Power System Analysis
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Lecture - 29
Unbalanced Fault Analysis (Contd.)

Welcome to lesson 29 on Power System Analysis. In this lesson we will continue with Unbalanced Fault Analysis, the asymmetrical faults that we were considering, and a previous lectures, where the short circuit.

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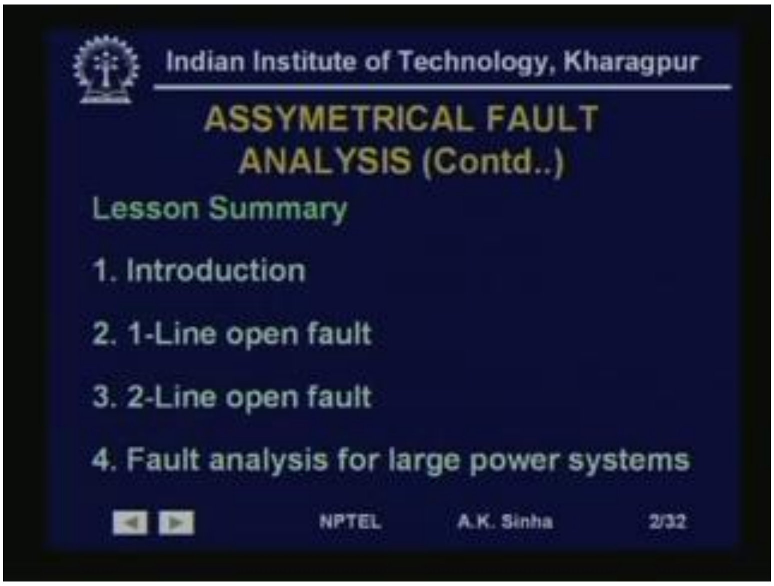

In this lecture we will consider the open circuit faults. So, here we will start with an introduction. Then we will discuss 1 line open fault and then 2 line open fault. And after that we will discuss a little about fault analysis for large power systems.

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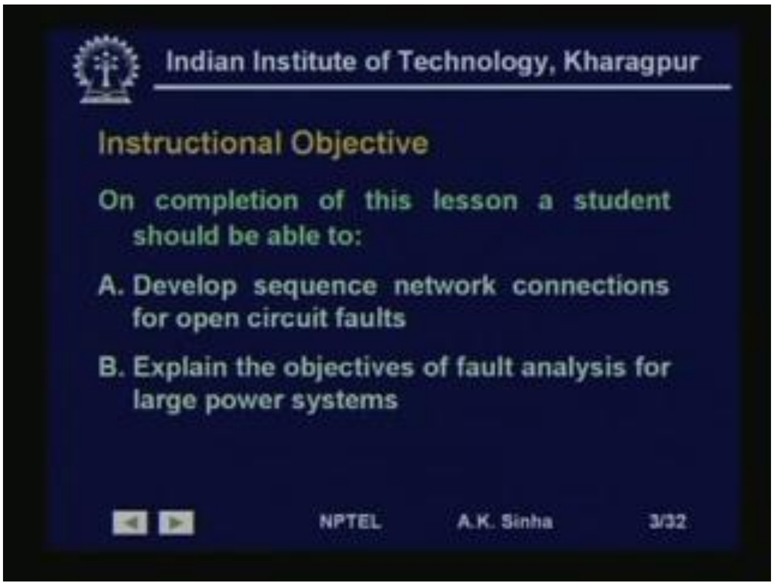

Well, on completion of this lesson you should be able to develop sequence network connections for open circuit faults. And you should be able to explain the objectives of fault analysis for large power systems.

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As we discussed and a previous lesson, the there are different kinds faults which occurring power system. Such as line to ground fault or line to line to ground faults and line to line faults these are asymmetrical faults. Similarly, 3 phase to ground faults there a symmetrical fault.

All these faults are basically short circuit faults. Whereas, we have other types faults which are basically open circuit faults. Like a single phase open that is 1 line gets open or 2 line gets open. In both these cases the fault again is an asymmetrical fault. Because, the voltage and currents and in all the 3 phases are not balanced asymmetrical.

Now, when we 1 question which comes to mind as we can understand studying the short circuit faults. Because in case of short circuit have a currents are going to flow in the circuit. And we need to protect our equipment from damage because of this heavy currents. What happens in case of open circuit faults. Well open circuit faults in most to the cases will lead to over voltages. And that is why we need to study them, because these over voltages can sometimes cause insulation failure and thereby resulting in a short circuit. So, we need to study these open circuit faults also to make sure that our system design for insulation can take care of the over voltages cause by the open circuit faults.

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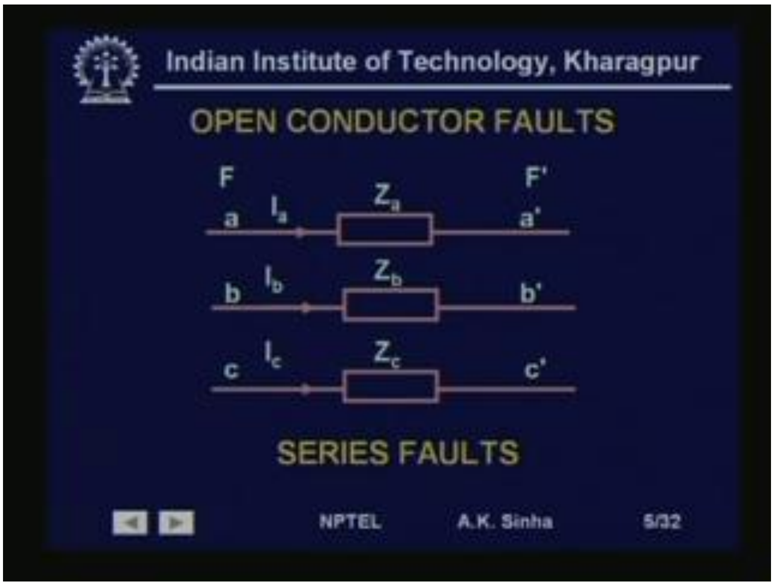

Now, how do we simulate these open circuit faults. Well, if you see here we have phase a, b and c in the 3 phases we have impedances Z a, Z b and Z c. Now, we are considering a fault occurs as between these points F and F dash on 2 sizes of these impedances. These impedances can be the line impedances themselves and the point F and F dash can be the 2 bus pass.

Or it can be any 2 points, where the line gets broken or there is an open circuit in any equipment. So, here as we have shown phase a is caring current I a, phase b is carrying current I b and phase c is carrying current I c. The impedances Z a, Z b, Z c or not same and thereby the currents will also be not same. That means, we have asymmetrical operating condition here.

Now, these if we assume Z a to be infinite very large. We can simulate a fault which is an open circuit on phase a. Similarly, Z b are Z c can be make infinite or a very large which will simulate of fault of open circuit of phase b and c. So, in this way if we by making these impedance values very large or infinite we can simulate open circuit faults on this system.

And that is why these open conductor faults or open circuit faults are sometimes called series faults. That means what we are doing is we are introducing a large impedance in series with the circuit and for simulating these faults. Now, what happens in case of these series faults or open conductor faults.

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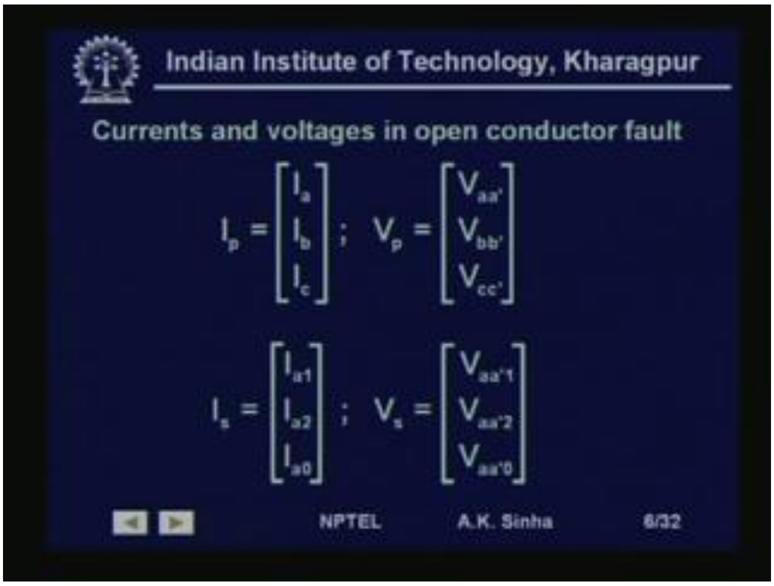

Let us see how to be defined the currents and voltages in case of open circuit faults or open conductor faults. The currents are in phase variable I a, I b and I c and the voltage across the faulted portion. If you see this across this portion that is between F and F dash of this system. We see the voltages as v a a dash V b b dash V c c dash as seen here that is voltage between a and a dash b and b dash c and c dash and so on.

We can convert this into asymmetrical component variables and we can write this as I s, which is symmetrical component of for the currents. So, we have I a 1 I a 2 I a 0 as the symmetrical component currents for the system. And V s is equal to V a a dash 1 V a a dash 2 and V a dash 0. So, this is the transformed currents and voltages in the sequence network.

Now, for this system compare to the short circuit that we have done. There is some difference. The difference that we find here is that here we have 2 points a and a dash for the faults and all the phases a a dash, b b dash and c c dash. That is we have 2 point F and F dash in the system, which involve the fault. Whereas, in case of short circuit faults we had seen we had only 1 point F which there the fault had occurred.

