Power System Protection
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Lecture 04
Fault Analysis Review - Sequence Components (Cont'd)

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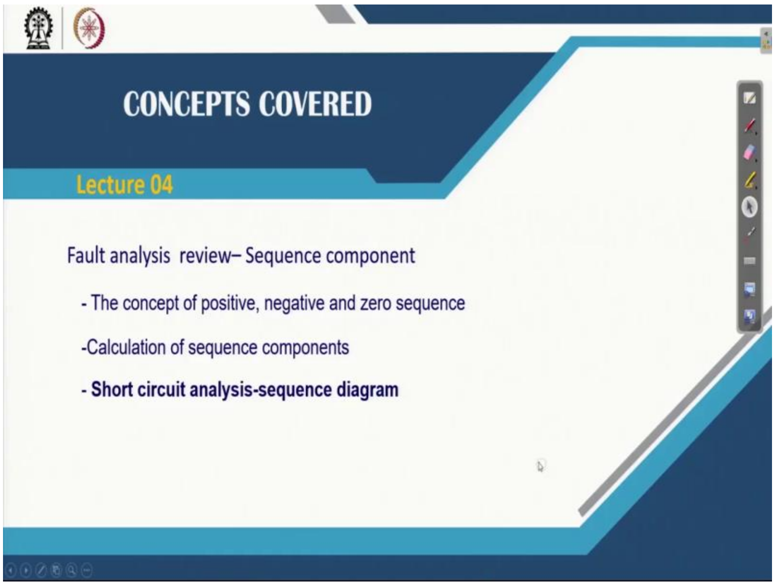

Welcome, in this fourth lecture, we will continue with the review on the fault analysis, we will go with the sequence component also there, we will emphasize here more on how to calculate the fault current, voltages at different points and so, that we call short circuit analysis, by drawing the different sequence diagrams and the connections, we will analyze how such a platform or tools are used in framing the different numerical relaying algorithms and so.

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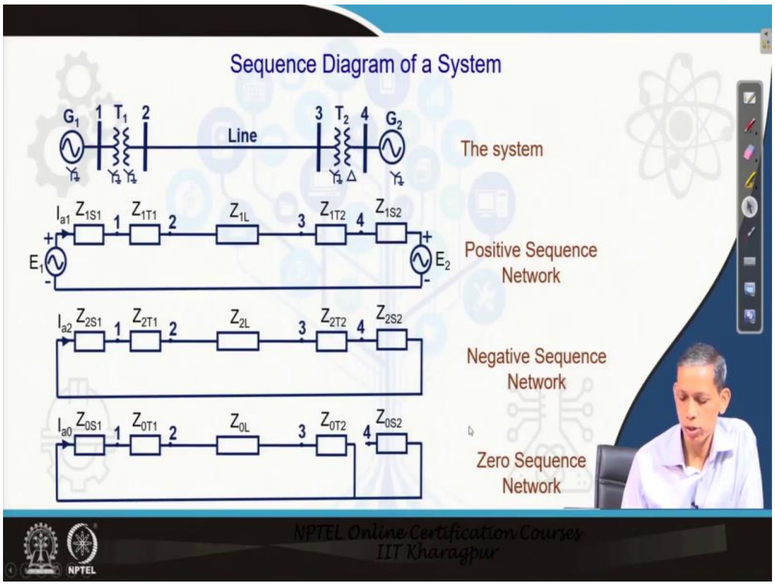

Let us consider a system like this as we have seen earlier also two sources connected by a transmission line through two transformers, so this system available to us. Now, as we have already seen, we will draw first the different sequence diagram for the system which will be useful for the fault analysis. So, we already have discussed about the positive sequence components of each element of the system. For the generator, we have a source and the corresponding associated impedances. So this is source 1, so Z_{1S1}, Z_1 for the positive sequence impedance of the generator and S1 for the first source, and then for the transformer the positive sequence impedance Z_{1T1} and for the transmission line impedance Z_{1L} and Z_{1T2} for the second transformer for the transformer 2 and Z_{1S2} for the second source G_2 and the associated voltage for this. So, as already we have mentioned that the positive sequence diagram contains the corresponding sources, E_1 and E_2 in this case for this G_1 and G_2 but when you go to the negative sequence diagram, we see there is no voltage because the sources being considered balanced in nature, so there is no negative sequence voltage components. So, each of the component are associated with the negative sequence impedances are provided here; Z_{2S1}, Z_{2T1} for the transformer 1, Z_{2L} and Z_{2T2} and Z_{2S2}, Similarly, if we will go to the zero sequence components, only difference is for the transformer and these generators, so you can say that the zero sequence component connection becomes different and particularly here 2 transformers are there and they are associated with the impedances Z_{0T1} and Z_{0T2} here. Note that here in the left hand side, they are star grounded, star grounded, so the transformer zero sequence impedance is connected in series to the line side and the source side, and for the right side, transformer be T_2, where one side, you can say delta connected; therefore, circulating current will be there, so that is connected with the reference in this perspective and this is not connected to the source side; because in the line side of the delta connections the zero sequence current will not flow. So the corresponding zero sequence diagram becomes like this with associated zero sequence impedances. So, you got, the positive sequence network, negative sequence network and zero sequence network for the given system.

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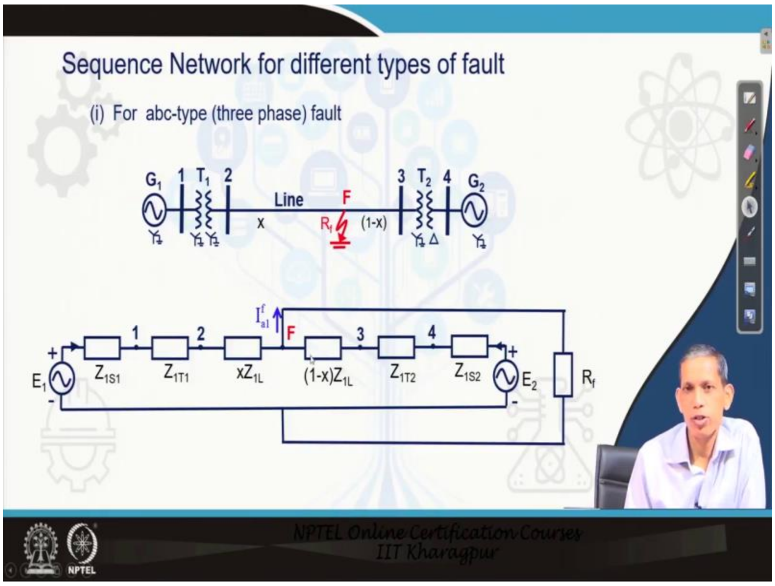

Now, for different faults as we have already discussed in earlier lecture that for different kinds of fault, how the corresponding sequence diagrams will be there and how the corresponding connectivity will be there that we like to analyze. Let us consider for the same system if fault happens to be there in this line locates at x portion of the line from the left side and (1-x) portion from the right side, with a fault distance of R_F.

We will consider first the three phase balance fault. This is a balanced fault case; therefore, we say that only positive sequence component will be there and no negative sequence and zero sequence, as I have already mentioned in the last lecture. So, we have only the positive sequence diagram and the corresponding fault path has a fault resistance of R_F, and in this fault path, I_{a1} fault current flows and we do not have any negative sequence or zero sequence current in this case.

Now you can say that, if you like to analyze the corresponding system here, if you see here this is the voltage source with corresponding positive sequence impedance, transformer impedance, line impedance up to the fault point from the left hand side, xZ_{lL} from the right hand side bus 3, (1-x) Z_{1L}; second transformer Z_{1T2} and the second source Z_{1S2} with its voltage E_2. So, for this case, the corresponding diagram becomes this, and you can analyze much easier, instead of we will go and put the three phase voltages V_a, V_b, V_c or associated currents and all this in the diagram.

So, once we have this corresponding sequence current (I^f_{a1}) in this path, you can find the sequence currents from both the sides also; different voltages in the systems, given that in the case of fault analysis it is considered that the corresponding E_1 as an $1\angle 0^0$ per unit and these other sources also in the systems with an angle of 0 degree and magnitude of 1 per unit. So, with that consideration, the corresponding analysis is being carried out and you can find the different currents and different voltages in the systems.

