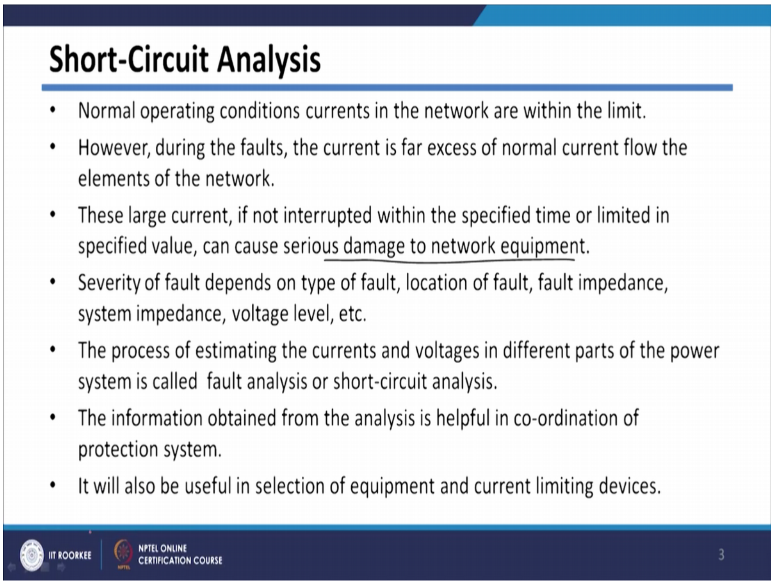
Electrical Distribution System Analysis
Dr. Ganesh Kumbhar
Department of Electrical Engineering
Indian Institute of Technology, Roorkee

Lecture – 34
Sequence Component Based Short Circuit Analysis

In the last lecture, we have seen or we have finished load flow analysis and in particular in load flow analysis we have seen 2 3 methods, one is based on backward forward sweep algorithm another is based on direct approach for load flow analysis ah. Initially we have used a direct approach for radial system and then we have extended same approach for weakly meshed system and then finally, we have seen one more method that is gauss implicit Z matrix method.

Today onwards we will start Short Circuit Analysis, so before going to the short circuit analysis let us see why we need a short circuit analysis. So, we know that in normal operating condition the current which is flowing to the various part of distribution system is within the limit specified limit. However, whenever there is short circuiting distribution system the magnitude of current is very large as compared to your rated current or normal limit of your equipment.

(Refer Slide Time: 01:39)

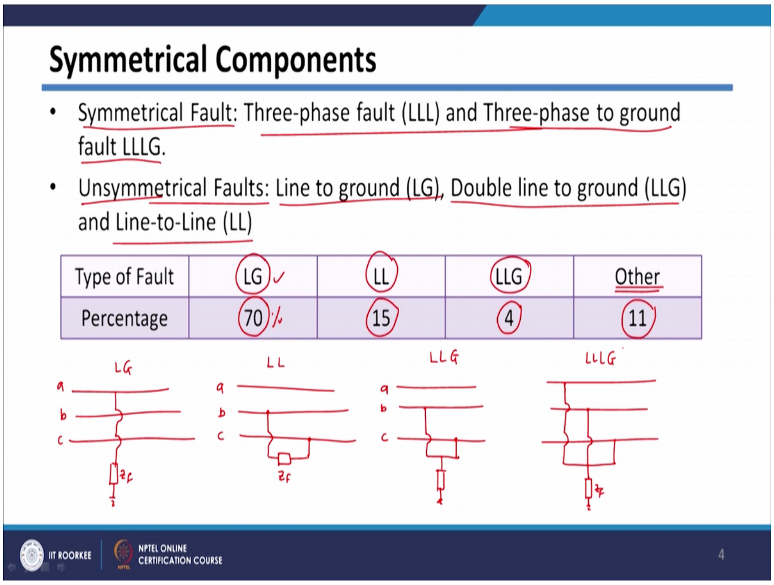


And if this large current if it is not interrupted or it is not within the limit of magnitude ah; it will cause serious damage to the network equipment, so I just written it here it may cause the serious damage to your network equipment and the severity of this fault depends on your type of fault location of fault, fault impedance, system impedance and system voltage level.