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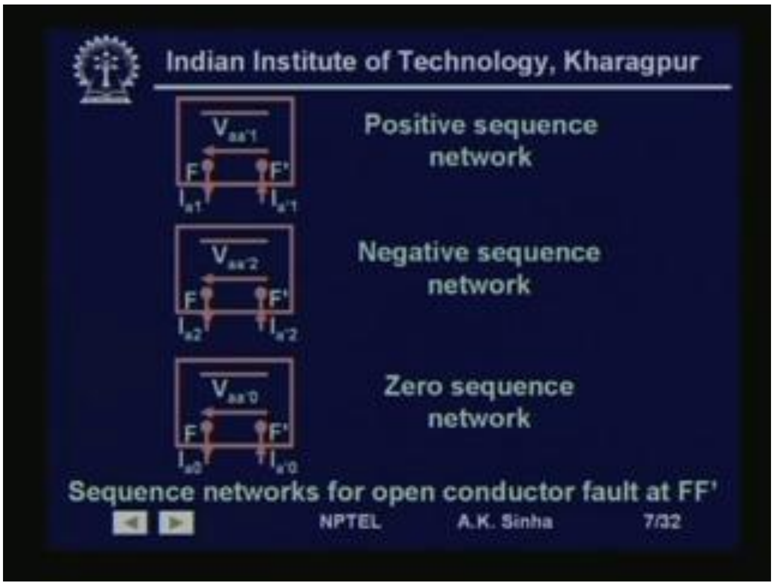

So and trying to obtain the sequence network for this we will also have these 2 points F and F dash. So, this is the reference there is the positive sequence network there is there is the reference. And we have F 1 F dash as the 2 points of indicating the fault. And voltage between these 2 points is v a a dash 1 which is the positive sequence voltage. And the current flowing is i a 1 and entering I a dash 1.

In fact, as we will see these currents will be equal. Similarly the negative sequence we have the reference here. And we have 2 points F and F dash where the current I a 2 is and coming out from F and I a dash 2 is entering F dash. Now, in cash of negative sequence network V a dash 2 is the voltage between F and F dash.

Similarly, we have the zero sequence network reference here 2 points F 1 F dash I a 0 coming out from F I a dash 0 entering F dash and V a a dash 0 is the voltage between F and F dash for this network. Now, what we need to do is we need to find out the connection between the 3 sequence network for different types of fault. But, here what we find is the situation is somewhat more complexes.

Then what we are seen in case of a short circuit here we have 2 points F and F dash. That means, we have to get Thevenin's equivalent between F dash and reference as well as between F 1 reference. That means we have to think of Thevenin's equivalent in terms of 2 port network, because here we have a 2 port network between F dash and the reference and F and reference for each of the sequence network.

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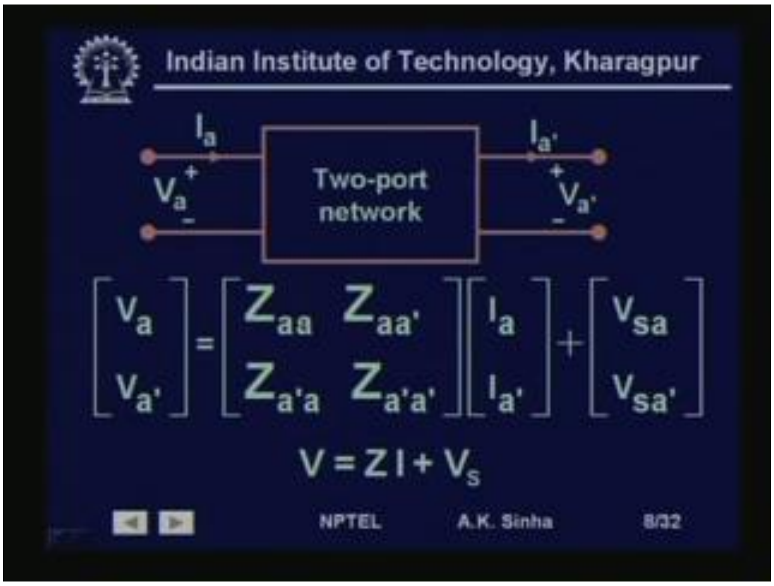

So, we need to take care of this using the theory from 2 port network. So, here I have shown this as a 2 port network, where we have I F flowing n on the input side. So, this side we have I a flowing n and V a is the voltage. And this side I a dash going out and V a dash is the voltage. Now, we can write down the voltage and current relationship for this 2 port network as V a V a dash is equal to Z a a Z a a dash Z a dash a and Z a dash a dash into I a I a dash.

Now this, these impedances are basically called the open circuit impedance for this network. That is you will get this impedance by keeping this open and supplying current here. If see you was supply 1 ampere current here and you measure the voltage here. Then you will get Z a a dash this is Z a a.

Similarly, if you supply a current here keeping this open. If you measure the voltage here you will get Z a a dash. And so in this way we can find out these impedances. And here we have written this V s a and V s a dash. Now, these are basically the voltages or the voltage sources, which are connected in this system, so on this side as well as this side. So, they are taken care by means of this V s a and V s a dash. Therefore, in short we can write this relationship as V is equal to Z I plus V s.

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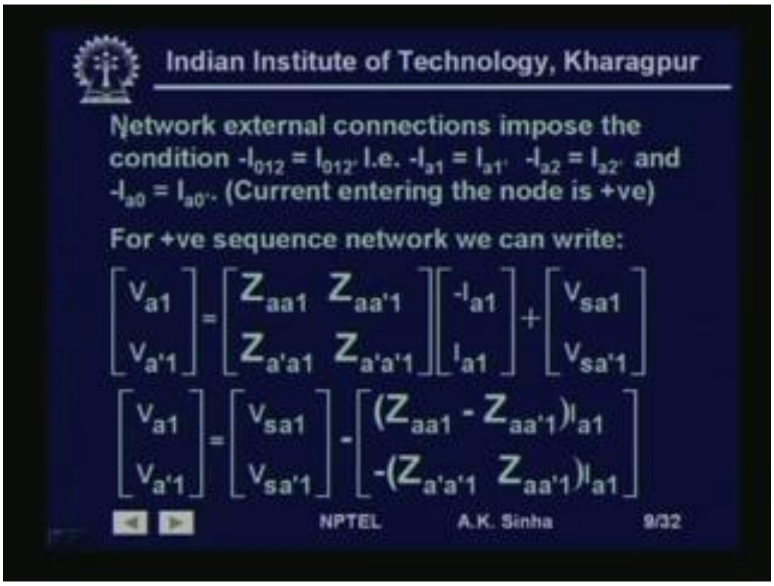

So, how to be use this 2 port network relationship, in case of our sequence networks. Now, as we have as seen that we have in this case a system, where we have I a 1 coming out and I a dash 1 going in. Now, in case there is no crossover of wires; that means, the phase are not coming in contact with the other phase. Then we will the external conditions of the system. We will see that the value of I a 1 and I a dash 1 will be same. That is the current flowing out of the positive sequence network will be same as the flowing in into the positive sequence network at this point F dash. So, the network external connections impose the condition that minus I 0 1 2 is equal to I 0 1 2 dash.

That means the current the sequence currents flowing out of the F point are same as that flowing into the F point. That is minus I a 1 is equal to this is equal to I a dash 1 minus I a 2 is equal to I a dash 2 these dashes should come here. And I a minus I a 0 is equal to I a 0 I a dash 0 current entering the node is considered positive.

So, current coming out that is from the terminal F have been put as negative here. Therefore, for positive sequence network we can write V a 1 and V a dash 1 is equal to Z a a 1 Z a a dash 1 Z a dash a 1 Z a dash a dash 1, these are the open circuit impedances for this 2 port network.

That we have and is into minus I a 1 because we have put this minus I a 1, because we are taking current entering as positive. So, minus I a 1 and plus I a 1, because I a dash I a 1 dash I a dash 1 is basically equal to I a 1. So, here we have this minus I a 1 and I a 1 here, because the magnitudes are same for both as we have said that next network external connections impose this condition. When there is no crossover of the phase. So, plus V s a 1 and V s a dash 1, these are the internal voltage sources in the 2 sides of the network. So, this we can write again as V a 1 V a dash 1 is equal to this, we have taken on this side into this. We have simplified this, then we get this Z a a 1 minus Z a a dash 1 into I a 1 and minus Z a dash a dash a dash 1 I a 1 plus Z a a dash 1 into I a 1.

So, after simplifying if we write this Z a 1 into minus I a 1 Z a a dash 1 into I a 1. So, minus has been taken here. So, this minus comes here now this Z a a Z a dash a 1 this is minus here and this minus is missing here. So, minus we have taking here. So, this is positive, because Z a a dash a dash a dash 1 into I a 1 is here, so Z a dash a dash 1 into I a 1. Now, since it is positive this is minus we have taken here. So, minus is here and this will be minus here. So, this becomes plus and then this becomes minus. So, it is finally, minus Z a a dash 1 into I a 1.

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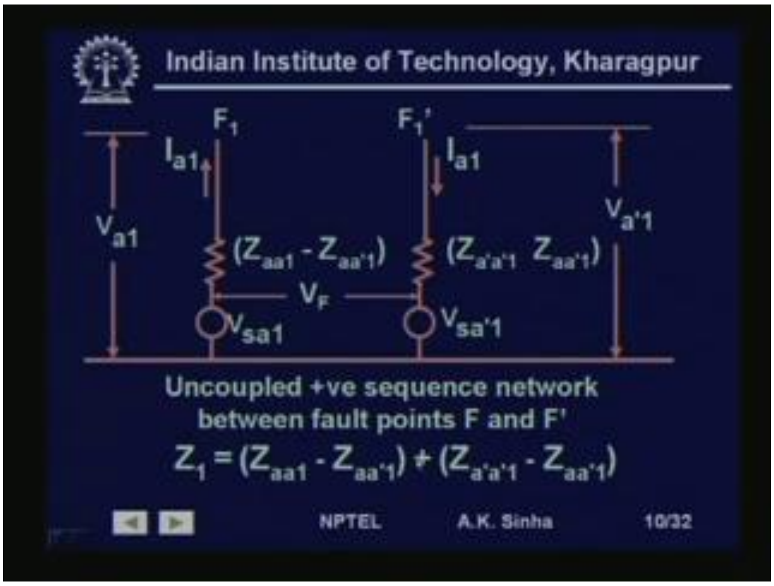

So, this is the relationship that we get which we can write in circuit form like this, where we have V s a 1 is the voltage of the internal voltages in the system. So, that is put here and we have the impedance Z a a 1 minus Z a a dash 1 as the series impedance connected to this source. And I a 1 is the current coming out at this point F 1. Similarly for the other side on the F dash side.

We have V s a 1 dash V s a dash 1 that is the internal voltage on that side. And the impedances Z a a dash a dash a dash 1 minus Z a a dash 1 this minus sign is missing here. So, and the current is entering this node as F 1 dash and the voltage across this is V a dash 1 and the voltage here is V a 1. That is if we remember this we are saying this voltages V a 1 and this is V a dash 1. So, between reference n point F 1 F dash.

