Power System Analysis
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Lecture - 55
Power System Stability

So, here we have that that numerical is not yet completed. So, just we have seen that I a1 is equal to V f 0 the pre fault voltage right divided by your Z 1 plus Z 2 plus Z 3 and this is an equivalent circuit right.

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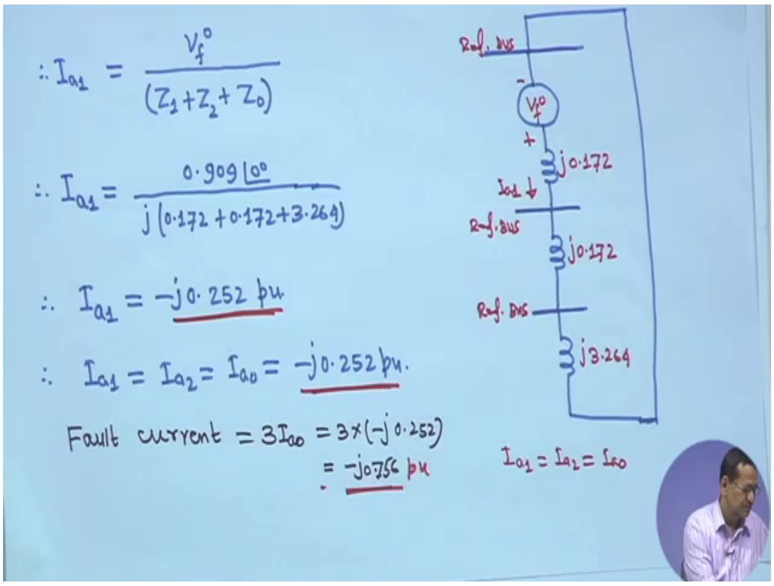

So, I a1 is equal to 0.909 angle 0 degree divided by j in bracket all the your positive negative and 0 sequence impedances here it is reactances because R is not there. So, the I a is equal to minus j 0.252 per unit and I a1 not shown here I a1 is equal to I a 2 is equal to I a 0 because it is a series circuit. So, I a1 is equal to I a 2 is equal to I a 0 that is minus j 0.252 per unit. Therefore, fault current is equal to 3 I a 0 this we have seen our before. So, is equal to when we are deriving all sort of your what you call that circuit connection for line to ground double line, line to line and double line to ground fault.

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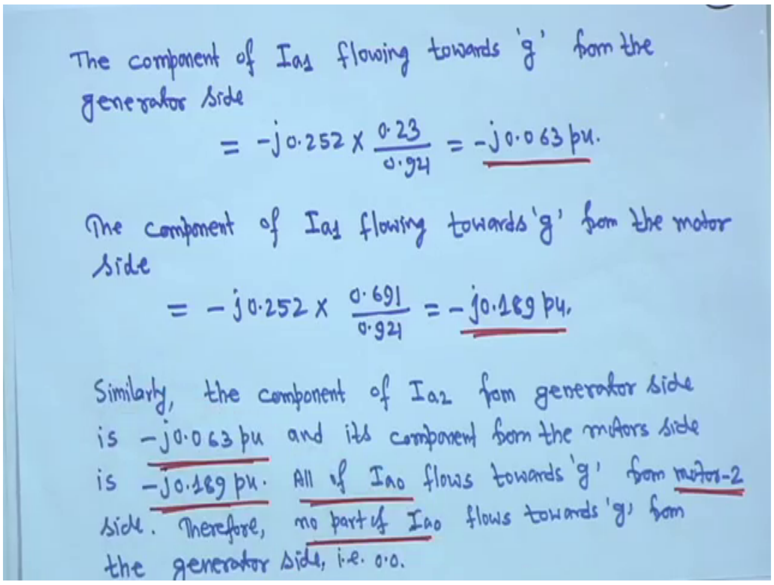

So, fault current is equal to 3 I if I recall this equation number perhaps 7 right is equal to 3 in to minus j 0.252 that is minus j 0.756 per unit. So, this is the fault current now if you see this one that component of I a1 flowing towards g; that means your this is a your what you call a parallel circuit, this equivalent impedance is this one for positive sequence this equivalent impedance this side is this.

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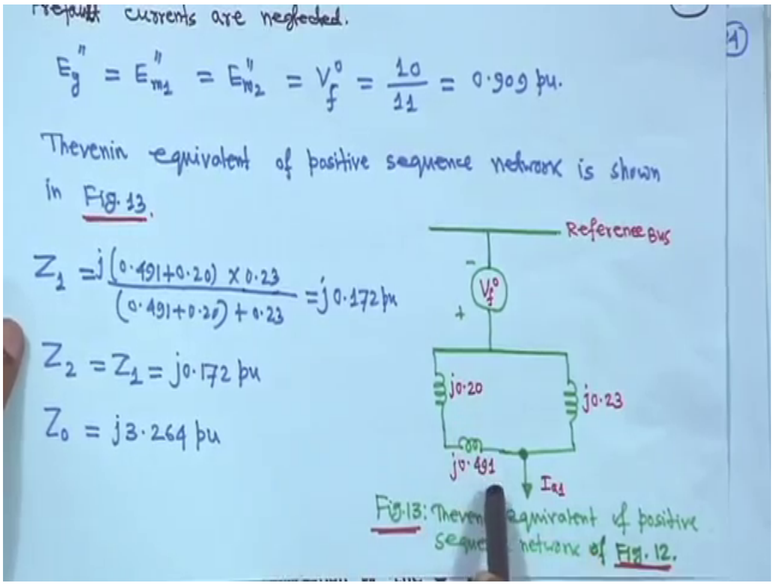

So, this is j 0.23 and this side is j 0.20 and j 0.491. So, this is equivalent to these 2 are parallel right.

