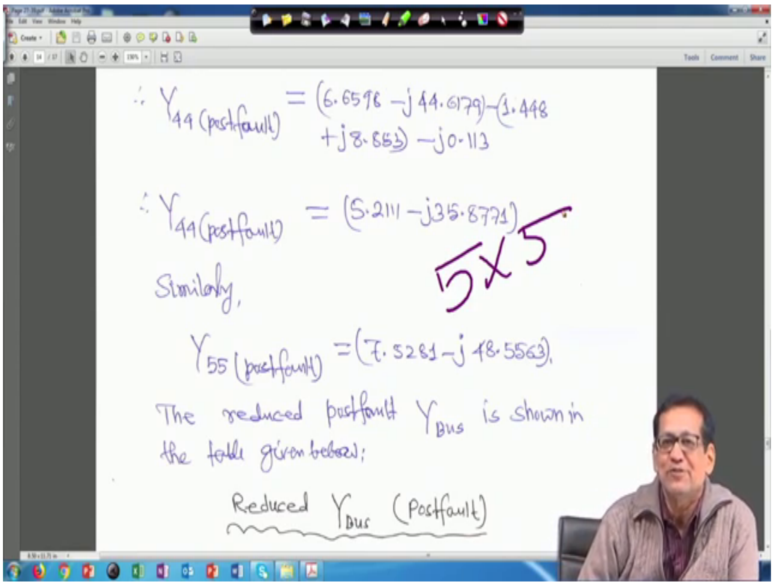

Whatever it comes, that is actually 5.2111 minus j 35.8771, right.

Similarly, that y 5 5 post fault, you will get 7.5281 minus j 48.5563 right. Now, the reduced you are what you call post fault bus is shown in the given thing actually this matrix actually that post fault matrix actually your 5 into 5 matrix right. After that, you are reducing this. So, in that case for same philosophy you follow that Y n n that is 3 into 3 matrix you just partition, you just partition and then you reduce it to your 3 into 3 matrix do all these things are not shown because it is a little bit lengthy right. Only I have shown the reduced y bus for 3 into 3 1 it is 5 into 5, then you make it 3 your y n n 3 into 3 y n r 3 into 2 2 into 3 and that was Y r r it is 2 into 2 right.

So, accordingly, you just you just you your what you call you just calculate and just and you will get this one right.

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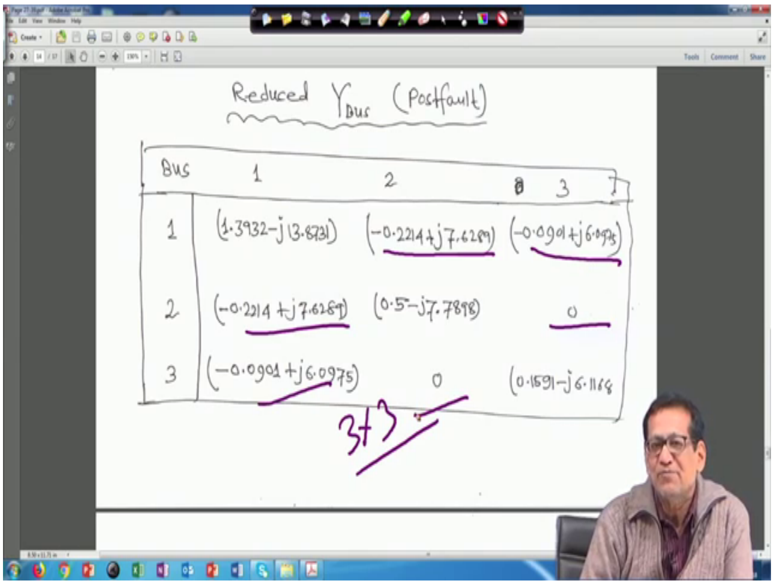

So, this is your reduced matrix. So, if you look if you look here also that this one and this 1 y 1 2 y 2 1, it is a symmetric matrix then y 1 3 y 3 1 and y 2 3 and y 3 2 there are all same right. So, it is actually 3 into 3 that reduced matrix because you have a number of machines. So, accordingly you can reduce this one right, this already we have seen before.