So, here that is what we get. So, this is and the V F and the voltage at the fault point which is equal to your V a dash 1 minus V a 1 minus V a dash 1 is the voltage, which is coming between these 2 points. That is V a a dash. So, for the positive sequence and this is the voltage or the open circuit voltage across the fault point, which we get as the Thevenin's equivalent voltage, which will be coming.

So, this is the uncoupled positive sequence network between the fault point F and F dash. Here we can write the if we say that the total current, which flows on the first sequence current which flows through the network encounters, Then positive sequence impedance of the network than the positive sequence impedance red one can be seen as this impedance, and this impedance in series because this is I a 1 flowing and through this flowing through the other parts of the network comes out like this.

So, the current I a 1 is seeing this impedance and this impedance in series. So, we get Z 1 as Z a a 1 minus Z a a dash 1 plus. That is this impedance plus, this impedances plus, this impedance is Z a dash a dash 1 minus Z a a dash 1. So, this is what we will get as the total positive sequence impedance for this network.

Similarly, we can get the uncoupled negative sequence network between point F and F dash. For the system in the same way in the impedance in this case will be Z a a 2 minus Z a a dash 2 and Z a dash a dash 2 minus Z a a dash 2 minus should be here. And the points these are F 2 and F 2 dash and the current flowing here is I a 2. And the current same current after flowing through the parts of the circuit will be entering this point F 2 dash as I a 2 dash, which is same as I a 2 this will be entering here.

Now, again since we have said the negative sequence impedance is the impedance offered, but by this network to current negative sequence current flowing into the network. So, this is the negative sequence current flowing into the network. So, the impedance offered by the network to this current will be this impedance plus this impedance. So, we can write Z 2 is equal to Z a a 2 minus Z a a dash 2 plus Z a dash a dash minus Z a a dash 2. So, this is the total negative sequence impedance seen by the current for the network or this is the negative sequence impedance of the network for this system.

Similarly, we can get the zero sequence network for this F 0 and F 0 dash points. So, here again the impedance is Z a a 0 minus Z a a dash 0 and this impedance is Z a dash a dash 0 minus Za dash a dash 0. And we see that negative and zero sequence network do not have any voltage sources associated with them, which is what we had seen earlier also. So, here also there will be no such sources.

So, uncoupled zero sequence network between fault points F and F dash is like this. And the impedance offered to zero sequence current by this network will be equal to some of these 2 impedances that is Z 0 is equal to Z a a 0 minus Z a a dash 0 plus Z a dash a dash 0 minus Z a a dash 0. So, this is the total impedance which will this network we will see.

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Now, for simulating the open conductor faults since we are simulating only 1 conductor or 2 conductor open faults. In case of 3 conductor open faults we do not need any analysis as such, because in that case there will be no current flowing through the system. System again will be symmetrical open circuit system.

So, a since we are simulating only 1 phase open or 2 phase open. So, what we can do is we can use Z a as infinity. If we are assuming or we are simulating phase single conductor open that is 1 phase open and. So, phase a open with Z a infinity or when we are when we are simulating 2 phases open. Then be can assume Z b to be infinity. So, we do not need to create this for separate Z a Z b Z c.

In fact, we can assume for simulation Z b and Z c and equal and Z a is separate in phase a. So, when we want to simulate for 1 conductor open Z a can be made infinite where Z b will be finite. If we want to conductor open Z b will be infinite and Z a will be finite. So, this way we can simulate this. Now, let us see with this situation what happens.

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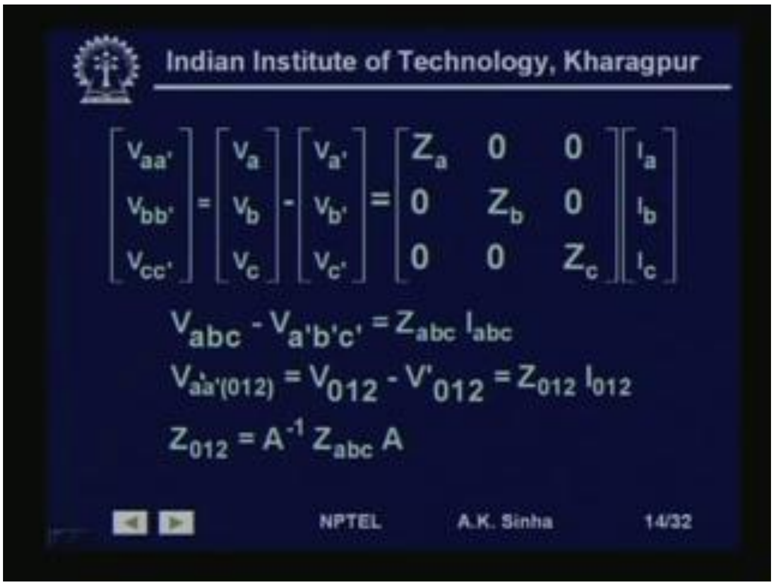

So, again we can write down the voltage equation for the system as V a a dash V b b dash and V c c dash in phase components. So, we this will be equal to V a minus V a dash V b minus V b dash V c minus V c dash, which will be equal to Z a into I a Z b into I b and Z c into I c.

That is if you see here V a minus V a dash will be nothing but I a into Z a here we are assuming there are no mutual couplings between these phase impedances. So, in this way we can write this relationship in this simple form. That is we can write V a b c minus V a dash V a dash b dash c dash is equal to Z a b c into I a b c.

Now, this can also be written in terms of sequence component as V a a dash 0 1 2 is equal to V 0 1 2 minus V dash 0 1 2. That is positive sequence voltages at point F and positive sequence voltages at point F dash. So, subtraction and these 2 will be equal to Z 0 1 2 into I 0 1 2. Where this Z 0 1 2 as we have seen earlier will be nothing but equal to a inverse Z a b c into a where a is the symmetrical component transformation matrix.

So, Z 0 1 2 is equal to a inverse Z a b c into a, this is what we will write for this to get this Z 0 1 2. And then we find that V 0 1 to minus V dash 0 1 2 is equal to Z 0 1 2 into I 0 1 2. That means the phase quantities are now converted into sequence quantities.

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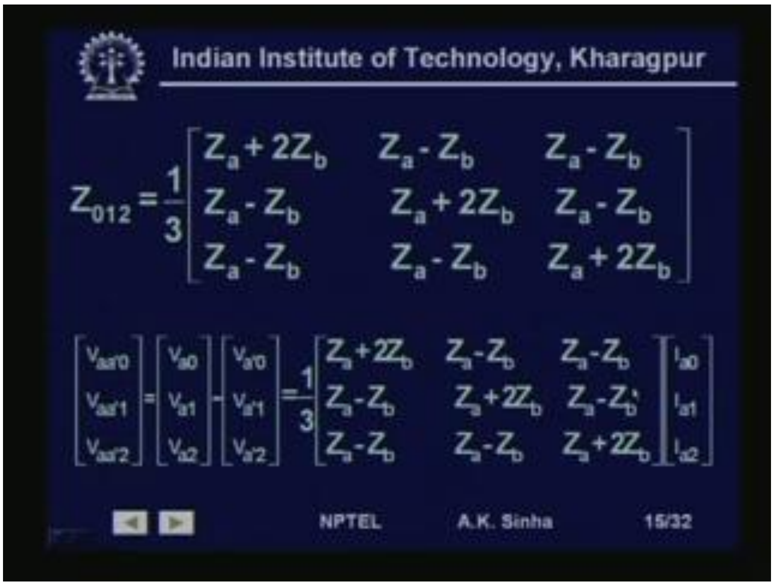

Now, if we do this then we find that Z 0 1 2 is equal to 1 by 3 into Z a plus 2 Z b Z a minus Z b Z a minus Z b. So, that is what we are finding that in this case the diagonal elements are equal to Z a plus 2 Z b. And all the off diagonal elements are equal to Z a minus Z b like this is a symmetric matrix with all the diagonal elements having the same value.

And all the off diagonal elements having the same value. The diagonal elements have Z a plus 2 Z b. Whereas the off diagonal elements or Z a minus Z b. And of course, this 1 by 3 comes, because of the transformation that we have. So, in this cash we can write this as V a dash 0 is equal to V a 0 minus V a dash 0. Similarly, for positive this sequence V a a dash 1 is equal to V a minus 1 minus V a dash 1 V a 2 is equal to V a 2 minus V a dash 2. This is equal to this Z 0 1 2 into I 0 1 2 that is I a 0 I a 1 I a 2. So, this is what we will get.

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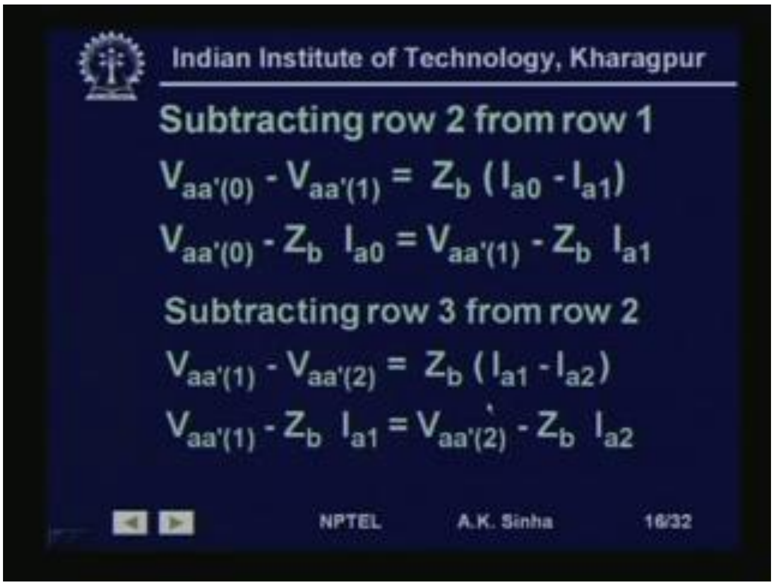

And if we use this relationship, that is subtracting row 2 from row 1. That is from this row 2 ((Refer Time: 27:14)) if we subtract this is Z b Z a minus Z b into I a 0 Z a plus 2 Z b into I a 1 plus Z a minus Z b into I a 2 this we subtract from row 1. That is Z a plus 2 Z b into I a 0 plus Z a minus Z b into I a 1 plus Z a minus Z b into I a 2. Then an arranging this we will get V a a dash 0 minus V a a dash 1 is equal to Z b into I a 0 minus I a 1.