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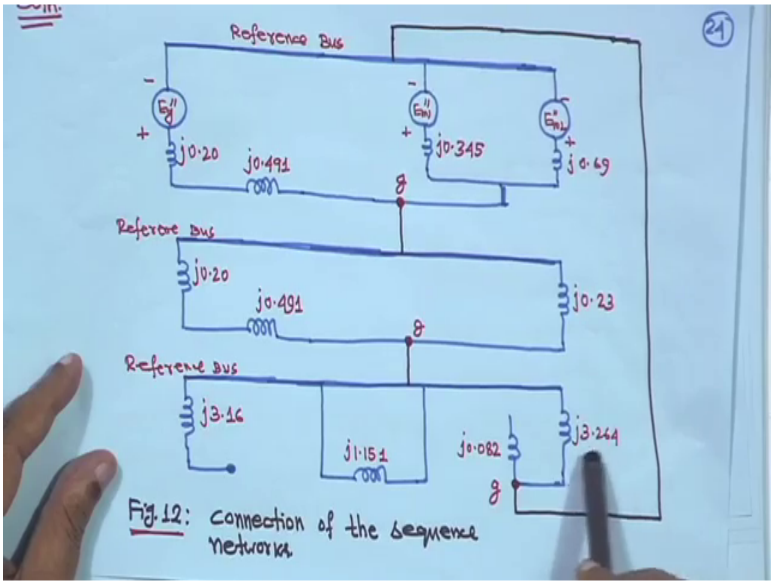

So, equivalent we have taken this one out as pre fault voltage. So, parallel of the these 2 thing here it is given here, this point j 0.345 and j 0.69. So, that is j 0.23 and this side is your j 0 0.20 0.491. So, we are writing the component of I a1 flowing towards g from the generator side.

That means this is your I mean that component of I a1 that is flowing from this generator side towards this point g right it is a parallel circuit. So, current accordingly current will be divided. So, this one actually minus j 0.252 in to 0.23 up on 0.921 that because this is your this side this equivalent of these 2 motor reactances is 0.23 right therefore, this is coming actually minus j 00.063 per unit.

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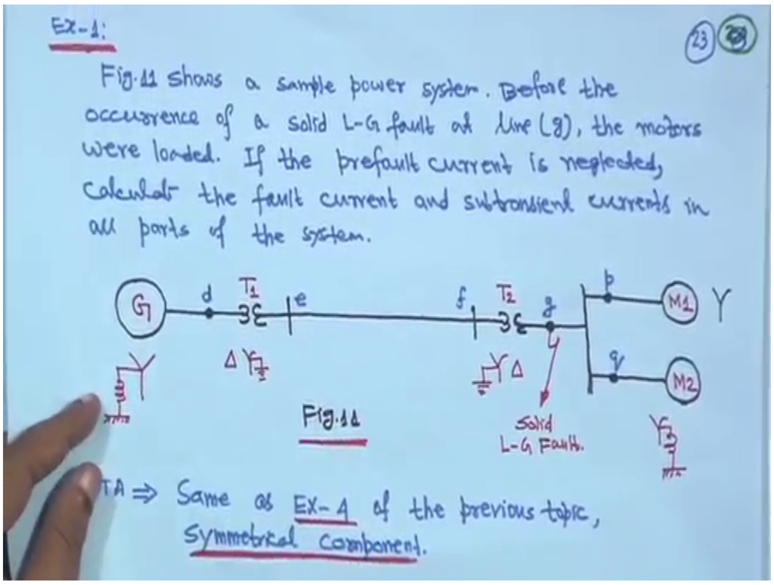

Now component of I a1 flowing towards g from the motor side; that means, that means from these 2 motors are there which from motor side how much current is flowing to the g; that means, right. So, in that case it will be your minus j 0.252 in to 0.691 up on 0.921 minus j .189 p u. So, this is this, now similarly the component of I a 2 from generator side is same because this negative sequence it is same only the voltage sources are not here, but this is same and, but there you are for your negative sequence reactances all are same therefore, the component of I o 2 from generator side is minus j 0.063 per unit and its component from the motor side is minus j 0.189.

Same as before identical right, but all the I a 0 flows towards g from motor 2 side because motor 2 in this diagram the motor 2 actually is your what you call that is grounded and this is ungrounded star connected and ungrounded, but right therefore, all of I a 0 will flows through towards g from motor 2 side therefore, no part of I a 0 flows towards g from the generator side that is 0; that means, if you look at the diagram then this is the 0 sequence network right whatever things will come it will be like this and finally, it is j 3 0.260, but if you look at the generator side this is isolate there is an isolation. So, no 0 sequence current can flow from the generator side; that means, there is that means, that no part of I a 0 flow flows towards g from the generator side that is it is 0 0.0, in that case now the fault current from the generator towards g now we know I a1, I a 2 I, a 0.

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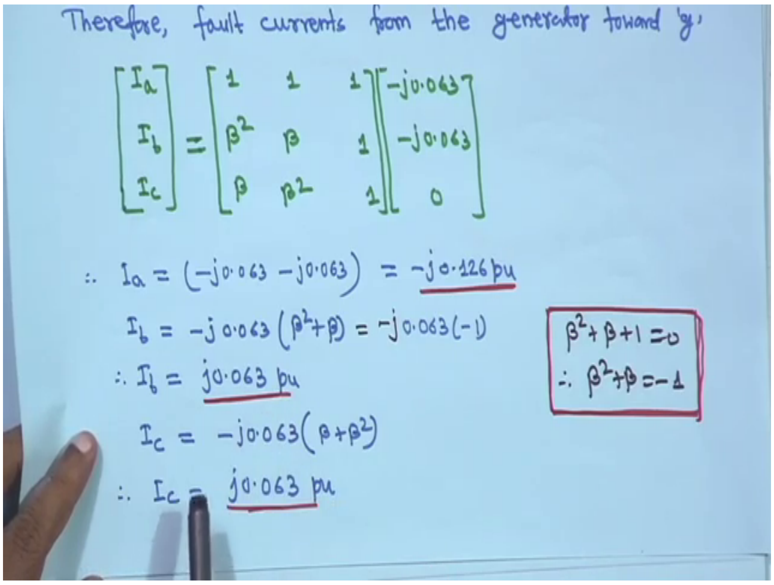

