Power System Analysis
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Lecture - 50
Symmetrical Components (Contd.)

So, again we will come back. So, therefore, we can write that I a0 plus I b0 plus I c0 plus I n is equal to 0, this equation, this is equation 30 because neutral conductor is also, neutral conductor is also there it is shown here.

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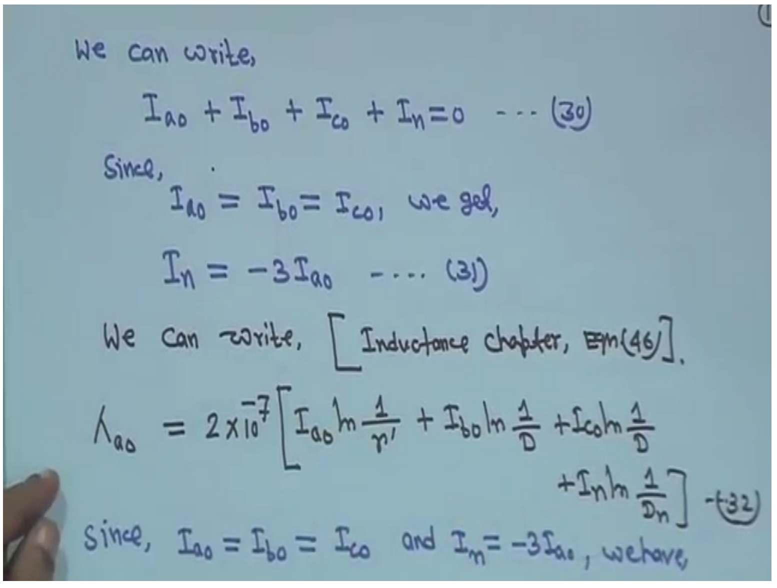

You see I made a green circle with a dot right, it is shown here.

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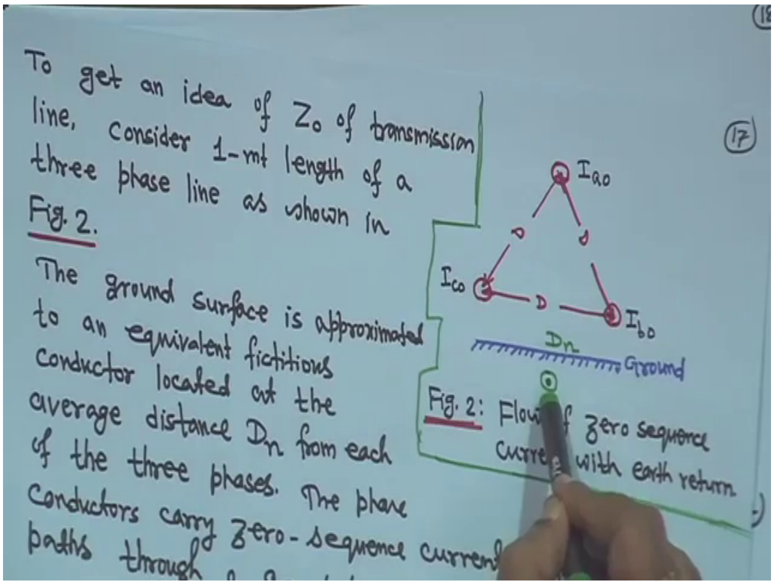

So, that means, but I a0 is equal to I b0 is equal to I c0 therefore, we get I n is equal to minus 3 I a0 this is the equation 31.

Now we have studied that inductance thing I mean much before. So, in that topic you go to are in that chapter you go to equation 46. So, same equation 46 from the inductance chapter I am rewriting. So, that is a first link is of your conductor a due to that 0 sequence current right, so that means lambda a0 is equal to 2 in to 10 to the power minus 7 in bracket I a0 ln 1 upon r r dash plus I b0 ln 1 upon D plus I c0 ln 1 upon D plus I n ln 1 upon D n this is equation 32. From equation 46 only same equation we are applying here right. So, lambda a0 is equal to this one. Since I a0 is equal to I b0 is equal to I c0 and I n is equal to minus 3 I a0 here we have seen equation 31. So, what you do you put all these things here you put all these things here if you do. So, just hold on.

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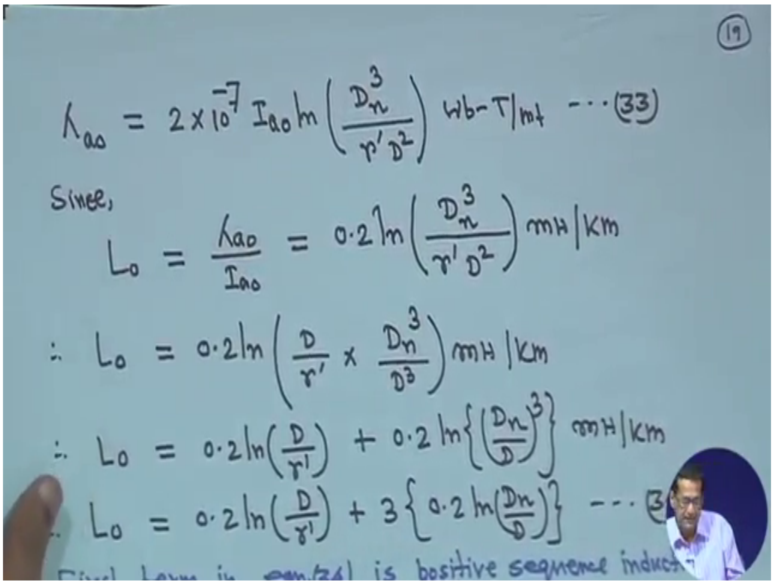

If you do so, you will get lambda a0 is equal to 2 in to 10 to the power minus 7 I a0 ln D n cube r dash D square were about transfer meter because you have consider only 1 meter length of the transmission line. So, this is equation 3. Nnow since L 0 is equal to the lambda a0 upon I a0 for inductance chapter several times you have seen this lambda by I several times. So, L 0 is equal to lambda a0 upon I a0 that is 0.2 ln the D n cube by r dash D square this part can be written as L 0 is equal to 0.2 L n, then this part can be D I multiplied here, multiply numerator and denominator by D; that means, you will get 0.2 ln D upon r dash in to D n cube upon D cube. So, this D here it is D square. So, it is D cube, but multiply numerator denominator by D milli Henry per kilo meter.

Now this one you can write L 0 is equal to 0.2 that your 0.2 L n, this first part 0.2 ln D upon r dash plus 0.2 ln D n cube D n upon D whole cube that is milli Henry per your kilo meter I can put bracket here. So that means, this is this is equal to you can write that L 0 is equal to 0.2 ln upon D r dash plus this 3 in to your 0.2 ln D n upon D this is equation 34; that means, first term of equation 34 is positive sequence inductance. And this second term it is 0.2 ln D n by D n it is defined as X x n right that is your you can define that the your ground this thing, ground reactance are that react the ground reactance right or neutral reactance right. So, that you can defined it is point ln D n upon D this is equation 34.