That is, if we do this subtraction of the row 2 from row 1 this is what we are going to that. And this we will we can write as Z a a dash 0 minus Z b into I a 0. This term we are taking on this side. Now, this time we are taking on right hand side. So, this becomes positive. So, V a dash 1 minus Z b into I a 1. So, this is what we will get by subtracting row to from row 1.

Now, similarly subtracting row 3 from row to we will get V a a dash 1 minus V a a dash 2 is equal to Z b into I a 1 minus I a 2 which we will give us V a a dash 1 minus Z b into I a 1 Z b into I a 1 we are taking on this sides. So, it becomes negative, this V a a dash 2 we are taking on this side. So, it becomes positive minus I a 2 into Z b. So, this is minus Z b into I a 2. So, these 2 relationships that we are getting here like this.

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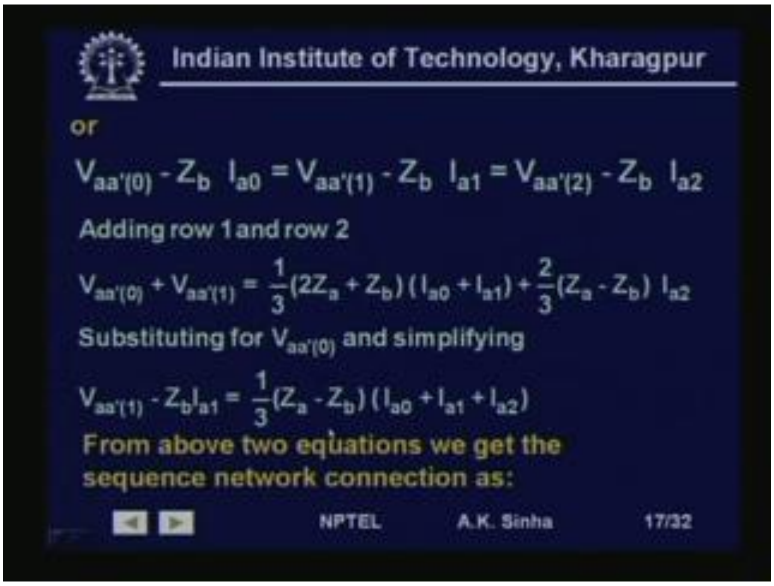

Now, from this what we are seeing V a a dash 0 minus Z b into I a 0 is equal to V a a dash 1 minus Z b into I a 1 is equal to V a a dash 2 minus Z b into I a 2. That is if we see here this term this term V a a dash 1 minus Z b into I a is here also. So, which means this term is equal to this term is equal to this term.

So, this is what we are writing here. That is V a a dash 0 minus Z b into I a 0 is equal to V a a dash 1 minus Z b into I a 1 is equal to V a a dash 2 minus Z b into I a 2. Now, adding row 1 and row 2 what we will get. That is again if we go here and add row 1 and row 2 what we are going to get. We will get V a a dash 0 plus V a a dash 1 is equal to 1 by 3 in to 2 Z a plus Z b into I a 0 plus I a 1 plus 2 by 3 Z a minus Z b into I a 2.

Now, substituting for V a a dash 0 and simplifying that is from here we can substitute value by putting this side on this side. And simplifying we will get V a a dash 1 is the minus Z b into I a 1 is equal to 1 by 3 Z a minus Z b into I a 0 plus I a 1 plus I a 2.

That is would we have done is substituting the value of this. Here from this one and then we will get this V a a dash 1 minus Z b into I a 1 is equal to this 2. So, from above 2 equations we get the sequence network connections as now what does this say. This is saying V a a dash 0 minus Z b into I a 0 is equal to V a a dash 1 minus Z b into I a 1 and V a a dash 2 minus Z b into I a 2 means this Z b is connected in series with this negative sequence network positive sequence network and zero sequence network.

And we also have from this that V a a dash 1 minus Z b into I a 1 is equal to 1 by 3 Z b minus Z a minus Z b into this that is sum of all these 3 currents will also flow through this impedance. So, if we use this, these two this equation and this equation. Then we will get connection of the circuit like this.

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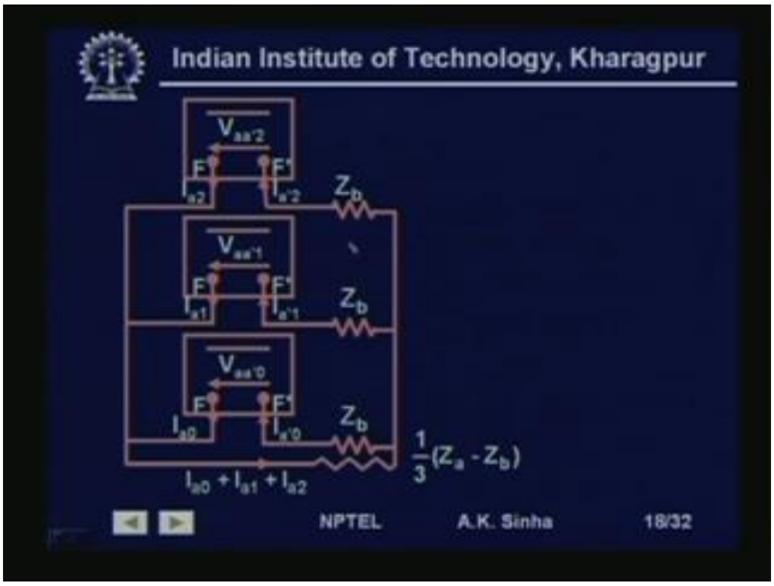

That is V a a 0 in which though the Z b is connected in series with this. So, I a dash 0 is flowing into this. So, this is V a a dash 0 minus Z b into I a 0 is the voltage across these two points. Similarly, V a a dash 1 minus Z b into I a 1 is the voltage, which is coming across these two points.

Similarly, V a a dash 2 minus Z b into I a 2 dash I a 2 is giving as voltage between these two points. So, that is why and these are equal. So, we have connected them. We also see that the current this current is flowing this is I a 2 I a 1 and I a 0 is flowing through the impedance 1 by 3 Z a minus Z b and this is equal to this voltage which is same as this voltage.

So, this is the circuit that we get in case of this system where we have a Z a in phase a and Z b and Z b in phase b and c respectively. So, this is the sequence network connection that we are getting. Now, if you want to get simulate 1 conductor out or a single phase open. Then we can to that very easily by substituting Z a is equal to infinity.

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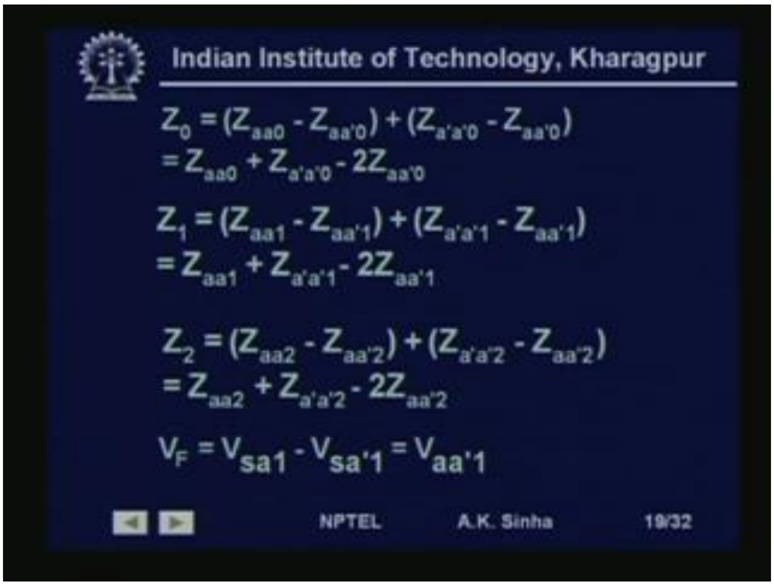

And Z b a finite, but before we to that we need to compute the value of Z 0 Z 1 and Z 2 for the circuit. So, if we see here what is the current which is flowing through that is Ia 1 is flowing through which circuit.

Then we find this Z b is there and the circuit that we had seen for this positive sequence network that will be there. So, Z b is in series with that. And similarly for this we will find for Z 2 will be in series with this Z b. And Z 0 in series with this and of course, 1 by 3 Z a minus Z b is in parallel with these.

So, if we do this circuit reduction then we have Z 0 is equal to Z a a 0 minus Z a a dash 0 plus this. So, this we have seen is equal to this Z 1 we have seen is equal to this Z 2 we have seen is equal to this. That is simply adding this is what we get and V f is equal to V s a 1 minus V s a dash 1 this is equal to V a a dash 1, this is what we had seen in this circuit earlier.

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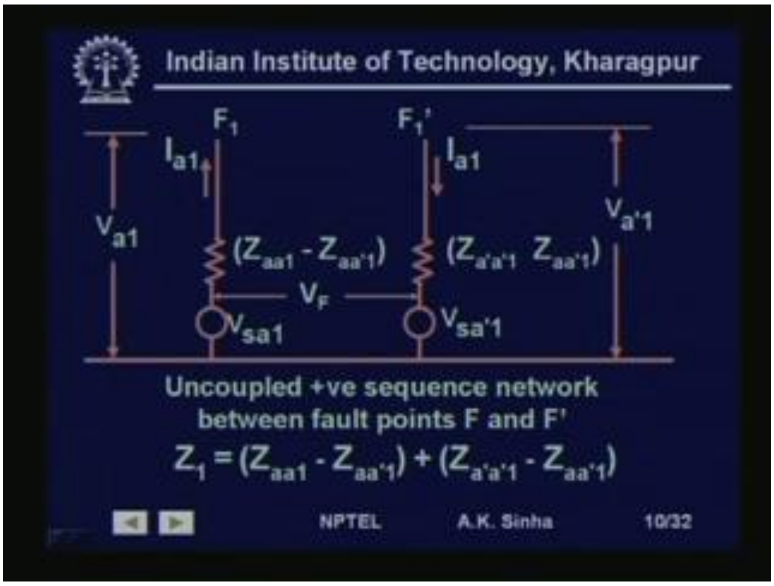

V f is equal to V s s V s a 1 minus V s a dash 1 this is what we have seen this is equal to V f. So, this is what we have. So, V f is this we have Z 1 Z 2 Z 0 ((Refer Time: 35:42)) that we have calculated earlier. So, these can be substituted here.