Therefore, fault current from the generators towards g we know I a, I b, I c equal to 1 1 1 beta square beta 1, beta, beta square 1 this is I a1, I a 2 and from the generator side no 0 sequence current. So, it is 0 just I told you it is 0. So, if you simplify then I a will become minus j .126 per unit because if you multi this this is your this one you are what you call I a is equal to this 1 in to this one this 1 in to this 1 in to 0, minus 0.126 per unit. Now I b is equal to take where this is beta square in to this plus beta in to this. So, it is minus j 0.063 in bracket beta square plus beta, but beta square plus beta plus 1 is equal to 0 we know that. So, beta square plus beta is equal to minus 1.

So, it is I b is equal to j 0 0.063 per unit and I c is equal to minus j 0 again same as before 0.063 in bracket beta plus beta square which is minus 1 therefore, I c is equal to j 0.0063 per unit. This is the fault current from the generator side similarly fault current from the motor side from the motor side I a, I b, I c same as before 1 1 1 beta square beta 1 and beta beta square 1.

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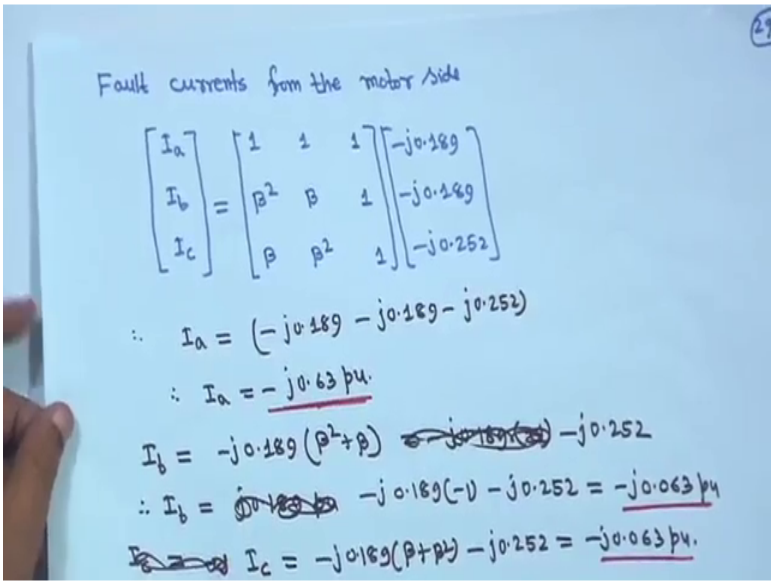

So, this is your I a1 from motor side then I a 2 right and this is your that I a 0 minus j 0.252. So, in that case your if you simplify I will become minus j 0.63 per unit, similarly I b will be minus j 0.189 look, I told you from the your what you call from the motor side that I a 0 is equal to minus j 0.252. Therefore, I a is equal to minus j 0.63 per unit similarly I b is equal to minus j 0.189 in bracket beta square plus beta that is equal to minus 1 right.

So, it will your. So, that is minus o that is one thing I b is equal to this one, then minus 0 point j 0.252 because multiplied by one right one in to this one. So, if you simplify it will become minus j 0.0063 per unit similarly I c is equal to minus j 0.189 in bracket beta plus beta square minus j 0.252 is equal to minus j 0.0063 per unit. So, from this. So, this is the answer. So, from this example we have seen that how to connect positive negative and 0 sequence network and to find out the fault current from the generator side as well as from the motor side and exercise I am giving to you will take the same diagram same parameters, I mean all the parameters will remain same as an example four of the previous topic what you will do you will take a fault at this point say near e you will take a fault near e and this fault should not be there at the time there will be no fault here, but you take a fault at here and accordingly you draw the your that circuit connection, and compute everything all the fault currents; I a1, I a 2, I a 0 and that your current from the generator side fault current from the generator side and fault current from the motor side.

So, this is an exercise for you that you will take a fault here, but at that time you should not consider this next is another example.

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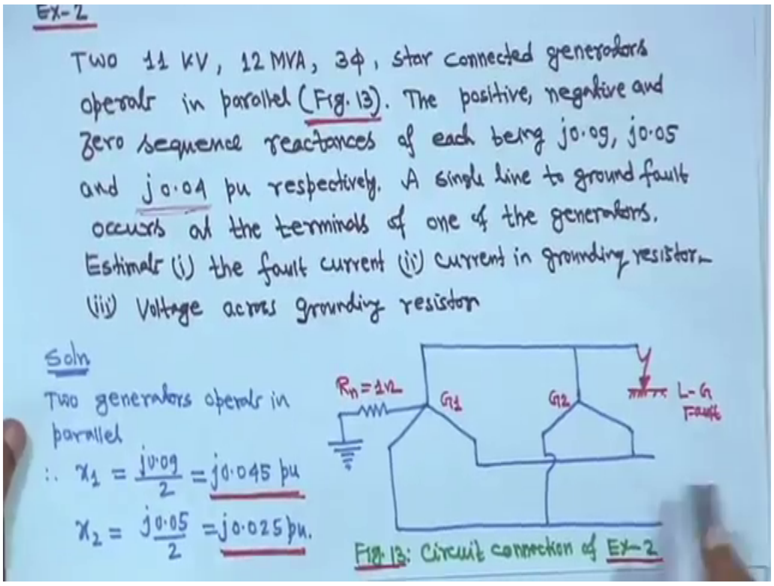

Suppose you have a 2 generators that operating in parallel, they are operating in parallel. So, it is 11 k V 12 m p a MVA 3 phase star connected generators operate in parallel. So, the positive negative and 0 sequence reactances of each being j 0.09 j 0.05 and j 0.04 per unit respectively.