So, depending upon this fault current may vary and the process of estimating these currents and voltages in the distribution system whenever fault is occurring is called a short circuit analysis or fault analysis. And whatever information we are of obtaining from this fault analysis that is voltage voltages or currents after fault, they will be used for various purposes like they may be required; if you are actually coordinating your protective system. So, for coordinating your relays or protective system we need these information of fault currents and post fault voltages.

We also need this information for selection various equipments, so various equipment will be having some short circuit ratings. And to select par particular equipment in particular location of distribution system, we may need this information like fault current value or post fault voltage values. We also need it for selecting say if you want to put some kind of current limiting device into your distribution system, then also this information will be required. So, if you see or if you classify the faults in the distribution system.

(Refer Slide Time: 03:14)



The faults can classified into 2 there is symmetrical faults and unsymmetrical faults. So, symmetrical faults whenever there is three phase faults, that is three phase faults that is LLL faults it is called as or three phase to ground fault that is LLLG fault.

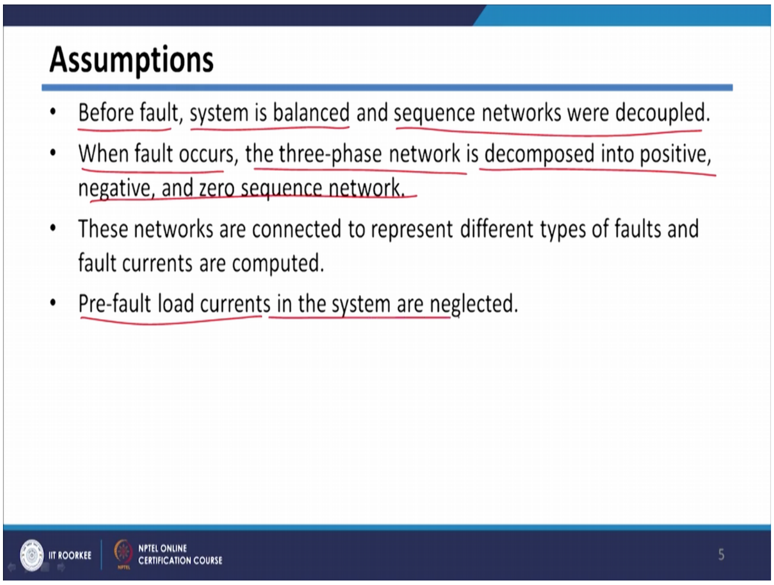
Unsymmetrical faults are 3 types that is line to ground fault where 1 line is falling on the ground, double line to ground faults 2 lines are in contact with ground and then there is third type which is line to line fault where 2 lines are getting short circuited. And if you observe the percentage of these faults probability or percentage of this fault occurrence; the 70 percent faults which are occurring in the distribution system they are LG fault.

So, this is percentage so line to ground fault has a maximum probability of happening; then second is LL fault which is having probability of 15 percent LLG fault is having probability of 4 percent and other faults including your 3 phase fault that is triple L fault or triple LG fault or open conductor fault, they are having probability of 11 percent all other faults. And we know that for our fault studies say in case of line to ground fault as I told you we consider if there are 3 lines, one line will be in contact with ground it may be through some fault impedance, so this is your fault impedance say this is phase a, b and c.

So, here we I can say that the there is line to ground fault on phase a, then in case of line to line fault you will be having said these through line 3 lines a b c phases and if your say b phase and c phase getting short circuited through some impedance or directly this ZF may be 0 or some value it is called as line to line fault. So, this is your LG fault, this is your LL fault and in case of LLG fault again these are the 3 phases a b c and I am talking about LLG fault.

So in this case 2 lines will be in contact with the ground through some impedance or directly and then in case of 3 phase fault 3; s, in case of three phase faults all the 3 conductors will be in contact together so it is called as triple L fault and if there is ground be involved it will be triple LG fault so this is LLLG fault.