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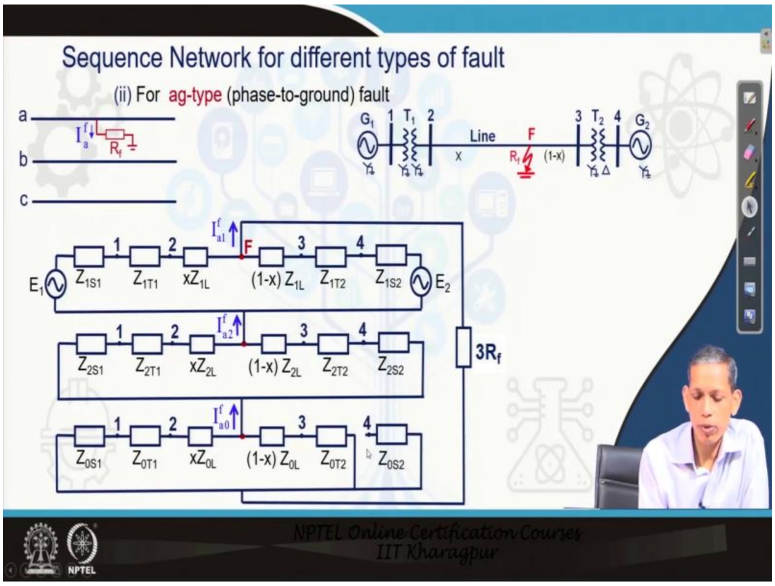

We can go to other types of fault, now in the second one we are going to the line to ground fault case or phase *a* to ground fault case as you say. Let us consider a phase *a* to ground fault, in this case. The corresponding sequence diagram is given for the fault at F, and phase *a* to ground fault happens to x portion from left side and (1-x) portion from right hand side as we have already discussed in the earlier slide; with this, for the same system we have positive sequence diagram, we have negative sequence diagram and we have zero sequence diagram. In the last lecture, we have seen that for a line to ground fault case, phase *a* fault means, the positive sequence diagram, negative sequence diagram and zero sequence diagram will be connected in series, so that

$$I^f_{a1} = I^f_{a2} = I^f_{a0}$$

,and with that perspective the corresponding sequence diagram becomes this. So these, R_F would be $3R_F$ here and with this diagram, we can analyze this circuit, you can find out I_{a1}^f and I_{a2}^f and I_{a0}^f, and then, we can find the different voltages and currents in the sequence diagram perspective. Once we have this sequence voltages and currents at different points, we can get back the corresponding phase quantities by the proper relation as you have seen in by multiplying the $[T]^{-1}$ with the sequence currents.

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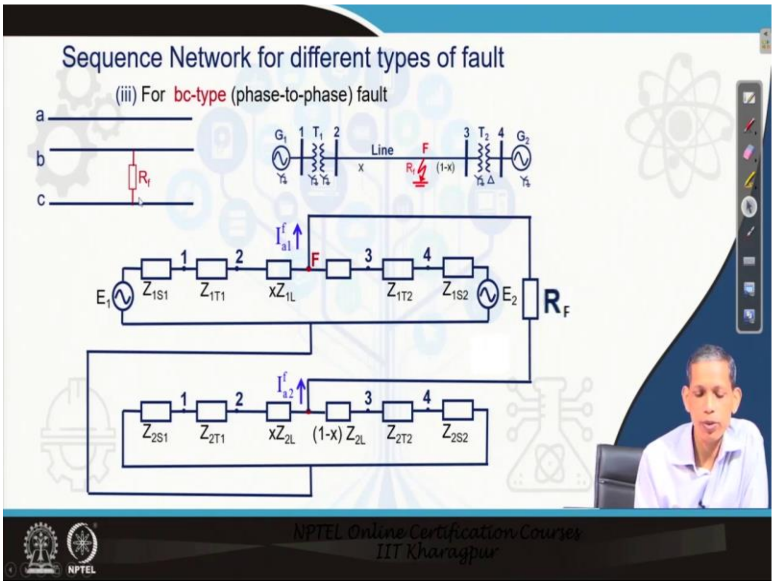

Next, that type of fault *bc* type fault. So, here you can see that phase to phase fault happens to be there in the *b* and *c* phases and with a fault distance of R_F. For this case only positive and negative sequence component happens to be there, and therefore, positive and negative sequence are connected in parallel, and in this case,

$$I_{a1}^f = -I_{a2}^f$$

That results in the sequence diagram like this

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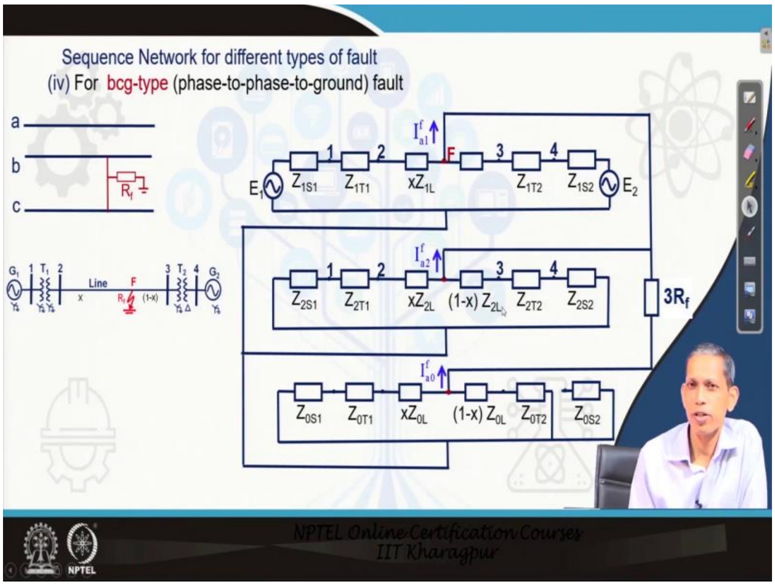

Then, next one of the *bcg*-type or phase to phase to ground or double phase to ground otherwise call also, with an R_F resistance here. Therefore, for the system the same F point happens to be there, then we have positive negative and zero sequence components and they are in parallel, and in this case,

$$I_{a1}^{f} = -(I_{a2}^{f} + I_{a0}^{f})$$

with the corresponding R_F and all these things. Consequently, we can analyze each individual connectivity here and you can find the different currents and voltages at different nodes and the corresponding phase quantities as mentioned in earlier case also.

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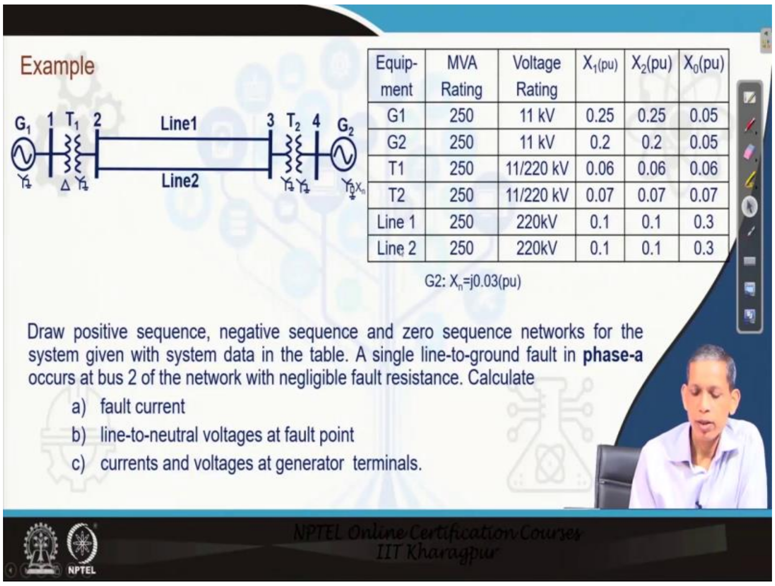

Let us consider one example, here. So, this is a system where we have two sources here connected by, double circuit transmission line, circuit 1 and circuit 2 and then they are connected by a transformer, T_1 and T_2 and the T_1 here is connected into delta (Δ) to the generator side and star ground (Yg) to the line side and the right hand side T_2 is connected in star grounded- start grounded (Yg-Yg) to both the sides, you can see that in this case.

And the corresponding per unit (pu) reactance of the individual element G_1, G_2, T_1, T_2 and their transmission highlight. T_1 and T_2 circuits are given here and, we see here, with their MVA rating and the kV rating of the system in terms of that, also the corresponding reactance through the ground of the second generator is in terms of 0.03pu; that is available to us. Now, the task here is that to draw the positive sequence, negative sequence and zero sequence networks for the system.

