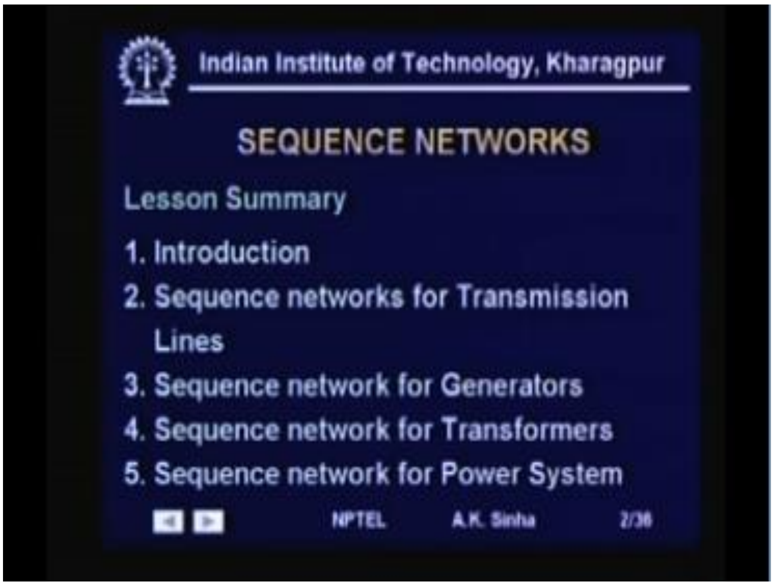
Power System Analysis
Prof. A.K. Sinha
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 27
Sequence Networks

(Refer Slide Time: 00:52)

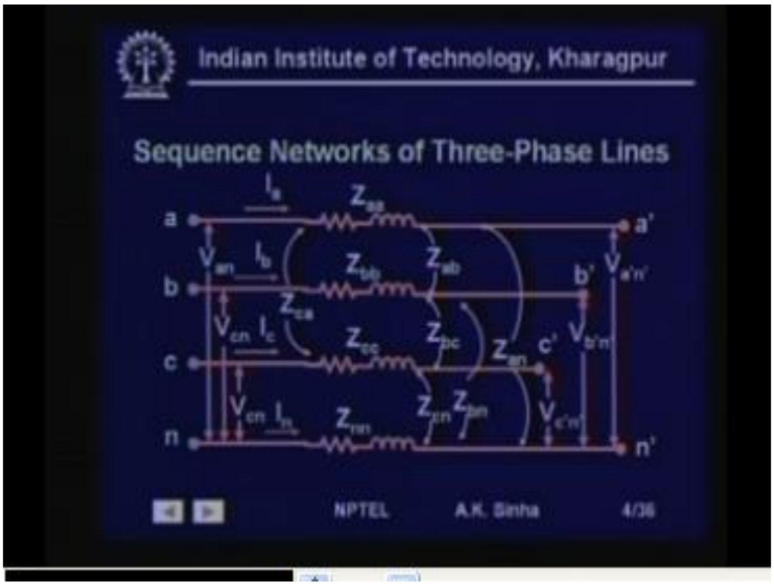


Welcome to lesson 27 on Power System Analysis. In this lesson, we will discuss about the Sequence Networks. First, we will start with an introduction and we will talk about sequence networks for transmission lines. After, that we will discuss the sequence network model for generators and then, we will discuss the sequence network model for transformers. After, we have built models for the various equipments. We will now go into the building up of the sequence network for power systems.

Well, once you go through this lesson, you should be able to develop the sequence network for transmission lines, for generators and transformers. And finally, you should be able to assemble sequence network, for small power systems. Well, if you recall our previous lesson, we talked about symmetrical components and it is advantages and analyzing unbalanced power systems. We also discussed about the sequence model for the loads.

In this lesson, we will be developing the sequence models, for the other components, such as transmission lines, generators and transformers. And finally, we will be assembling these models to form small power system networks and sequence components.

(Refer Slide Time: 02:53)



First, we will take up the sequence network model of three-phase transmission lines. If you recall three-phase transmission lines, have series impedance, which consists of it is resistance and the inductance. For all the phases, as we have shown here has Z a a, Z b b and Z c c, for the three phases. We have also considered the neutral wire or the earth wire of the system, which forms as the return current path in case of unbalance system operation.

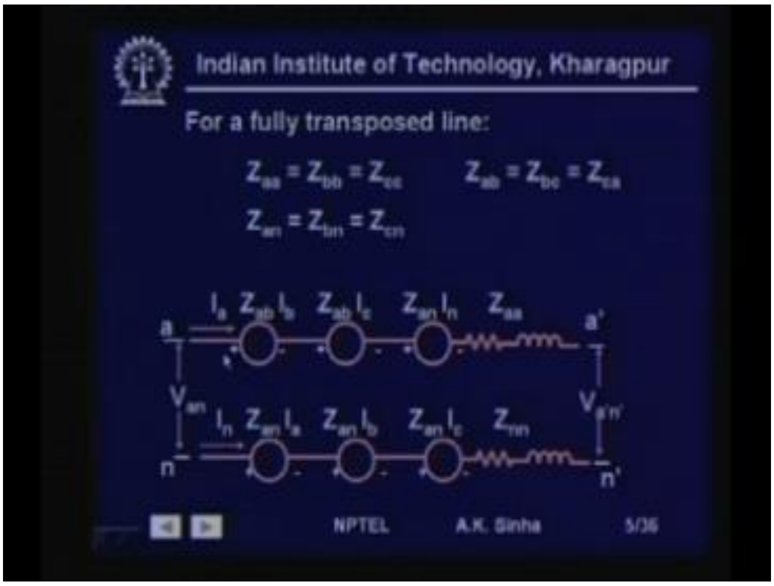
Now, if you recall our lesson on transmission line modeling, you had remembered that, we have the ground wires or the earth wires at the top of the tower. And these ground wires are grounded at a certain intervals. That is at the tower at each tower by the tower footing resistance. So, we have this return path, which is made up of metallic conductor, the ground wires on top of the tower and also the path through the earth.

Here, we are considering this as ground wire or the neutral wire, as the conductor on the tower. Now, we have also, since these transmission lines the phase conductors are near to each other as well as near to the earth wire. So, we will also have mutual impedances between them. That is Z a b between a and b conductors, Z b c between b and c conductors, Z a c or c a between a and c conductors.

Similarly, between each conductor and the ground, we will have the Z a n between conductor a and n and b n between conductors b and n and c n between conductors c and n. We are assuming that, the two ends of the line are represented by a, b and c and n on one side and a dash, b dash, c dash and n dash, on the other side. The voltage for phase a, between neutral and phase a is V a n, at the sending inside V b n, this should V b n for voltage of phase b, with respect to neutral and B c n for voltage of phase c, with respect to neutral.

Similarly, on the other side, we have voltage V c dash n dash, for the phase c conduction on the side and V dash n dash for phase b and V dash n dash for phase b and V dash, V a dash n dash, for phase a. So, this is the complete circuit model. That we have here current I a flows in phase a, I b flows in phase b and I c flows in phase c, in this direction. And I n is flowing in phase n, that is the neutral conductor.

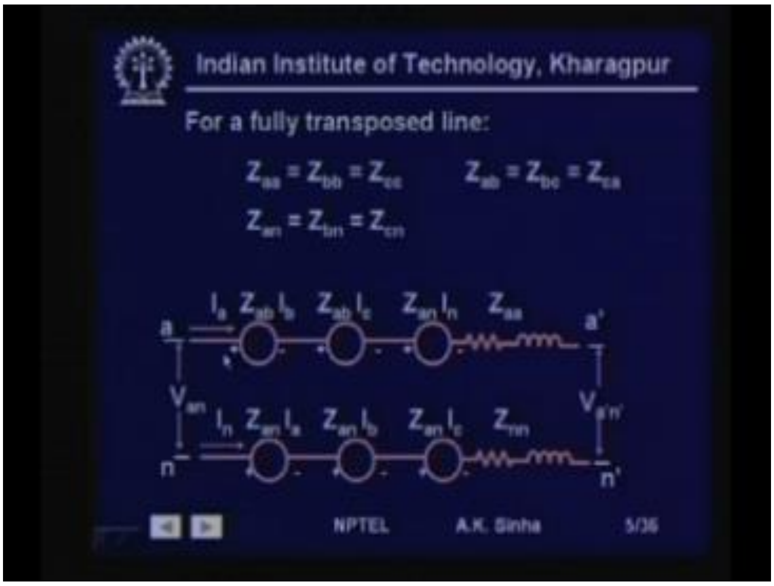
(Refer Slide Time: 06:49)



Now, for this system, we can write the relationships using Kirchhoff's law. If you recall for phase a, if you want to write the relationship, what we will have is, there is going to be voltage drop. Because, of current flowing in I a, as I a into Z a a, that will be there. But, because of current flowing in b also there is going to be a voltage drop, which will be Z a b into I b.

Similarly, for current flowing into c, there is going to be a voltage drop in this, phase a that will be Z c a into I c. And similar voltage drops, will be there in the neutral conductor also. That is N n into Z n n will be because of I n flowing. But, because of the other currents flowing in c, current in phase a. We will have Z a n into I a, which will be is also a drop from this side to this and b n into I b will be a drop in this and c n into I c will be again a drop in this conductor. So, voltage from here to here, it can be shown like this, for phase a conductor. The current I a is flowing Z a into I b is the drop here.

(Refer Slide Time: 08:17)

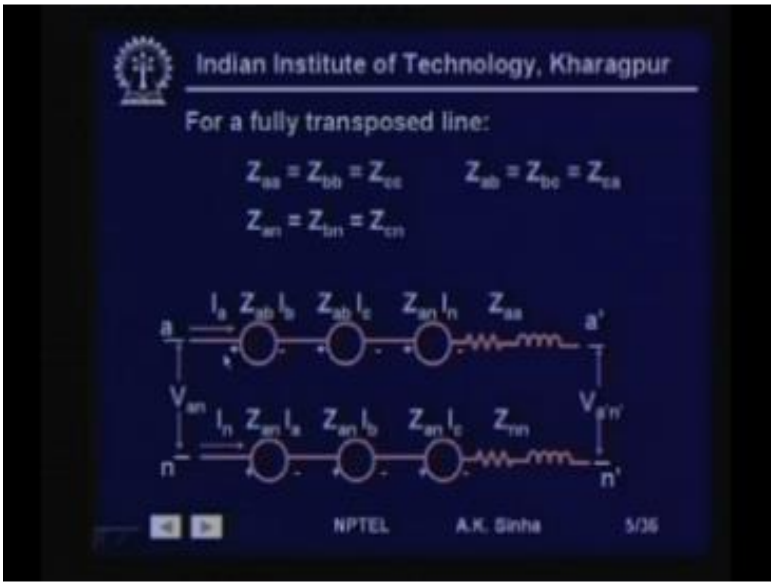


Now, here what we have assumed is, that the transmission line is fully transposed. Now, what does this really mean, as we have already discussed that, we do transposition to make the line symmetrical. That is, all the impedances over the complete distance of the line are going to be symmetrical for the transmission line, which simply means, that Z a a is equal to Z b b is equal to Z c c. And the mutual impendence, between the phase conductors are also going to be equal is Z a b is equal to Z b c is equal Z c a.

Similarly, for the mutual impendence between the phase conductors and the neutral also will be equal. So, Z a n will be equal to Z b n is equal to Z c n. So, this we are assuming for the transmission line, because most of the long distance transmission line, will be transpose lines. Even, in case, when they are not transposed, the asymmetry is not very large and for most of the analysis purpose, we assume the line to be fully symmetrical.

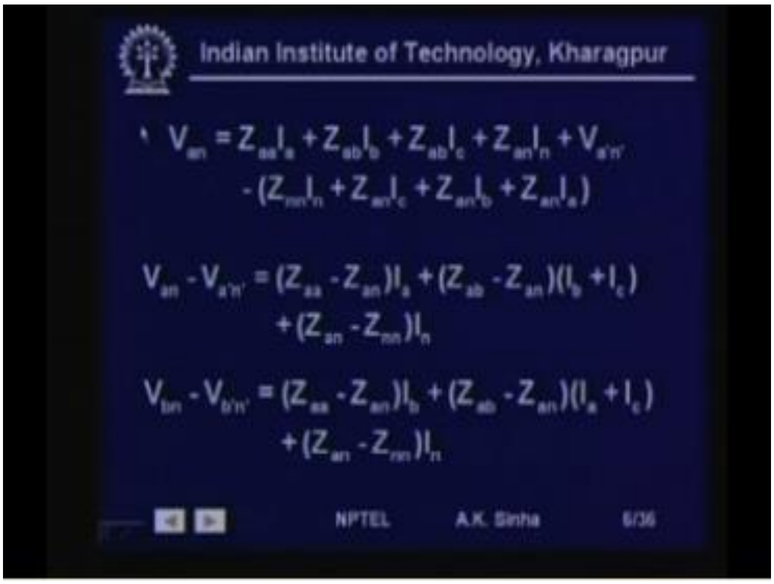
Therefore, we have Z a b into I b the voltage drop due to current flowing in I b, Z a b, which is basically Z a c. So, Z a c is equal Z a b. So, we are writing Z a b into I c plus Z a n into I n plus Z a a into I a, this is total drop from this point to this point. Similarly, from for this current, I n flowing on this conductor, the neutral conductor. We will have a drop Z a n, I a in this direction, Z a n, I b in this direction and Z a n, I c in this direction and Z n n and I n in this direction.