So; that means, it is 3 times multiply if this term is your X L 0 sorry X ln it will be 3 your X ln. So, anyway, so that means, this one; that means, we can make it as this is as this is inductance right. So, this can be conducted in to reactance multiply by omega this also can be multiplied by omega.

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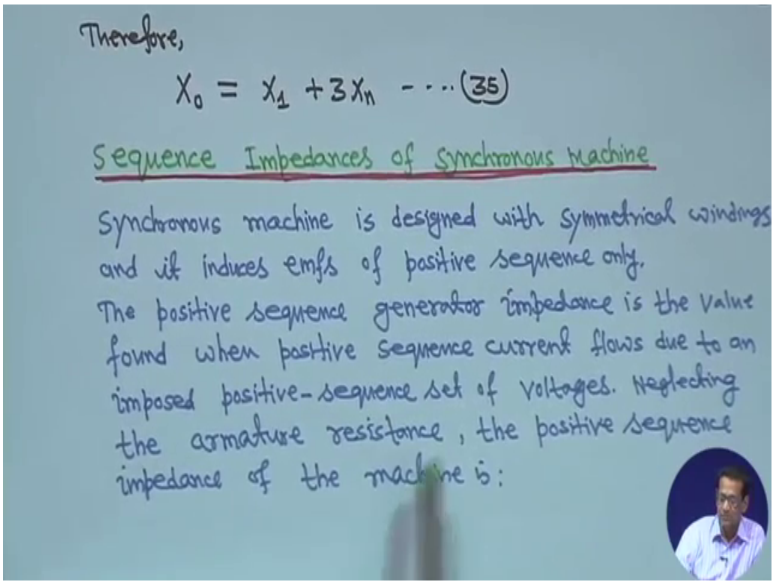

That means your X 0 that is the 0 sequence reactance can be met in the X 0 is equal to X 1 plus 3 X n. So, this X n your what you call this X n is equal this is your this is actually L 0 sorry this is actually your L 1 and this is L l. So, it is basically L 1 plus 3 ln I am not writing here, but it is simple thing will understand and if you multiply by omega both side. So, it will be your omega L 1 that is your j your X 1 and it is with 3 your omega your this one is say ln. So, it will be 3 X n. So, X 0 is equal to X 1 plus 3 X n this is 35; that means, you are for transmission line that positive and negative sequence impedance they are same say Z 1 is equal to Z 2, here actually we can write also Z 0 is equal to Z 1 plus 3 Z n same philosophy. So, there should not be any confusion and for the 0 sequence we can see things are different. So, this is equation 35.

Now, sequence impedance of synchronous impedances of synchronous machine. So, in this case for the in the case of synchronous machine that it is designed with symmetrical windings that you know and it in you induce a Emf's of positive sequence only the positive sequence generator impedance is the value found when positive sequence current flows due to an imposed positive sequence set of voltages this also known to you.

So, neglecting the armature resistance because r a is very small. So, you can neglect it the positive sequence impedance of the machine is I mean it depends on you. That means, synchronous machine actually basically designed with symmetrical windings and induces Emf of positive sequence only therefore, the positive sequence generator impedance is the value found when positive sequence current flows due to an imposed positive sequence set of voltages.

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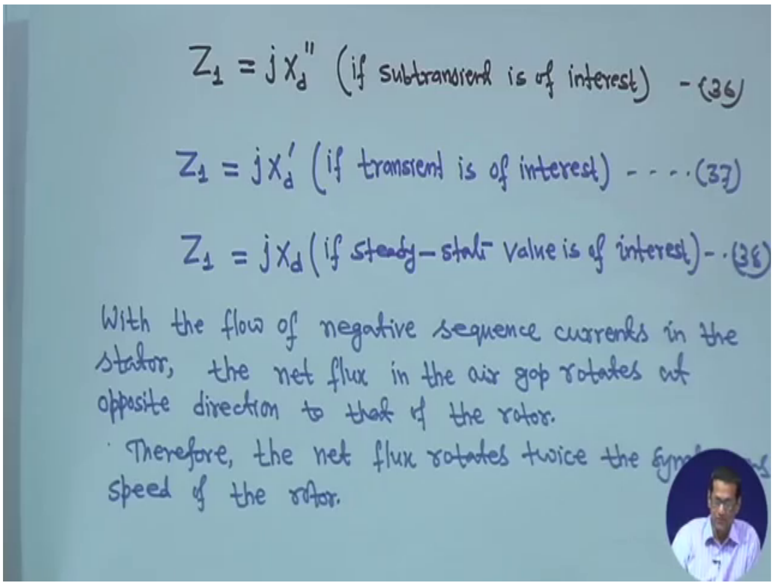

So, neglecting the armature resistance the positive sequence impedance of the machine is as per your requirement the Z 1 can be written as j X d double dash if sub transient is of interest this equation 36, Z 1 is equal to j X dash if transient is of interest equation thirty 7 and Z 1 is equal to j X d if steady state value is of interest this is equation 38.

So, depending on your problem statement accordingly whatever will be means whatever will be ask, so accordingly to take the values. So, with the flow of negative sequence current in the stator right the net flux in the air gap rotates at opposite direction to that of the rotor because it is, because of this negative sequence current right in the stator the net flux in the air gap rotates at opposite direction to that of the rotor; that means, the net flux rotates twice the synchronous speed of the rotor. This is also known to you from the your electrical machines.

So, in this case field winding actually has no influence that field winding has no influence because field voltage actually associated with the positive sequence variables and only the damper winding produces an effect in the quadrature axis. So, therefore, the negative sequence impedance is very close to the positive sequence sub transient impedance.

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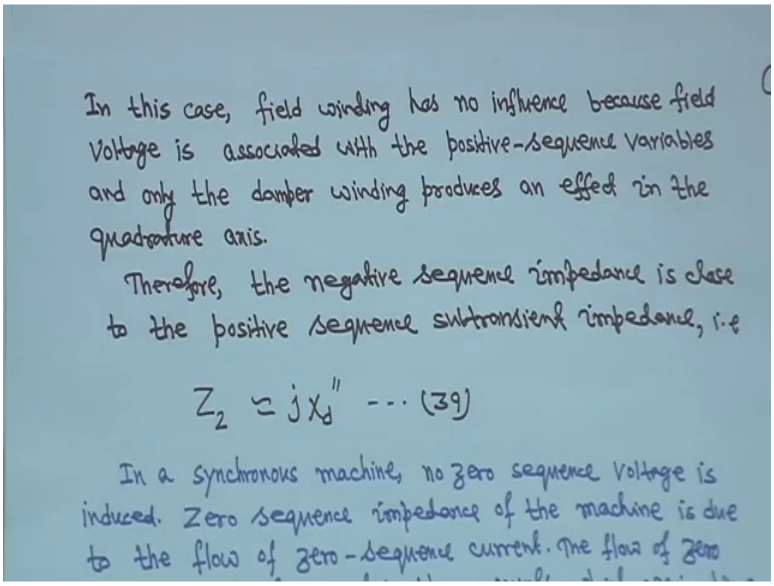

For example, Z 2 is approximately equal to j X d double dash this is equation 39 that means field winding also has no influence and because of field because field voltage is associated with the positive sequence variables and only the damper winding produces an effect in the quadrature axis. So, therefore, the negative sequence impedance is very close to the positive sequence sub transient impedance that is Z 2 is approximately equal to j X d double dash that is per synchronization negative sequence impedance and in a synchronous machine actually no 0 sequence voltage is induced.