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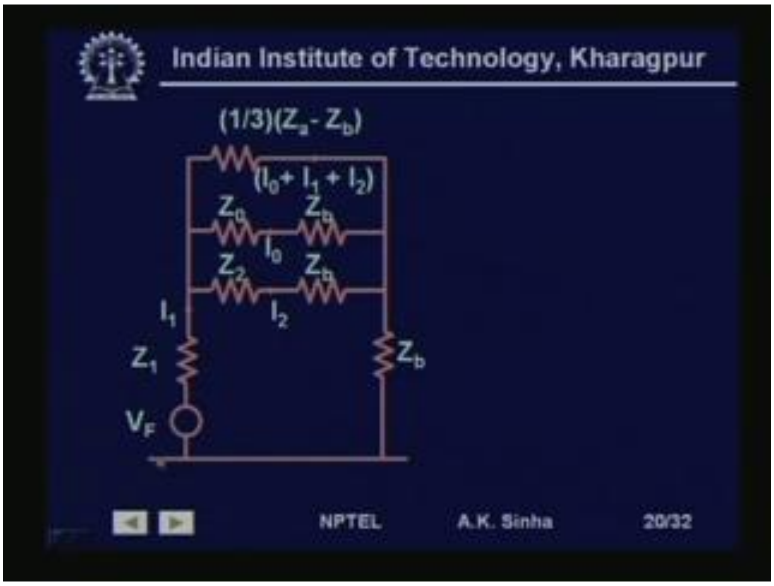

So, we have the complete circuit now like this. V f Z 1 in series with that and we have now this current I 1 flowing through this. And then we have Z b here and this is the point where we have this. This is the point these two the points of the circuit, and then again if we take zero sequence or negative sequence.

Then we have Z 0 and Z b in series. So, we have Z 0 and Z b in series. Similarly, Z 2 and Z b in series and here I 2 is flowing here I 0 is flowing and here we have I zero plus I 1 plus I 2 flowing. So, this is I 1 flowing this is I 2 flowing this is I 0 flowing through the circuit and I 1 plus I 2 plus I 0 flowing through the circuit like this. So, this is complete circuit which defines the sequence network connection for the system, where we have an impedance Z a in phase a and impedance Z b in phase b as well as phase c.

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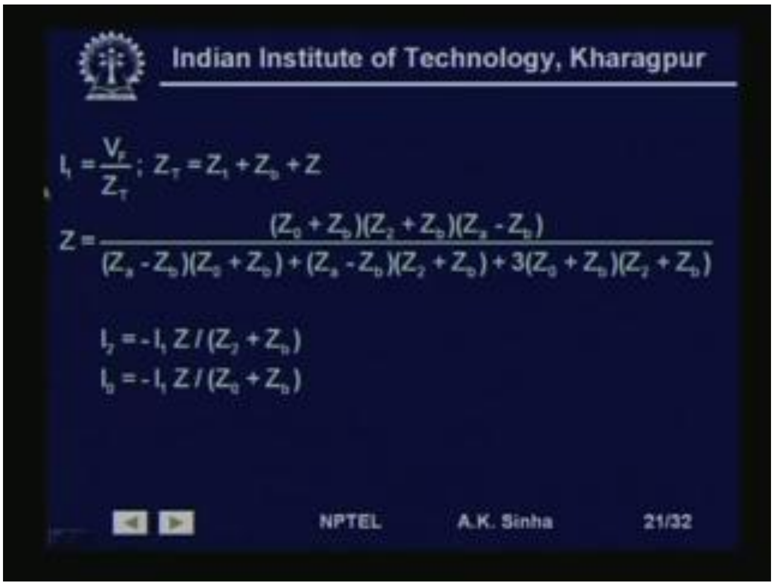

Now, as we said we can calculate the positive, negative and zero sequence current for this circuit. So, we can do that I 1 will be equal to V f by Z t that is if we see this circuit. V f is the voltage and this is the total impedance of the circuit is the Z t and we need to find out what is Z t.

So, Z t will be equal to Z 1 plus Z b that is again if we see this is a Z 1 in series and Z b in series which I 1 flowing. And this rest of the circuit is again can be reduced in to 1 impedance connected between, these 2 points. So, if we do that that is these 3 impedance arms are in parallel. So, we need to find out and equivalent for these three. So, that is Z and we can right this Z is equal to Z 0 plus Z b into Z 2 plus Z b into Z a minus Z b divided by Z a minus Z b into Z 0 plus Z b plus Z a minus Z b into Z 2 plus Z b plus 3 times Z 0 plus Z b into Z 2 plus Z b.

That is what we have done is ((Refer Time: 38:32)) reduce these 3 arms into a single impedance Z. Then we have Z 1 plus this Z plus Z b that is equal to Z t. So, if we do that then we have this I 1 computed like this. I 2 is the part of current, which is flowing in that. So, this can be written as minus I 1 Z divided by Z 2 plus Z b and I 0 will be minus I 1 Z divided by Z 0 plus Z b.

So, since I 1 is flowing and total impedance as we had seen is this impedance is Z. A part of this goes through this rest will go through this. So, we have this ratio coming into picture. So, Z by Z 2 plus Z b and Z by Z 0 plus Z b for I 0 and I 2 we have Z by Z 2 plus Z b part of the current I 1 will be flowing. So, this is how we can calculate the positive negative and zero sequence current flowing into this system.

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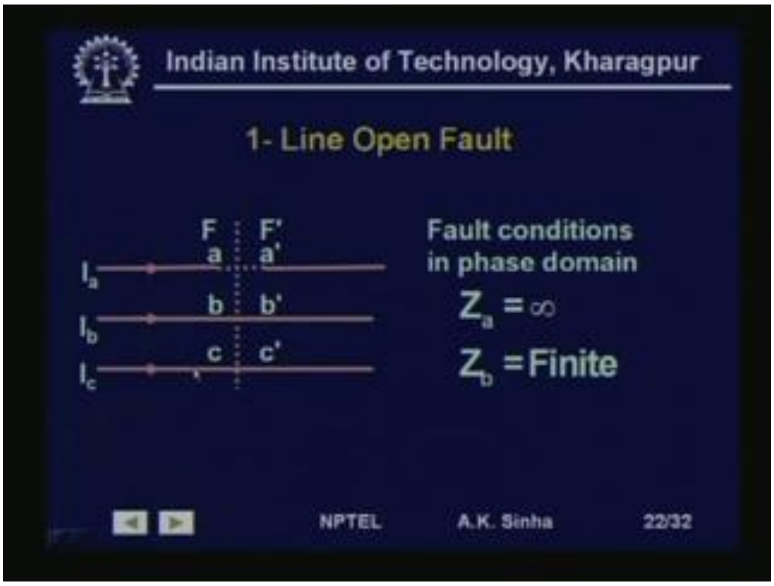

Now, we want to simulate 1 line open for a single phase open fault. Again here as we have seen we have this fault created between 2 points F and F dash. Now, in this case what we have Z a is infinite. If we see the previous system and Z b is finite. So, substituting Z b as finite. So, these 2 lines are connected and we have a finite impedance here infinite impedance here. There is a infinite impedance here because it is open here.

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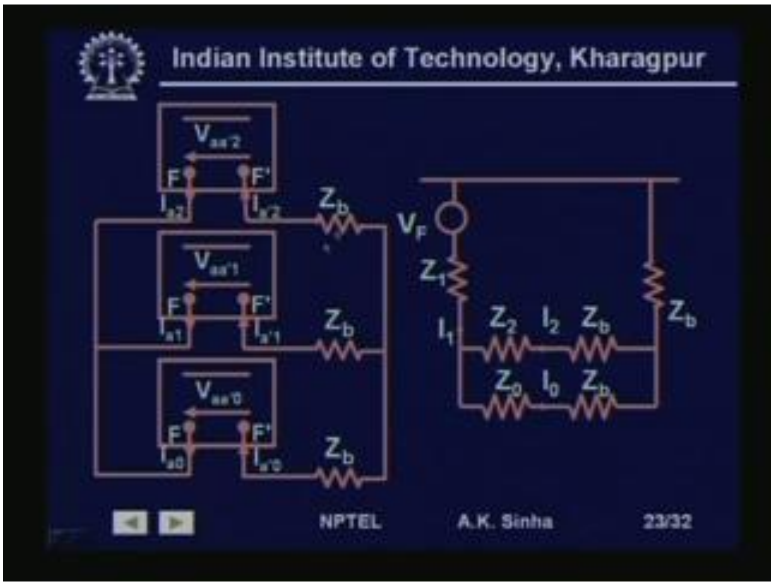

So, with this if you see then what happens if we go back to this circuit. What we find substituting Z a is equal to infinite means this becomes infinite. So, this is an open circuit, rest of the circuit, we do not have Z a. So, rest of the circuit remains as the case. So, this is what we get in this case that is this is the system, that we have, where we have Z a as here.

We have a Z a minus Z 1 by 3 Z a minus Z b that part is now infinite. So, it is open. So, when we reduce this circuit we reduce it to this form that part here 1 by 3 Z a minus Z b is no longer connected parallel that is open. So, this is the total circuit that we have and we can calculate I 1 I 2 and I 0 for this circuit.