(Refer Slide Time: 10:46)



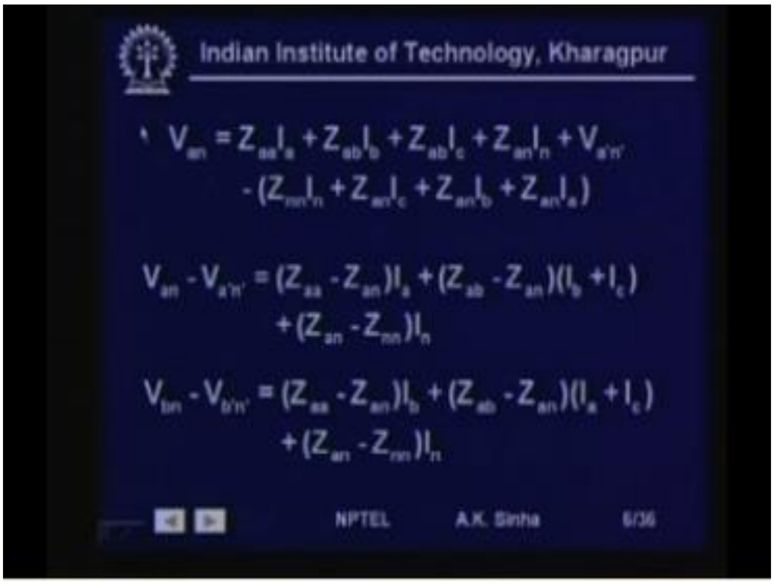
So, if we look at the circuit like this, then we can write down the relationship as V a n. The voltage at this point is going to be equal to this voltage plus the drop here minus all the drops here. That is from here these voltages plus this voltage plus this voltage. So, since, we will move in this direction, therefore these will be negatives.

(Refer Slide Time: 11:30)



So, if we write like that then V a n is equal to Z a a, I a plus Z a b, I b plus Z a b, I c plus Z a n, I n, this is this part plus V a dash n dash plus this voltage V a dash n dash. Minus this, because we have assumed current I n to be flowing like this. So, minus I n into Z n n minus. So, minus I n into Z n n Minus I c into Z a n, which is Z c n basically.

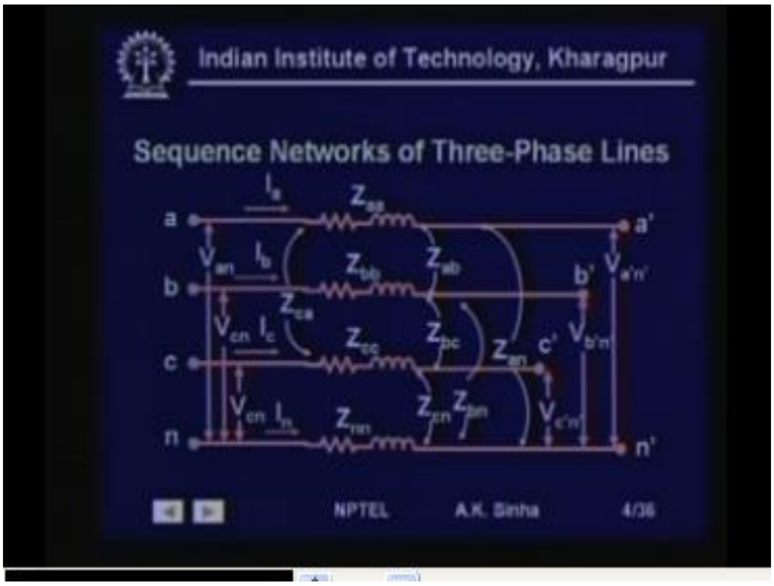
(Refer Slide Time: 11:54)



So, Z c n is equal to Z a n. So, we are writing everything in terms of a. So, Z a n into I c plus Z a n into I b plus Z a n into I a. That is taking care of these voltage drops with their directions taken into account. So, this is, what we will get for V a n. So, if we take this V a dash n dash on this side, then V n minus V a dash n dash is equal to arranging these in terms I a, I b and I c. We will get Z a a minus Z a n, I a plus Z a b minus Z a n into I b plus I c, because this will be same for I b n, I c. So, Z a b minus Z n into I b plus I c plus Z a n minus Z n n into I n.

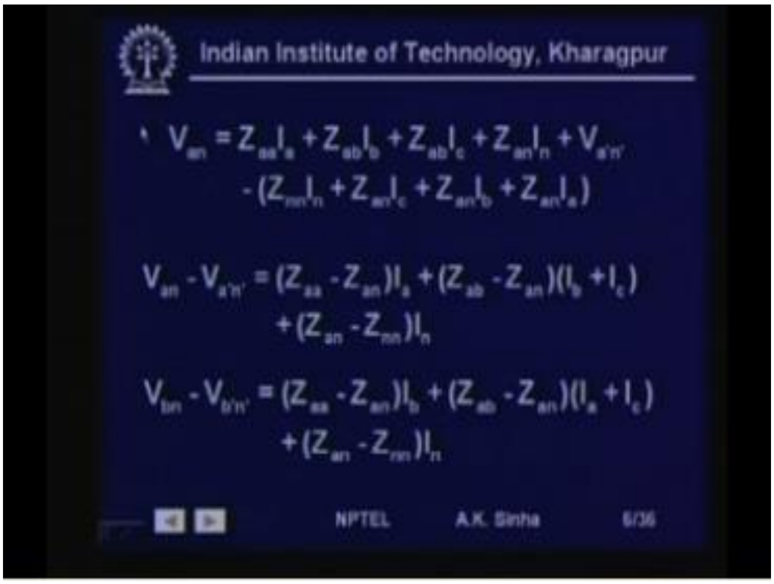
Similar relationship, we can write for phase b. So, we will have V b n minus V b dash n dash is equal to Z a a minus a Z a n into I b plus Z a b minus Z a n, I a plus I c in this case plus Z a n minus Z n n into I n. And similarly, for the phase c, V c n minus V c dash n dash is equal to Z a a minus Z a n into I c plus Z a b minus Z a n into I a plus I b plus Z a n minus Z n n into I n. Now, we know that, for the system I n is equal to the sum of all the currents and the direction will be the reverse, so minus sign will come here.

(Refer Slide Time: 13:55)



That is, if we see here I a plus I b plus I c will be flowing and the return will be through this. So, any unbalanced current will return through that. So, the direction of current will be in this direction. Since, we have taken I n in this direction as reference. So, we have to use negative sign there.

(Refer Slide Time: 14:20)



So, I n is equal to negative of I a plus I b plus I c. If we use this relationship, then finally, we can write V a n minus V a dash n dash is equal to Z a a plus Z n n minus 2, Z a n into I a plus Z a b plus Z n n minus 2 Z a n, I b. Plus, Z a b plus Z n n minus 2, Z a n into I c.

Now, this is, what we will get by substituting for this I n minus of I a plus I b plus I c. So, we have eliminated I n and we get relationship in terms of I a, I b, I c.

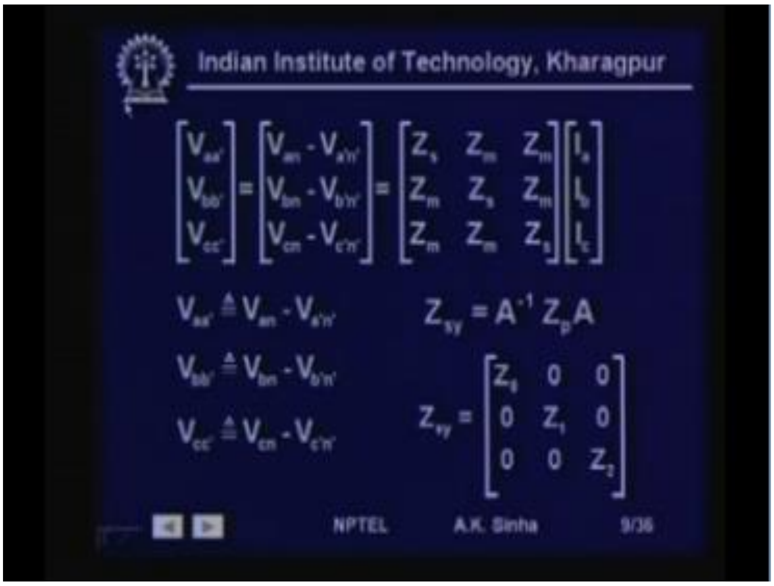
Similarly, a for phase b, V b n minus v dash, V b dash n dash is equal to this term Z a b plus Z n n minus twice Z a n, I a plus Z a a plus Z n n minus twice Z a n, I b plus Z a b plus Z n n minus twice Z a n, I c.

(Refer Slide Time: 15:37)

And for phase c, we have V c n minus V c dash n dash is equal to Z a b plus Z n n minus twice Z a n, I a plus Z a b plus Z n n minus twice Z a n, I b plus Z a a plus Z n n minus twice Z a n, I c. So, this is what we get for all the three phases. Now, we see here, these terms Z a b plus Z n n minus twice Z a n is coming for the currents in the other phases. So, these are basically the mutual terms. So, for this is same thing is coming for I a and I b, whereas for I c, the term is coming as Z a a plus Z n n minus twice Z a n.

Similar terms, if you see are coming for a n and b n, here Z a a plus Z n n minus twice Z a n is coming for I a and these terms are coming for the other currents. So, here, again this term is coming for I b and these two terms are the similar terms are coming for other phase currents. So, we can write this term as Z s or self impedance. So, Z s is defined as Z a a plus Z n n minus twice Z a n and these terms as mutual terms. So, mutual impedance terms, so Z n is defined as Z a b plus Z n n minus twice Z a n.

(Refer Slide Time: 17:20)

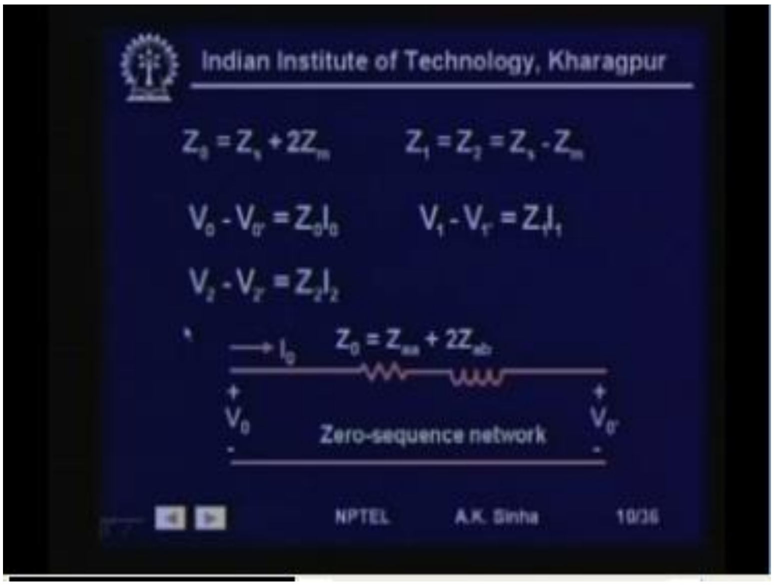


Now, with this definition of Z s and Z n, so we can write this relationship as V a a dash is equal to V a n minus V a dash and n dash is equal to Z s into I a plus Z m into I b plus Z m into I c and so on for V b b dash, which is V b n minus V b dash n dash. again, Z m into I a, Z s into I b and Z m into I c, V c c dash is equal V c n minus V c dash n dash is equal to Z m into I a plus Z m into I b plus Z m into Z s, Z s into I c.

So, this is, how we can write this relationship, we are writing here V a a dash as V a n minus V a n dash, so on. Now, this is the impedance, that we get for the transmission line, in terms of self and mutual impedances. Here, what we see is, this is a symmetric impedance matrix and a 3 by 3 matrix. With, all the terms present in when we that the relationship between voltage and current for as three phase transpose line.

Now, as we have shown earlier, we can get the symmetrical component impedance for the transmission line, as an inverse Z p into a, where this matrix is the Z p matrix. So, if we do this, then we will get Z symmetrical components as Z 0, Z 1 and Z 2. That is, three independent impedances. Only, diagonal elements are there, all the diagonal terms will be 0, which is the characteristics symmetrical components transformation. When, we do it for a symmetrical circuit.