(Refer Slide Time: 06:03)



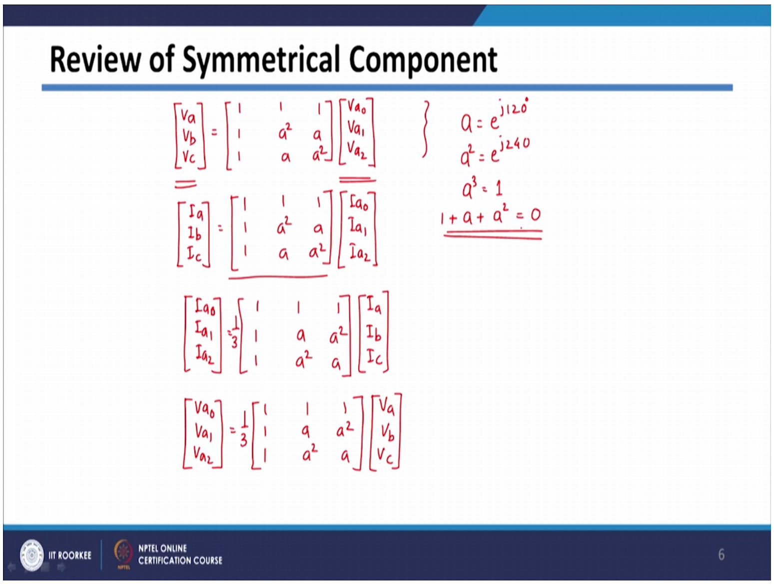
So, the basic of method which is used for short circuit analysis which you might have used in your B Tech course; that is symmetrical component based analysis. So, we know that whenever there is unsymmetrical fault, so we use symmetrical components based method to analyze this one.

So, here the assumptions for symmetrical component based system is; we assume that before fault, the system is completely balanced one and sequence networks were decoupled. Basically we assume that since it is balanced only positive sequence network will be existing before fault.

But when the fault occurs the 3 phase networks will be connected and this connection will depend upon what type of fault is existing. So, depending upon your fault there will be different connections of these sequence networks . In this case pre fault load currents of the system will be neglected. So, we are not considering the load current because, the fault current is considered as very large as compared to your load current; so pre fault load current will be considered as negligible.

Now, let us see review your symmetrical component theory, so before going to symmetrical component theory let us revise what we have studied.

(Refer Slide Time: 07:33)



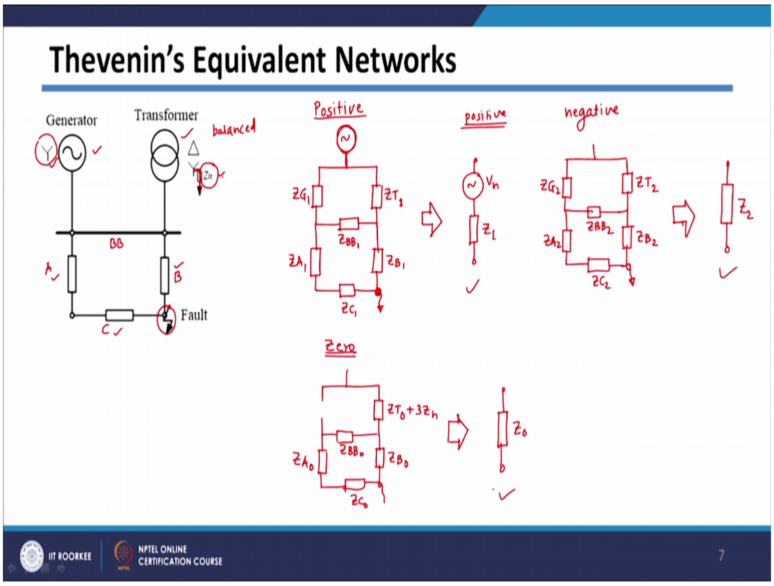
So, you have studied that symmetrical component, so voltages Va Vb and Vc 3 phase voltages can be written in terms of 3 symmetrical components, those are Va0 which is 0 sequence component Va 1 positive sequence Va 2 negative sequence and the matrix which converts this sequence component to the phase component is given like this is 111 1 a square a, 1 a a square. And where we know that your a is e raised to j 120 degree and a square will be then e raised to j 240 degree and then a cube we know that it is equal to 1 and one more identity we know that 1 plus a plus a square is actually equal to 0.

We also this side this relation in case of current that is current Ia, Ib and Ic all the 3 currents phase currents can be written in terms of their sequence component, those are Ia 0, Ia 1 and Ia 2. And there were same matrix that exists here that is 1 a square a then 1 a a square and if you want to you better studied this and then if you want to back convert this, you will be having this relation.

So, you want to calculate sequence components I a 0, Ia 1 and Ia 2, sequence component we want to calculate form your phase components that is Va sorry Ia Ib and Ic. So, this current here is Ia and here we are having this inverse of this matrix. So, it will come 1 by 3 here and then 1 1 1 and then 1 a a square 1 a square a.