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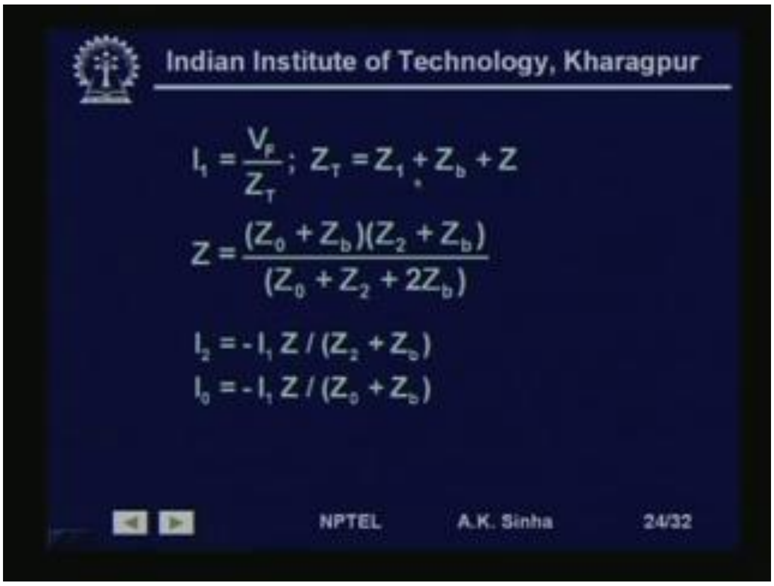

So, we get I 1 is equal to V f by Z t and Z t in this case will be equal to Z 1 plus Z b plus Z. That is again Z 1 plus Z b plus Z, which is the parallel of these 2 arms. So, we can do this Z is equal to Z 0 plus Z b into Z 2 plus Z b plus divided by Z 0 plus Z 2 plus 2 Z b. And once we have we know I 1 we can calculate I 2 is equal to minus I 1 into Z by Z 2 plus Z b and I 0 will be minus I 1 Z divided by Z 0 plus Z b. And so this way we can compute. All the 3 currents sequence currents and then we can convert them 2 phase values and we can calculate the voltages in the same way.

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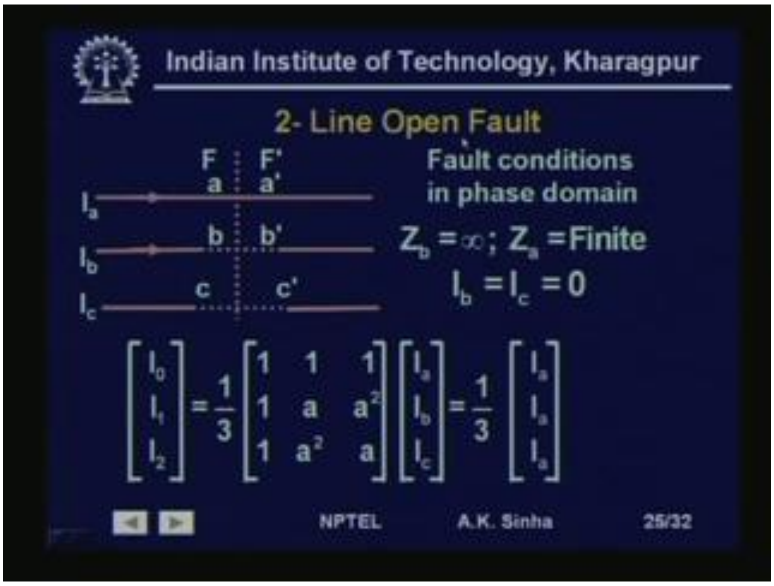

Now, for a 2 line open fault that is phase b and c are open. This can be simulated by putting Z b is equal to infinite and Z a as finite. That means I b and I c in this case is equal to 0. Now, if that is the situation then we can right this I 0 I 1 I 2 is equal to 1 by 3 into this is the transformation matrix. That we have inverse and this is I a I b and I c. Now, I b and I c are 0. So, what we get we get I 0 is equal to 1 by 3 into I a I 1 is equal to 1 by 3 into I a I 2 is equal to 1 by 3 into I a these 2 are 0. So, we get 1 by 3 I a I a I a. So, what does this say. This says that the 3 sequence currents are equal which means the 3 sequence current networks connected in series. So, this is what we will get.

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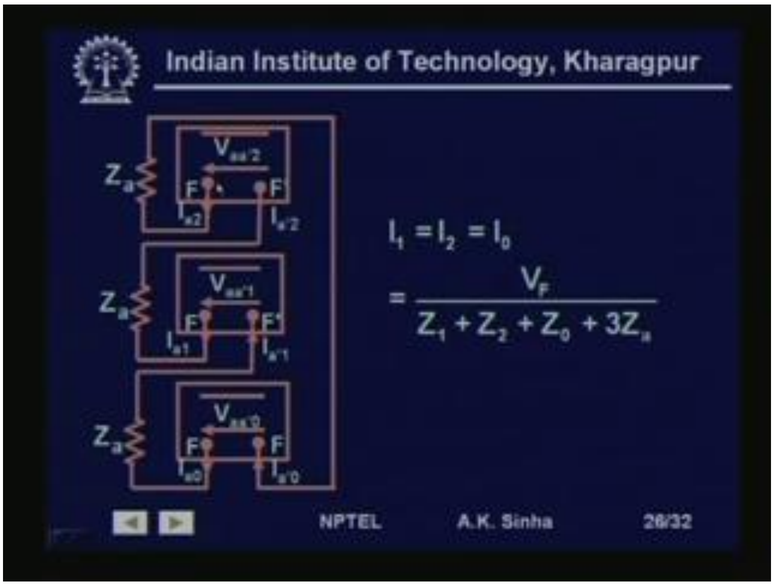

Here the, this is the zero sequence network Z a is connected in series like this. To F dash then from F again Z is connected to F here and then F dash here and then from F Z a connected and it comes to this point. So, the 3 networks are in series as such is Z a Z a and Z a connected here therefore, we get I 1 is equal to I 2 is equal to I 0. This is equal to V f divided by Z 1 plus Z 2 plus Z 0 plus 3 Z a.

So, in this case this is how we calculate the current sequence currents. Once we know the sequence currents. We can calculate the sequence voltages at any point and converting them. We will find out the phase voltages at fault point or any another point in the system. So, this is how we can solve open circuit faults using the sequence network connections.

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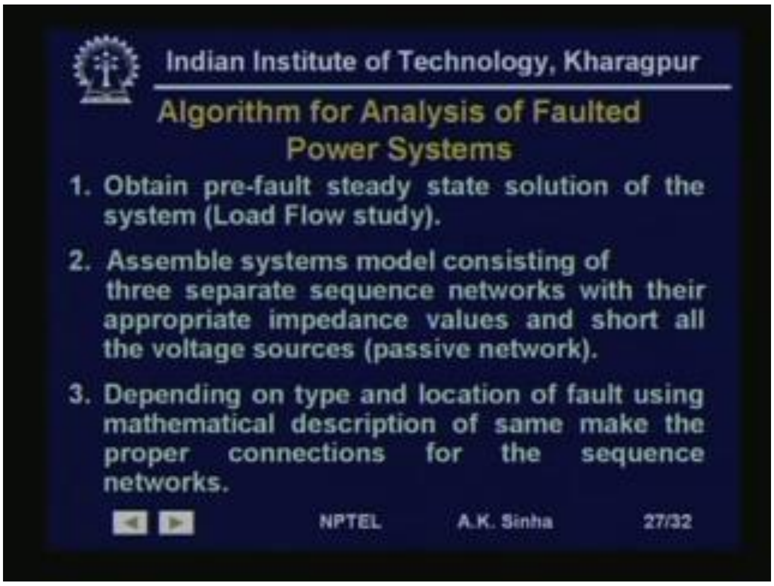

So, after this we will summarize whatever we have a done. Tell now in case of faulted system analysis how do we carry it out. So, what we do is we will right down the algorithm for analysis of faulted power system. What we do first is obtain pre fault steady state solution of the system. That is the pre fault conditions we find out if we can if we do not know or do not want to these values. Or we have unloaded system that is we have a assumed that the system is initially unloaded. Then of course, we know the voltages are one and the currents are zero.

So, but if we want to take into account the loaded system condition at which the fault has occurred. Then we can of course, dual load flow study and find out the voltage and currents in various parts of this system. So, we know that pre faults steady state solution of the system by doing a load flow study.

Now, after this assemble the system models consisting of 3 separate sequence networks. That is we create the 3 sequence networks, positive, negative and zero sequence networks with their appropriate impedances. Which means if we are interested in the fault current immediately after the fault has a occurred. Then we get the subtransient impedances, if we are interested in finding out the current after sometime, that is when the breaker opens.

The circuit may be after 2 cycles or 5 cycles like that. Then we may substitute transient impedances instead of the subtransient impedances. And if we are interested in sustain fault current that is steady state fault current. Then we need to substitute the steady state impedances, which is the synchronous impedances for the machines as such.

So, appropriate impedance value and short all the voltage sources that is we have seen earlier that. What we do is for computing the fault currents using the Thevenin's theorem principle. What we are trying to do is find out the changes caused by introducing this fault.

That is we had seen that fault is acting as a structural change. That is inclusion of an impedance fault impedance into the system. And this we can simulate by using Thevenin's theorem. That is by putting impedance at fault point equal to this impedance in series with the voltage, which is opposite to the open circuit voltage at the fault point

So, that is what we do in this case. So, for this purpose we have already eliminated all the voltage sources. That is the all the generators are shorted and replace by their appropriate impedances. Depending on the type on location of the fault using the mathematical description of the of the same, make proper connection for the sequence network. That is depending on the type of all fault if it is single line to ground fault. Then it all the 3 impedance as 3 sequence networks will be connected in series and so on. So, we need to do that. So, make the proper connections for the sequence network. Then excite the positive sequence network at the fault point.

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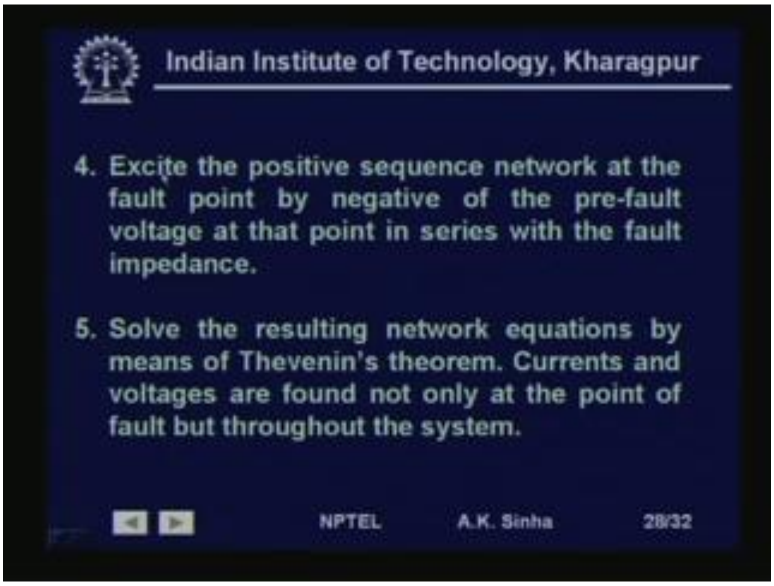

As what I said excite the positive sequence network at the fault point by negative of the pre-fault voltage at that point. In series with the fault impedance, this is what the Thevenin's theorem says that .We have reduced the network passive network by shorting all the voltage sources and replacing them by their appropriate impedances

Now, at the fault point we have we connect the voltage source of value which is equal to the negative of the open circuit voltage at that point that we had found using in the Thevenin's theorem. And in series this voltage is connected the series with the fault impedance at the fault point. So, between the fault point and the reference.