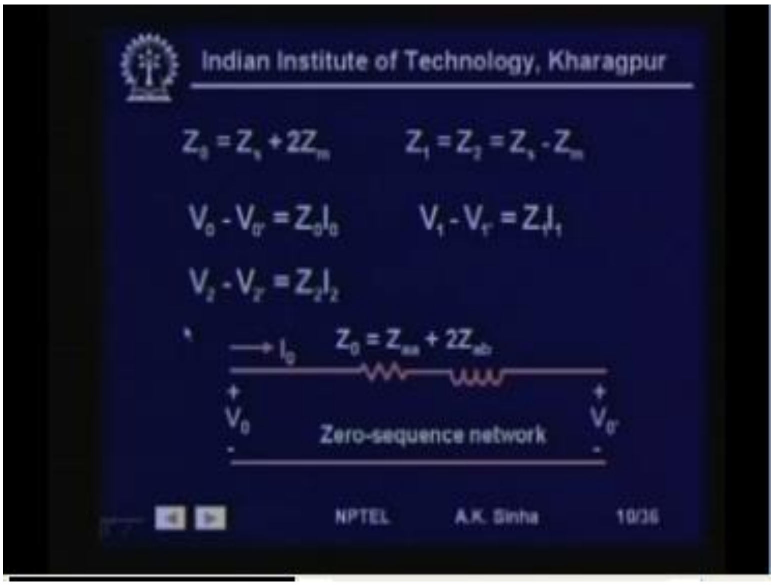
(Refer Slide Time: 19:20)



So, this is what we get, where we will have Z 0 is equal Z s plus 2 Z m and Z 1 and Z 2 will be equal and that will equal to Z s minus Z n. So, what we find from this relationship is, that the three networks, we will have V 0, V 1, V 2 is equal to Z s into I 0, I 1, I 2. So, this relationship will be independent. That is, we can write V 0 minus V 0 dash is equal Z 0, I 0.

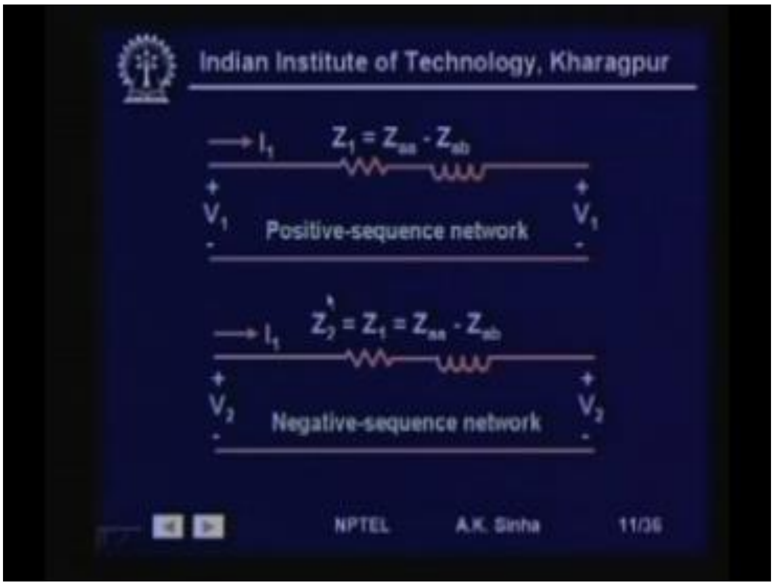
Similarly, V 1 minus V 1 dash is equal to Z 1 into I 1 and V 2 minus V 2 dash is equal to Z 2 into I 2. That is, we get three independent networks. So, zero sequence network can be shown as V 0 on this side and V 0 dash on the other side of the transmission line and an impedance Z 0, which is equal Z a plus twice Z a b. Z 0, which should be equal Z s plus twice Z m, where Z s and Z m values are given here.

(Refer Slide Time: 20:51)



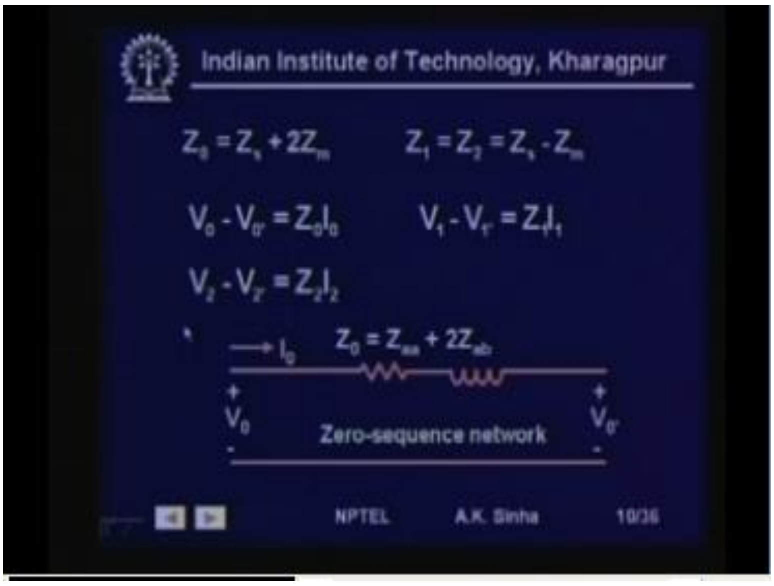
This value comes, if we do not have neutral wires. So, when we have the neutral wire, then the value will be, this will be Z s plus twice Z m and the current I 0 will flow in this.

(Refer Slide Time: 21:04)



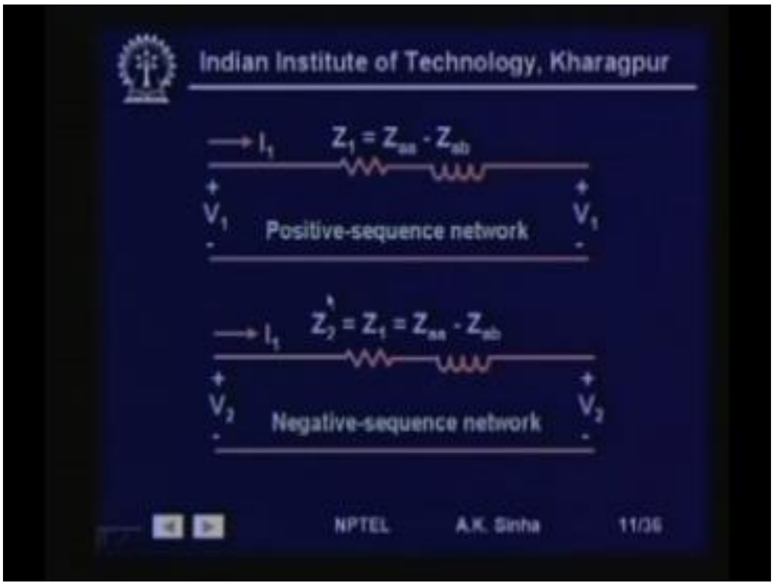
Similarly, the positive sequence network will be independent V 1 on this side and V 1 dash on this side and the impedance will be Z 1, which will be again Z s minus Z m. So, this is not Z a a, it should be Z s minus Z m. And similarly, Z 2 will be for the negative sequence network will be V 2 and V 2 dash on this side and the impedance will be Z 2 current I 2 will be flowing in this. This should be I 2 not I 1. So, this should be Z s minus Z m as shown here.

(Refer Slide Time: 21:45)



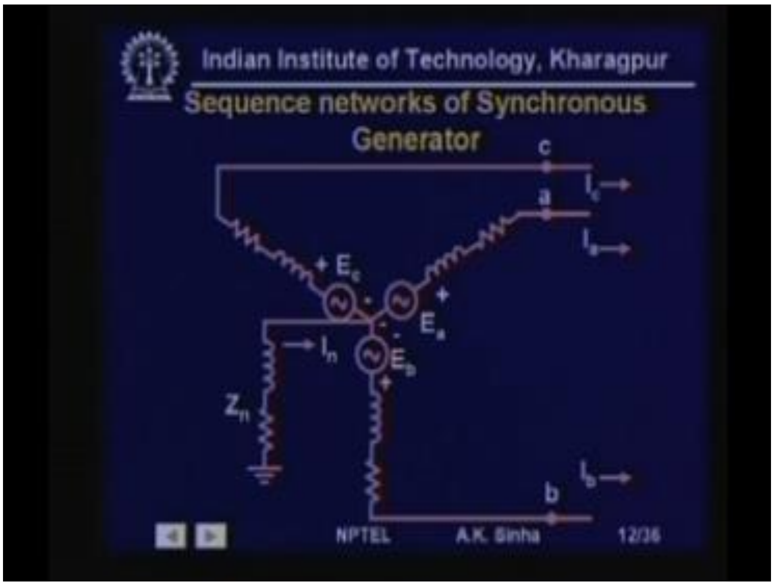
Z 1 is equal to Z 2 is equal to Z s minus Z m and Z 0 will be equal to Z s plus twice Z m.

(Refer Slide Time: 21:55)



So, this is, how we build the sequence network model for the transmission line, which consists of series impedances Z 0, Z 1 and Z 2. And the three networks are independent of each other, these are passive networks.

(Refer Slide Time: 22:22)



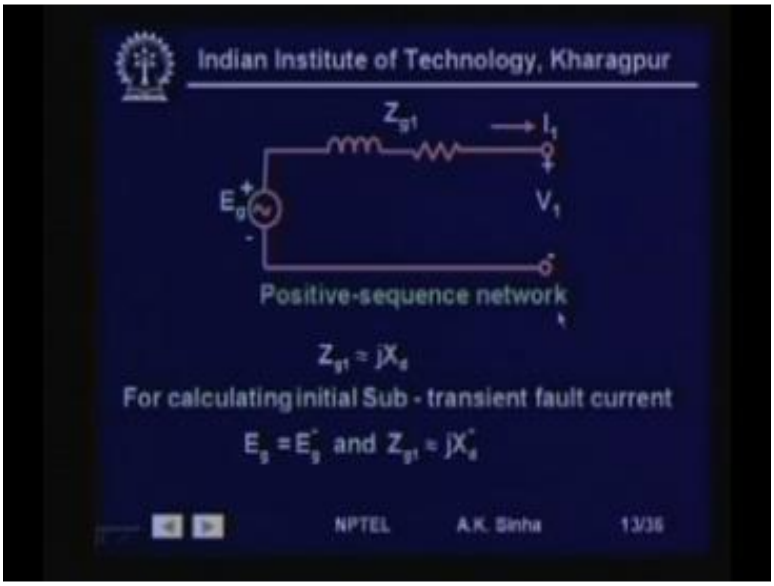
Now, we will take up the modeling of synchronous generators, in terms of the sequence networks. Now, this is a diagram, which is showing the synchronous generators circuit model. We have the three phase voltages E a, E b and E c. The phase sequence, mean a, b c. So, here, we have current I f flowing through phase a, I b through phase b and I c through c and we have the impedances Z a, Z b and Z c for this.

The neutral of the generator is grounded through an impedance Z m. And a current I n, in this direction is flowing through this grounding impedance. So, this is the basic circuit of a three phase generator. Now, since the generator is designed, such that all these winding impedances winding is symmetrically placed and uses the same wires and same number of terms. So, the windings will be having same impedances.

So, it will be symmetrical, as well as the three voltages, that will be developed in these windings will also be equal in magnitude. But, they will one twenty degree outer phase from each other. When the generator works a normal balance mode or symmetrical currents are flowing through it, no current will flow through this neutral impedance.

But, in case of unbalance, that is I a plus I b plus I c is not equal to 0. Then, in that case, that return current will be flowing through this, which will be the current I n flowing through the neutral.

(Refer Slide Time: 24:40)



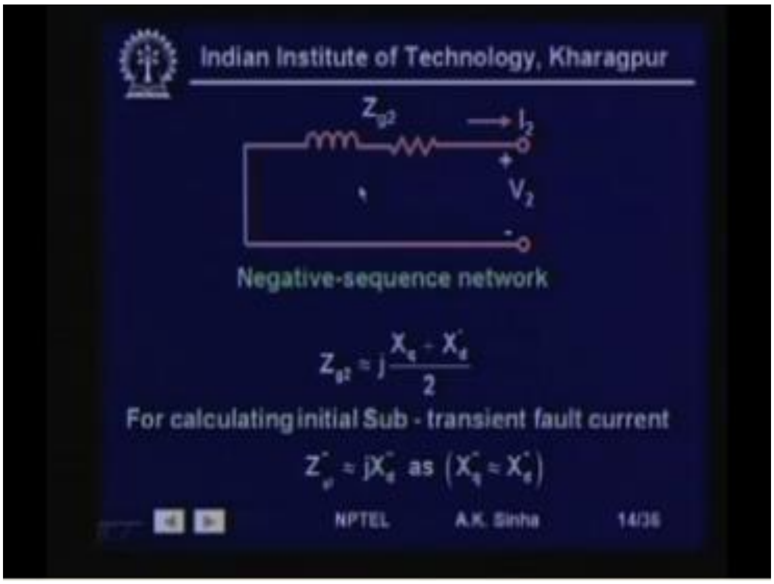
Now, we can build the sequence network model, for the generators. Now, since the generator is designed to generate positive sequence voltages by the rotation of the rotor, with the field winding, exited the voltages in all the three phases, which are generated, are equal in magnitude and 120 degree out of phase. And having the phase sequence same as the direction of rotation of the rotor, which is in this case shown as a, b, c phase sequence.