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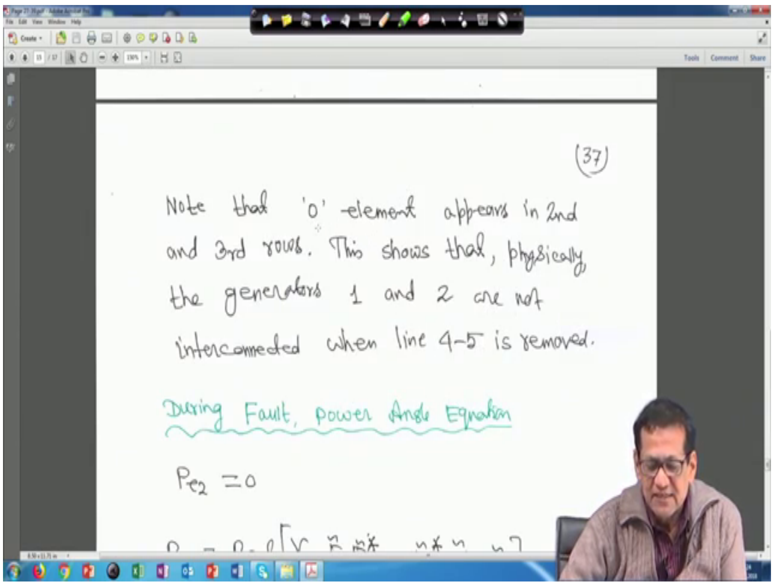

After this, after this note that that 0 element appears is second and third rows right. This shows that physically the generators one and 2 are not your interconnected when line 4 and 5 is removed. So, if you if you look into that, the 0 element appears in second and third rows right. If you look into that this, this your y 2 3 and y 3 2 both are 0 right see; that means, the generators one and 2 are not interconnected when 4 and 5 is removed right.

So, from that it is it is some kind of you know physical interpretation looking at this looking at this matrix right.

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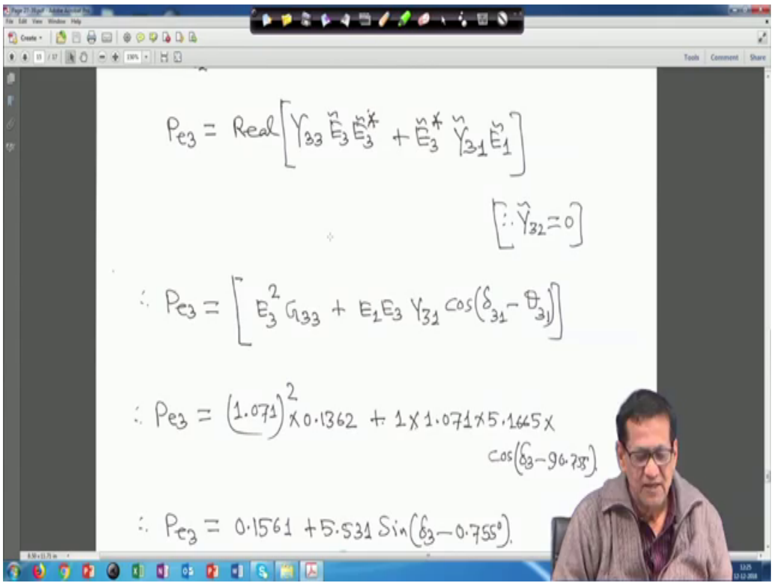

So, now, during fault, the power angle equation so, fault as your what to call P E 2 will be is equal to 0 right during fault right because if you go back to this diagram, if you go back to the if you go back to this diagram right, just hold on here because fault has occurred actually fault has occurred at bus 4 right and this is your generator one right.

So, basically P E 2 will be equal to 0 right. So, just hold on. Let me go down here right. So, during just just just amplify this one now. So, P E 2 is equal to your 0 right and P E 3 that real of y 3 3, then your E 3 tilde E 3 conjugate plus E 3 tilde then y 3 1 tilde, E 1 tilde I mean all are complex quantity and y 3 2 is equal to 0. So, you can a real part of this one will be basically P E 3. So, you know all these from your load flow studies right. So, you can easily compute.