A single line to ground fault occurs at the terminals of one of the generator. So, you have to find out first the fault current, second one current in grounding register; that means, this one and third voltage across grounding register. So, this is 2 generators are in parallel and your their identical 11 k V and 12 MVA 3 phase star connected, in line 2 ground fault has occurred here and therefore, and this is your grounding resistance is given R n is equal to 1 ohm. So, as they are in parallel and will go for that whenever you do such thing will go for per phase analysis. So, x 1 will be equivalent one j 0.09 by 2 because both are having same positive sequence reactance. So, it is j 0.05 similarly for x 2 j 0.05 by 2 that is j 0.025 per unit. So, once I mean first you have to make all these things, then Z 0 it is given that your 0 sequence your impedance or reactance is j 0.04 that is given, but at the same time on grounding resistance is there R n is equal to one ohm here, here and this machine rating is 11 k V and 12 MVA.

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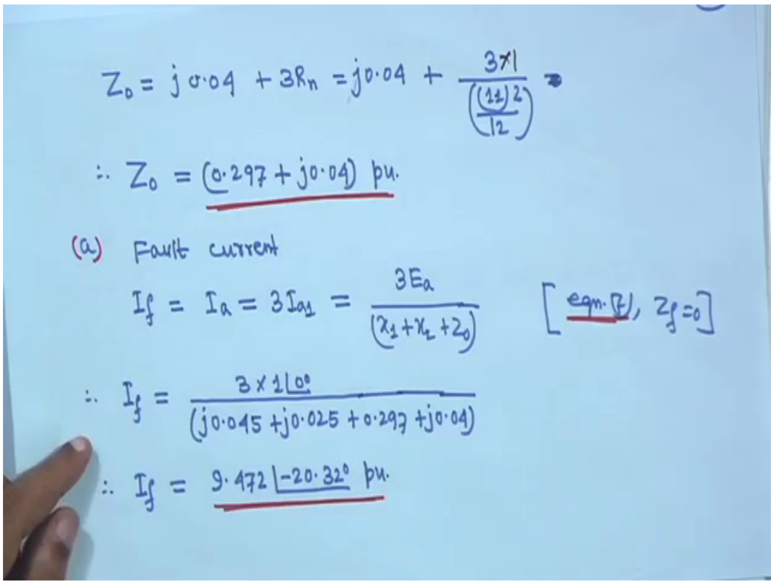

So, this one we have to convert it to per unit values on its machine rating that is machines base will take. So, in that case Z this is given 0.0 given plus 3 R n all these things we know. So, j 0.04. So, it is 3 in to one that 3 R n means R n is equal to one ohm. So, it is 3 in to 1and it is k V and divided by base impedance. So, base impedance is that generator your voltage is 11 k V terminal voltage and base your general rating is 12 MVA. So, this is your 11 k V base and MVA base is 12. So, your 3 in to 1 divided by 11 square by 12. So, then we will convert it to per unit and it will be Z 0 is equal to total 0 0.297 plus I mean this one this one we are writing fast this one we writing fast 0.297 plus j 0.04 per unit.

Now, fault current actually I f is equal to I a is equal to 3 a 1 that is we are writing from line for line to ground fault from equation 7 we are writing because fault impedance is 0 Z f is 0. So, it is a single line to ground fault occurs. So, the terminal of one of the generators, but your it is your solid fault right that is there is your there is no your ground impedance. So, Z f is equal to 0. So, in this case I f equal to is I a is equal to 3 I a1 this is coming from equation 7, when Z f is equal to 0 you go back to equation 7 and put Z f is equal to 0. Therefore, I f is equal to 3 in to one angle 0, E a is one angle 0 divided by you put all these value x 1 x 2 and Z 0 here you will get I f is equal to 9.472 angle minus 23.32 degree per unit this is that fault current in per unit. Now once you get this fault current you have to find out the your its exact value this is per unit it is a its value in kilo ampere.

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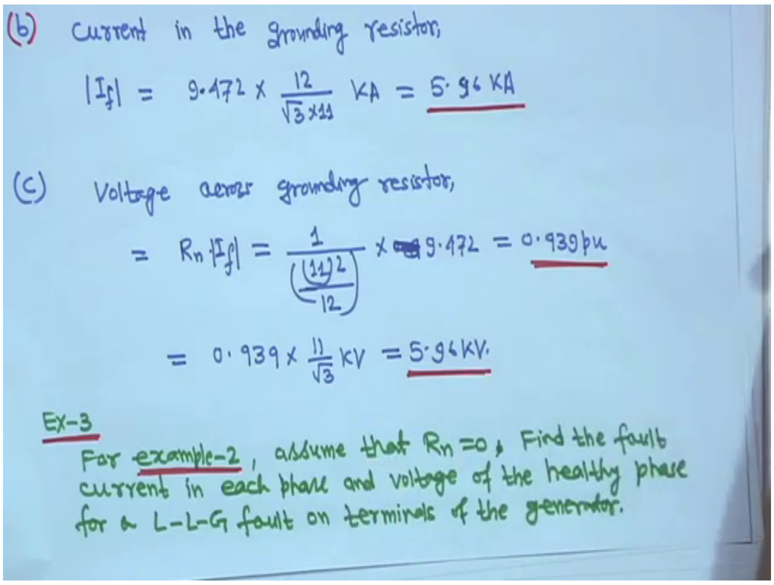

So, in this case this is per this magnitude of the fault current. So, in this case 9.472 is your per unit and this is 12 MVA because generator rating is 12 MVA divided by root 3 in to 11 that is 11 k v. So, ultimately the unit of this kind actually given as kilo ampere. So, this is actually base current of the generator on it is I mean it is 12 MVA, 12 MVA divided by root 3 your k V that is 11. So, if you do so, it will be 5.96 kilo ampere.