So, the generator is design to generate positive sequence voltages. So, we have a positive sequences voltage source, for this model. And the generator has the winding resistance, as well as armature reaction reactances coming into picture. So, the total reactance offered by the generator, can be seen and that will be in steady state condition, as the synchronous impedance of the generator. And that is also in the positive sequence impedance of the generator.

But, in case of fault analysis in most of the cases, we are interested in finding out the currents immediately after the fault. In such cases, we as we seen from the generator model, we need to use the sub-transient impedance of the generator. And also, the voltage source here will be based on the sub-transient or the voltage behind the sub-transient reactance.

This voltage, when for a loaded generator, we had seen that a terminal voltage is kept consent. So, depending on this current, the loaded for a loaded generator, we find out the generated voltage and that voltage is taken as the voltage. Here, in this case and the impedance used in this case is normally the sub-transient impendence. Normally, the resistance of the generator winding is much smaller compared to it is reactance. Therefore, that is neglected and generally the positive sequence impedance is taken as the sub-transient reactance of the generator. So, this is the model for the positive sequence network for the synchronous generator.

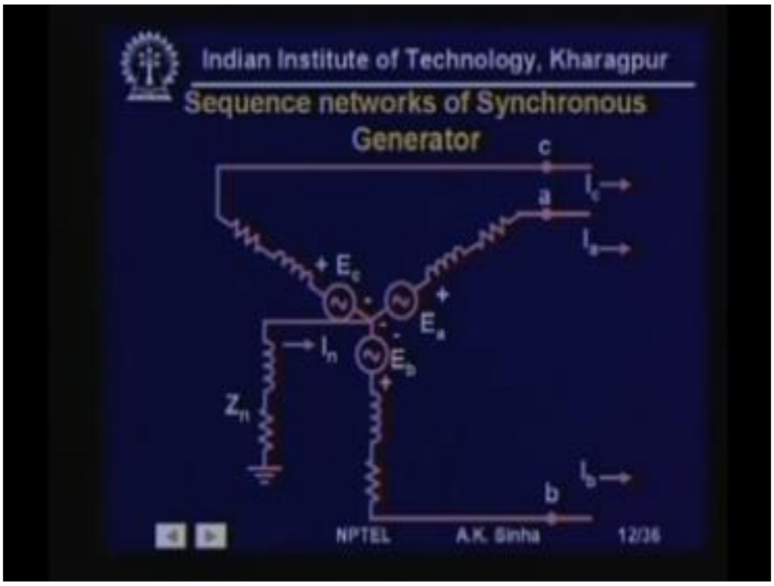
(Refer Slide Time: 27:50)



Now, negative sequence network, normally the generator is designed to generate positive sequence voltage. It does not generate a negative sequence voltage. So, there would not be any voltage source in this case. So, there is no voltage source, for the negative sequence network. Now, what about the impedance, how do we find the impedance to the negative sequence currents, flowing in the generator?

Now, if you look at the generator and we want to find out it is negatives sequence impedance. Then, what we need to do is, we can run this generator, with it is rotor short circuited. And we provide a three phase current, which is n reverse sequence to the direction of rotation of the rotor of the generator. That means, negative sequence currents will start flowing in this.

(Refer Slide Time: 29:00)

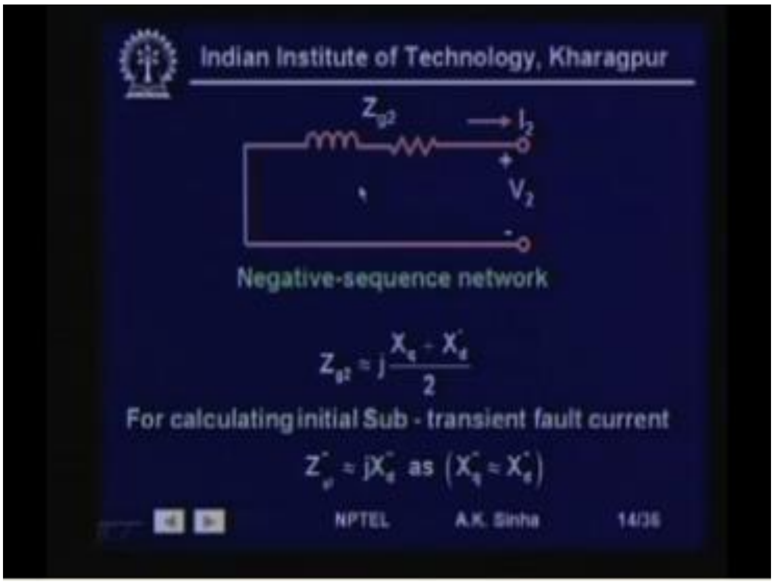


Now, when negative sequence currents start flowing in the winding of the generator, what they are going to see? Now, since the rotation of three symmetrical currents, which is flowing through this generator will produce a rotating magnetic field. Because, the phase sequence of the currents is reverse to that of the rotation of the rotor. So, there is going to be a rotating magnetic field, which will be rotating at the synchronous speed, but in the reverse direction to the rotation of the rotor.

So, that is there is going to be this relative speed between the two is going twice the synchronous speed, which means, these currents, which are producing magnetic field. Currents flowing in these windings will produce magnetic field and this field will be seeing two types of reluctances, one in the direct axis and another in the quadrature axis. That is, as it moves around, it will see reluctance, due to direct axis, when the axis of the rotor coincides, with the axis of the rotating magnetic field.

And just sometime after that, it will see the reluctance, because of inter polar gap, in which the field will have the maximum reduction. So, it is going to see, that reluctance after some time, and this will keep on repeating.

(Refer Slide Time: 30:46)



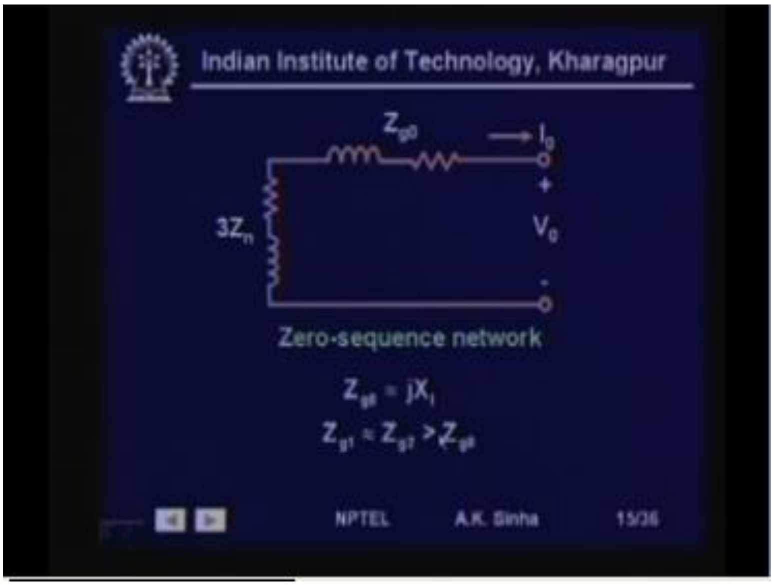
So, what happens is, it is going to see, basically two reactances one will be X q, other will be X d. In fact, it will X d dash, because this will be moving at the directions sub-transient reactance is going to see. So, X d dash X q is what is going to see and therefore, the negative sequence impedance seen will be an average value of that. So, it will j X q plus X d dash divided by 2.

But, if we are talking of situation, just after, if this generator has the damper windings, then this damper winding is basically damper rods placed in the rotor, whole phases and which is short circuited, since this rotor. There is a relative motion between rotor and magnetic field produced in the air gap and by the current flowing in the straighter winding. There is going to voltage and therefore, current flowing in the damper winding, because of which the damper circuit is also going to active.

In that situation, the reactance seen by these negative sequence currents will be very similar to that of sub-transient reactance. So, therefore, we will get Z g 2 double dash that sub-transient reactance in the negative sequence is going to be equal to j X d double dash, because X q double dash is very much equal to X d double dash, because there it is the damper circuit, which dominates this reactance in the sub-transient period.

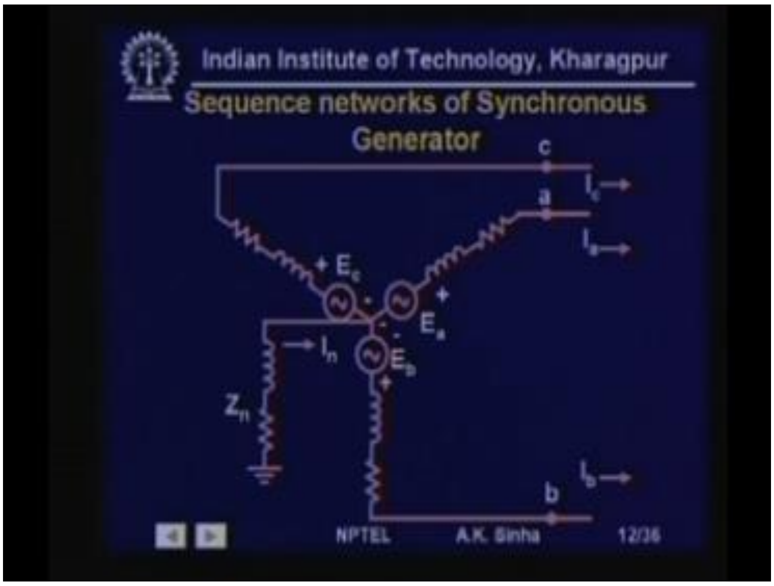
Therefore, we have the negative sequence sub-transient reactance, which we will use, when we are trying find out the fault current immediately after the fault. And that will be equal to the sub-transient reactance after generator.

(Refer Slide Time: 33:13)



Again, we would like to find out the zero sequence reactance. Now, again zero sequence reactance can be found by supplying a zero sequence current to the three phases. Now, how do, we supply zero sequence current three phases.

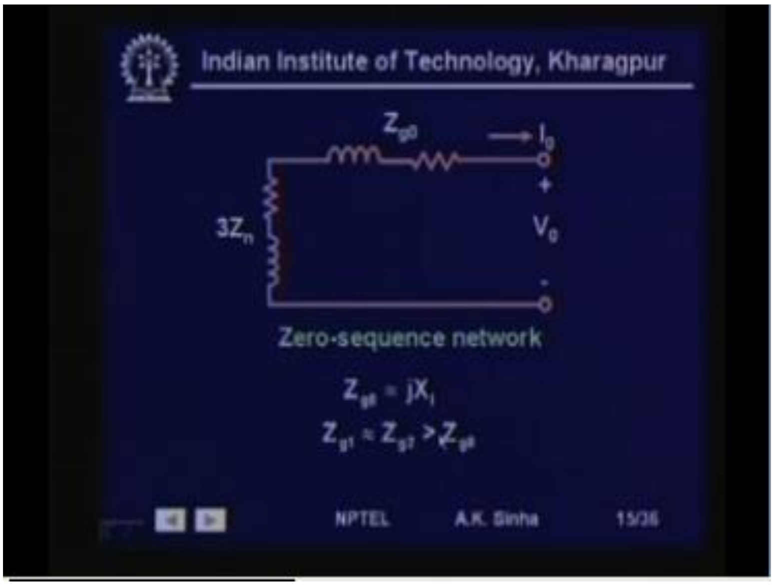
(Refer Slide Time: 33:33)



Since, all the three zero sequence current, means basically all the three phase currents are going to be having same magnitude and same phase. So, it is similar to connecting these 3 and supplying a single phase source connecting it to a single phase source. Then, all these phases will have the same current and the current with the same magnitude and phase flowing through them.