A single line to ground fault in phase *a* occurs at bus 2 of the network with negligible fault resistance, that is $R_F = 0$. Calculate fault current; fault current means current through the fault, line to neutral voltages at fault point that is the corresponding line voltages of phase *a*, phase *b*, and phase *c*. Current and voltages at generator terminals, that is current supplied by the G_1 current supplied by the G_2 and the corresponding voltages at terminal 1 and 4; V_a, V_b, V_c at bus 1 and bus 4, are to be calculated. So, now we will see first how the corresponding sequence network have been drawn.

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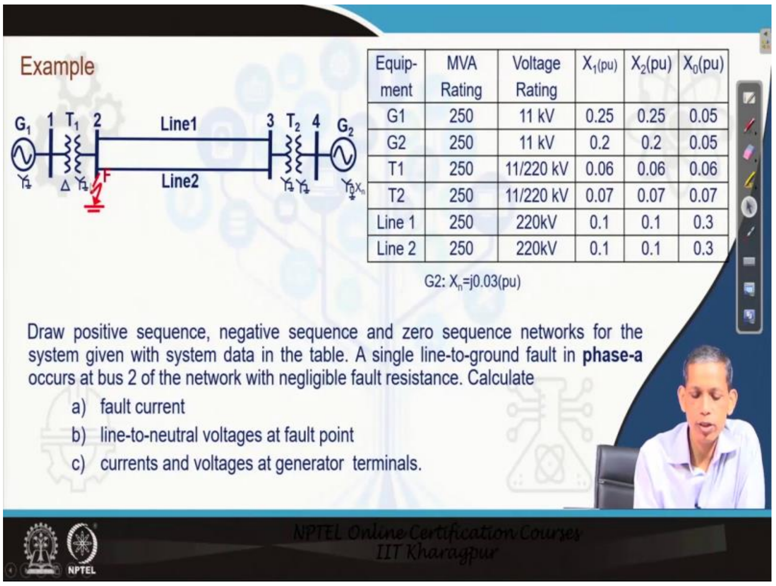

Equip-ment	MVA Rating	Voltage Rating	X_1(pu)	X_2(pu)	X_0(pu)
G1	250	11 kV	0.25	0.25	0.05
G2	250	11 kV	0.2	0.2	0.05
T1	250	11/220 kV	0.06	0.06	0.06
T2	250	11/220 kV	0.07	0.07	0.07
Line 1	250	220kV	0.1	0.1	0.3
Line 2	250	220kV	0.1	0.1	0.3

Now you see the fault is being here in this case. For this system, we have positive sequence, negative sequence and zero sequence diagram. The positive sequence diagram for this case, we have line-1 and line-2, are in parallel; so you see here from bus 2 to bus 3 both the lines are in parallel. Therefore, we can make them, to a single impedance or single reactance as shown here. So with this replacement each impedance or the corresponding reactance for each element of the system we get the positive sequence diagram. Similarly, for the negative sequence diagram and then for the zero sequence diagram. In this case, this side you can say delta connected. Therefore, this becomes open from this perspective that is with the connectivity diagram. This is an *ag* type fault; therefore, the corresponding sequence diagram and connections will be in series and then the R_F here equals to 0 so, $3R_F$ will be 0 in this case. We can say that is the corresponding connectivity.

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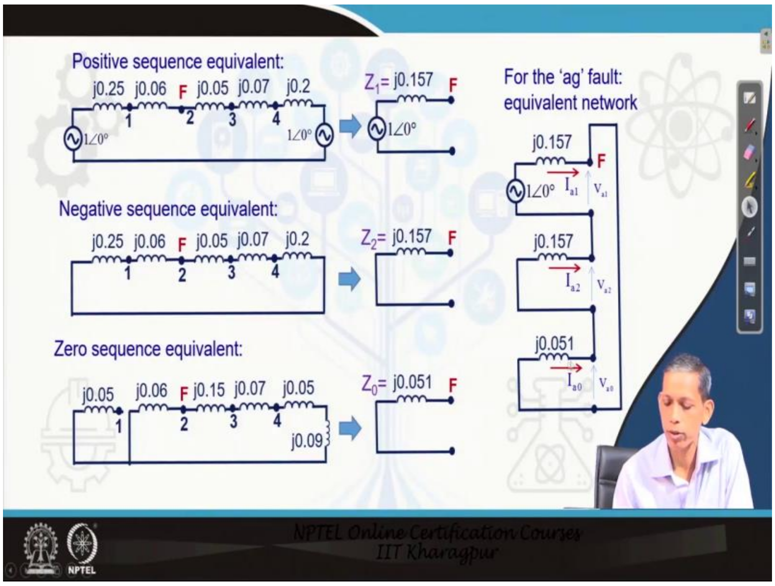

Now we will try to simplify the diagram to calculate the different currents and voltages in the systems. So, these about the positive sequence equivalent diagram as you have seen in earlier one, we assigned the corresponding voltages to be $1\angle 0^0$, as I mentioned. Then we can say that for this case, the equivalent from the point F, if you look to left and to the right then you get the corresponding thevenin's equivalent voltage and corresponding impedance to be like this. Therefore, this becomes one and one so no pre fault current will be there, no circulating current in this case will be there; therefore, the voltage becomes $1\angle 0^0$ and then from the left hand side and the right hand side the thevenin equivalent impedance becomes

$$Z_1 = (j0.06 + j0.25)||(j0.05 + j0.07 + j0.2) = j0.157$$

Next, you can say to the negative sequence component like this. So, from F, again we will see, the corresponding equivalent. So, if we see the equivalent these two circuits will be in this side and this side will be parallel. This parallel impedance again gives sequence impedance

$$Z_2 = j0.157$$

Because the positive sequence impedance and negative sequence impedance are same for the both the cases. Now, going to the zero sequence component again, from the fault point of basis the equivalent impedance seen can be expressed as

$$Z_0 = (j0.06)||(j0.15 + j0.07 + j0.05) = j0.051$$

So, that gives us, an impedance of a reactance of 0.051 for this one, so we got the equivalent circuit for the positive sequence, negative sequence and zero sequence.

Now, we will go for the connections as per we have made for this. So, at F point, they will be connected with R_F equals to 0, and there the connection diagram becomes this. So, what you see here, that for this case, the current which is flowing to the fault point, I_{a1}^f rather in this case; and the I_{a2}, I_{a1} and I_{a0} all three are same. Therefore, what we say that, from this diagram we can easily calculate the corresponding I_{a1}, I_{a2} and I_{a0} and also the corresponding V_{a1}, V_{a2}, and V_{a0}, we know here, the corresponding

$$V_{a1} = 1\angle 0^0 - (j0.157)I_{a1}$$

$$V_{a0} = -(j0.157)I_{a2}$$

and,

$$V_{a0} = -(j0.051)I_{a0}$$

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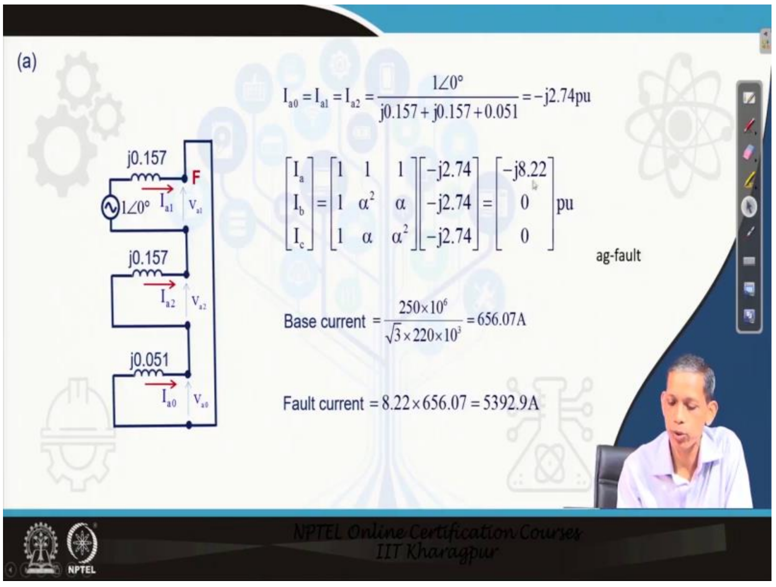

So there at least, from this sequence diagram, connectivity, we can find out this

$$I_{a0} = I_{a1} = I_{a2} = \frac{1\angle 0^0}{j0.157 + j0.157 + j0.051} = -j2.74$$

Thus the corresponding per unit current to be minus of j2.74. Now, the fault current which is flowing through the fault can be calculated in terms of phase *a*, phase *b*, phase *c* perspective. From this sequence components by substituting this sequence components and multiply [T] then we will get the corresponding I_a, I_b, I_c, like this.