Similarly, the voltage across grounding register. So, that is R n in to your fault current. So, R n is 1 ohm it is one ohm and this one converted to per unit one divided by 11 square by 12. This is a base impedance of this generator if you take 11 k V base voltage as 11 k V and base MVA 12 that is a generator rating. So, this is per unit value these in to you multiply 9.472 that is in per unit current that will become 0.939 per unit. So, therefore, your is equal to 0.939 in to your 11 by root 3 k V because we there your we want that voltage across the across grounding resistor. So, it will be phase voltage. So, 0.939 and 11 is 11 k V is line to line. So, 11 by root 3 k V that is 5.96 k V this is the answer. So, these problems are I mean I have taken from this class I mean classroom point of view that quite not very lengthy problem otherwise this unbalanced fault some of the problems are too lengthy. So, within the time frame all these things cannot be I mean solved here, but some inter, but most of the things are basically or everything depends based on your symmetrical component.

So, similarly for the same example you assume that R n is equal to 0 I mean example 2 you for the same example you assume that R n is equal to 0. So, find the fault current in each phase and voltage of the healthy phase healthy phase of a double line to ground fault on terminals of the generator. So, you assume that there is a double line to ground for now and R n is equal to 0. So, same example, but double line to ground fault.

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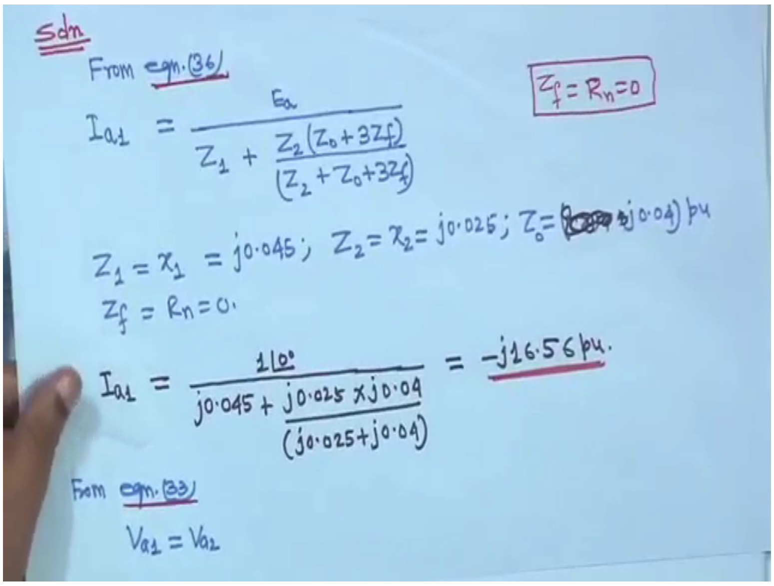

So, in this case this is from equation 36 for double line to ground fault the expression of the positive sequence current I a1 is equal to E a upon Z 1 plus Z 2 in bracket Z 0 plus 3 Z f divided by Z 2 plus Z 0 plus 3 Z f, but in this case Z f is equal to R n is equal to 0 is given. So, this is 0.

And Z 1 is equal to x 1 that is j 0.045 j 2 is equal to x 2 that is j 0.025 these are all parameters from the previous example and Z 0 as R n is equal to 0 . So, Z 0 is just j 0.04 per unit this is 0.04 per unit and Z f is equal to R n is equal to 0 this is given. So, if you substitute all these parameters here all these parameters here you will get our I a1 is equal to minus j 16.56 per unit this is a positive sequence current. Now from equation 33 if you go back to the equation 33 for your double line to ground fault. So, not showing it here because these are understandable that V a 1 is equal to V a 2 this is one another one is another equation that 35 this is from equation 33 that go back to that double line to ground fault and this one from equation 35 V a 0 is equal to V a 1 plus 3, Z f in to I a 0 this is from equation 35.

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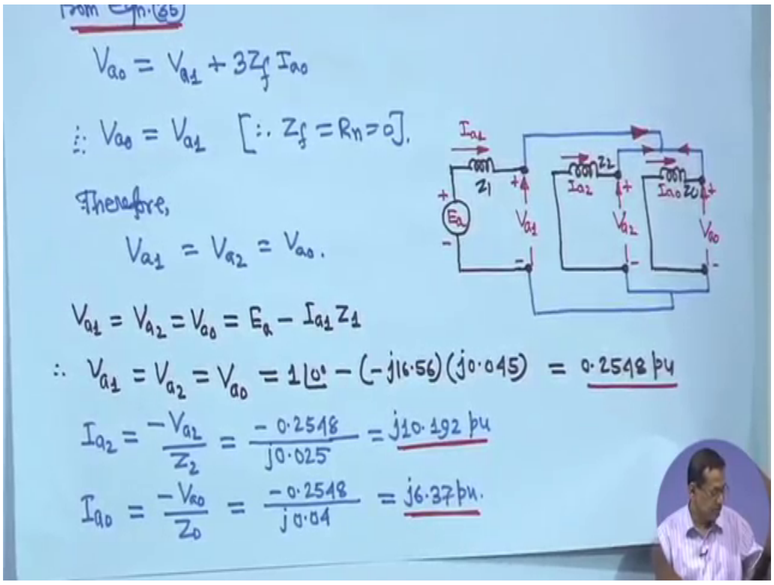

Now, here as fault impedance Z f is equal to 0 because Z f is equal to R n is equal to if you put here then actually it is V a 0 is equal to V a 1; that means, V a 1 is equal to V a 2 from equation equation V a 1 is equal to V a 2 from equation your 33 and from equation as fault impedance is 0 that is V a 0 is equal to V a 1 therefore, V a 1 is equal to V a 2 is equal to V a they are same this suggest what it suggests a parallel connection anyway. So that means if you look in to that that V a 1 is equal to V a 2 is equal to V a or V a 0 one angle 0 minus this one; that means, when you did the long double line to ground fault there are the 3 Z f impedance here because of this equation V a 0 is equal to V a 1 plus 3 Z f I a 0 now Z f is not there Z f is 0; that means here that this is a direct connection. So, that 3 Z f term is missing here rest same as the double line to ground fault I did not put any figure number here, but in the same diagram for that positive negative 0 sequence how it will be connected.