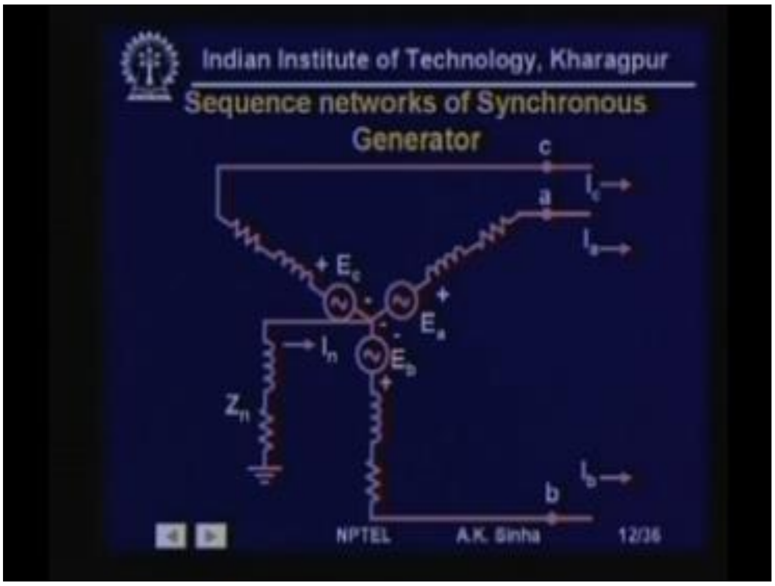
Now, if that is the case, then the current will flow in through this, because if I a, I a, I b and I c are flowing like this. Then, I n will be equal to I a plus I b plus I c, which is same as 3 times I 0. And therefore, if we see the voltage drop from this point to this ground point, then this will be 3, I 0 into Z n, which we can write as I 0 into 3 times Z n. So, the impedance seen, from this point to this point, if it voltage drop will be similar to an I 0, flowing through thrice this impedance.

(Refer Slide Time: 35:00)



So, this is what we see here, 3 Z n with I 0 flowing through it and we will also see an impedance of the machine which will be Z g 0. Now, what is going to be the value of Z g 0? In the sense, the resistance in the most of the cases is very small. So, we will be having basically the reactance, which is coming and what is going to be this reactance.

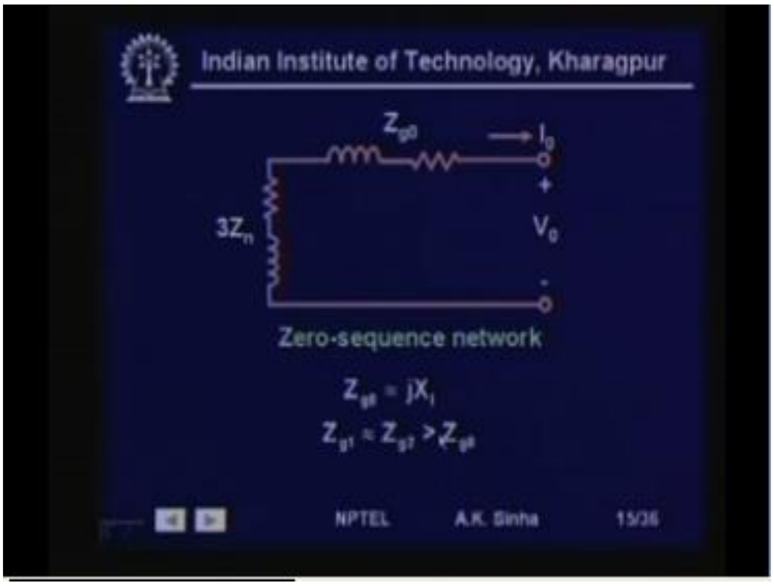
(Refer Slide Time: 35:36)



Now, if we see the three phase currents, flowing in these windings, which have 120 degree displaced from each other in space, will be having the same magnitude and the same phase angle Therefore, the sum of the m f f produced by them is going to be 0 in the air gap. In fact, in actual practice, these three currents, may not exactly sinusoidal. So, there will be some residual effect.

But, if we take the ideal situation, where the three currents are sinusoidal currents and their phases are exactly same. Then, in that case, the m m f produced by these three windings, three currents flowing in the winding is going to be 0. And therefore, the impedance seen by these currents and this machine is going to be just equal to the leakage reactance of the windings.

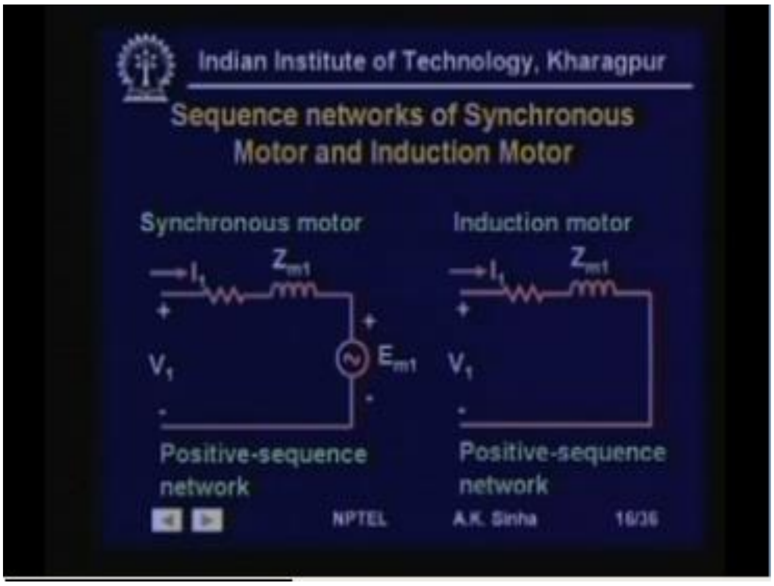
(Refer Slide Time: 35:49)



So, that why we will get here Z g 0, Z g 0 is equal j X l the leakage reactance. Since, leakage reactance is much smaller than the sub-transient reactance of the machine. Therefore, we have said Z g 1 is nearly equal to Z g 2 and this is going to be greater than Z g 0, which is just equal to the leakage reactance of the generator. The typical values of Z g 1, especially when we are using the sub-transient reactances will be the order of 8.08 to 0.14 or something like that. So, Z g 1 will be in that range.

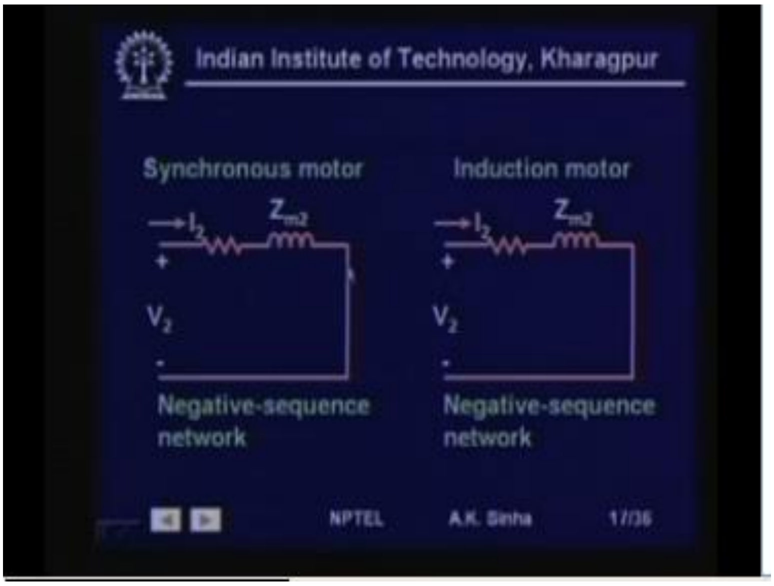
We are talking of this impedance in per unit. So, about 8 percent to 12 to 14 percent is the value where the positive and negative sequence reactances will have and Z g 0, which just a leakage reactance will be of the order of 5 to 7 percent. So, 0.05 to 0.07 per unit, so these are some other typical values it depends from machine to machine these values may vary. So, this is about the synchronous machine model.

(Refer Slide Time: 38:34)



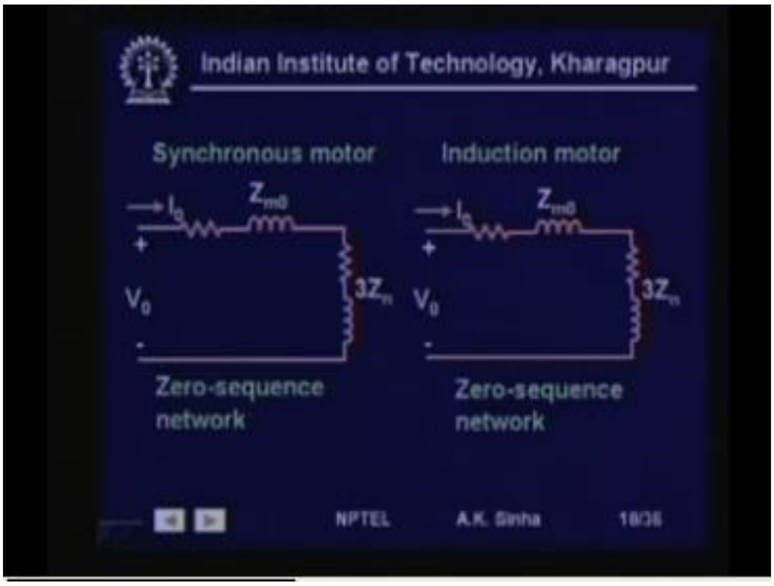
Next, we will talk about the synchronous machine model and next we will talk about the synchronous motor and induction motor model. Now, in case of synchronous motor, since we have is as ((Refer Time: 38:45)) generator. For induction motor, we do not have a voltage source and we have ((Refer Time: 38:55)) sequence impedance of the machine, which is same, as well winding impedance.

(Refer Slide Time: 39:07)



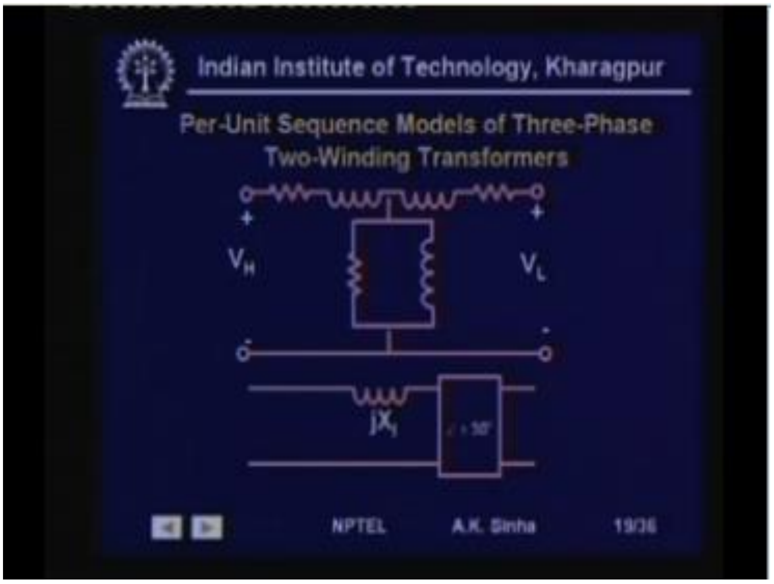
Similarly, for negative sequence, there is no voltage source. But, they are going to negative source impedance of the synchronous motor, which is going to same as that of synchronous generators. In case of induction machine, also we will have negative case impedance of the motor. And zero sequence, similarly most of the power system modeling synchronous motor, especially the large once at thing as the synchronous condenser, also is from times model. Whereas, small induction, machines are hardly vary model and the large induction machine in some cases and ((Refer Time: 40:04)).

(Refer Slide Time: 40:20)



((Refer Time: 40:12)) as shown here. Positive sequences for the synchronous motor will have voltage source, whereas there would not be any voltage source for induction machine. The negative l 0 sequence networks are basically the ((Refer Time: 40:31)) networks having the negative l 0 sequence impedance of the machines.

(Refer Slide Time: 40:38)



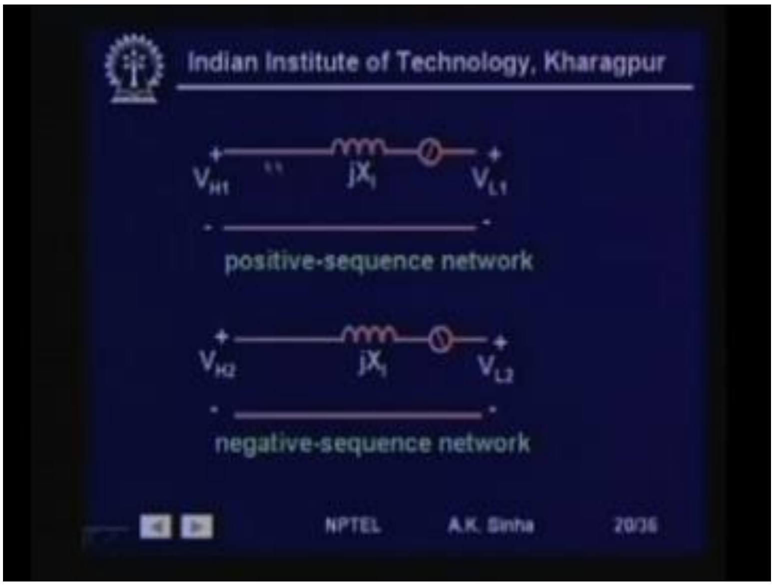
Next, we come to the transformer models, the sequence models for transformers. Now, for transformers as we have said earlier in our earlier lectures, we always use the per unit. In fact, for all the components, when we work in the power systems, we use the per unit system. But, for the transformers it should be used, otherwise you will have to keep on the voltage and current ratios always into account. We have seen that, by using per unit model, the ideal transformer Vanishes and only the impedances come into the picture.

