Power System Protection
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Lecture 15
Positive Sequence Directional Relay

Welcome to NPTEL Power System Protection Course. We are on module 4 Directional Relaying. Today's lecture is on Positive Sequence based Directional Relaying.

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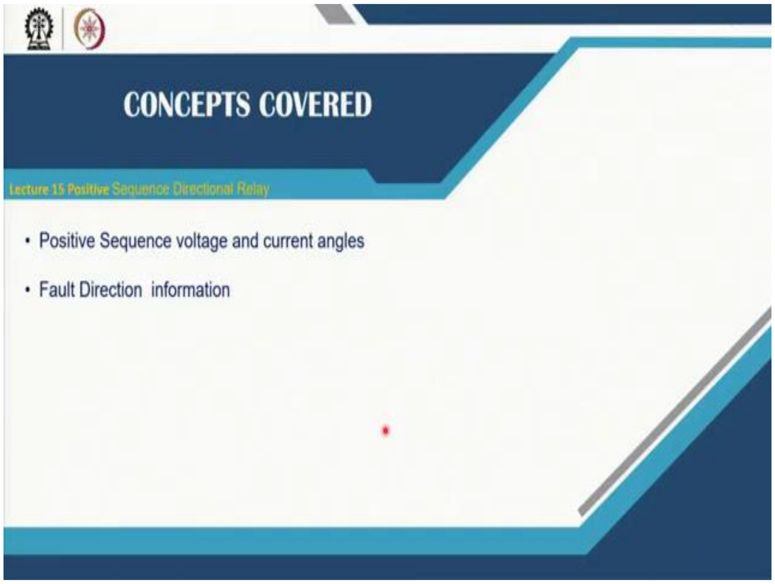

Here we will talk about how positive sequence voltage and current information is useful for obtaining the direction of fault.

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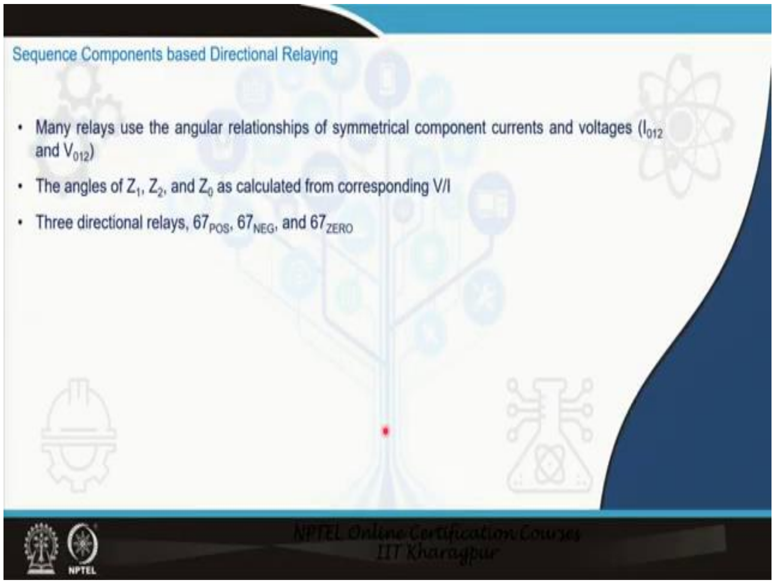

Last class we discussed about how sequence component can be also useful for obtaining the direction of fault. Modern relays use the angle information of voltage and current phasors to decide on direction of fault. Some relays use the impedance positive, sequence, negative sequence and zero sequence obtained from the corresponding voltage and current phasors.

So, we have three varieties of such relays positive sequence, negative sequence, and zero sequence relays based on sequence components. 67positive, 67 negative, 67 zero sequence are for the over current directional relays with the corresponding sequence components, we will go one by one.

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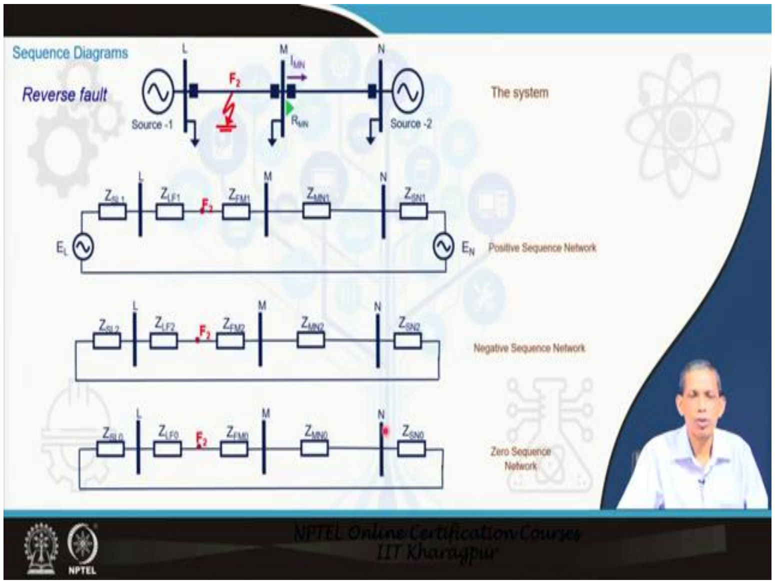

First we will go with positive sequence approach. But before going to that let us see the sequence diagram and from there we will derive the corresponding directional relaying principle. Same system, three bus system to understand the concept, so at bus N we have this relay and it is forward looking in this direction. The corresponding current through this relay will be I_{MN}.