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} -j2.74 \\ -j2.74 \\ -j2.74 \end{bmatrix} = \begin{bmatrix} -j8.22 \\ 0 \\ 0 \end{bmatrix}$$

Now, what you see here that the I_b and I_c are 0 and I_a equals to -j8.22 per unit. So, this clearly is an agreement with point that this fault which is, we created, in that system is phase *a* to ground fall. So, only phase *a* current is there, in the faulted path, phase b and phase c, currents are 0. So, with a base current nothing, but

$$Base\ current = \frac{Base\ MVA}{\sqrt{3}\,V_L} = \frac{250\times10^6}{\sqrt{3}\times220\times10^3} = 656.07\text{A}$$

This relates to base currents to be 656.07A and therefore the fault current becomes

$$\text{Fault current} = 8.22 \times 656.07 = 5392.9\text{A}$$

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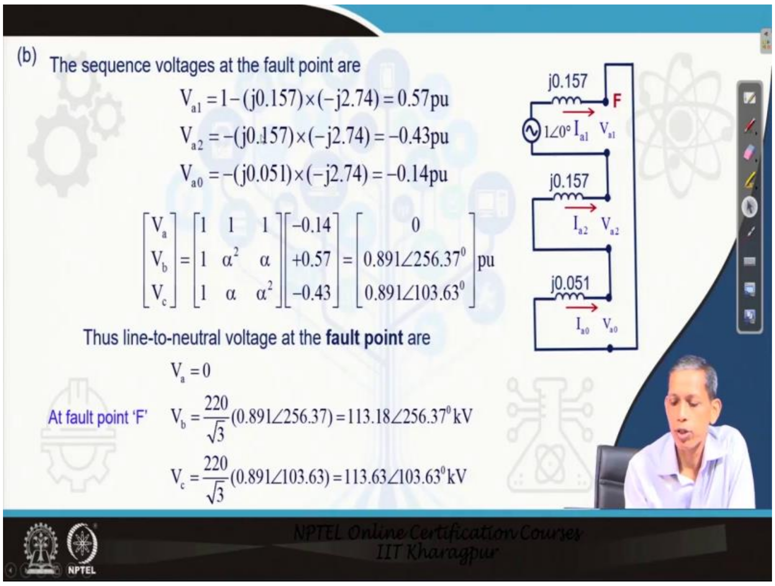

And, the sequence voltages at the fault point because this is, fault is created in phase *a*. So, we expect the corresponding voltage phase *a* voltage to be 0. Now, you got the corresponding sequence voltages at the fault point are obtained by

$$V_{a1} = 1\angle 0^0 - (j0.157)(-j2.74) = 0.57\text{pu}$$

$$V_{a2} = -(j0.157)(-j2.74) = -0.43 \text{ pu}$$

$$V_{a0} == -(j0.051)(-j2.74) = -0.14 \text{ pu}$$

Therefore, you got different per unit voltages, correspondingly the phase voltages V_a, V_b, V_c are given by

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} -0.14 \\ 0.57 \\ -0.43 \end{bmatrix} = \begin{bmatrix} 0 \\ 0.891\angle 256.37^0 \\ 0.891\angle 103.63^0 \end{bmatrix} \text{pu}$$

So, this we got V_a to be 0 as mentioned and V_b with $0.891\angle 256.37^0$ and Vc to be $0.891\angle 103.63^0$. Now, this gives us V_a, V_b, V_c at the fault point. Therefore, the fault point voltages in terms of kV.

$$V_a = 0 \text{ kV.}$$

$$V_b = \frac{220}{\sqrt{3}}(0.891\angle 256.37^0) = 113.18\angle 256.37^0 \text{ kV.}$$

$$V_c = \frac{220}{\sqrt{3}}(0.891\angle 103.63^0) = 113.18\angle 103.63^0 \text{ kV.}$$

So, at fault point, in terms of this kV, we got the corresponding voltage to be this. These are obtained, from the sequence component voltages as obtained from the sequence diagram perspective.

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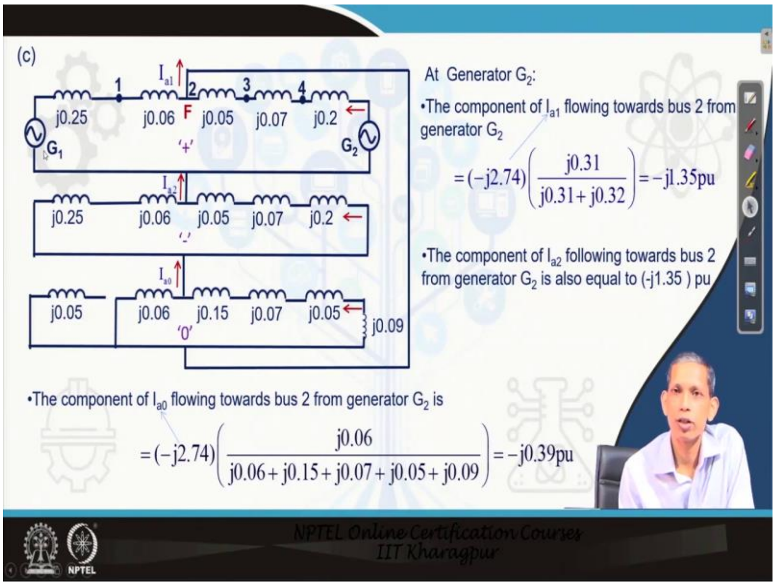

Now, the next we will see how the corresponding generators contribute to the fault current and the associated voltages at the bus terminals and so. The components of I_{a1} flowing towards bus 2 from G_2 depends on the parallel path combinations because both the sources consists of $1\angle 0^0$; therefore, this I_{a1} current into impedance of this side divided by this provides the current from the G_2. That is

$$(-j2.74)\left(\frac{j0.31}{j0.31+j0.32}\right)=-j1.35 \text{ pu.}$$

Therefore, the corresponding current to be -j1.35 contributed from the G_2 side. The components of I_{a2} flowing towards bus 2 from G_2 is also equals to I_{a1} as the impedances in both positive and negative sequence components are same for this problem. Therefore, we say that becomes also -j1.35 pu. It is observed $I_{a0} = I_{a1}$; the components of I_{a0} which is flowing towards bus 2 from the G_2 side is

$$(-j2.74)\left(\frac{j0.06}{j0.06+j0.15+j0.07+j0.05+j0.09}\right)=-j0.39 \text{ pu}$$

This gives us the rise to I_{a0} from the G_2 side becomes equals to -j0.39 pu.

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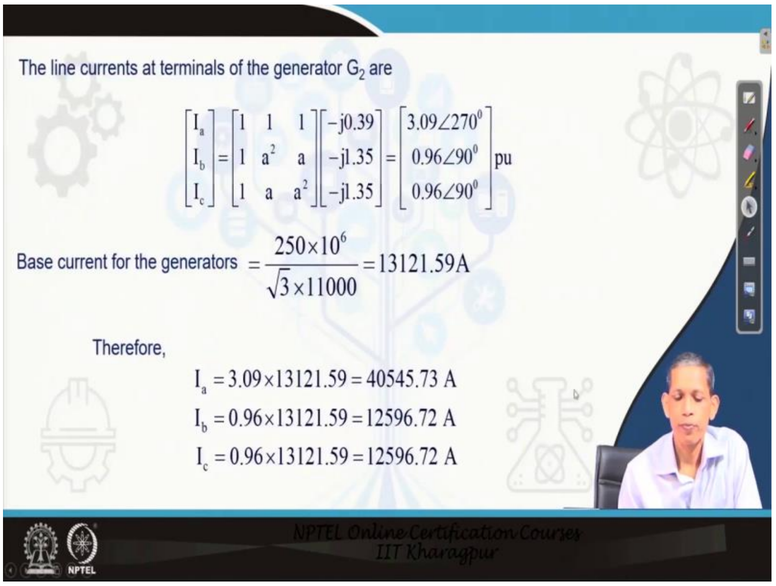

So therefore, the line current terminal from the generator 2, can be find out from the sequence components multiply by T matrix,

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} -j0.39 \\ -j1.35 \\ -j1.35 \end{bmatrix} = \begin{bmatrix} 3.09\angle 270^0 \\ 0.96\angle 90^0 \\ 0.96\angle 90^0 \end{bmatrix} \text{pu}$$