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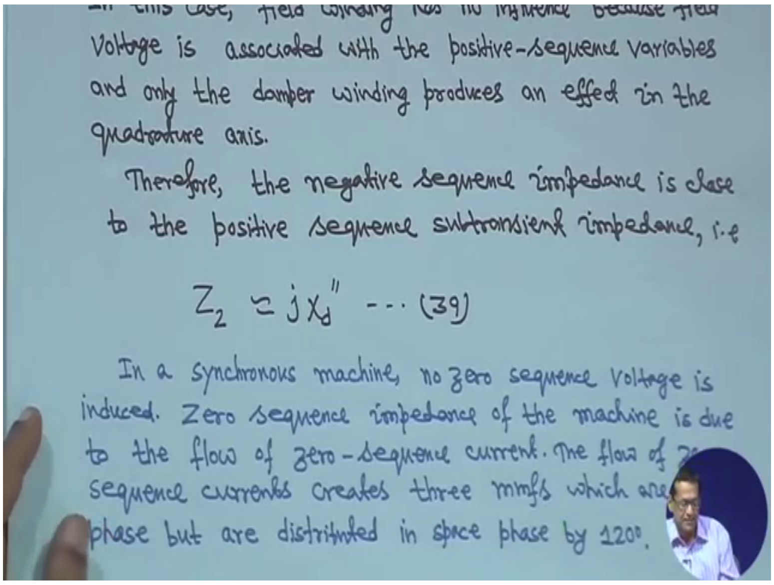

So, 0 sequence impedance of the machine is due to the flow of the 0 sequence current. The flow of 0 sequence current creates 3 mmf’s which are in time phase, but are distributed in space phase by 120 degree; that means, the resultant is 0 right. So, I repeat this one that in a synchronous machine actually no 0 sequence voltage is induced and 0 sequence impedance of the machine is due to the flow of 0 sequence current the flow of 0 sequence current creates 3 mmf’s which are in time phase, but are distributed in space phase by 120 degree.

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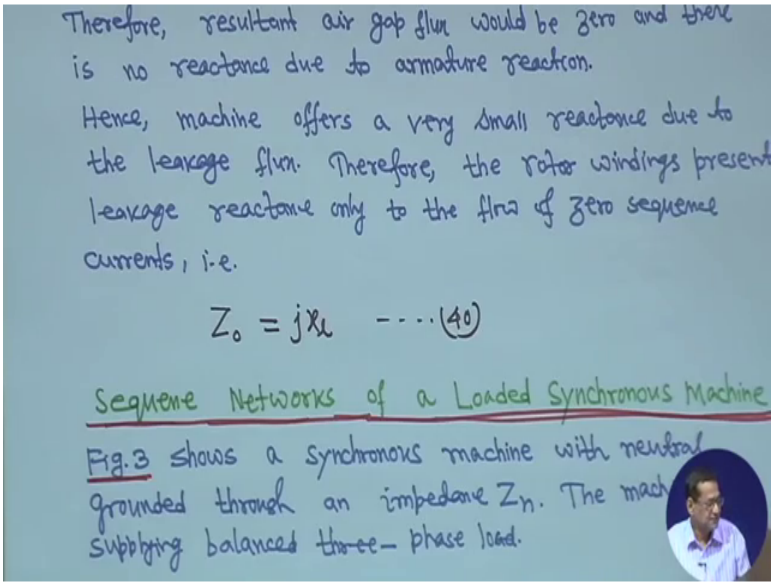

That means, the therefore, the resultant air gap flux would be 0 and there is no reactance due to armature reaction. Hence machine only offers a very small reactance due to its leakage flux therefore, the rotor windings present leakage reactance only to the flow of 0 sequence current and that is Z 0 is equal to j X L, this equation 40.

So, this is the 0 sequence you what you call your impedance of the synchronous machine it is nothing, but that leakage reactance j X L and sign your negative sequence will be approximately j X d double dash approximately sub transient reactance and positive sequence of course, it depends on your requirement sub transient, transient or steady state. Now this is actually positive sequence negative sequence, now we have seen positive sequence, negative sequence and 0 sequence impedance for transformer and synchronous machine.

Now, let us see this one, now sequence network of a loaded synchronous machine because these are very rare these are necessary. So, figure 3 I will come to that, so as synchronous machine with neutral grounded through an impedance Z n the machine is supplying your balanced 3 phase load. So, this is that your synchronous 3 phase synchronous machine.

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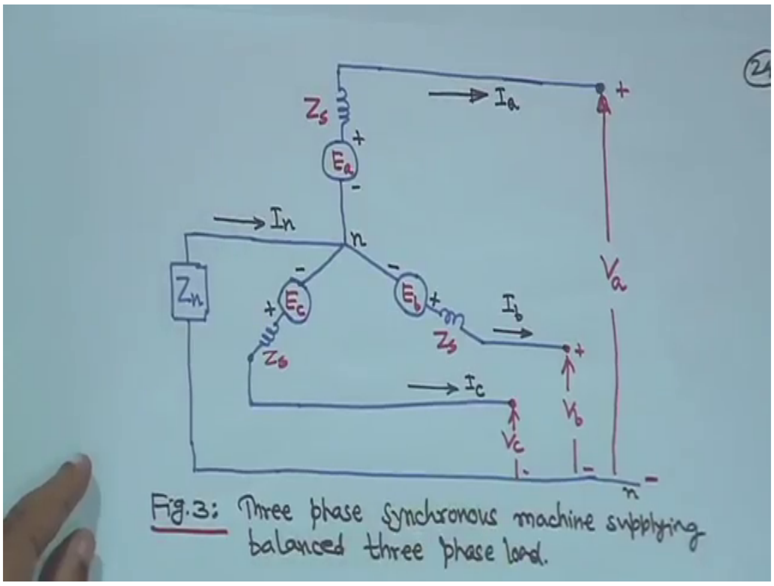

Supplying balanced 3 phase load this load is connected, but not shown right. So, this is your and your synchronous Z s Z s Z s all are reactance is given for the machine and it is your neutral your what you call that neutral is grounded through that impedance Z n that is taken and this is the V a phase voltage V a V b and V c and current is I a I b and I c and these are the your that magnitude is same this is balanced actually E a E b E c, but they are separated by your what you call 180 degrees.