So, basically it will be E 3 square g 3 3 because real part we are writing plus E 1 E 3 y 3 1, then cosine delta 3 1 minus theta 3 1, right.

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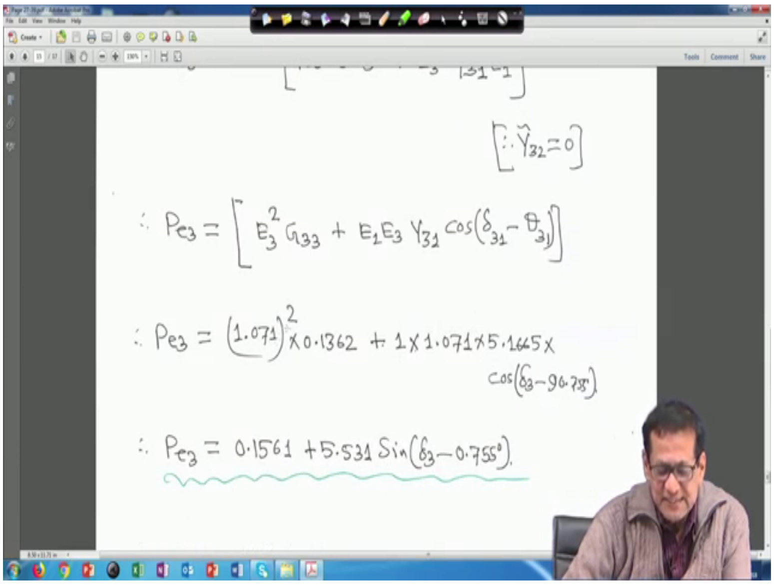

Therefore, P E 3 is equal to all these values substitute E 31.071 square into g 3 3 point 1.362 plus your one into 1.071 because E 1 is 1 E 3 is this much right and then cosine of delta 3 minus the theta 3 1 will be 97 point your what you call 90.755 degree that is the angle of y 3 1 right. So, that is theta 3 1. So, if; that means, P E 3 is 0.1561 plus 5.531 sine delta 3 minus 0.755 degree right.

So, now post a post fault power angle equation.

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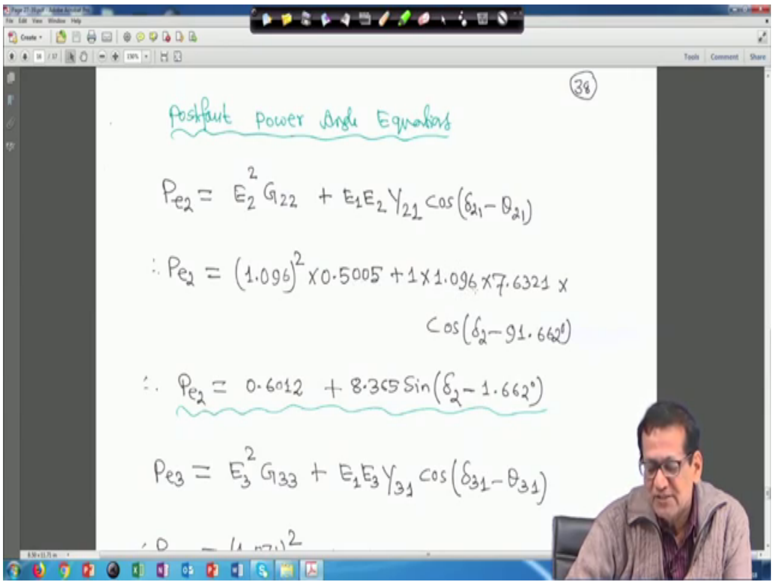

So, post fault case directly you can write when fault is cleared right. So, that is your that you have to use that last matrix 3 into 3 right. So, P E 2 E 2 square g 2 2 plus E 1, E 2 y 2 1 cosine delta 2 1 minus theta 2 1. So, from that you substitute P E 2 is 1.9096 square plus sorry into 0.5005 plus one into 1.096 into 7.6321 into cosine delta 2 minus 91.662 degree right.