We can get the I_a, I_b, I_c contributed from this G_2 side, becomes $3.09\angle 270^0$ in phase *a*, $0.96\angle 90^0$ in phase *b* and $0.96\angle 90^0$ in phase *c* pu. Base current for the generators

$$= \frac{250\times 10^6}{\sqrt{3}\times 11000} = 13121.59 \text{ A}$$

So, therefore, if you get the corresponding base current 13121.59 A, so multiply this base, currents to these per unit values, you will get the corresponding set of currents for the phase *a* phase *b* and phase *c* contributed from the G_2 side.

$$I_a = 3.09 \times 13121.59 = 40545.73 \text{ A}$$

$$I_b = 0.96 \times 13121.59 = 12596.72 \text{ A}$$

$$I_c = 0.96 \times 13121.59 = 12596.72 \text{ A}$$

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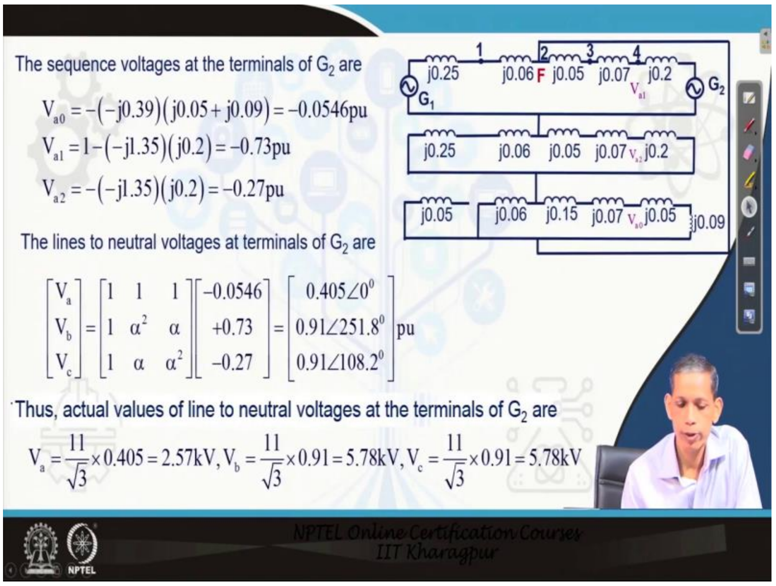

Similarly, you can find out the sequence voltages at the terminals of G_2 (node 4) is given by

$$V_{a0} = -(-j0.39)(j0.05 + j0.09) = -0.0546 \text{ pu}$$

$$V_{a1} = 1 - (-j1.35)(j0.2) = 0.73 \text{ pu}$$

$$V_{a2} = -(-j1.35)(j0.2) = -0.27\text{pu}$$

Therefore, from these V_{a0}, V_{a1} and V_{a2}, the phase voltages are obtained from

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} -0.0546 \\ 0.73 \\ -0.27 \end{bmatrix} = \begin{bmatrix} 0.405\angle 0^0 \\ 0.91\angle 251.8^0 \\ 0.91\angle 108.2^0 \end{bmatrix} \text{pu}$$

Thus we get the phase *a* phase *b* phase *c* voltages they are found out to be $0.405\angle 0^0$, $0.91\angle 251.8^0$ and $0.91\angle 108.2^0$ per unit. Simultaneously, in terms of kV the line to ground voltages at the G_2 terminals can be represented as

$$V_a = \frac{11}{\sqrt{3}} \times 0.405 = 2.75 \text{ kV.}$$

$$V_b = \frac{11}{\sqrt{3}} \times 0.91\angle 251.8^0 = 5.78\angle 251.8^0 \text{ kV.}$$

$$V_c = \frac{11}{\sqrt{3}} \times 0.91\angle 108.2^0 = 5.78\angle 108.2^0 \text{ kV}$$

The corresponding voltages associated with phase *a* is 2.57 kV, phase *b* is 5.78 and phase *c* is 5.78 kV at node 4 you can see that which is connected to the generator terminal 2.

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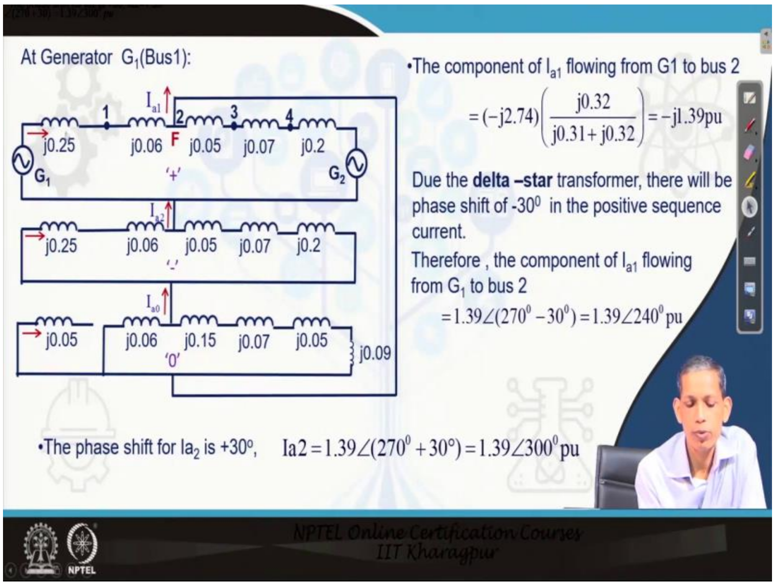

Similarly, for the generator G_1 side the corresponding contribution from the generator 1 in positive sequence, negative sequence and zero sequence are the parallel path combinations as you did for the generator 1 perspective. The component of I_{a1} flowing from G_1 towards bus 2

$$= (-j2.74)\left(\frac{j0.32}{j0.31+j0.32}\right) = -j1.39 \text{ pu}$$

I_{a1} becomes equals to - j1.39 and similarly, we can find out the I_{a2} and I_{a0} also. The delta star transformer, there will be phase shift of 30 degree, for this case. See here, because the transformer, which is there in the G_1 side is having a delta – star configuration, delta into the generator side and star to the line side. As far from the analysis and convention, that if you are going from to low voltage to the high voltage, the positive sequence voltage and currents, we have $+30^0$ and if you are going from the high voltage to the low voltage it is -30^0 and in case of negative sequence diagram the reverse to that of the positive sequence perspective.

Therefore, in this case the phase shift of minus 30 degree is taken into account. So, the component of I_{a1} flowing from G_1 towards bus 2 is

$$1.39\angle(270^0 - 30^0) = 1.39\angle240^0$$

The phase shift for I_{a2} as mentioned, because you are going from the high voltage to the low voltage. Therefore, you had to consider plus 30 degree, so I had to consider

$$1.39\angle(270^0 + 30^0) = 1.39\angle 300^0$$

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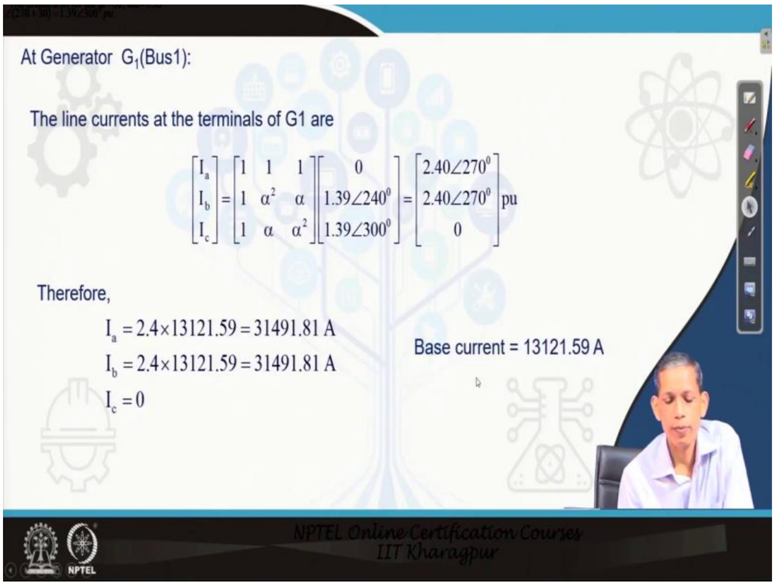