Similarly, for voltages also we can write voltage Va 0, Va 1, Va 2 sequence voltages will be equal to 1 by 3 the same matrix 1 1 1 1 a square 1 a square a into your phase voltages that is Va Vb and Vc. So, this is how we convert from phase quantities to the sequence quantities and from the sequence quantities to the phase quantities and the variable which we are using it here is a which is e raise to j 120 degree.

(Refer Slide Time: 10:34)



Now, let us see if you are having any distribution system, how we can convert this distribution system into various sequence networks. But this sequence networks we want something like Thevenin's equivalent network. So, let us consider this particular distribution system very simple distribution system I have taken it here, let us say this is generator here the transformer, which is delta and y grounded with some impedance there is this 3 lines which are forming the loop and let us say your fault has taken place at this location.

In this case also we can easily draw a positive sequence, negative sequence and 0 sequence diagrams for this, let us say we are drawing positive sequence network. So, positive sequence network will be something like this, so the both the source can be clubbed together into one source, then there will be impedance of your generator, this is impedance of your transformer, then this is impedance of your bus bar, and this is say this is say line A, this is say line B and this is say line C. So, this will be impedance of line A, this is impedance of line B, and this is impedance of line C and your fault has taken place at this location.

So, in this case this is your source of this network, this impedance will be since it is positive sequence network I can say it is ZG 1, ZT 1 positive sequence transformer impedance, this will be ZBB1 this is, so this is bus bar I can say ZBB this is ZA 1, ZB1 and this is ZC 1 and we can actually using series parallel combination of impedances or sometimes you may need to convert are you to use star delta conversion and by after doing that, we can convert this network into this network, equivalent Thevenin's equivalent to a positive sequence network.

So, this is your positive sequence Thevenin's equivalent network which will be having source say this source is Vn Thevenin's equivalent source, and this is your Z 1 equivalent theories Thevenin's equivalent impedance, which at this fault location point.

Exactly similar way we can draw negative sequence network also, so if you also considering negative sequence network, it will be similar only thing is there will not be source here because, as I told you we are considering source which is perfectly balanced. So, the sources which are coming from both the sides are perfectly balanced.

So, therefore they will not be source negative sequence source into the network, only positive sequence source will be existing. So, this is related to generator so ZG 2, this will be ZT 2, this is ZBB 2, this is ZA 2, this is Z B 2, and this is Z C 2 and fault is taken place at this location.

Now, this network also we can simplify using series parallel combination or star delta conversion, we can have a simple impedance network, which will be converted into single impedance and this impedance I am calling it Z 2. So, negative sequence network will be converted into single impedance here, it will not be having any kind of source.

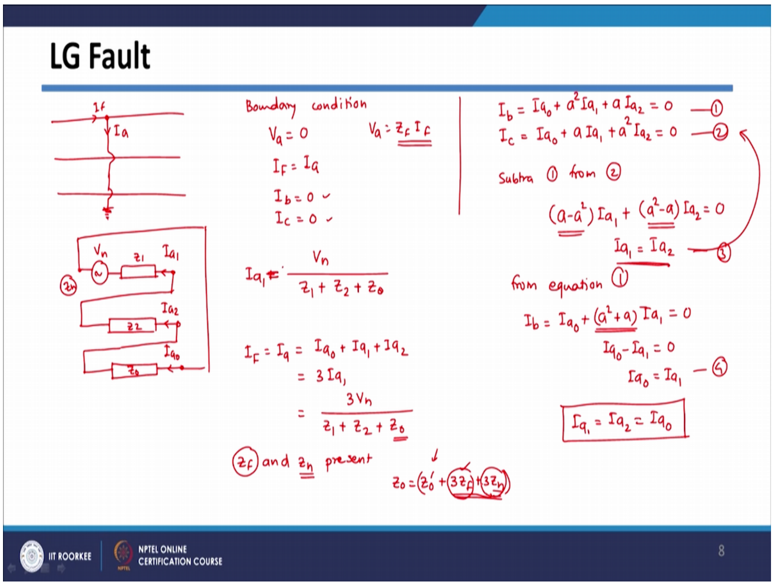
Similarly, in case of 0 sequence network, so in case of 0 sequence network since the neutral of the generator is not grounded, there will not be 0 sequence current path for this network through generator. So, here if you draw this network since there is no path for 0 sequence through generator this will be open here, then there will be impedance of transformer will come here, plus there is some impedance, which is in the neuta in the grounded circuit or arc circuit of this transformer.