So, if you go I mean go I mean go through that go back to that double line to ground fault then you will see. So, in this case just hold on. So, in this case one can see that V a 1 is equal to this is this voltage is one angle 0 not shown here only E a it is shown e a is one angle 0 minus of j 16.56 in to Z j 0.045 that is I a1 in to your Z 1, and you have got I a1 is equal to minus j 16.56. So that means, your V a 1 is equal to V a 0, V a 2 is equal to V a 0 all are same that is coming 0.2548 your per unit. So, this is your voltage V a 1, V a 2, V a 0 now in the in this here if you put your what you call that apply k V l then your this it will be Z 2 in to I a 2 plus Z, Z 1 Z 2 and Z 0 not so shown here, but it is understandable you know this is your Z 1 this is this impedance Z 2 and this is Z 0. So, in this case it will be I a 2 in to Z 2 plus V a 2 is equal to 0.

That means your I a 2 will be minus V a 2 up on Z 2. So, it is minus 0.2548 divided by j 0.025 that is actually j 10.192 per unit. Similarly here also same way you can do it I a 0 in to Z 0 plus V a 0 is equal to 0. So, you will get I a 0 is equal to minus V a 0 up on Z 0 that is your minus 0.2548 by j 0.04 that is j 60 your 6.37 per unit now this. So, this one I mean another thing another thing from there right just hold on that if you look at this one this current all currents are meeting at this point, because that your fault you have you have considered the line to line faults in phase b and c. So, I a is equal to 0; that means, I a1 plus I a 2 plus I a 0 is equal to 0.

So, that is why all these things are meeting at this point this is your I a1, this is I a 2 and this is your I a 0. So, I a1 plus I a 2 plus I a 0 is equal to 0 same diagram only Z f is not there because Z f is equal to 0.

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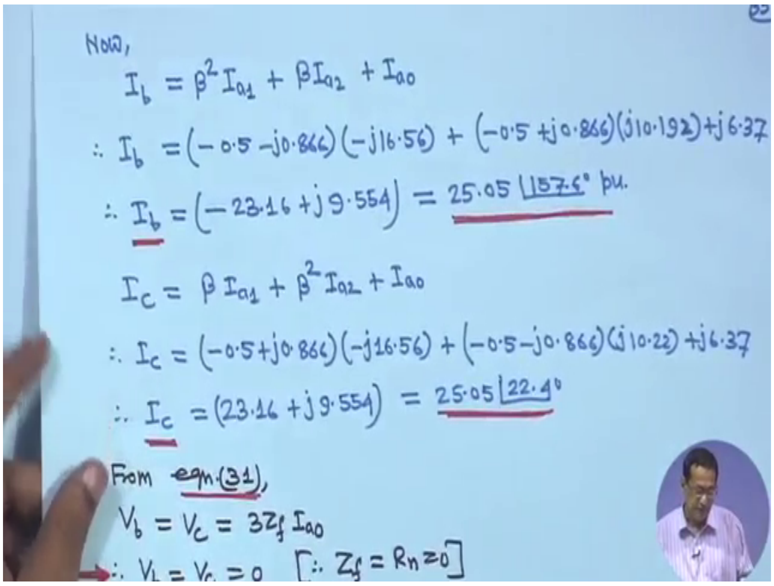

So, once you have got I a1, I a 2 and I a 0 right so; that means, I mean next one is that I b is equal to beta square I a1 plus beta I a 2 plus I a 0 now. Beta square is actually e to the power j 240 degree. So, it is minus 0.5, minus j 0.866 in to that I a1 is minus j 16.56. Similarly beta is equal to e to the power j 120 degree. So, minus .5 plus j 0.866 in to j 10 0.192 and I a 0 is equal to j 6.37. Therefore, if you simplify I b will be actually 25.05 angle 157.6 degree per unit. Similarly I c is equal to beta I a1 plus beta square I a 2 plus I a 0. So, same as before beta value substitute then you multiply by I a1 plus beta square in to your I a 2, plus I a 0 j 6.37. So, in that case I c also you will get 25.05 angle 22.4 degree. Now from equation 31 V b is equal to V c is equal to 3 Z f I a 0 this we have seen for double line to ground fault so, but Z f is equal to R n is equal to 0; that means, V b is equal to V c is equal to 0.

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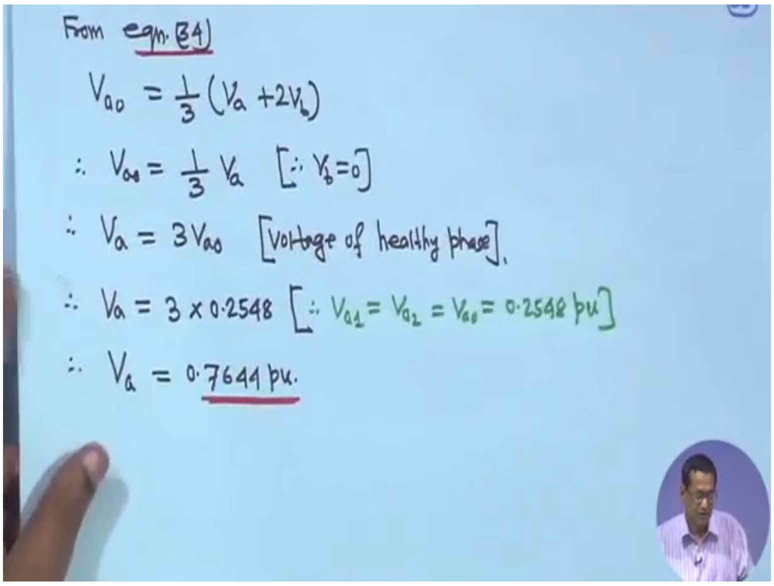