Thereby, we have got the corresponding sequence components: zero sequence, positive sequence and negative sequence; zero sequence component is not available because the delta side connections. So, substituting these values and multiplying the T matrix, we got the phase components I_a, I_b and I_c at generator terminal G_1,

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} 0 \\ 1.39\angle 240^0 \\ 1.39\angle 300^0 \end{bmatrix} = \begin{bmatrix} 2.40\angle 270^0 \\ 2.40\angle 270^0 \\ 0 \end{bmatrix} \text{pu}$$

that gives us a value of $2.40\angle 270^0$, $2.40\angle 270^0$ and 0, to the per unit value perspective. Now, you see here the fault was in the phase *a* only in the transmission line but because of the delta connections we get currents in phase *a* and phase *b*. Now, multiplying the base currents for this generator 1, we get the corresponding current in terms of amperes 31491.81 A in both phase *a* and *b*; whereas, I_c current being 0.

$$I_a = 2.4 \times 13121.59 = 31491.81 \text{ A}$$

$$I_b = 2.4 \times 13121.59 = 31491.81 \text{ A}$$

$$I_c = 0 \text{ A}$$

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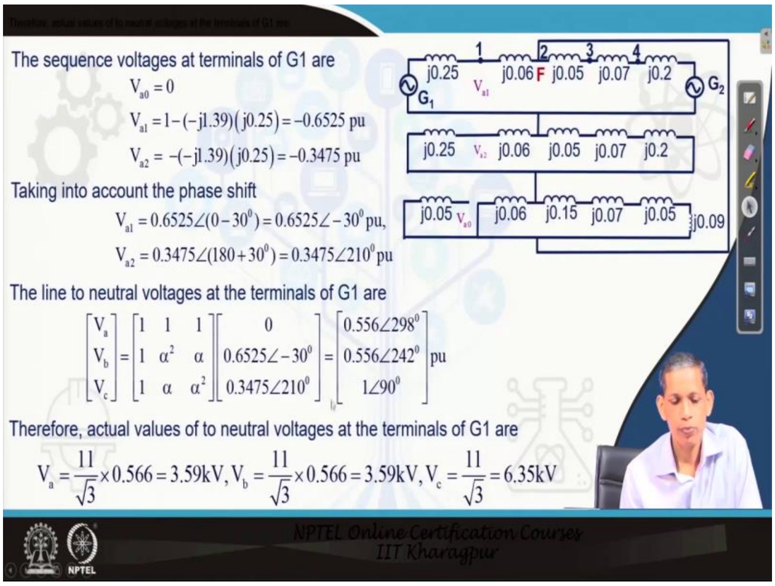

For the voltage calculation also similar to, what you did for the generator 2 also, we will do that for the positive sequence,

$$V_{a0} = 0 \text{ pu}$$

$$V_{a1} = 1 - (-j1.39)(j0.25) = 0.6525 \text{ pu}$$

$$V_{a2} = -(-j1.39)(j0.25) = -0.3475 \text{ pu}$$

Now, in addition to that, as I already mentioned, we are going from the high voltage the low voltage So, therefore, in the positive sequence diagram, we put, the minus 30^0 perspective and for the negative sequence, negative sequence value, we get the corresponding plus 30^0 perspective.

$$V_{a1} = 0.6525\angle(0^0 - 30^0) = 0.6525\angle -30^0 \text{ pu}$$

$$V_{a2} = 0.3475\angle(180^0 + 30^0) = 0.3475\angle 210^0 \text{ pu}$$

And considering those angles and all these things, we get the corresponding V_{a1} and V_{a2} in per units like this, and then we can say that to the phase components V_a V_b V_c multiplying the T matrix to the sequence components, we get the corresponding per unit voltages for this case.

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} 0 \\ 0.6525\angle -30^0 \\ 0.3475\angle 210^0 \end{bmatrix} = \begin{bmatrix} 0.556\angle 298^0 \\ 0.556\angle 242^0 \\ 1\angle 90^0 \end{bmatrix} \text{pu}$$

Finally multiplying the, base voltage of (11 /√3) kV, we got the *a, b, c* components for this system, and that we got 3.59 kV for the V_a, 3.59 kV for the V_b and 6.35 kV for the phase V_c voltages.

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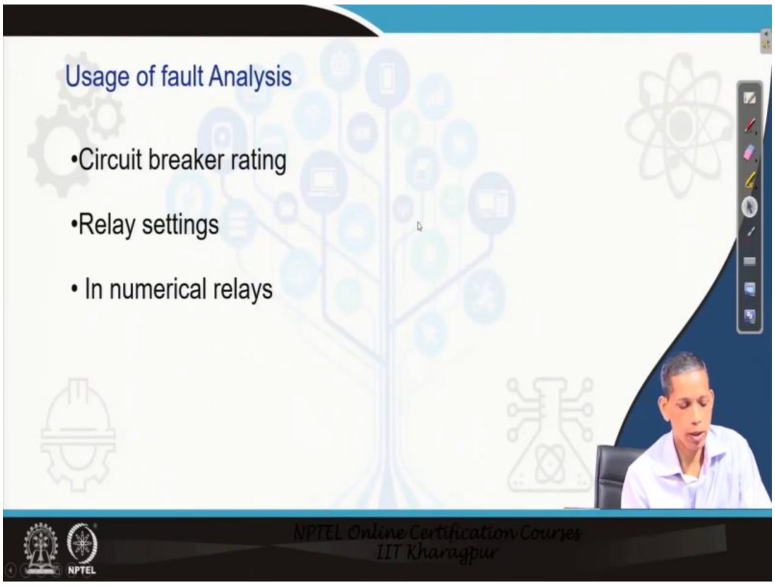

Now from this above analysis, we say that for a given fault in a system we can get the corresponding fault currents, fault voltages in different phases, and also at different nodes; you can get the different currents and voltages including that for the generator terminals and so, That gives a platform for a fault analysis and thereby, which will be beneficial to the relay and any protection system perspective and all these things.

So, we see, at any protection arrangement, any node or for any transmission line or any element like generator, transformer the circuit breakers that has to be fixed depends upon the associated current at that point and the corresponding voltages and so; therefore, this fault analysis being very much useful for circuit breaker rating specification and other details of the circuit breaker. Relay settings, how much minimum current, maximum current, we will see in details further classes about that becomes very useful tools for relay settings perspective. In addition to that, this analysis is very useful for numerical relays, how that is, we will see right now.

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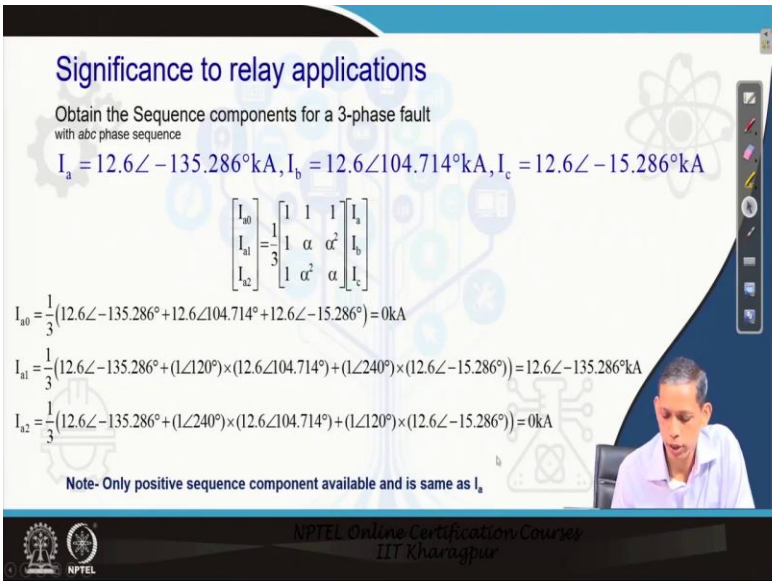

Let us analyze, this system for a case, see here this phase *a*, phase *b* and phase *c* values are given to us. So, obtain the sequence components for the 3 -ϕ fault. This is a 3-ϕ fault as I_a, I_b, I_c magnitudes are same and they are 120^0 apart. Now, it is concluded that if we calculate the sequence components using

$$\begin{bmatrix} I_{a1} \\ I_{b1} \\ I_{c1} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

Then the corresponding zero sequence component is 0, positive sequence component is same as the corresponding I_a as you have already seen earlier also and the negative sequence component is 0. So you see here which component remains for the balance fault case?

Only positive sequence component remains and that becomes same as phase *a* current, for this case.