So, this is how we do that this when we do this will give us the currents and voltages caused by the introduction of the fault. That is the changes caused by this fault and this can be added or superimposed on the pre-fault values. And therefore, we will get the final values. Solve the resulting network equitation's by means of Thevenin's theorem currents and voltages are found not only for the point of fault, but throughout the system.

So, once we find these changes what we do is we added to the or superimposed on the pre-fault conditions that we have. And then we know the voltages and currents are various points in this system. So, this is the algorithm that we use for solving the faulted system. That is the solving or analyzing the system under fault conditions.

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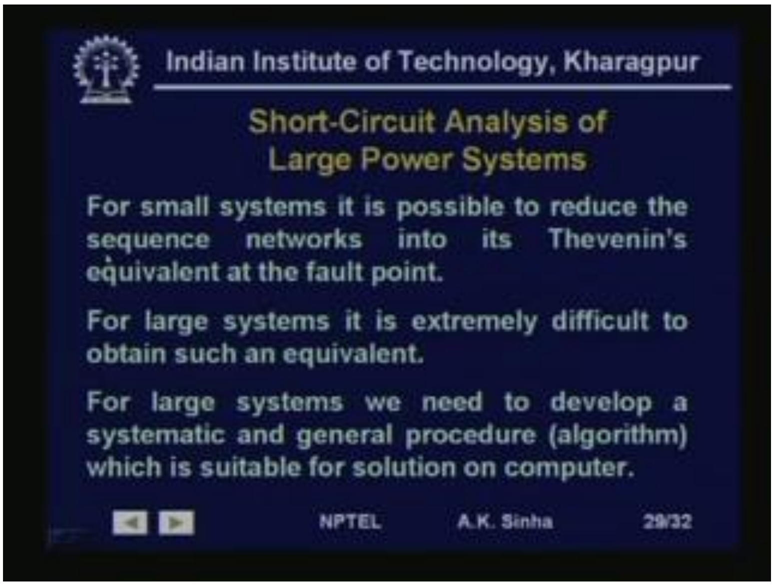

However, this does not what work very well for large system. Because, here we need to find out the reduce network. Reduce possible network at the fault point, which is very difficult to obtain for large systems So, for small systems it is to possible to reduce the sequence network into establish equivalent at the fault point.

But for large system it is extremely difficult to obtain such an equivalent. That is very complex to do that for a large system, which has large number of lines and nodes in the system that is bus wires in the system. For large systems therefore, we need to develop a systematic and general procedure. That is some algorithm which is suitable for solution on computer we need to do this for large systems. And we will see how we do it in detail in the next class. So, what we do before we start analysis large system we need to define the problem or state the problem

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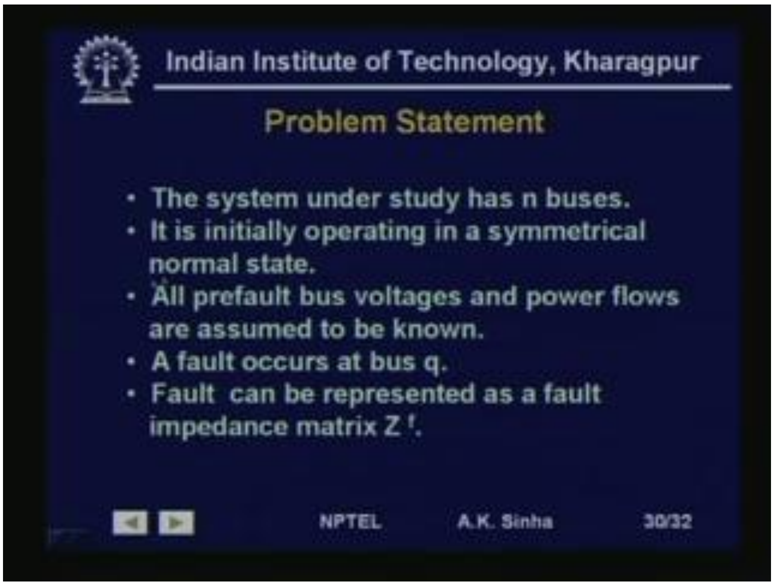

So, what we do is we say that the system under study has n buses, where n is very any number and large number normally. It is initially operating in a symmetrical normal state. That is what we assumed that initial conditions are steady state conditions all pre-fault bus voltages and power flows are assume to be known.

That is we have done the load flow study. And the know the voltage and power flows at a fault occurs at some bus q. So, any bus it can be any bus q fault can be represented as a fault impedance matrix Z f. This again we will see how to do it. So, that is if you see the system. We can define this is the n bus power system.

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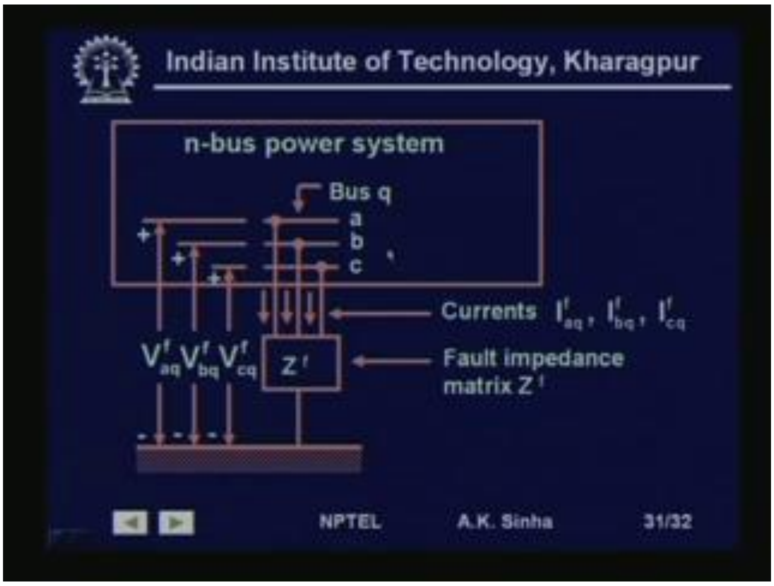

In which we have taken this bus q at which the fault has occurred the fault impedance is Z f and the a, b, c phase voltages are shown here for the bus q. So, with this we end today. In the next lesson we will talk about how to develop an algorithm for short circuit studies on large power systems.

Thank you very much.

Preview of Next Lecture

Lecture No. # 30

Fault Analysis for Large Power System

Welcome to lesson 30 on Power System Analysis. In these lessons we will discuss Fault Analysis for large power system. We will start with an introduction. Then we will discuss fault analysis for last power system using Y bus matrix.

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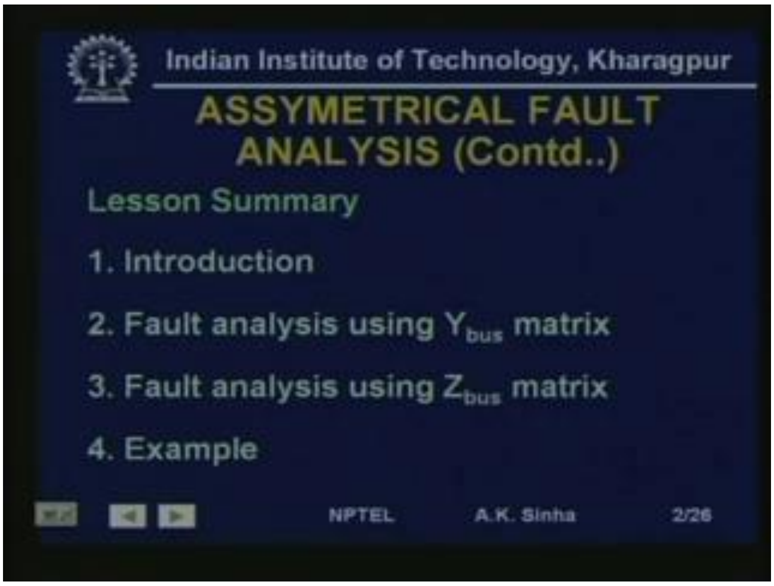

Then we will talk about fault analysis using Z bus matrix and then finally, will solve one example using Z bus matrix.

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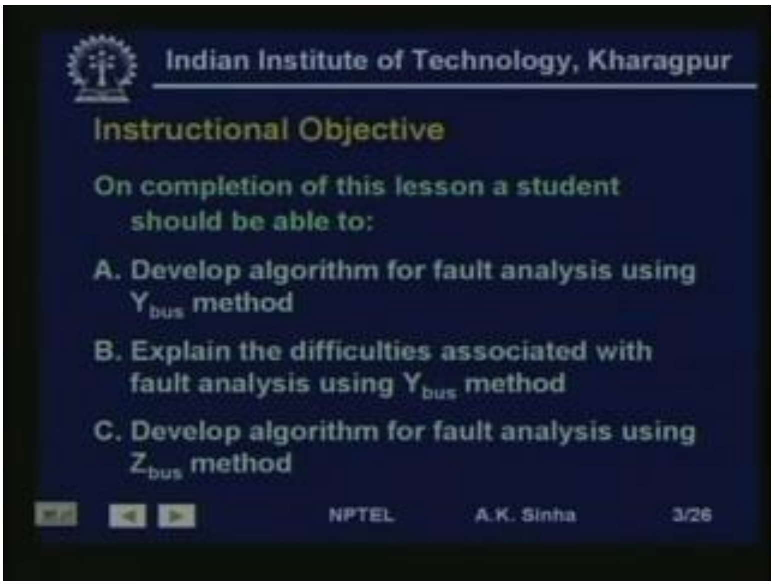

Well, the instructional objective for this lesson is that on completion of this lesson, you should be able to develop algorithm for fault analysis using Y bus methods. Explain the difficulties associated with fault analysis using Y bus method. Develop an algorithm for fault analysis using Z bus method.