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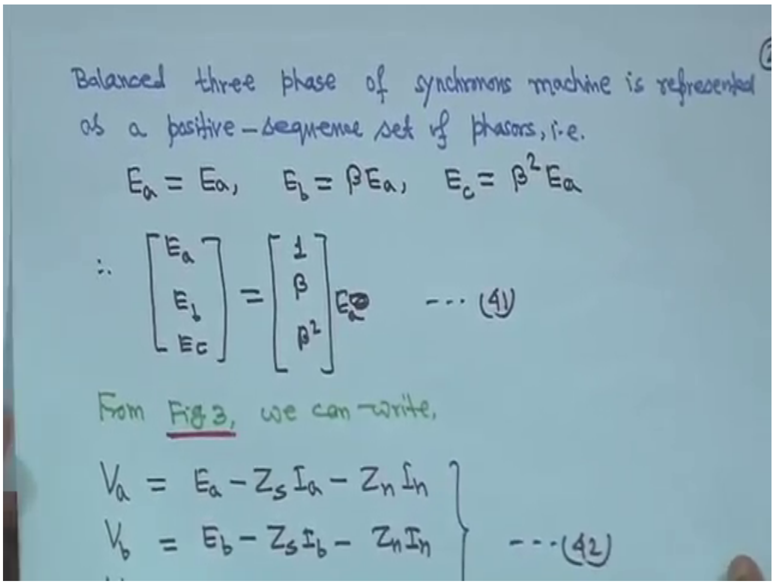

Therefore, balanced 3 phase of synchronous machine is represented as a positive sequence set of phasors that is E a we can same as before only instead of V here it is E e a is equal to E a E b is equal to beta E a and E c is equal to beta square E a. Therefore, we can write like this E a E b E c is equal to 1 beta beta square in to E a this is equation 41.

Now from figure 3 I mean from this equation it is a from this equation you can write equation for E a E b and V a V b and V c each phase you can your this thing this equation you can write apply k V L from this thing. So, you can write V a is equal to E a minus Z a I a minus Z n I n; that means, your you apply k V L like this the way I am showing here.

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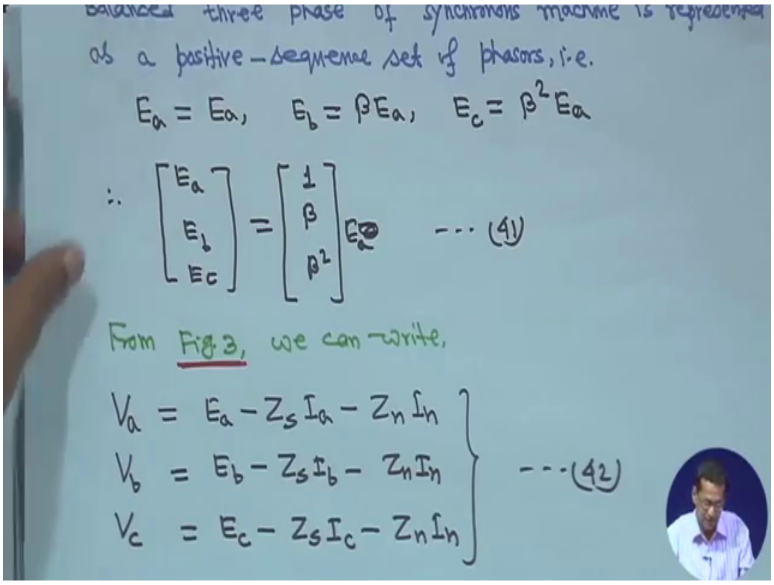

It is make it plus V a right then your move like this, move like this then Z n I n right minus your E a minus your E a in to Z s in to I a this way you write then you will get V a is equal to E a minus upper simplification V a is equal to E a minus Z a I a minus Z n I n just, let me show you this.

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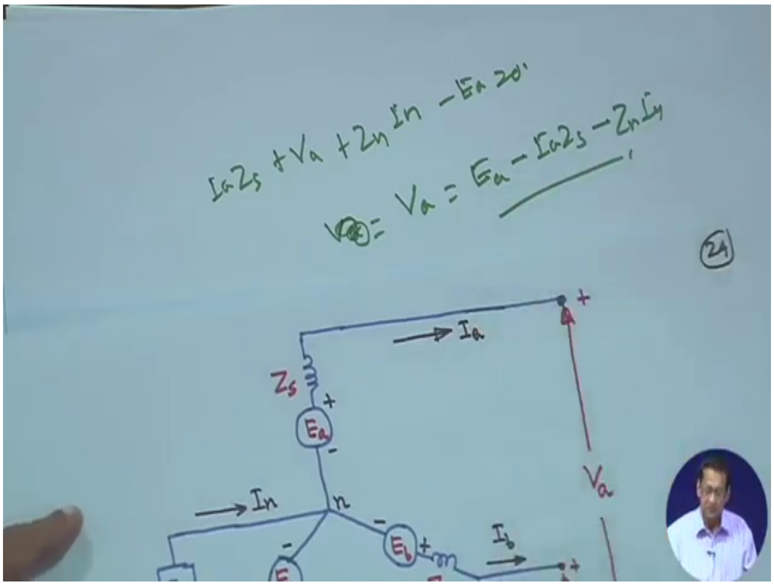

Look this is actually current flowing through this phase it is I a Z s right then plus V a plus V a then it is current neutral current is flowing plus Z n your I n right minus E a is equal to 0; that means, from this equation you can write that your V a I a Z s plus V a from this equation you can write that V a is equal to E a minus your I a Z s minus Z n I n right. So, similarly for phase b and c, so that is why, that is why I am writing this V a is equal to E a minus your Z s I s minus Z n I n then Z s I a minus V b is equal to similar E b minus Z s I b minus Z n I n and V c is equal to E c minus Z s I c minus Z n I n; that means, from this k V L if you apply k V L you will get this 3 equation this is actually 42, now equation 42.

Now, another thing is that this current I n is entering here this way direction you have taken this is leaving this thing I a is leaving this term terminal here I a here it is I b I c I n is equal to I a plus I b plus I c.

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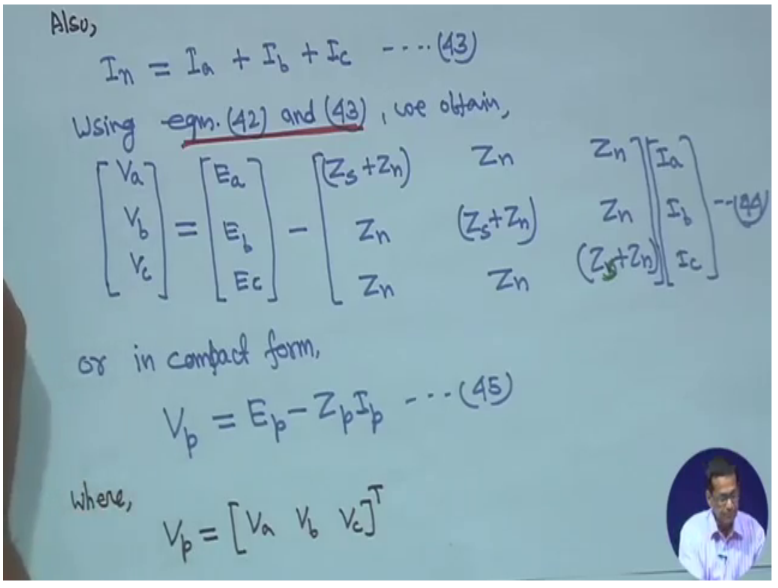

That means this also that neutral current I n that is equal to I a plus I b plus I c. Now using equation 42 and 43, so this is equation your 42 right and this is I n is equal to given this I n you substitute here this I n from here I n is equal to I a plus I this is plus I c you substitute in equation 42 if you do. So, you will get in this form that V a V b V c is equal to E a E b E c minus Z s plus Z n then Z n then Z n Z n Z s plus Z n Z n Z n Z n Z n plus sorry Z s it will be Z s plus Z n Z s plus Z n and this is actually I a I b I c this is equation 44. Or in compact form if you write then V p will be this we define as a V p right V p will be is equal to E p minus this 1 will be Z p and this 1 will be I p, this way you write in compact form, later we define.