Now, as shown here the transformer has winding impedance consists of the resistance and the leakage inductions of the winding on the high voltage side. Sending leakages induction of winding and the resistance of the winding on the low voltage side, this part is showing the core losses and this is showing the magnetizing current part. So, this is normally has we seen earlier is the model for the transformer.

Normally, this current as much smaller and therefore, these part of the circuit distant circuit part the circuit is not included. So, this part is neglected and also the resistance of the transformer winding is much small compared to the reactances. So, there are also neglected. So, what we finally, is basically the leakage reactance of the winding on the both sides added together in per unit.

In case of star delta transformers, as we seen earlier, there is going to a phase displacement of plus minus 30 degrees Now, in case of star delta transformer the normal practice, which is used, is based on ANSI standards, that the American national standards institutes, standard which says, that for a star delta transformer.

(Refer Slide Time: 40:38)

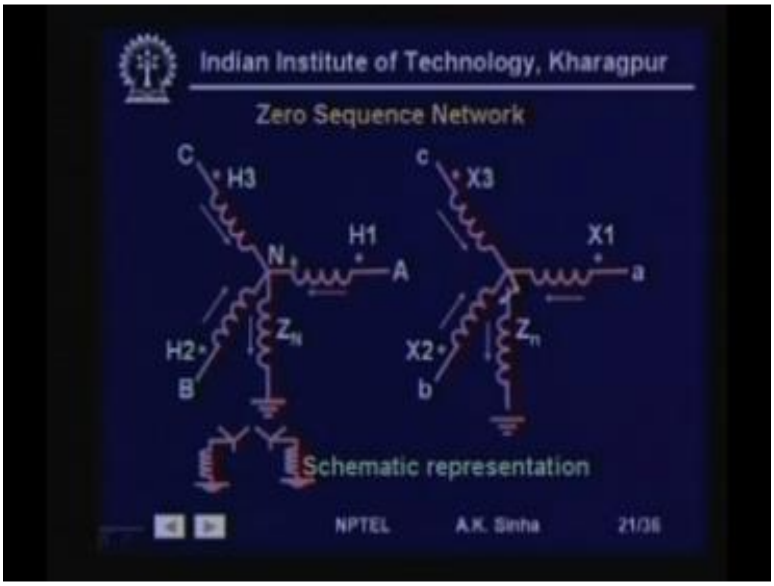


The pause the high voltage on this side voltage is going to leak the low voltage side voltage by 30 degrees. So, this shown by leading by 30 degree likes this, whereas, the low voltage side is lagging by 30 degrees can be shown like this. So, here positive sequence, in case of positive sequence mode voltage, the high voltage side voltage leads the voltage low voltage side voltage by the 30 degree. And the positive sequence network, can be shown like this were this is showing a 30 degree phase leak.

In most of the cases, we do not take care of the phase lead or lag also, but if one is interested, one can always take care of that. In case of negative sequence, again we will have the leakage reactance of the transformer. Because, this is a passive network the reactance is going to be same.

So, again, here we have the reactance of the transformer and leakage reactance of the transformer. But, in this case, the high voltage side will be lagging the low voltage side by 30 degrees. Because, the phase sequences is reversed. So, in case of negative sequence the high voltage side will be lagging by 30 degrees.

(Refer Slide Time: 44:24)



Now, for zero sequence, we have some complication in case of transformers, because of the various types of the connections are used. If you look at this diagram, here we are showing this is phase a, phase b and phase c. This H 1, H 2, H 3 is showing the terminal, H is showing the high voltage side and X shows the low voltage side. Similarly, small case letters are used for low voltage side and upper case letters are used for high voltage side.

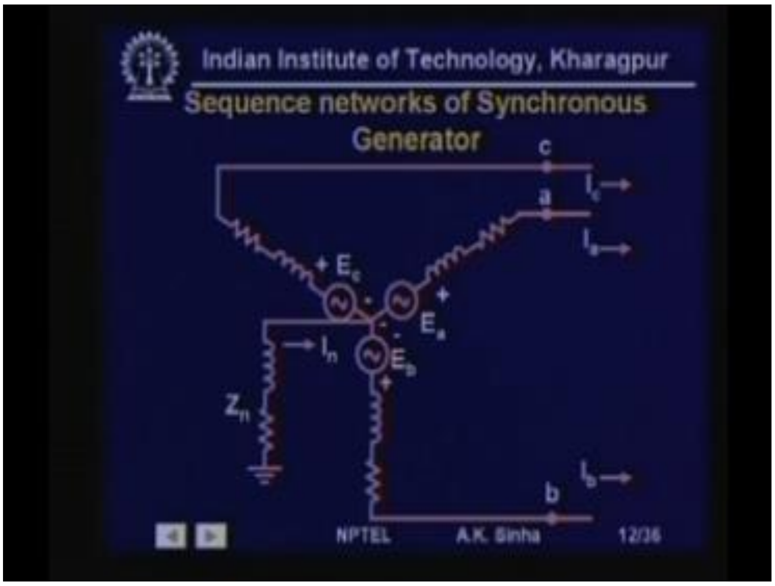
Now, we are showing a current I a flows like this, I b flowing like this and I c flowing like this. If these three currents are not balanced in case of zero sequence, these three currents will be having the same phase. And so they will need a return path and that is provided by the neutral connected to the ground. Similarly, same is the case here on this L b side I a, I b and I c currents are flowing and the return path is through this impedance Z n.

Now, here, there is, if the neutral is not connected. That is neutral is not grounded through an impedance or without an impedance. Than in that case, there is no return path available are which means this appears as an open circuit for the zero sequence currents. Whereas, if the neutral is provided, there is this all these currents will flow through this. So, if you see I a 0, I b 0, I c 0 will be flowing through this.

Total current will be sum of these three currents, which is flowing through this, which again same has three I 0. So, instead of that you write I 0 flowing through three Z m. So, the voltage drop from here to here can be represented as I 0 flowing through three Z m for three I 0 flowing through Z m. Same in case here, in case the neutral is not grounded, then I 0 cannot flow, because there no return path.

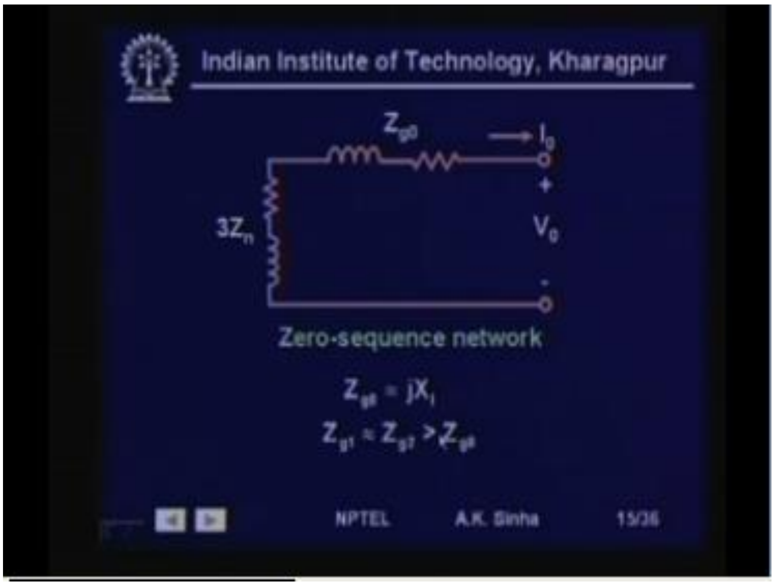
That is all these currents cannot flow in this, because they will need a path for it or a close path for it to circulate. So, when neutral is not grounded, zero sequence currents cannot flow, same is the case of the generators as well.

(Refer Slide Time: 47:29)



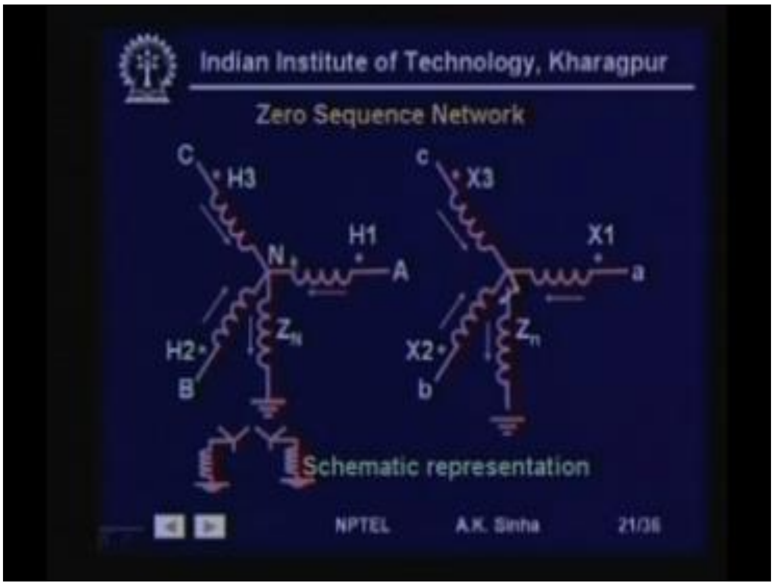
If you remember here, if this was not connected, that is the neutral was ungrounded.

(Refer Slide Time: 47:45)



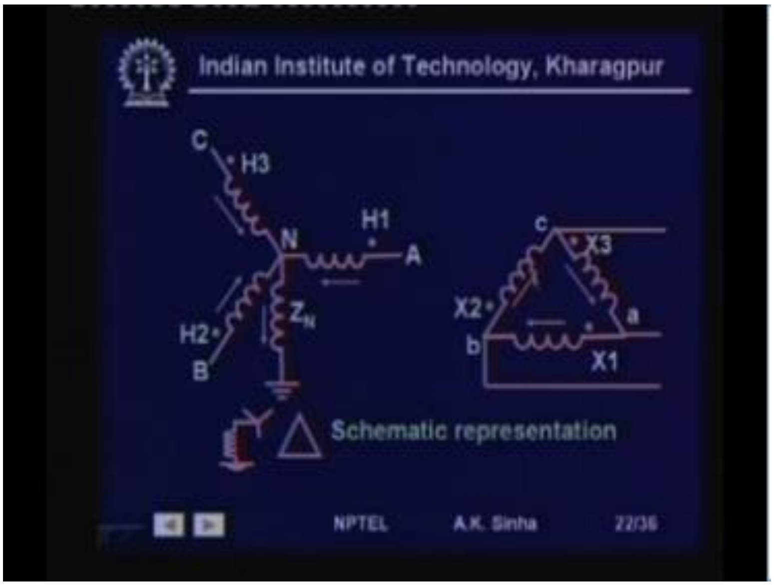
Then, in that case, you will find that this Z g 0 is basically having this 3 Z n also and these 3 Z n, when it is open is infinite. So, this will be open circuit and no I 0, can flow.

(Refer Slide Time: 48:04)



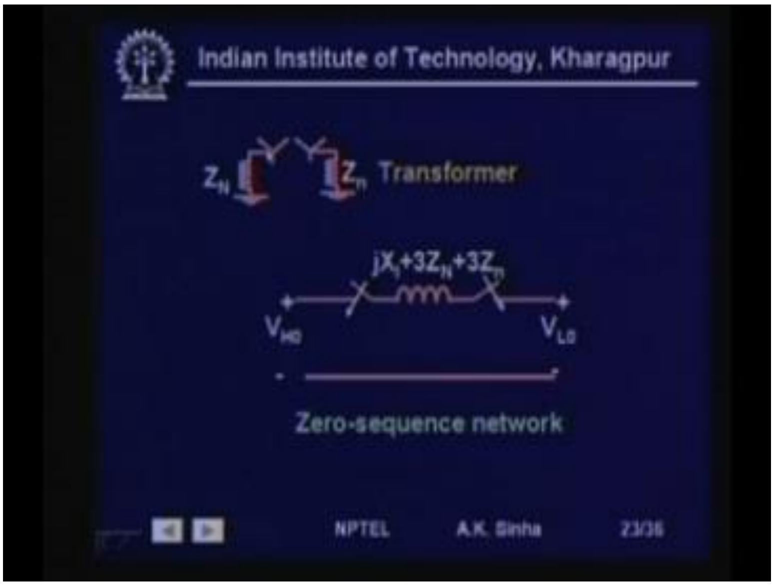
So, here we find in case, there is no ground connection is available, no zero sequence currents can flow like that.