So, this impedance will be ZT 0 transformers 0 sequence impedance, plus 3 times your ZN that is impedance in ground path and then this will be your other things will remain same. So, and the fault I will taken plate at this location, so this will be 0 sequence impedance of bus bar. So, I can Z 0 ZB V0 this is ZA0, ZB0 and ZC 0.

So, this all this 0 sequence network also we can simplify and this network can be converted into single impedance and this single impedance will be called as Z0. So, we have got all the 3 of Thevenins equivalent sequence network, this is positive sequence network, negative sequence network and 0 sequence network and using this network.

For a different types of fault depending upon which fault is there on the system we can connect these network accordingly and do the fault analysis. So, in case of this sequence component analysis based analysis, we first get this sequence network till fault point and then according to fault, we connect this network to get the fault current.

(Refer Slide Time: 16:43)



So, let us say you are analyzing LG fault, so in case of LG fault as I told you let us say there is fault on phase A, which is getting faulted. So, in this case you are the boundary conditions, so we can see that since this is getting grounded your voltage Va will become equal to 0 ah, if there is some fault impedance it will not be exactly 0 if there is fault impedance this Va will be equal to ZF into if so there is some fault impedance in this path.

Another boundary condition this fault current will be equal to your current Ia because, this current Ia is actually basically become your fault current. And then other currents in that case will be negligible as compared to Ia. So, Ib will be equal to 0 and Ic will be equal to 0.

Now, we can get your sequence networks, your sequence networks are something like this is your positive sequence network, this is your negative sequence network and this is your 0 sequence network. So, this is your Z 1 this is your Z 2 and this is your Z 0 and we want to check how they are getting connected to check that let us see what we can do.

So, you are we have seen that Ib is actually equal to from the sequence component point of view, you see it will be I a 0 plus a square Ia 1 plus a, I a 2. Similarly if you write the equation for Ic it will be Ia 0 plus a, I a 1 plus a square Ia 2 and we have seen that Ib and Ic both are 0, so they will be equator.

So, say this is equation 1 and equation 2 subtract 1 from 2, so Ia 0 Ia 0 cancelled out. So, it will be a minus a square into Ia 1 plus it will be a square minus a into I a 2 is equal to 0 and if you put the values of a square minus a or a minus a square it is just opposite of each other then we can just say Ia 1 will be equal to your I a 2 and if you put this equation into equation number 1.

So, from equation 1 we can write by putting Ia 1 is equal to Ia 2. So, I can say Ib will be equal to Ia 0 plus a square plus a into I a 1 will be equal to 0 and we have seen that this is nothing but minus 1. So, Ia 0 minus I a 1 will be equal to zero. So, I can say Ia 0 will be equal to Ia 1.

So, you can see this from equation number 3 and 4, your Ia 1 is equal to Ia 2 is equal to your I a 0. So, means since all the 3 currents are equal, so this is your current Ia 1, this is your current Ia 2 and this is current Ia 0 and since they are equal your network should be connected in series like this then only these currents will become equal.

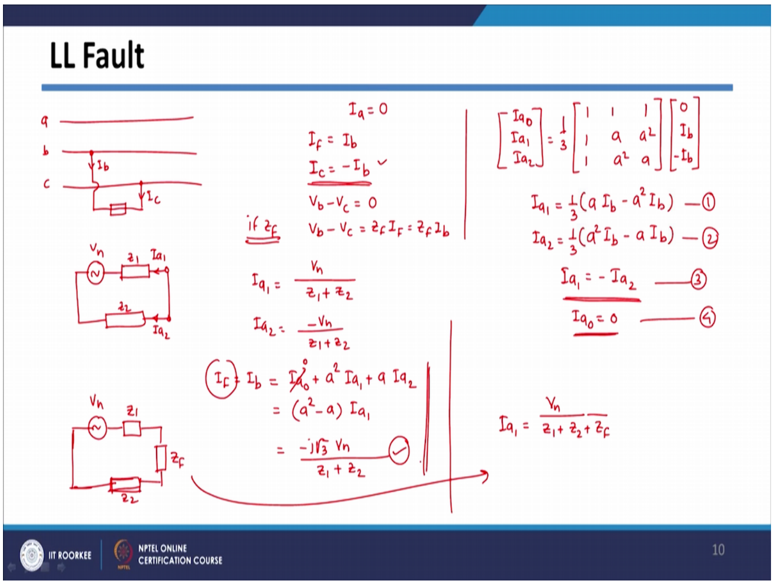
So, these networks will be connected in series and you can easily calculate now all these currents which are Ia 1 will be equal to whatever source voltage Vn. So, this will be Vn divided by your Z 1 plus Z 2 plus your Z 0 and we know that your fault current is actually your fault current Ia, which is basically equal to Ia 0 plus Ia 1 plus Ia 2 all of them are equal. So, I can say 3 times Ia 1 and therefore your fault current will be 3 Vn divided by Z 1 plus Z 2 plus your Z 0.