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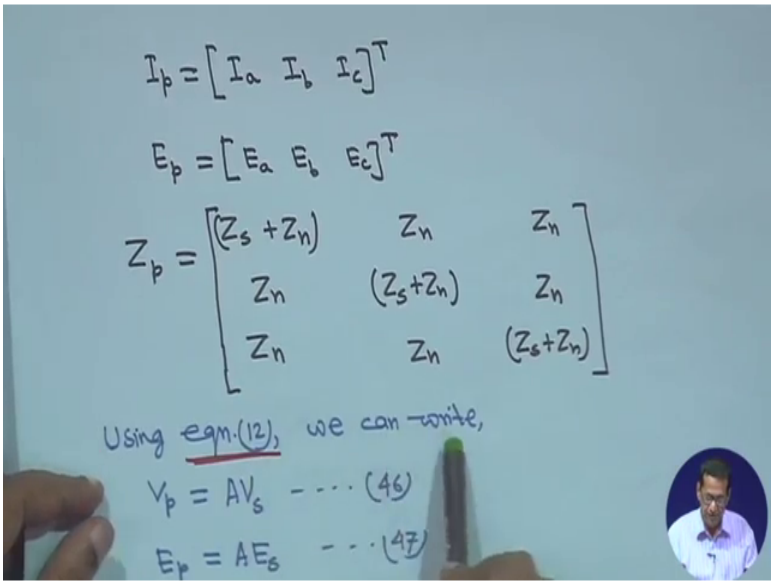

So that means, that means I p is equal to this equation actually this equation right to I p is equal to we write I a I b I c transpose, E p is equal to E a E b E c transpose and Z p is equal to this matrix and using equation 12, earlier I am not showing again equation 12, this we have to this you know now V p is equal to a V s. So, same way you can write E p is equal to a E s right, same way we are writing; that means, and similarly we can write same way we can write that your I p is equal to a I s this is that this equation is 47, this is 47 and this equation is your 48.

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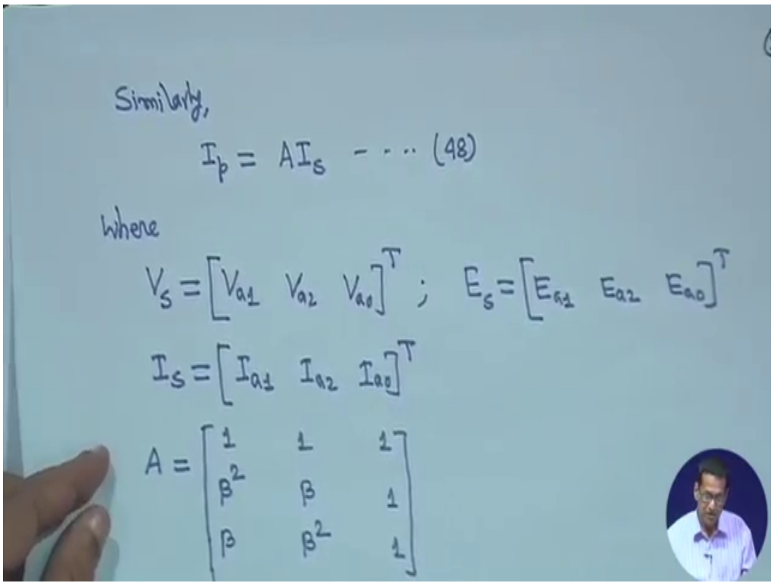

That means V s is equal to you know we have seen before V a 1 V a 2 V a0 transpose, E s is equal to E a 1 a 2 a0 transpose and I s is equal to I a 1 I a 2 I a0 transpose and a matrix we also know we have already defined right.

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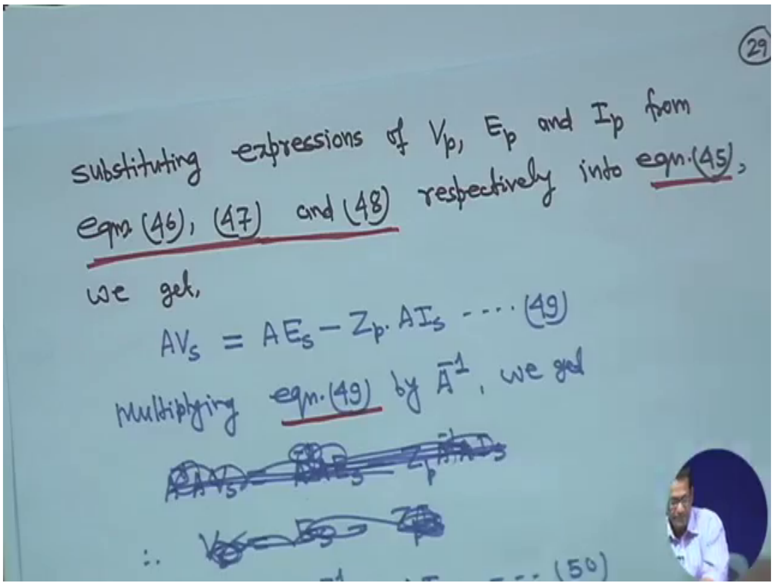

Therefore you substitute you substituting expression of V p E p and I p from equation 46 and; 46 47 and 48 respectively in to equation 45; that means, this equation whatever has been defined in this equation you substitute every everything from equation 46 47 and 48. Then what you will get you will get a V s is equal to a E s minus Z p in to a in to I s this is equation 49 and this equation 49 you multiply both side by a inverse multiply.