So that means, from equation thirty four if you go back to equation 34 it is V a 0 is equal to one third V a plus 2 V b. So, as V b is equal to 0 V b and V c both are 0. So, V is equal to V a 0 is equal to one third V a; that means, V a is equal to 3 V a 0 that is voltage of the healthy phase, because we have taken double line your double line to ground fault that is phase b and c.

So, V s would be 3 in to 0.2548 that is V a is equal to 0.7644 per unit because V a 1 is equal to V a 2 is equal to V a 0 is equal to 0.2548. So, this way you have to solve.

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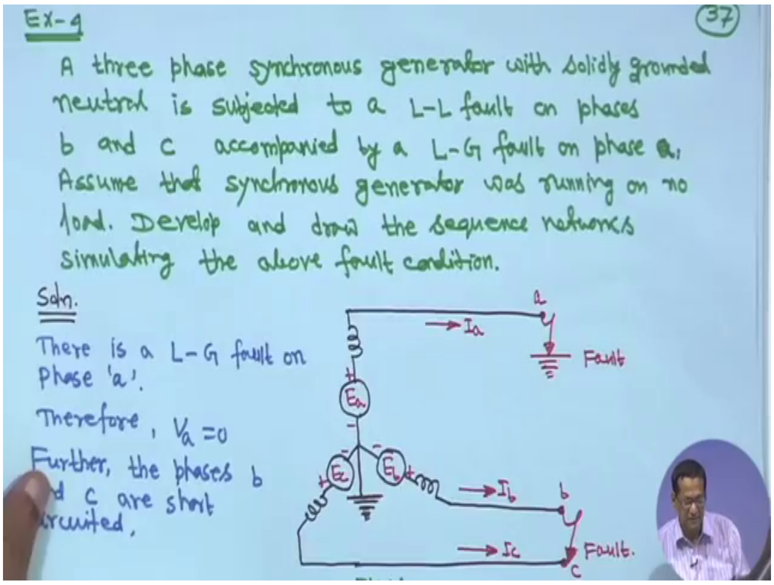

So, no need to recall these formulas or put it in your memories, but you have to little bit practice. So, another one is. So, this is that although this kind of occurrence of this kind of fault is your very rare. So, what we what you will do it that simultaneous 2 faults one is that a phase a there is a line to ground fault, and at the same time phase b and c also there is a short circuit. So, that is another fault. So, simultaneous occurrence of this type of fault very rare, but will see if it happens what will be the sequence network diagram I mean how that how will connect it. So, that is why a 3 phase synchronous generator with solidly grounded neutral is subject in here no no ground impedance right solidly grounded neutral is to a line to line fault on phases b and c I mean these phases b and c line to line fault, and accompanied by a line to ground fault on phase a. So, assume that synchronous generator was running on no load. So, you have to develop and draw the sequence network, simulating the above fault condition. So, there is a line to ground fault on phase a first you have to put the boundary condition, if there is a line to ground fault here; that means, V a is equal to 0. Similarly further the phases b and c are also short circuited; that means, in that case V b is equal to V c and I b is equal to minus I c.

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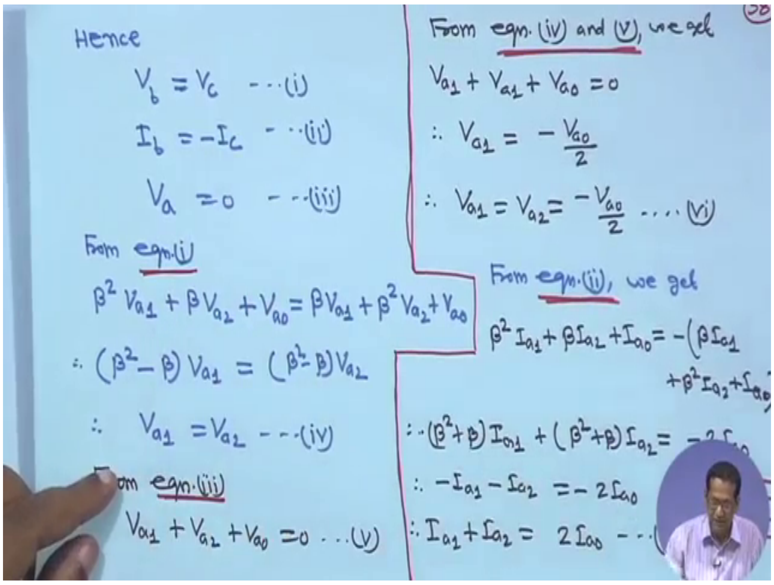

So that means, V b is equal to V c because of line to line fault and I b is equal to minus I c because this 2 are together it is there is a line to line fault. So, I b is equal to minus I c.

So, and V a is equal to 0 these are the 3 conditions, from equation one I mean from this one from this one, you can write just put it in positive negative and 0 sequence. So, V b is equal to beta square V a 1 plus beta V a 2 plus V a 0 is equal to V c that is beta V a 1 plus beta square V a 2 plus V a 0; that means, if you simplify it will be beta square minus beta V a 1 is equal to beta square minus beta in to V a 2.