So, if you come back to this right, if you come back to your this one right. So, whenever you will I mean computing this one, you please take those you are what you call take these values I mean these G values and your B values right whatever it comes. So, in this case in this case your this one it is 7.6321 right, whatever it is y 2 1 into your cosine delta 2 minus 91.662 degree, that is angle of y 2 1.

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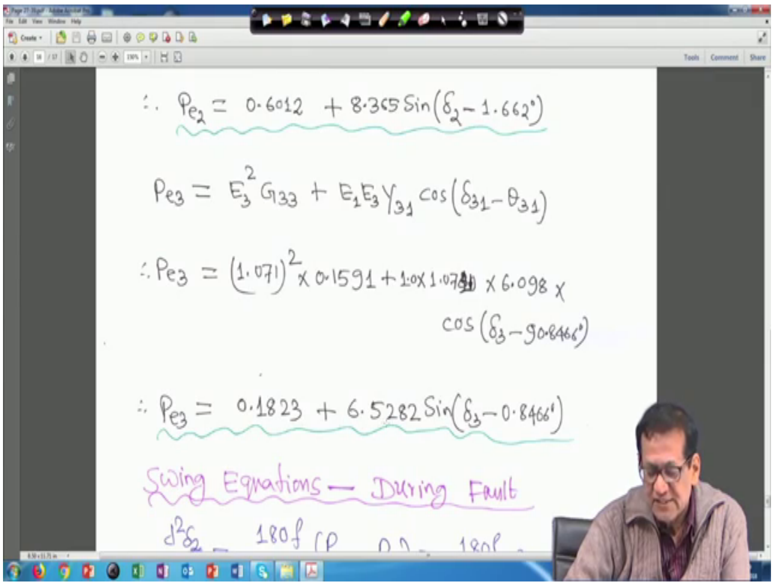

So, you will get P E 2 is equal to 0.6012 plus 8.365 sine delta 2 minus 1.662 right

Similarly, when you will make it this one, P E 3 when you will make it is E 3 squared G 3 3 plus E 1 E 3 y 3 1 that is your then cosine delta 3 one minus your theta 3 one right. So, in this case you substitute all these values, all these values right. So, you will get your what you call that 0.1823 plus 6.5282 sine delta 3 minus 0.8466.

Now, in this case you are what you call that you are Y 3 1 and your y 2 1 or Y 1 2 right. So, y 3 1 when you will go to this Y 3 1 and y 1 2, you will only take the magnitude of this one because it is magnitude of y right. So, when you do this that you will get this P E

3 equation like this right. So, P E 2 P E 3 equations we have got your post fault condition.

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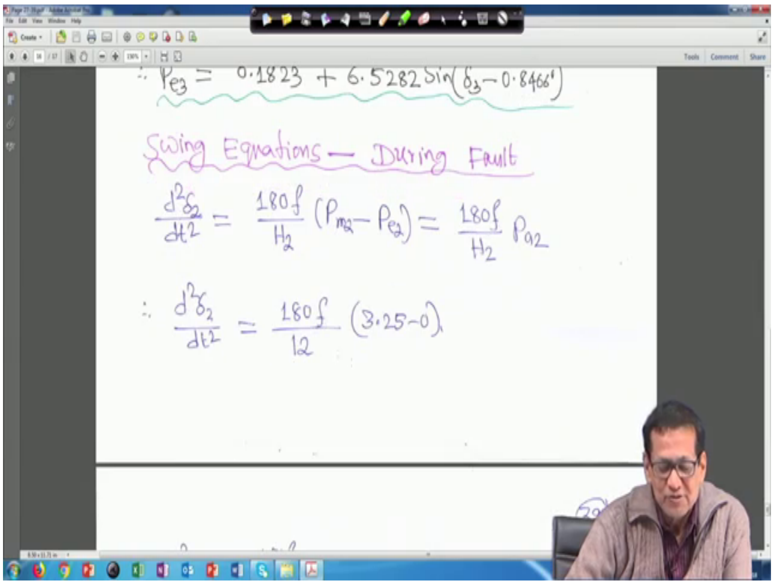

Now, swing equation during fault. So, we know that d square delta upon d T square 180 f upon h 2 p m 2 minus P E 2 is equal to P E 2 is 0 during fault right p E 2 is 0. So, it will be 180 f upon h 2 we are writing P a 2 the accelerating power, right. So, d square delta upon d T square basically 180 f upon 12 and it is basically 3.25. You go will go back to that your p g 2, right.