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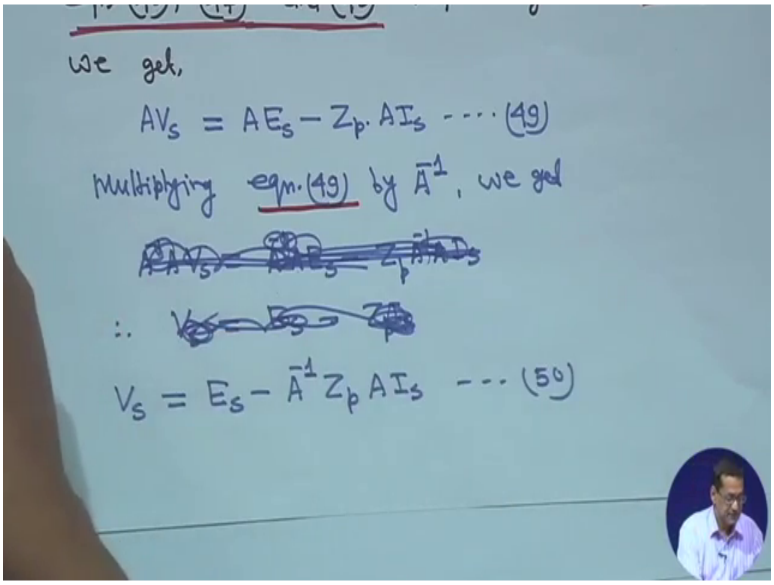

Then you will get V s is equal to E s minus a inverse Z p in to a in to I s this is equation 50. Then V s is equal to we can write E s minus Z s dash I s, this is equation 51 where Z s dash is equal to a inverse Z p in to a.

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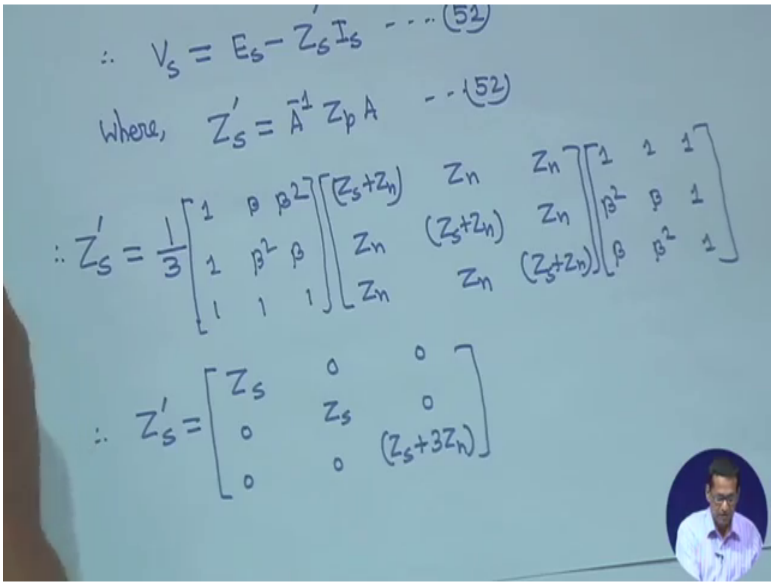

So, Z s dash is equal to this is your a inverse already we have defined and this is your Z p matrix and this is your a matrix. If you multiply all these right you will get Z dash is equal to Z s 0 0 0 Z s 0 and 0 0 Z s plus 3 Z n. So, this is your Z s dash; that means, your;

that means, from this equation V s actually V s is equal to E s minus this V s is equal to E s minus Z s dash I s, so V s actually V a 1 V a 2 V a 0.

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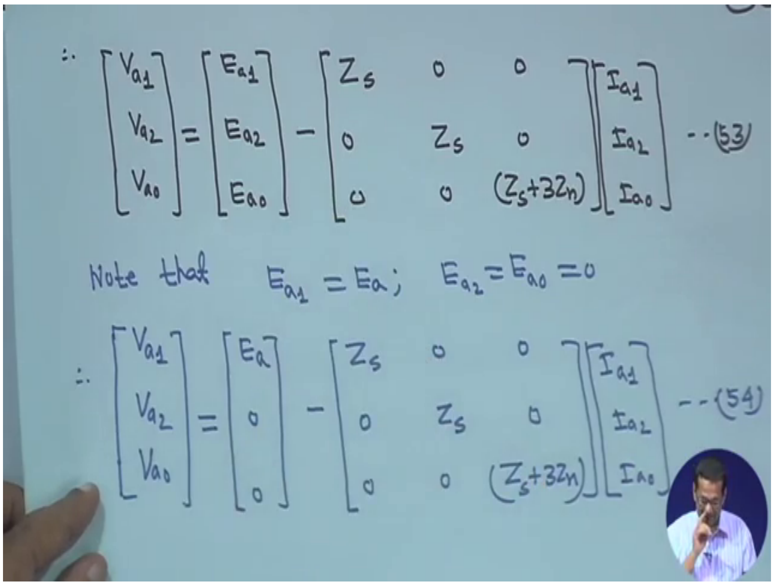

Your E s actually E a 1 E a 2 E a0 minus this is that your Z s dash matrix, this is Z s matrix in to I a s I a 1 I a 2 I a0 this is equation 53. So, from this note that E a 1 is equal to E a, E a 2 is equal to E a0 is equal to your what you call 0 because if you your what you call that; that means, V a 1 V a 2 V a0 that is your for synchronous machine that in that positives only the positive sequence voltage is induced right that is E a 1 is equal to E a, but there is no negative or 0 sequence voltages that is why E a 2 is equal to E a0 is equal to 0. That is why this equation can be written as V a 1 V a 2 V a0, this is E a E a 2 and E a0 this 2 will be 0 minus this matrix then I a 1 I a 2 I a0 right.

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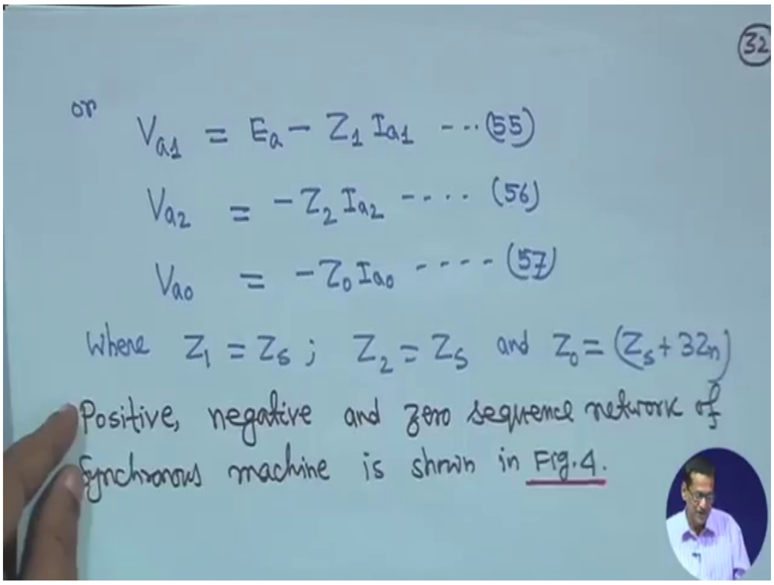

That means, that is V a 1 will be E a 1 E a sorry E a minus from this equation only we are writing from equation 54 only we are writing this right therefore, V a 1 is equal to E a minus Z 1 I a 1 that is equation 52, V a 2 is equal minus Z 2 I a 2 that is equation 56 we are giving and V a0 is equal to minus Z 0 I a0 this is equation 57 where Z 1 is equal to Z s Z 2 is equal to Z s and Z 0 is equal to Z s plus 3 Z n. That means, this is Z 1 is equal to Z s Z 2 is equal to Z s, and Z your Z 0 is equal to Z s plus 3 Z n. So, that is why we are writing here Z 1 is equal to Z s, this is actually Z 1 is equal to Z s Z 2 Z s and Z 0 is equal to Z s plus 3 Z n. So, positive negative and 0 sequence network of the synchronous machine is shown in figure 4.