Now a fault happens to be there in the system at F_2, for this relay there is a reverse fault. So, for this reverse fault, the different sequence component for this system, this is positive sequence network, negative sequence, sequence network and zero sequence network, this we have already learned in our basic on sequence diagram perspective. So, here if we see this is the fault point F_2 to the left of this M bus and the corresponding impedances of source, these lines section from F_2 and the other portion to be considered at ML line is Z_{FM1}.

And this is the line section MN. So, the corresponding positive sequence impedance is Z_{MN1} and this side source is Z_{S1} positive sequence impedance and then the corresponding voltage. Similarly, corresponding negative sequence impedances are here and source also has the zero sequence impedances in the zero sequence network. Note that these two negative and zero sequences are passive networks, they do not have any voltage source here, only the positive sequence network contains the sources.

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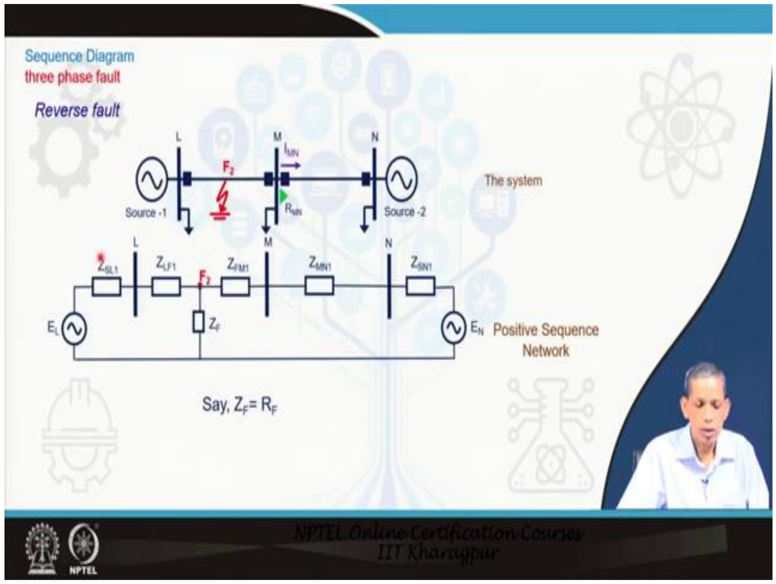

Now consider that the fault is three phase fault, the reverse fault for the relay R_{MN} then we say that it is only positive sequence component and associated with a fault resistance of R_F. So, we put Z_F in generics, so Z_F equal to R_F here. But the corresponding sequence network for fault F_2 reverse fault for three phase is the corresponding network becomes like this.

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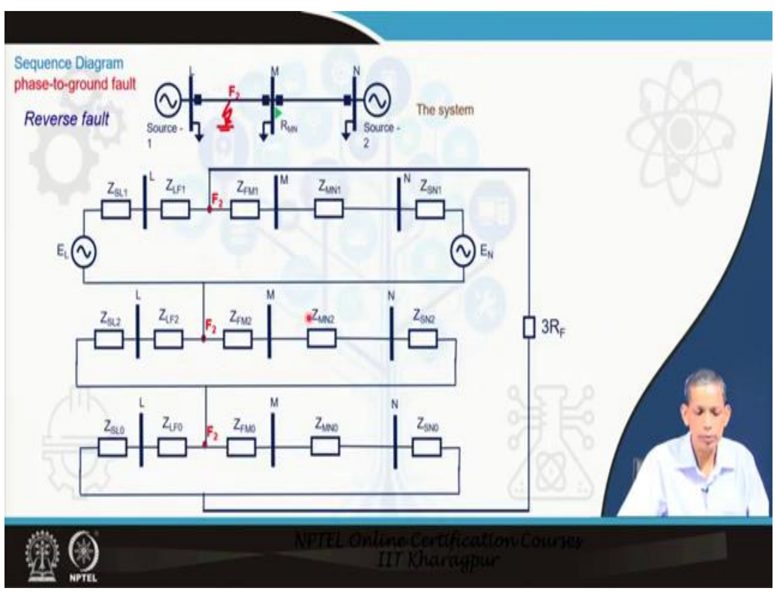

Now, when this corresponding fault happens to be phase to ground like AG fault, BG fault or CG fault, then in that case we know that the positive, negative and zero sequence networks will be connected in series with fault resistance being, $3R_F$ would be connected. So, what you see here that to this positive sequence component part where we have the voltage sources the negative sequence and zero sequence. These components are connected in series along with the $3R_F$.