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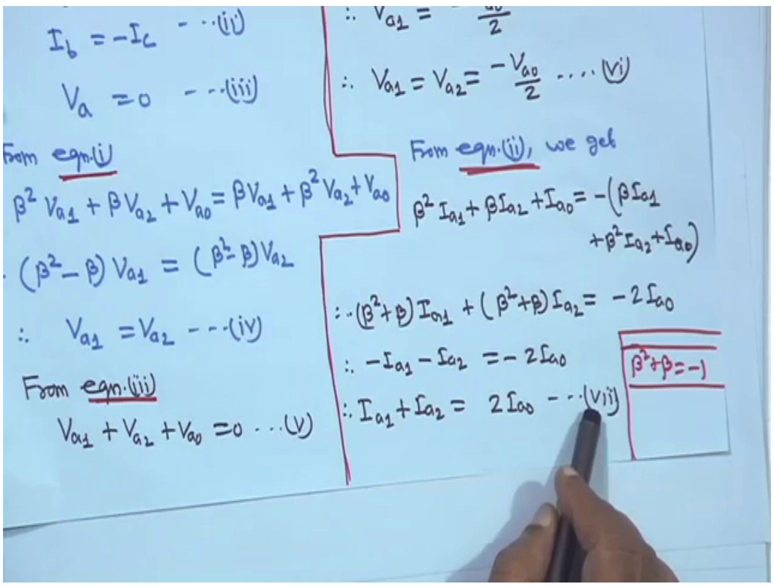

So that means, it will be V a 1 is equal to V a 2 because beta square minus beta, beta square minus beta will be cancelled. So that means, and again from equation 3 again from this equation 3 V a is equal to 0; that means, V a 1 plus V a 2 plus V a 0 is equal to zero. So, this is equation 4. So, from equation 4 and 5 here it is V a 1 is equal to V a 2. So, if you substitute here that V a your V a 2 is equal to V a 1 in this equation if you substitute V a 2 is equal to V a 1 then it will be your V a 1 plus V a 1 plus V a 0 is equal to zero; that means, V a 1 will be is equal to minus V a 0 up on 2. So, V a 1 is equal to then V a 1 is equal to V a 2 therefore, V a 1 is equal to V a 2 is equal to minus V a 0 up on 2 this is equation 6. Now again from your from equation 2, I mean from this equation that I b is equal to minus I c this equation also we what you have to do is that I b is equal to beta square I a1 plus this this this all we know from symmetrical component. So, I b is equal to beta square I a1 plus beta I a 2 plus I a 0 is equal to minus beta I a1 plus beta square I a 2 plus I a 0. So, if you simplify it will become beta square plus beta in to I a1 plus beta square plus beta in to I a 2 is equal to minus 2 I a 0.

That means beta square plus beta is equal to minus 1 because we have seen the identity that beta square plus beta plus 1 is equal to 0. So, beta square plus beta is equal to minus 1 you put it here put it here minus 1 minus 1, it is minus I a1 minus I a 2 is equal to minus 2 I a 0; that means, I a1 plus I a 2 is equal to 2, I a 0. So, this is equation 7 with this that means, V a 1 look now we have to we have drawn the sequence diagram for this one sequence.

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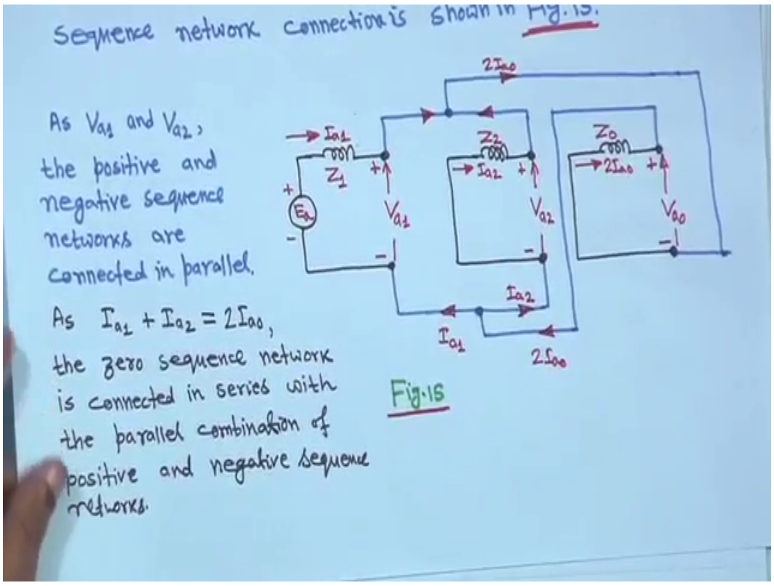

So, V a 1 as V a 1 and V a 2 the positive and negative sequence networks are connected in parallel because V a 1 is equal to V a 2. So, they will be connected in parallel. So, that is why this V a 1 and V a 2 they are connected actually in parallel. So, plus plus terminal connected minus minus connected. Now as I a1 plus I a 2 is equal to 2 I a 0. So, this current is I a1 this current is this current is I a 2. So, going leaving this terminal.

So, 2 I a 0 and this to this current actually flowing to the 0 sequence network; that means, that the 0 sequence network is connected in series with the parallel combination of the positive and negative sequence network; that means, this is positive sequence this is negative sequence and these 2 I a 0 current because these 2 are in parallel, and this this 0 sequence network is in series with the parallel combination of this so; that means, from here as it is in series.

So, it will come to the from here it will come to the negative terminal here and from here it will be here you are and from positive terminal from here it will be connected here such that here also if you apply your k c l, I a1 plus I a 2 is equal to 2 I a 0, here also if you do. So, that both the current I 1 I 2 leaving and this is entering. So, same philosophy that I a1 plus I a 2 is equal to 2 I a 0. So, this is that your what you call that here is your sequence the network connection for simultaneous occurrence of a line to ground fault, solid line to ground fault and line to line fault. So, with this we will close that unbalanced fault analysis.

Thank you.