Ah Now if there is so this we have derived if there is of fault impedance is 0. So, if there is some fault impedance ZF also, if there is some impedance in neutral circuit of your generator that will get added into this Z 0.

So, in that case whenever there is ZF and Zn present. So, ZF is nothing, but your fault impedance and Zn is nothing but your impedance with which your source is grounded. So, in that case your Z 0 will be consisting of Z 0 dash plus 3 times of ZF plus 3 times of your Zn.

So, this is nothing but your 0 sequence impedance of network and this is nothing but fault impedance, which is no getting multiplied by 3 and this is nothing, but your impedance with which your source is grounded that is Zn multiplied by 3. So, this is how we can calculate your fault current in case of LG fault. Now, if there is say LL fault so in case of LL fault.

(Refer Slide Time: 23:06)



Let us say again this is true let us say your this is phase a b and c your phase b and c they are short circuited. So, in this case yeah the boundary conditions are like this so your Ia will be equal to 0, your Ib so this current is nothing but your current Ib and this current is nothing but current Ic n. So, fault current will be nothing but current Ib and current Ic will be opposite of your current Ib Ic ah. So, Ic will be opposite of current Ib.

Also one more boundary condition when you can get that is Vb minus Vc will be equal to 0, if there is no fault impedance in the fault; if there is some impedance into this fault we can say Vb minus Vc is equal to ZF into Ib. But initially we are not considering this impedance here.

So, therefore it is directly short circuited like this. If you consider now these 2 equations that is so this equation I will take will later. So, it is V if ZF present then Vb minus Vc will be equal to ZF multiplied by your I F, which is multiple basically ZF multiplied by your Ib.

Now, let us see this 1 I a 1 or Ia 0, Ia 1 and Ia 2, it is actually equal to we have seen that is 1 by 3 1 1 1, 1 a a square, 1 a square a into this currents that is Ia Ib and Ic we are seeing actually minus Ib. So, instead of Ic I can put minus Ib into this case and Ia 0. So, instead of Ia also I can put 0 here, so Ia is 0. So, I can put it like this.

So, I can say that Ia 1 will be equal to 1 by 3 into a into Ib minus a square into Ib and Ia 2 also, it is 1 by 3 into a square into Ib minus a into Ib and if you see this equation 1 and equation 2, I can easily see that Ia 1 is equal to minus Ia 2.

So, from this equation we can easily find out also we know that actually Ia 0 will be equal to 0 because, ground is not involved here it is a LL fault, since the ground is not involved your 0 sequence a current will be equal to 0. So, from this equation say 3 and 4 we can easily draw the connections for this network connection. So, sequence again I am taking this 3 networks. So, it is positive sequence network and then this is your 0 sequence network and this is your current I a 1 and this is current Ia 2 and Ia 1 and Ia 2 just opposite of each other means we need to connect these circuits like this, then only they will be in opposite direction.