Note that because the corresponding current will enter into this zero sequence or negative sequence will be divided into two paths. So, therefore when you find the equivalent for this negative sequence or zero sequence, we have two parallel paths. So, equivalent of these two parallel paths for negative and zero plus the $3R_F$ is nothing but the corresponding impedance added between this point and this point of the positive sequence network.

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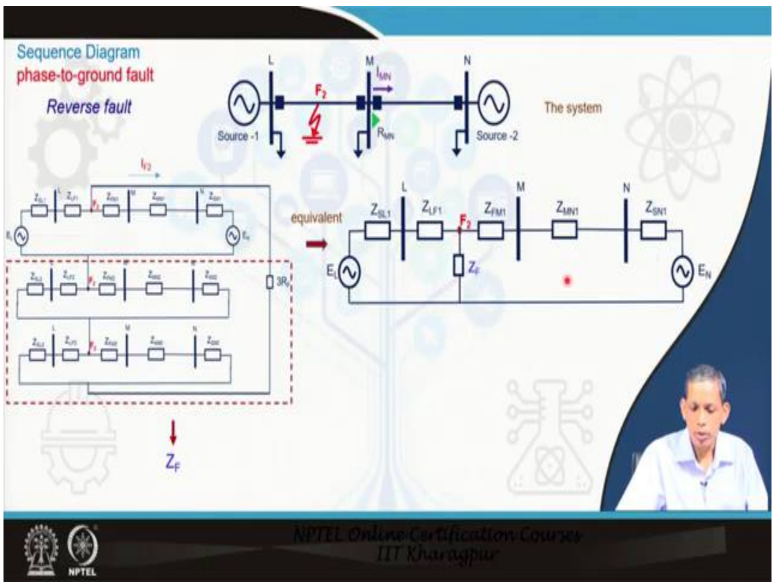

So, we say that if you take the equivalent of these passive portion as Z_F, then the corresponding equivalent of this network become like this. What you have seen for 3 phase network, this is phase two ground fault connection, series connection of positive, negative and zero with $3R_F$.

Now, this portion we can take an equivalent like parallel here, parallel here, combination of these two in series plus $3R_F$ is nothing but this Z_F, equivalent Z_F. So, we put this between these two points. Then this becomes Z_F and rest is nothing but the positive sequence network. Similar network we got in case of the three phase fault also.

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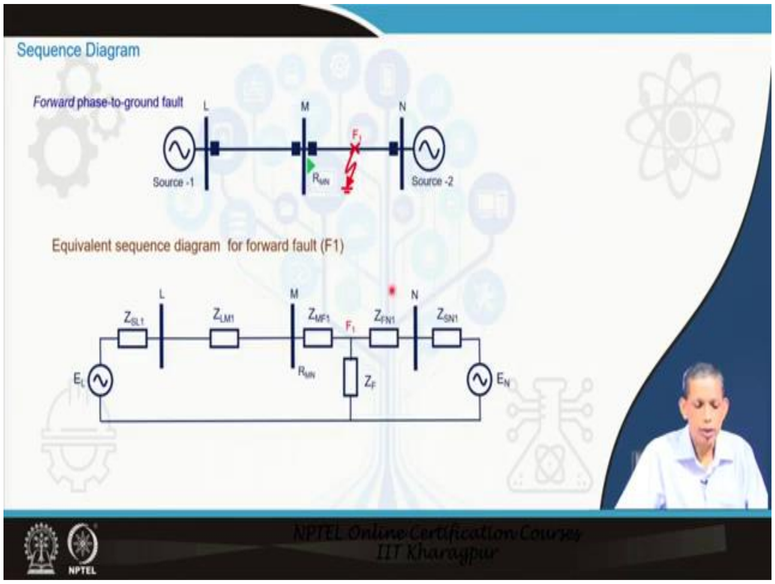

So, thus we can say that for phase to ground fault in the forward direction if we do. Now, F_1 fault becomes here. In a similar way we can put the positive, negative and zero sequence network with $3R_F$ in series and then we can get the corresponding equivalent network positive sequence network and equivalent Z_F combination of negative, zero and $3R_F$ series connection will be the equivalent Z_F and the network connections will be like this.