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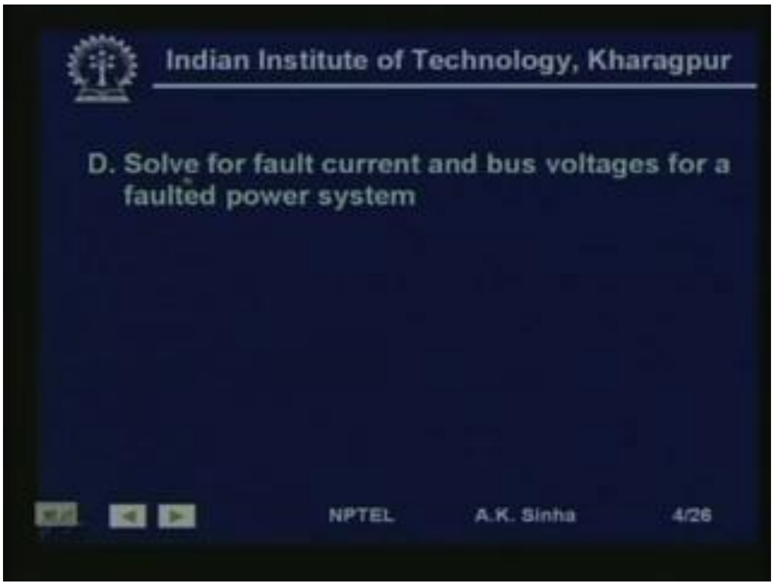

And solve for fault current and bus voltages for a faulted power system using the Z bus method.

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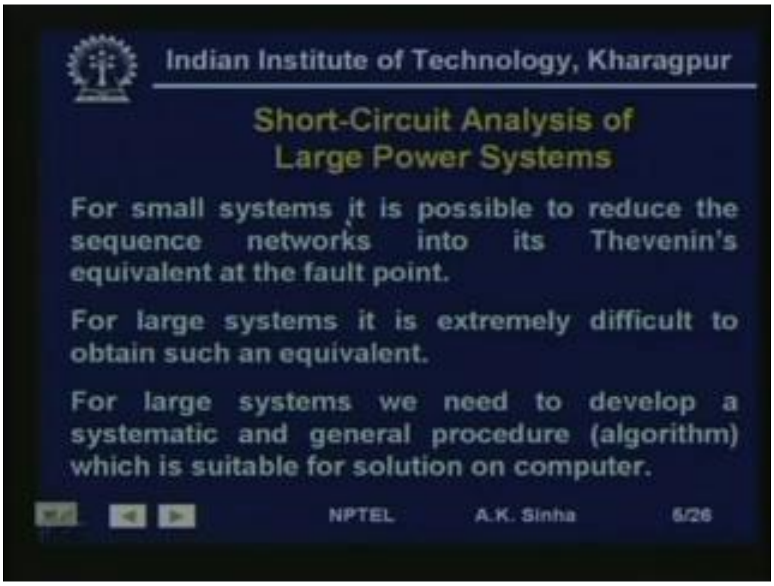

Well as we had discussed in lesson 29. That we can do symmetrical as well as asymmetrical fault analysis using Thevenin's theorem, but when we are trying to do it for a large system, trying to find out the Thevenin's equivalent of the network at the fault point as a very complex job.

For small systems it is possible to reduce the sequence networks into Thevenin's equivalent at the fault point. For large network it is extremely difficult to obtain such an equivalent. Because, you need reduction for very large network with large number of voltage sources in the system.

So, therefore, for these large systems we needs some kind of a systematic method to solve this problem using a digital computer. So, we need to develop a systematic and general procedure, which is suitable for solution on a computer.

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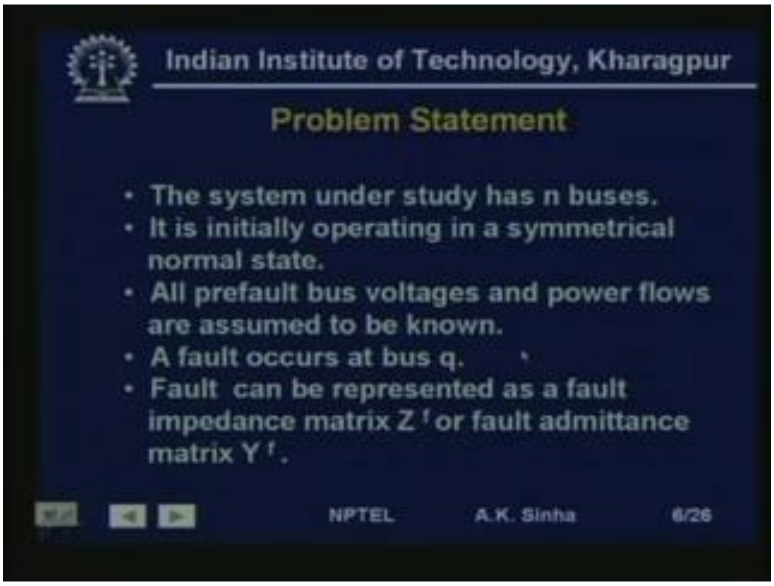

Now, how do we go about this. First what we will do is we will define or we will state the problem for a large power system. So, what will do is we will state a general problem in which we will say that system under study has n buses, where n is pretty large. It is initially operating in a symmetrical normal state that is before the fault has occurred. The system is working in a normal state, which is basically operating and a asymmetrical loading condition. So, voltages and currents in the system are normal they are not abnormal. So, node currents are there the system voltage is or the bus voltage is at various places will be very near to their rated values.

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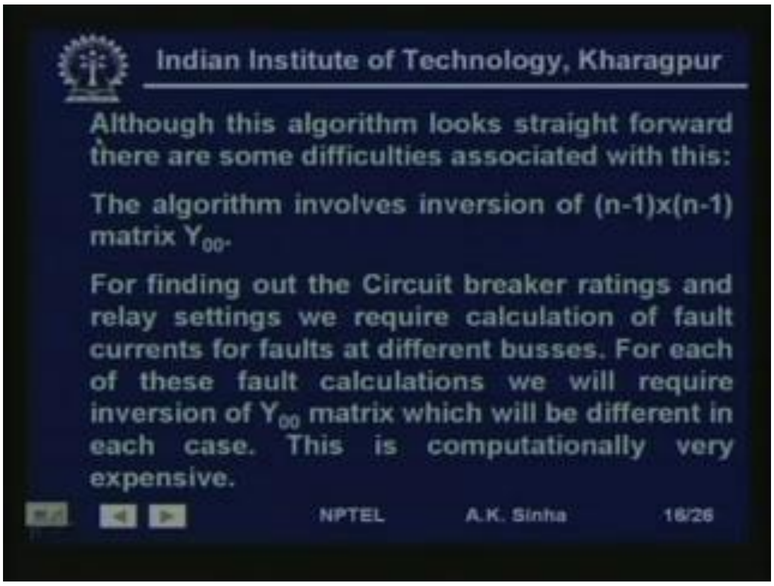

So, this is what will we have written here, that although, this algorithm looks straight forward there are some difficulties associated with this. The algorithm involves inversion of n minus 1 into n minus 1 matrix Y 0 0, for finding out the circuit breaker ratings, and relay settings. We require calculation of fault currents for faults at different busses. That is what we said at various buses we need to compute create the fault, and the find out that the fault currents and the voltages. For each of these fault calculations we will require inversion of Y 0 0 matrix which will be different in each case. This is computationally very expensive and this is the main reason Y Y bus based algorithm for fault analysis is not much prepared. Instead the prepared the stead bus based algorithm and we will see how this Z bus based algorithm to works.

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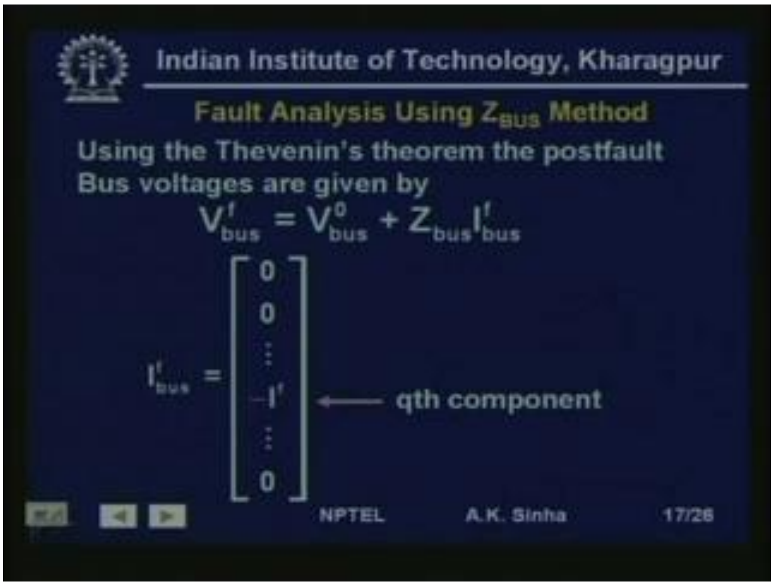

So, fault analysis using Z bus method. Now, again we have seen using the Thevenin's theorem the post-fault bus voltages can be returns as V bus as is equal to V bus 0 plus Z bus into I bus f. Now, what is this I bus f? I bus f is basically the current injections at various points when the fault as occurred.

Now, as we have seen for Thevenin's equivalent, what we have written is that this delta V involves this delta I. This is the because of the changes which have occurred and in case of finding out the changes, we have already eliminated all generating sources. The only source which is available in the system is the voltage source at the fault point. And that is the current I f and flowing from the bus towards the graph.

So, if we see in terms of current injection at all the other buses except the q th bus is going to be 0 and the q th bus the current injection is nothing but the negative of the fault current, because the fault current is flowing away from the bus to the ground. And since we write these equations in terms of current injections into the bus, therefore we write this as minus IF.