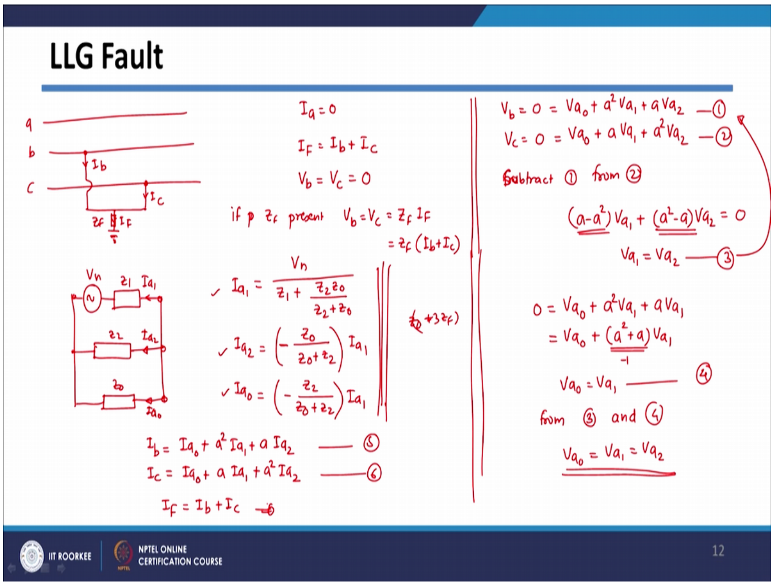
So, from this equation 3 and 4 we can draw equivalent circuit and from this we can easily find out the current Ia 1. So, current Ia 1 I can just write if the source is Vn here v n and this impedance is Z 1 this impedance is Z 2 because, this is negative sequence network here. So, Vn divided by Z 1 plus Z 2 ah.

Similarly Ia 2 will be equal to minus V n divided by Z 1 plus Z 2 and then we know that your fault current is basically your current Ib which is equal to Ia 0 plus a square into Ia 1 plus a into Ia 2. So, in this case Ia it is already 0 and they are just minus of each other. So, it will be a square minus a into Ia 1, which is basically minus j root 3 and Ia 1 we have got V n divided by your Z 1 plus Z 2.

So, this is nothing but your fault current equation, which is basically Ib. So, we can get the fault current using this equation here. If there is some impedance in fault path then this impedance will get connected. So, in this case the new connection of your sequence network will be something like this. So, this is your Vn this is your Z 1 this is your Z 2 0 negative sequence network and this is your ZF.

So, in this case your Ia 1 for this network your Ia 1 will be equal to Vn divided by Z 1 plus Z 2 plus ZF and then similarly I f will be calculated using the same relation. So, this is how actually we can get the fault currents in LL faults.

(Refer Slide Time: 29:24)



In case of LLG fault, so in case of LLG fault let us consider there are 3 abc phases and line to line to ground fault is occurring inside b and c phases. So, b and c phases they are getting shorted and they will be grounded it here, so initially I am considering the fault with 0 fault impedance.

So, in this case boundary conditions are something like this one boundary condition is that Ia is equal to 0 because, fault is not occurred on phase a. Then a fault current total fault current will be equal to Ib plus Ic. So, this is nothing but your current Ib and this is nothing but current Ic and Ib plus Ic will be nothing but this total fault current.

Another boundary condition we can have that is Vb will be equal to Vc will be equal to 0 because, they are actually both the both of them have grounded. If ZF is present if ZF present in that case Vb will be equal to Vc will be equal to Z f multiplied by your fault current and that is equal to ZF multiplied by fault current is actually Ib plus your Ic.

Now, let us see what we can get in this case, so we have actually Vb which is equal to 0 and Vb we know that Va 0 plus a square Va 1 plus a Va 2 similarly Vc which is equal to 0. So, I can say Va 0 plus a Va 1 plus a square Va 2 and if you subtract this equation 1 and 2 from each other. So, from subtract 1 from 2, so if you subtract this this will get cancelled out. So, it will be a minus a square into Va 1 plus a square minus a into Va 2 which will be equal to 0 and we have seen that these 2 quantities are just opposite of each other means sign will be is negative, in that case Va 1 will be equal to your Va 2.

After this same equation which is 3 if I put into equation number 1 I can get 0 is equal to Va 0 plus a square Va 1 plus a into Va 1. So, in this case Va 0 plus a square plus a into Va 1 and a square is nothing, but minus 1. So, in that case Va 0 will become equal to Va 1, so what we are getting it from this is say equation number 4. So, we are getting from 3 and 4 we can say that Va 0 will be equal to Va 1 will be equal to Va 2.