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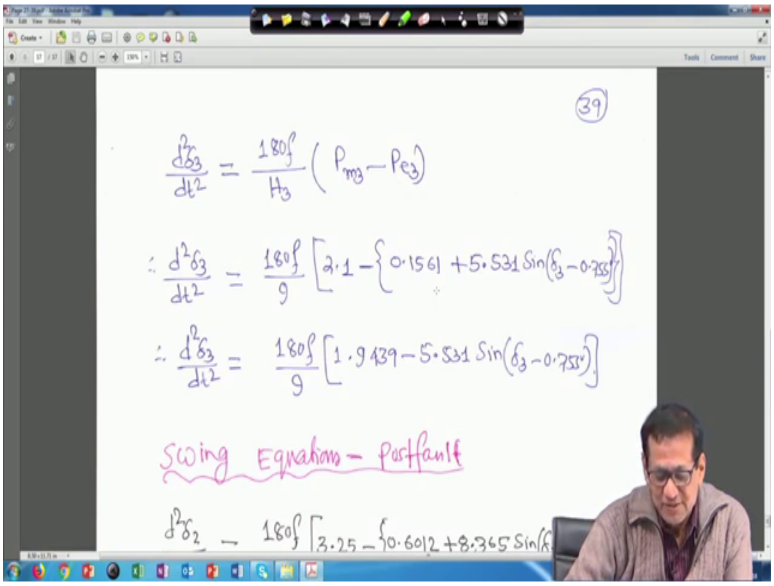

And similarly, your d square delta 3 upon d T square it is 180 f upon h 3 p m 3 minus p 3 h 1 was h 2 was 12 right. And similarly, h 3 was 9. So, 180 f upon p m and p m 3 is 2.1 right because we are assuming that it is a lossless turbine right.

So, 2.1 and minus p E 3 whatever you have computed.

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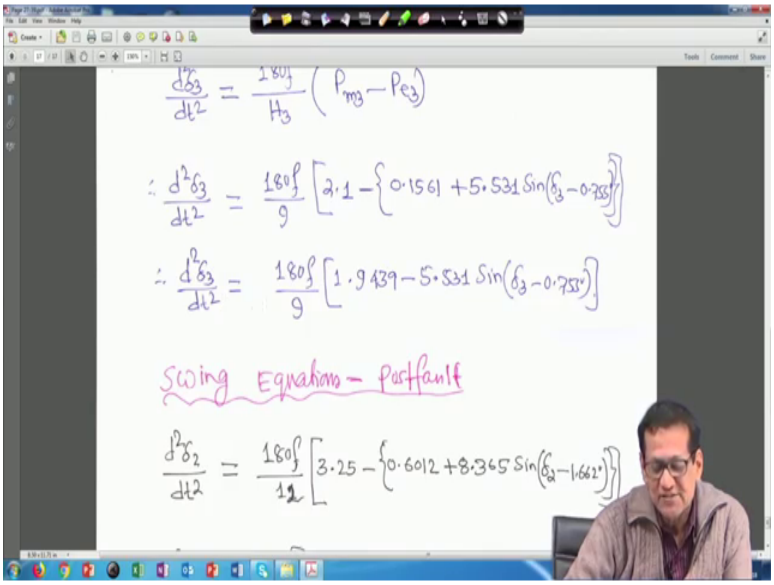

So, you will get your d square 3 the d square delta 3 upon d T is there d square delta 3 d T square is equal to 180 f upon 9 into 1.9439 minus 5.531 sine delta 3 minus 0.755 degree right and ah.

Thank you very much, we will be back again.