That means for synchronous machine the positive negative and sequence network it is something like this they are independent to each other.

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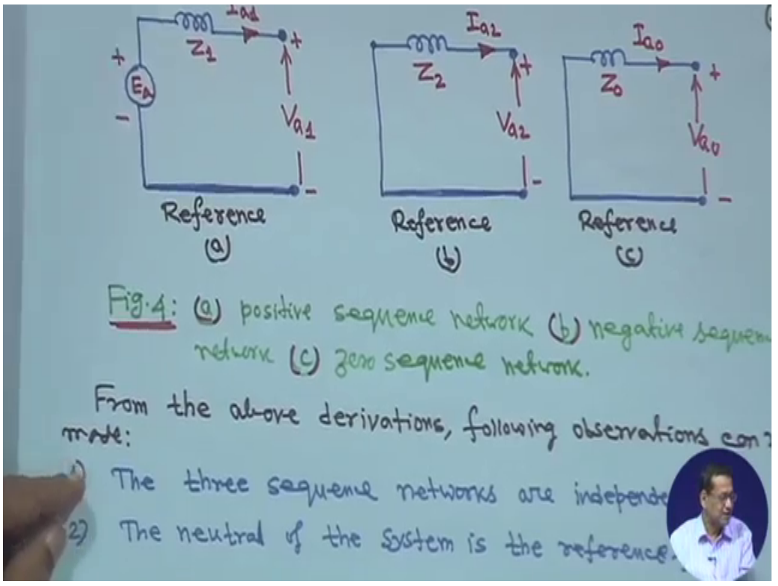

So, this is for your positive sequence network this is voltage E a plus minus this Z 1 current is given I a 1. So, negative sequence 0 your negative sequence or 0 sequence they have no voltage source. So, it is Z 2 I a 2 and it is Z 0 current is I 0, this is V a 1 V a 2 V a 0. So, this is a positive sequence network, b is negative sequence network and c is 0 sequence network for synchronous machine.

Now from the above your derivation some observations we can make, first one is the 3 sequence networks are independent this 3 networks are independent no connectivity. The neutral of the system is the reference for positive and negative sequence network; that means, for positive this is reference this is reference. So, for positive and negative, for positive and negative sequence network for synchronous machine that neutral actually is the reference whereas, for your 0 sequence network ground is the reference; that means, that neutral of the system is the reference for positive and negative sequence network, but ground is the reference for the 0 sequence network.

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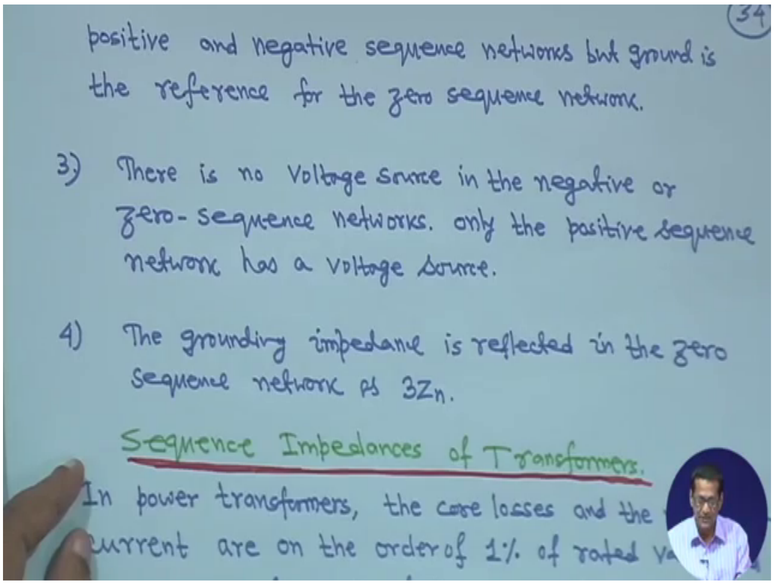

Number 3 there is no voltage source in the negative or 0 sequence network only the positive sequence network has a voltage source. And number 4, the grounding impedance is reflected in the 0 sequence network as 3 Z n although when we are drawing the diagram it is Z n, but the grounding your what you call that grounding impedance actually reflected in the 0 sequence network as 3 Z n.

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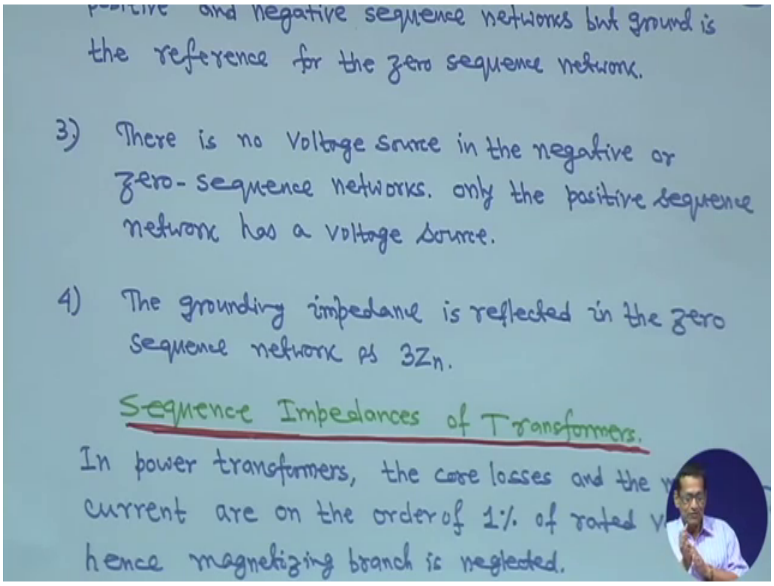

Now, see this is for the synchronous machine, the positive, negative and 0 sequence. Now next is the sequence impedance sequence impedances of transformer. So, transformer actually is a static device. So, there is no rotating part in the transformer. So, the core loss and the magnetizing current on the in the order of 1 percent of the rated value and the hence magnetizing branch is neglected. So, when you will find out the sequence impedance is of the transformer that magnetizing branch will be your neglected.