So, this 3 and 4 which will give us how these networks are connected. So, in this case these 3 networks I am just drawing it here. So, this is positive sequence network this is negative sequence network and this is 0 sequence network and this is current Ia 1 Ia 2 and Ia 0 and the voltage across all the 3 it is coming same means all these 3 networks will be connected in parallel. So, this is I will just say Z 1 Z 2 and Z 0 they will be connected in parallel like this.

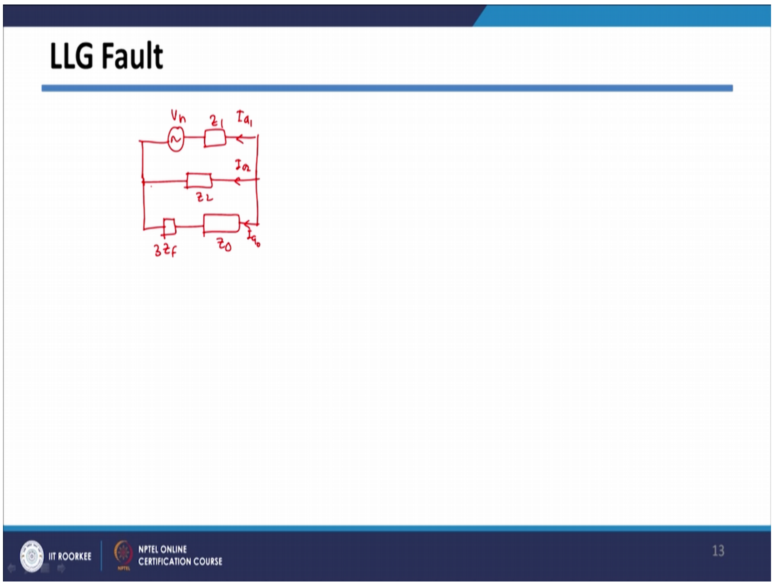
So, since they are connected in parallel we can write equation for Ia 1 which will be equal to say this is Vn, so it will be v n divided by total impedance of this circuit. So, this is the Z 2 and Z 0 they are coming in parallel and in series with Z1. So, it will be Z 1 plus this parallel combination of Z 2 and Z 0 will be Z 2 multiplied by Z 0 divided by Z 2 plus Z 0.

So, this will give me Ia 1 and once I get Ia 1 your Ia 2 will be equal to minus because, signs they are opposite minus Z 0 divided by Z 0 plus Z 2 into Ia 1. So, depending upon a current division the current will get divided into Ia 2 and Ia 0. So, Ia 2 will be proportional to the Z 0 divided by Z 0 plus Z 2 and Ia 0 will be proportional to minus Z 2 divided by Z 2 divided by Z 0 plus Z 2 into Ia 1.

So, once you get all the 3 current that is Ia 1, Ia 2, Ia 0 we can get the fault current which is basically Ib plus Ic. So, we can just say Ib will be equal to Ia 0 plus a square Ia 1 plus a Ia 2. So, Ib can I can get because Ia 1, Ia 2, Ia 3, Ia 1, Ia 2, Ia 0 already calculated and then Ic will be equal to Ia 0 plus a into Ia 1 plus a square into Ia 2. So, once you get this Ib and Ic your fault current total fault current in system will be equal to Ib plus Ic.

And if there is any fault impedance which present in the ground path. So, if there is a fault impedance ZF present here, then you need to connect 3 times of ZF in series with of Z 0 impedance. So, in this case this 3 0 Z F impedance will be connected here and then analysis will remain same.

(Refer Slide Time: 36:25)



So, new network with impedance will be something like this. So, you are having this positive sequence impedance then negative sequence impedance and this is 0 sequence impedance. But if there is fault impedance in the path, so it will be 3 ZF this will be Z 0 this is Z 2 and the Z 1 and Vn and this is nothing but Ia 1 Ia 2 and this is Ia 0.

So, we can easily get the values of Ia 1 Ia 2 and Ia 0 after solving this circuit and you can get value of IF Ia 1 Ia 2 Ia will be from this 1 and only thing is in ZF, you need to add actually plus 3 ZF there otherwise equation will remain same and you can get the fault current also which is basically Ib plus Ic.

So, in this particular lecture we have started with short circuit analysis and in the short circuit analysis we have started with symmetrical component based analysis because, we already studied it in power system analysis course basically it is used for transmission system widely because it is balanced. However, there are limitations of it is use in distribution system all these limitations of symmetrical component we have study we will see in the next lecture.

Thank you.