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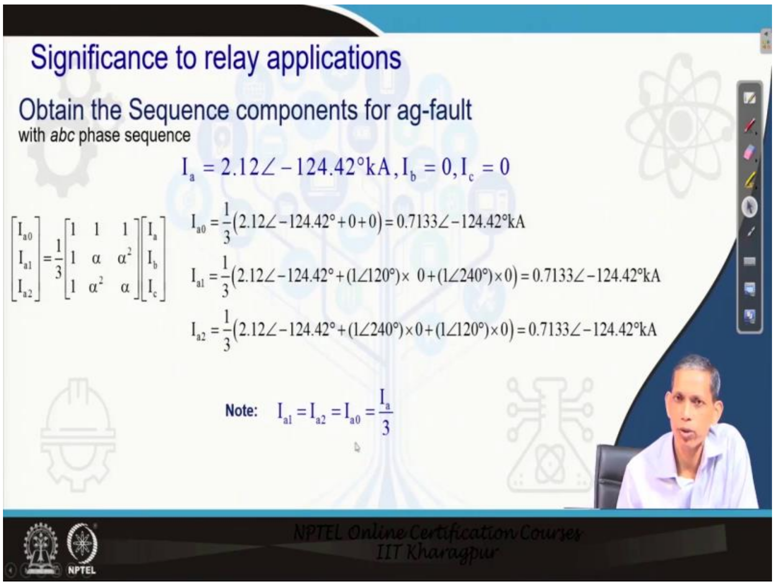

Now for the line to ground fault case; phase *a* only is involved with the fault, I_a is only there, I_b and I_c are 0 and by analyzing this what you get, I_{a0}, I_{b0}, I_{c0} all are having the same magnitude and angle. So, the relation for this is

$$I_{a1} = I_{a2} = I_{a0} = \frac{I_a}{3}$$

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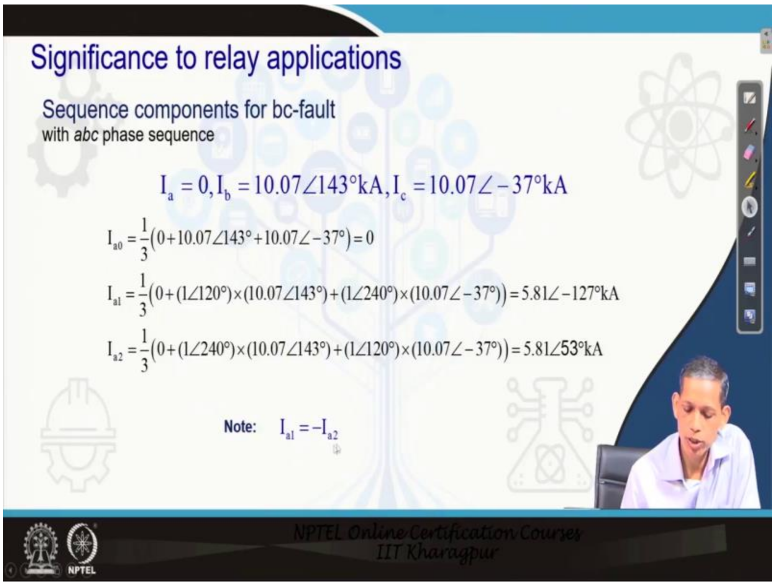

The other case, see here $I_b = 10.07\angle 143^0$ and, $I_c = 10.07\angle -37^0$ and if you analyze you can see that I_a current is no more, fault is involved with only phase *b* and *c*. So, we see here, in this case

$$I_{a1} = -I_{a2}$$

This is nothing but for the *bc* type of fault. For the *bc* type fault, we see there the corresponding sequence components has a relation like this.

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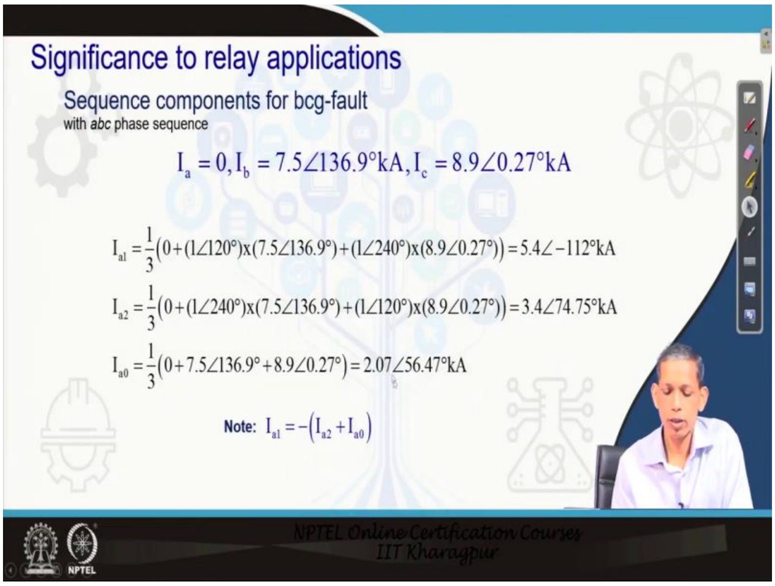

And, for the *bcg* fault if we like that, for this case *b* and *c* phases are involved with fault, *a* is not there and it is involved with the ground also. So, by analyzing this, I_{a1}, I_{a2}, I_{a0} we get I_{a0} is also available here because the ground is involved and finally, conclude that

$$I_{a1} = -(I_{a2} + I_{a0})$$

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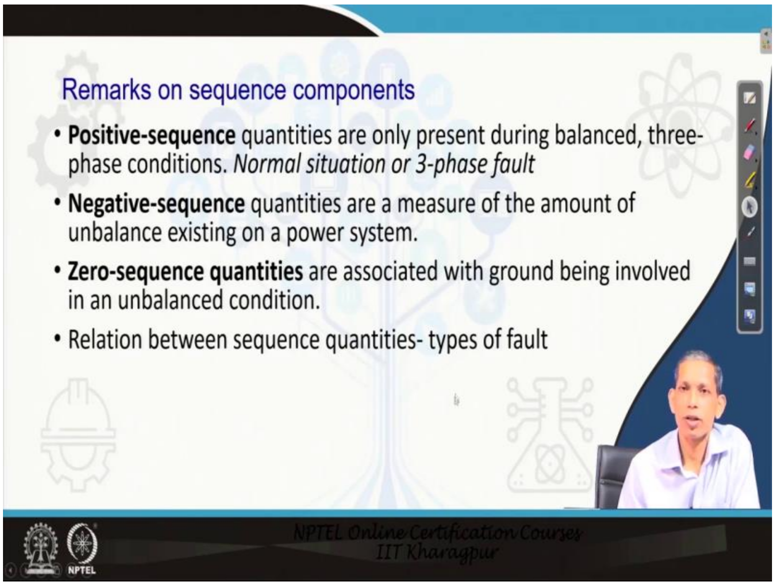

What we can say that conclude from this relations, that only the positive sequence quantities are present for the balance loading condition or balance fault condition, 3 phase fault conditions. Negative sequence quantities measure amount of unbalance in a system; that is available during any unbalanced condition or during any unbalance fault situation.

Zero sequence quantity is available whenever a ground is involved with the fault, and we can say that both zero sequence and negative sequence are available for any unbalanced fault involved with ground. These, relations what we see here is very much to identify the different types of fault, which is being used in different relay applications and so. Therefore, the sequence components also reveal information on the fault behavior at a given instant of time.

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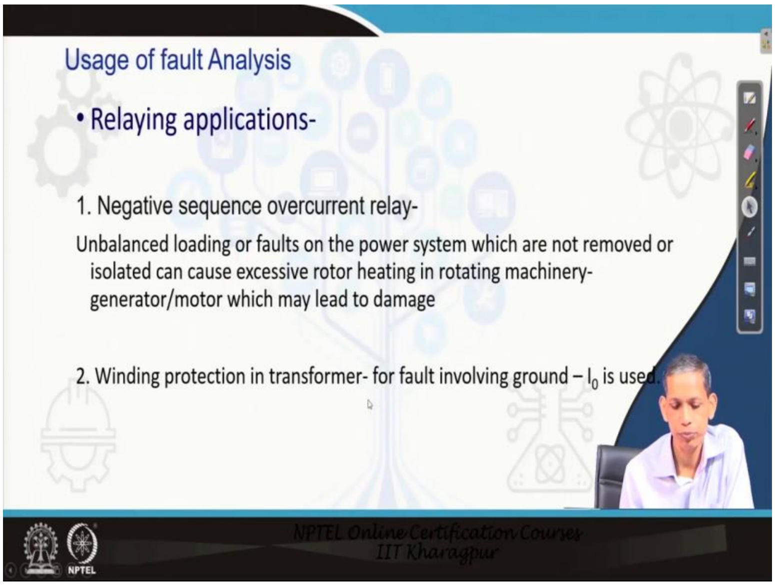

This fault analysis on the relay applications, how that is useful, let us have a look on this. Now, negative sequence over current relay is being useful for system unbalanced conditions, because any system unbalance conditions means from the generator side or from any rotating device. Negative sequence current means the corresponding rotor gets heated; therefore, in a long run perspective this becomes detrimental. So, relay in that case can use, negative sequence component and then it can trip the circuit for protection. For transformer protection the faults involving with ground means zero sequence component will be available and for many winding protection of the transformer zero sequence component is being use in terms of that.