(Refer Slide Time: 48:12)



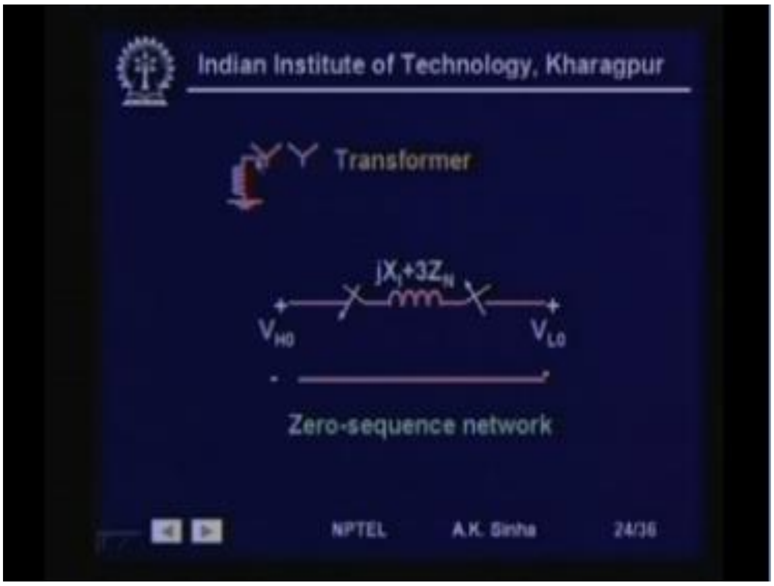
Now, let us see, what happens in case of star grounded in delta. In case of delta again, the currents, the zero sequence current can flow in the winding, because these are having same phase. So, it will appear as a close circuit to this, zero sequence current and they can flow in the winding, but they cannot flow in the lines. So, no zero sequence current can flow in the lines as such. When, we have delta, but they can flow in the winding and this is, what makes transformer connections very interesting for zero sequence case.

(Refer Slide Time: 48:55)



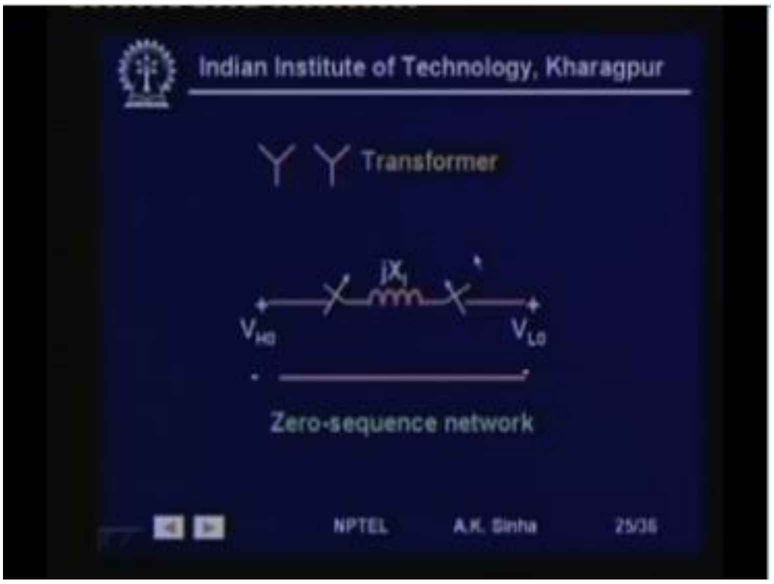
Now, let us take the transformer with star grounded star grounded. Now, this is the impedance from the transformer that will come in to picture j X l plus 3 Z N. This is the impedance of the Z n impedance of the grounding impedance on the high voltage sides Z small n is the impedance on the low voltage side. So, these is the total impedance and this both the sides, it will be connected, because zero sequence current can flow on both sides, because we have the return path available.

(Refer Slide Time: 49:30)



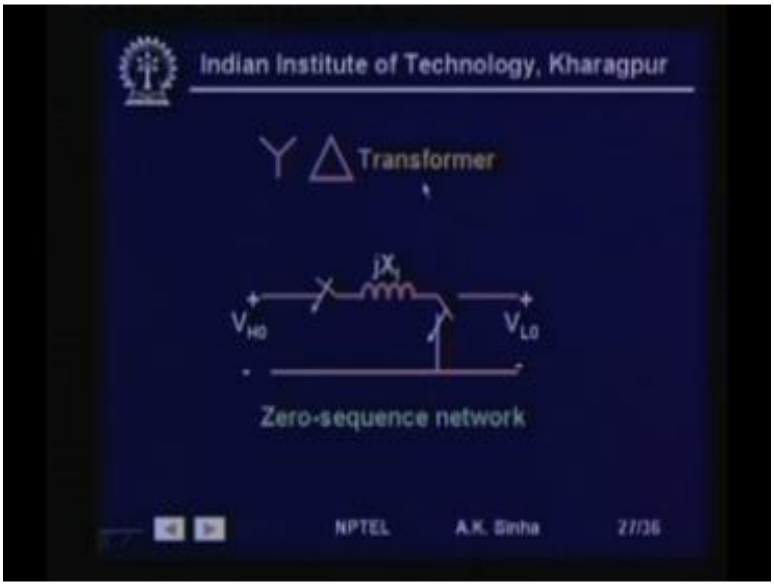
Now, let us see star grounded and star ungrounded transformer. In this case, on this side there will be connection because of zero sequence current can flow. There is a path, whereas on this side, that is the low voltage side, it is open because there no path for zero sequence current to flow. So, it will appear that this circuit is it open and the total impedance seen here will be j X l plus 3 Z n.

(Refer Slide Time: 50:00)



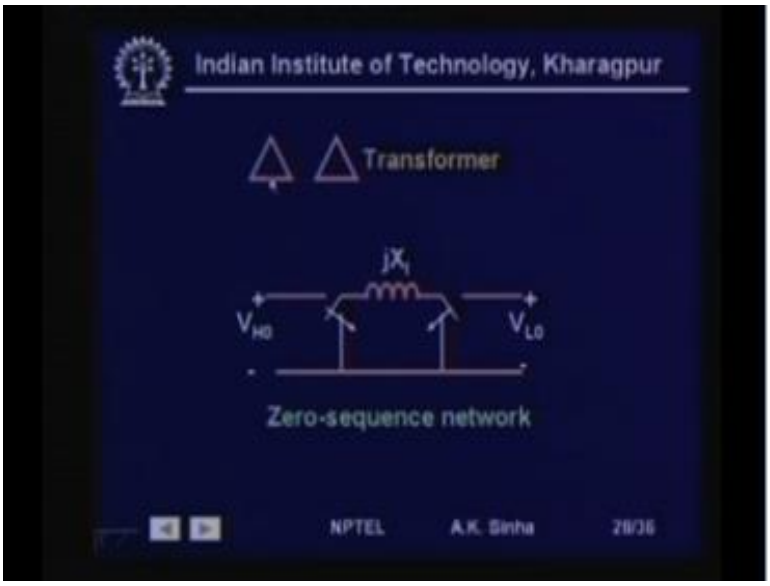
When, we have a star on both side ungrounded transformer, then this is certainly open on both the sides. So, no zero sequence current can flow from either side into the transformer. Now, if we look at star grounded delta connection for the transformer, this is grounded, which means zero sequence current can flow. So, this is connected and this is delta, which means it can flow in the winding, but it cannot go out. So, it cannot go out is this side is open, but it can flow in the winding. So, it is connected to the reference. So, the connection is like this.

(Refer Slide Time: 50:47)



Similarly, if we have star ungrounded delta, then sorry this should be reverse. This is open, because star ungrounded and this will be closed, because zero sequence can current can flow in the winding. So, this side will be connected to the reference, whereas this side will be open. This is the reverse, this should be open because it star ungrounded.

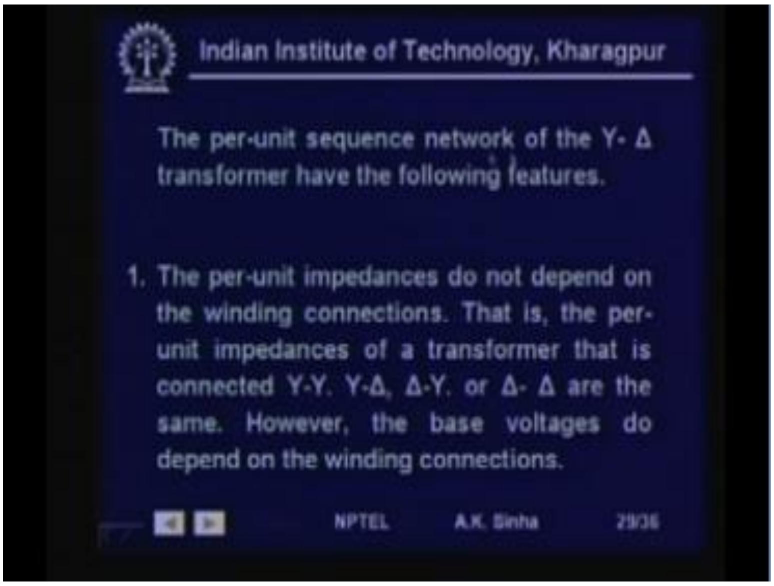
(Refer Slide Time: 51:18)



Now, we have a delta transformer, again here the zero sequence current can flow in the winding on this side, as well as on this side. So, this is the impedance is coming and this will be connected to the reference, as well as this side will be connected to the reference. So, this is, how zero sequence network for the transformer is very much dependent on the type of three phase transformer connections that we have.

That is, a zero sequence current can flow in the delta winding, but cannot flow out of it. Whereas, the zero sequence current can flow through the in a star winding, if the neutral is grounded, if it is ungrounded, it cannot flow. So, it is an open circuit.

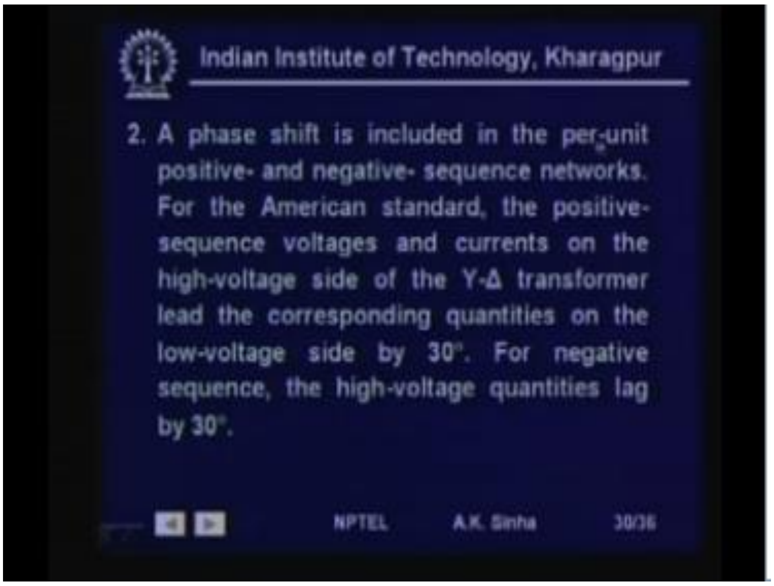
(Refer Slide Time: 52:18)



So, here we have just explained this, the per unit sequence network of the star delta transformer have the following features. The per unit impedance do not depend on the winding connections, that is the per unit impedance of a transformer, that is connected star, star, star, delta, delta, star or delta, delta are the same. However, the base voltages do depend on the winding connections. That is, if you make star or delta connection, then the voltage on the line side or going to change.

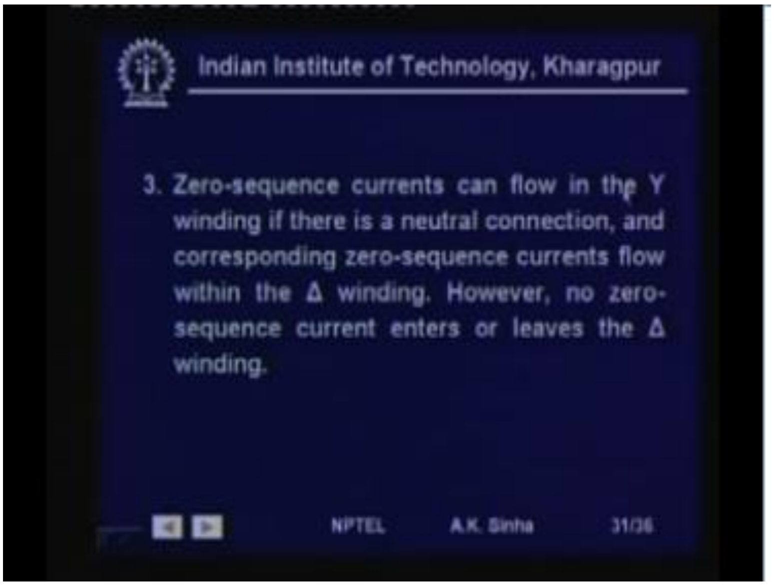
They will be, if it a star it will be root 3 times, the voltage what you will get delta connection. That does happen, but that is the line side voltages will become different. So, the base has to chosen as the lines side voltages on the two transformers. So, we have to use that way, the base voltages of the transformer, which is dependent on the trans ratio of the transformer.