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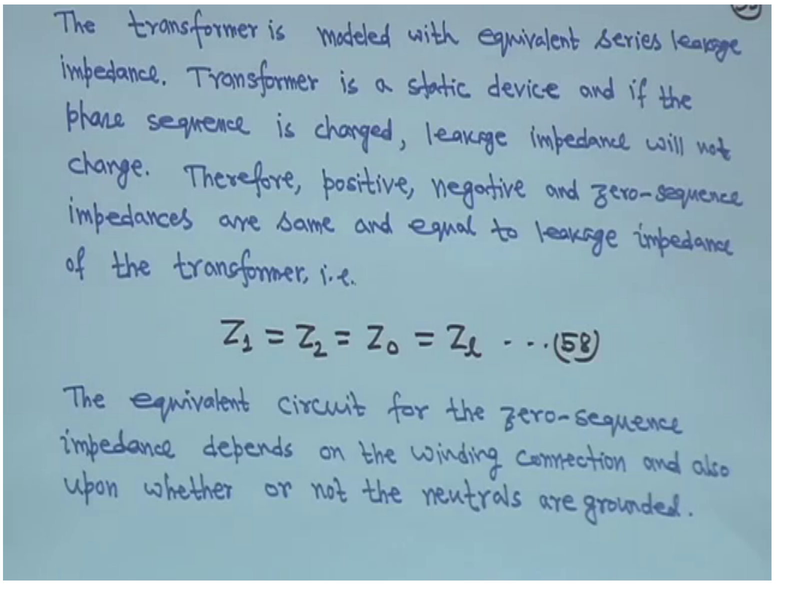

So, the transformer actually the transformer is modeled with equivalent series leakage impedance. So, transformer is a static device and if the phase sequence is changed leakage impedance will not change because it is a static device. Therefore, the positive negative and 0 sequence impedance are same and equal to leakage impedance of the transformer; that means, Z 1 is equal to Z 2 is equal to Z 0 is equal to Z l. So, for transformer it is straight forward therefore, the equivalent circuit for the 0 sequence impedance depends on the winding connection and also upon whether or not the neutrals are grounded; that means, start delta right.

The 0 sequence for the winding connection means start delta and also upon whether or not the neutrals are grounded, based on that the your what you call the 0 sequence network come. So, question is that this is 2 or there is 3 4 things for your for particularly the false studies the 0 sequence diagram is your quite important because for positive sequence you know it will be in voltage source will be there and all the parameters as usual.

For negative sequence there will be no voltage source, but all other parameters will be there, but for 0 sequence that that actually you have to understand that how one can drop how one can your analyze the things correct way particularly the 0 sequence diagram. This is from the aspect of student point of view that their confusion actually mainly your 0 sequence diagram network.

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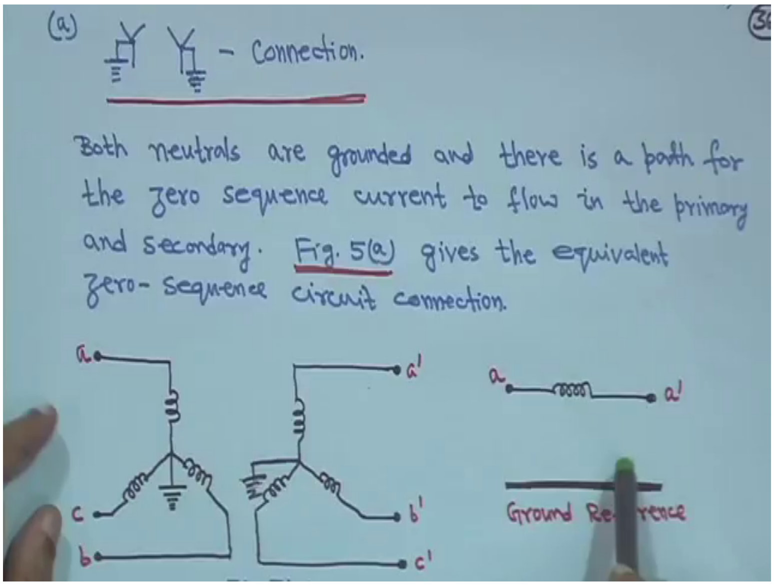

So, in this case for transformer case for example, you consider star star transformer both side it is grounded, it is both side is grounded right this star star connection. Look as both neutrals are grounded and there is a path for the 0 sequence current to flow in the primary and secondary because both are grounded. So, there will be path for 0 sequence current to flow. So, figure 5 again gives the equivalent 0 sequence circuit connection now this is star star. So, this is a b c, this way I have drawn this is also a dash b dash c dash I have drawn, the question is that your that this is grounded this is also this is also grounded both are both are grounded right this is also grounded, this is also grounded; that means, the ground is the reference you take and as both are grounded. So, there is a path for 0 sequence current to flow. So, this is a and a dash and this is your 0 whatever this you saw that for transformer positive negative and 0 sequence your impedance same as leakage your what you call leakage impedance that is your Z l.

So, this is a and a dash and this is a ground as reference. So, this is a0 sequence your network for the transformer for star star your connection, but both star are grounded.

Now next one is this thing, this thing you have to understand otherwise difficult to solve fault problem and difficult for the 0 sequence network.

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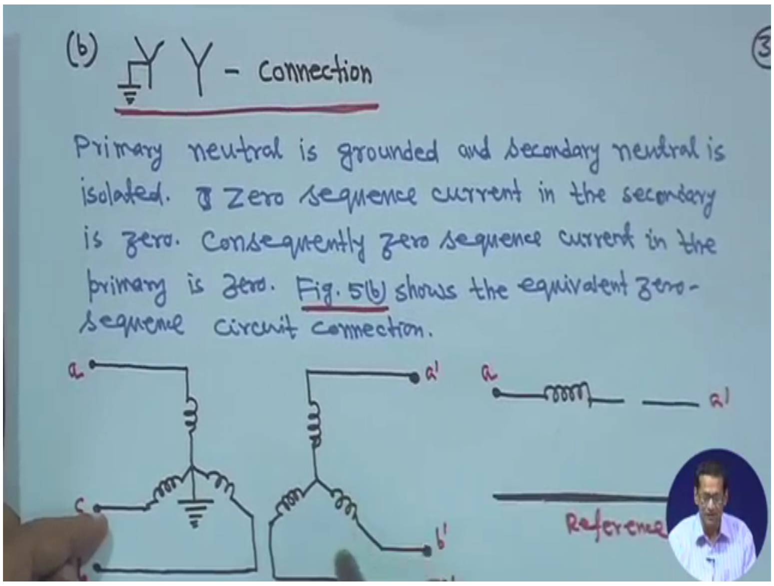

So, next one is that star star again, but this primary side is grounded, but secondary side is your ungrounded I mean no ground, so this is the connection. So, in that case this is your star right this side is ground, primary side is grounded this side is not; that means, that means that primary neutral is grounded, but secondary neutral is not grounded right it is isolated that secondary neutral is isolated. That means, 0 sequence current in the secondary is 0 because it is there is no ground no ground here.

So, there is no question of yours secondary side 0 sequence current will flow; that means, this a this diagram will be this, but this will be this will remain open because secondary side there is no 0 sequence current no it cannot flow. So, this is, but although this side is grounded, but this side is ungrounded. So, there is no secondary 0 sequence secondary current flow. So, that is why this will remain open, but this reference line you have to show. I have this part, I have this thing understood thank you again coming.