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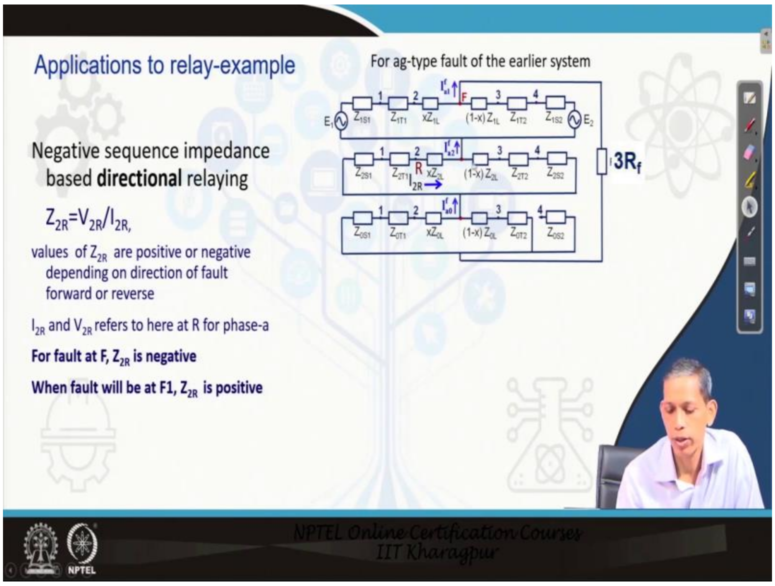

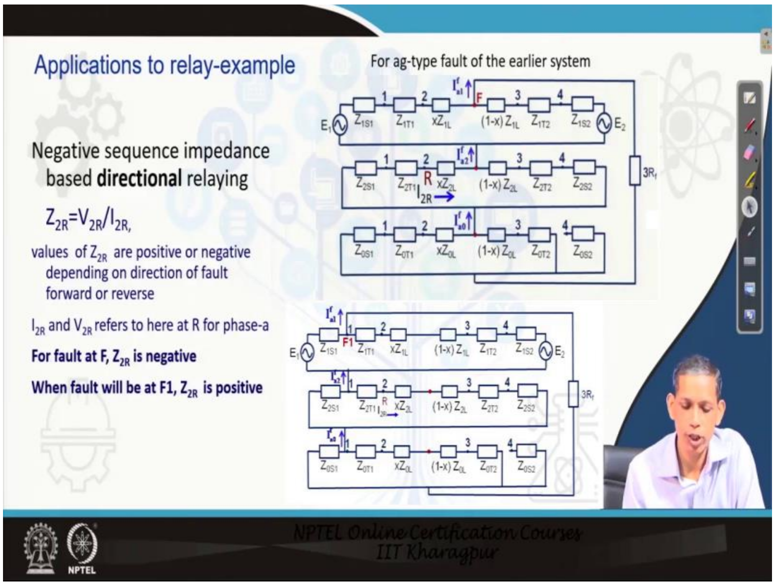

Now, let us, how for directional in purpose, negative sequence component is being very useful, see this sequence diagram which we have used earlier also. Let us see a line to ground fault case and then you can see that a fault happens to be there any of the point and then positive, negative, and zero sequence diagram also connected with the 3 times of the fault resistance perspective and we have connected like this. So see, when you talk about negative sequence diagram, let us say the relay position at bus 2 and a fault has occurred to the right hand side of the relay at this point.

Then we see there the corresponding current where, I_{2R} is flowing from bus 1 side to the bus 2. So the corresponding relations for this, the Z_{2R}, the impedance which will be seen by the relay will be

$$Z_{2R} = \frac{V_{2R}}{I_{2R}}$$

This V_{2R}, you can say being expressed in terms of

$$V_{2R} = -I_{2R}(Z_{2S1} + Z_{2T1})$$

Therefore, this at this point the Z_{2R} which will be observed by the relay at this point becomes negative. Now, in another case, when the fault happens to be the left of relay position this one, then the corresponding fault current will flows from this side to that side through the relay point. Considering, the positive direction of current for the relay to be I_{2R} in this case. Therefore, the impedance which will be noticed by the corresponding relay at that point, the Z_{2R} becomes positive.

So, negative sequence impedance based relay, which is being widely use, you can see that in network protection, distinguishes the fault in the forward direction and reverse direction by calculating the corresponding sequence impedance and negative sequence impedance Z_2 from the associated voltage and currents.

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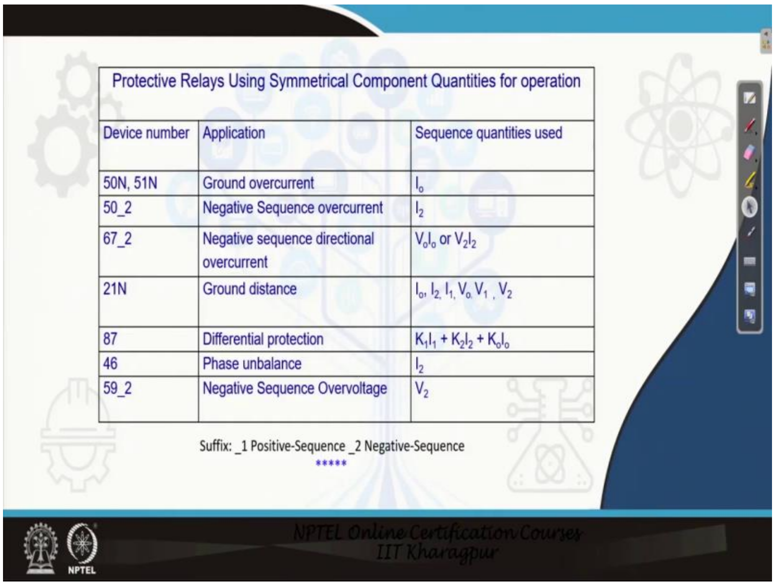

Protective Relays Using Symmetrical Component Quantities for operation

Device number	Application	Sequence quantities used
50N, 51N	Ground overcurrent	I_0
50_2	Negative Sequence overcurrent	I_2
67_2	Negative sequence directional overcurrent	V_0I_0 or V_2I_2
21N	Ground distance	$I_0, I_2, I_1, V_0, V_1, V_2$
87	Differential protection	$K_1I_1 + K_2I_2 + K_0I_0$
46	Phase unbalance	I_2
59_2	Negative Sequence Overvoltage	V_2

Suffix: _1 Positive-Sequence _2 Negative-Sequence

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So, this gives us an idea about that there are numerous scopes for the usage of sequence components in the numerical relaying perspective, at least we can say that a device number as we have already mentioned earlier also these are over current relays, instantaneous and time over current relay 50 and 51 involves with ground, so zero sequence current is being used, and 50_ 2, we consider this 2 refers for the negative sequence component, so negative sequence current is being used for the over current relaying principle.

67_2, this 2 refers to negative sequence directional overcurrent relay, either you can use zero sequence component or negative sequence component as we have already discussed in the earlier slide. 21 for the distance relay perspective; ground distance relay uses different sequence components for a successful decision making process. 87 for differential protections uses different sequence components for restraining purpose and negative sequence component is also useful for the decision process. 46 is phase unbalance and like that 59_2 is negative sequence over voltage and so. So, there are so many, relays provided by the manufacturers today using the sequence component for this perspective.

This is all from the lesson 4, how the sequence components are being useful in fault analysis, and thereafter how they can be used for the applications to different numerical relaying principle. In next class, we will have a general background how a numerical relaying platform is being prepared. Thank you.