(Refer Slide Time: 53:22)



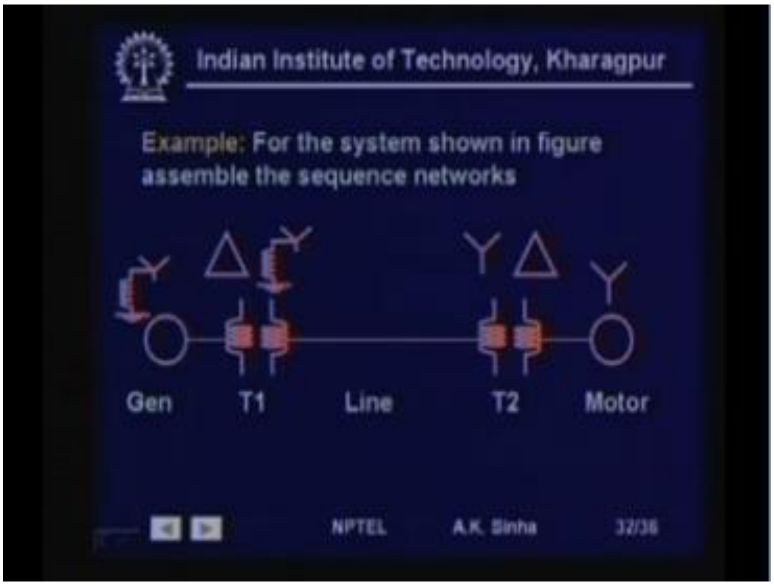
A phase shift is included in the per unit positive and negative sequence network. That is plus 30 degree phase shift for a high voltage to low voltage side based on the American standard. That is the positive sequence voltage and current on the high voltage side of the star delta transformer. Lead the corresponding quantities on the low voltage side by 30 degrees. For negative sequence the high voltage quantities lag by 30 degrees, the low voltage quantities.

(Refer Slide Time: 53:53)



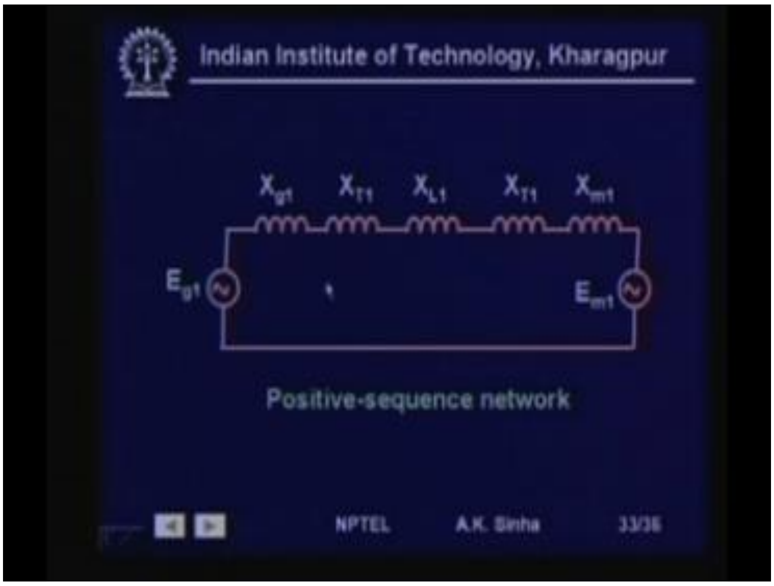
The zero sequence currents can flow in star winding, if there is a neutral connection. And corresponding to zero sequence currents flow, with in the delta winding, they can within the delta winding, but not outside. However, no zero sequence current enters or leaves the delta winding. That is, it cannot come in to the delta winding or leave out from the delta winding. So, this very important prospect in sequence network modeling, for three phase transformers.

(Refer Slide Time: 54:24)



Now, let us take a very simple example, for the system shown in figure here, we have a generator, we have a transformer and transmission line. Another, step down transformer and then, we have a motor. The generator has it is neutral grounded, whereas the motor has neutral ungrounded, whereas the transformer T 1 is a delta star grounded transformer T 2 as a star delta ungrounded, star ungrounded delta transformer.

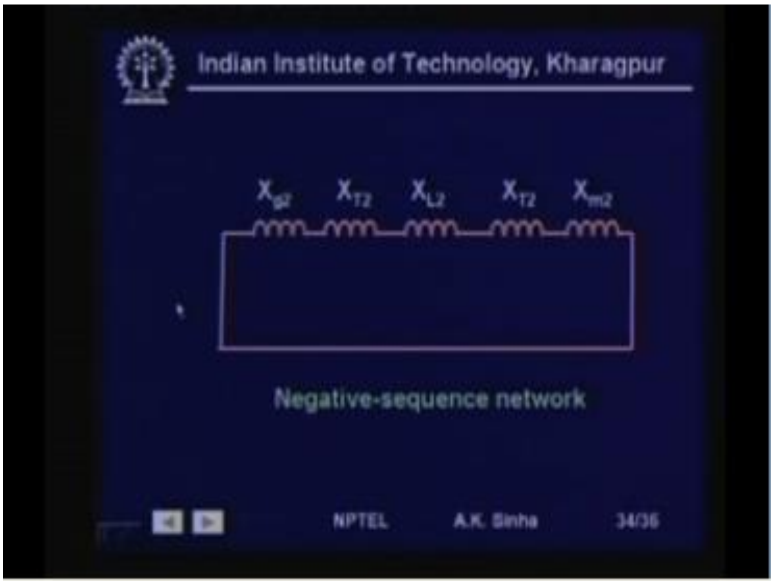
(Refer Slide Time: 54:56)



So, now we make the positive sequence network E g 1 and X g 1, against the network for the generator. X t 1, which is again the sub-transient reactance of the sorry, X g 1 will be the sub-transient reactance of the generator. X t 1 is the leakage reactance of the transformer. X L 1 is equal to Z s minus Z m. That is the positive sequence impedance.

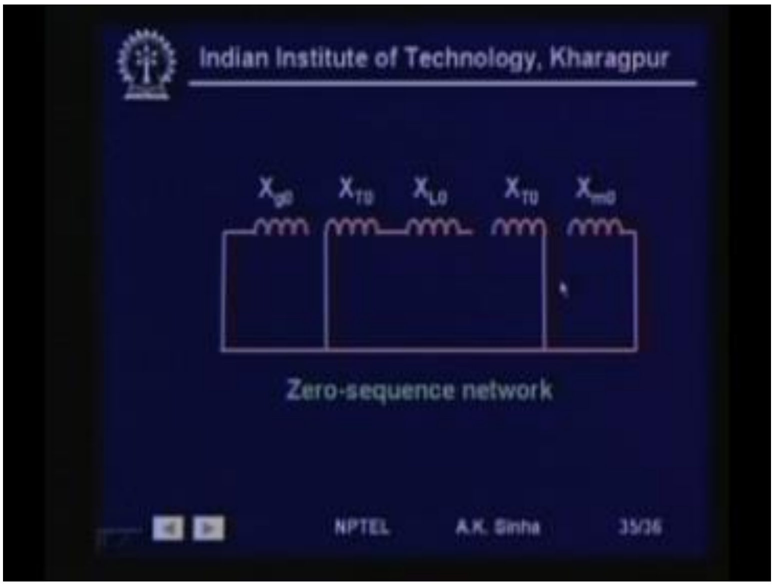
Normally, as we say that resistance is neglected, because it is much smaller. So, I am writing only the reactances. So, the X l 1 positive sequence reactance of the transmission line, X T 1 positive sequence of the reactance of the transformer T 2 and X m 1 is the a sub-transient reactance of the synchronous motors. And E m 1 is the voltage behind the reactance. So, this makes up the positive sequence network were the voltage source E g 1 and E m 1 are shown.

(Refer Slide Time: 56:04)



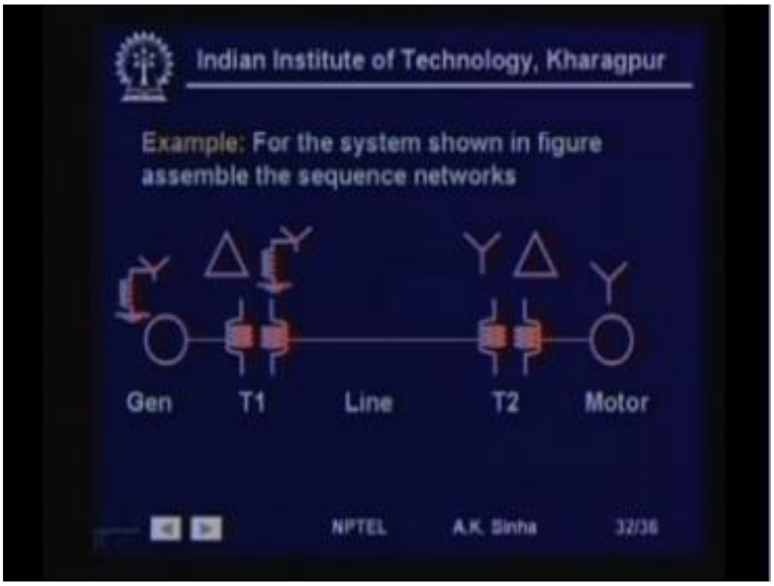
Negative sequences, we will be same expect that all the impedance are replaced by their negative sequence impedances and there is no voltage source in this case. So, this is basically at that network.

(Refer Slide Time: 56:17)



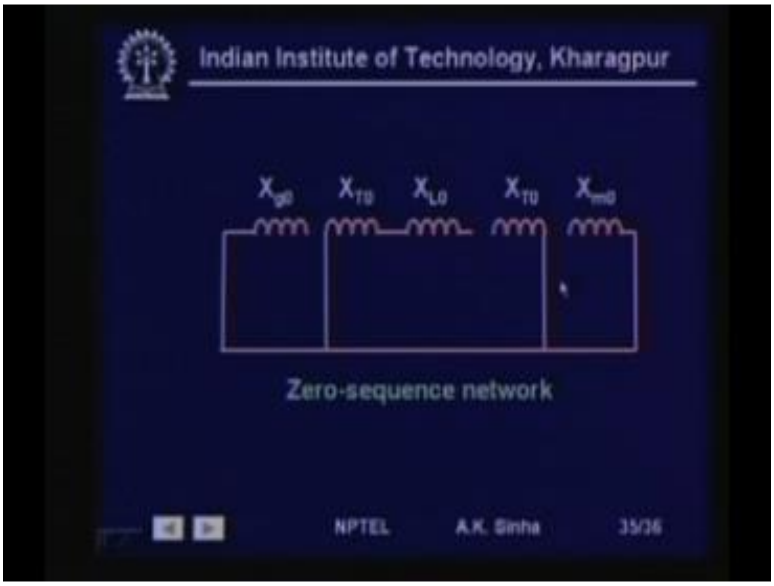
In case of zero sequence, we have the zero sequence reactance of the generator, the transformer as we see here.

(Refer Slide Time: 56:28)



Here, is delta on this side. So, this side is grounded is connected to the reference this side star grounded. So, it is connected towards the line.

(Refer Slide Time: 56:42)



So, this is what shown is connected towards the line and this side connected to the reference. This is the reactance, zero sequence reactance which is of the transmission line, which is equal to Z x plus 2 Z m. And again, this is the transformer and this side is star ungrounded. So, this is open this side is delta. So, the winding is connected to the reference. Then, again here this is the reactance of the zero sequence reactance of the motor, which is placed here and this will be the reference. So, this is the zero sequence networks.

So, this is how, we can assemble the sequence network for various components to build the sequence network for the power system. So, depending on the transformer, the zero sequence networks do change, whereas the positive and negative sequence networks are very similar to the each other, expect that, negative sequence network, does not, have any voltage source in it.

So, zero sequence and negative sequence networks are basically dead networks, only when there is a unbalance, than these networks get connected to the positive sequence network. And there is current flowing through them, because of the voltage sources available in the positive sequence network. So, with this we finish today and we will take up the unbalanced fault calculation in the next lesson.