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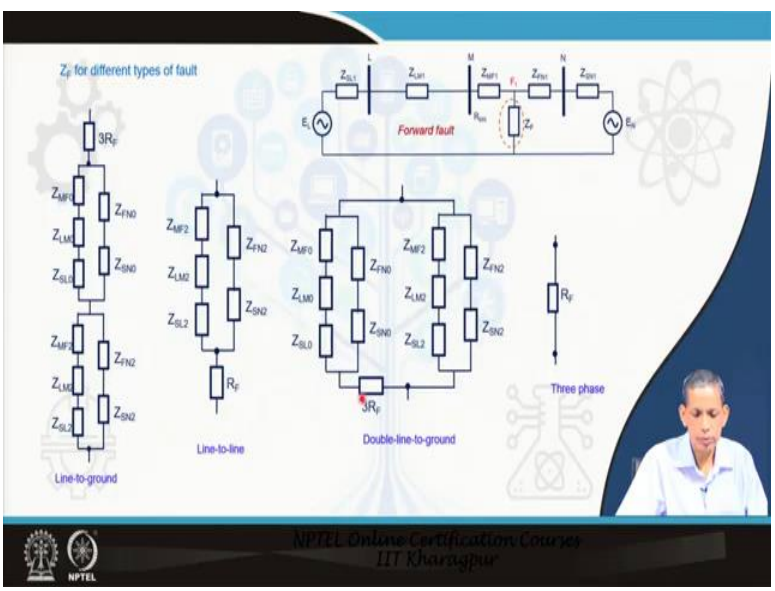

So, in general, we saw that for the 3 phase fault or for the line to ground fault the equivalent network of the 3 bus system becomes like this where you put a Z_F for the passive portion. At the fault point and the rest is the positive sequence network. In case of line to ground fault as we have already discussed that the $3R_F$ will be series with the parallel equivalent of the zero sequence and the parallel equivalent of the negative sequence. These we can say that constitute the Z_F this part. Similarly, for 3 phase fault this R_F constitute the corresponding Z_F. Now, for other faults phase to phase fault and the double phase to ground fault the corresponding sequence network for the corresponding Z_F equivalent becomes like this and this.

So, this is obtained from the positive and negative and the corresponding negative and zero sequence component of this equivalent system. In case of line to line fault, we do not have any zero sequence components, in case of double line to ground fault we have zero sequence component also. So, that leads to conclusion that for all types of fault, the system sequence diagram can be consider as an equivalent like this with positive sequence diagram. And at the fault point we can have a parallel path of Z_F where Z_F consists of these you can say that elements depending upon the type of fault.

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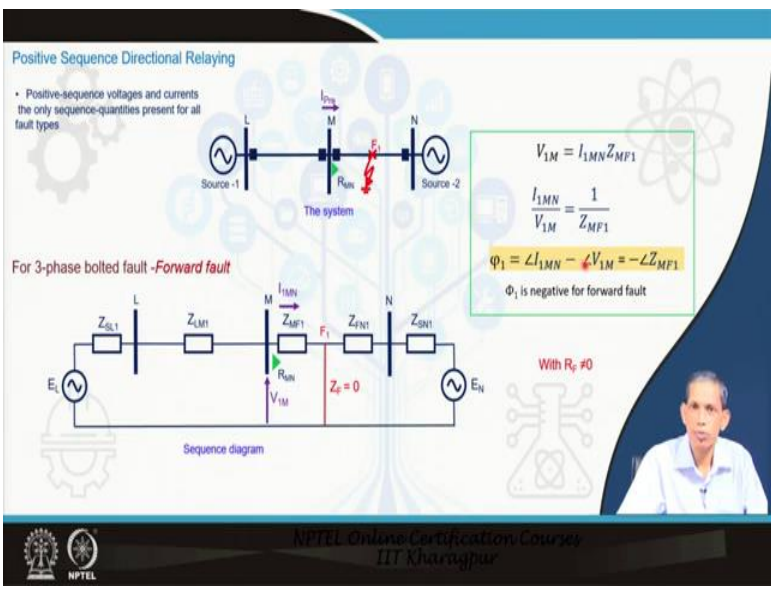

Now we will come to positive sequence equivalent diagram how we can exploit the directional relaying we will see. Note that before going to the principle the positive sequence components are available for all types of fault that it is strength. So, let us consider a fault in the forward direction F_1 then the solid fault.

So, then the corresponding this is a three phase bolted fault, then the positive sequence diagram and the corresponding Z_F, the Z_F becomes equals to zero here, because this is a bolted fault and this F_1 is the forward fault in this case. Now see here if you write the equation for this equivalent system for this three phase fault case then we see that the relay voltage at here will be V_{1M}, 1 for the positive sequence, M for the M bus relay. V_{1M} equals to this is F_1 point is having zero voltage because bolted fault.

Therefore the corresponding voltage in this portion is

$$V_{1M} = I_{1MN} Z_{MF1}$$

Z_{MF1} is the corresponding impedance of this portion and the I_{1MN}, the positive sequence currents to this path is I_{1MN} and that is what the relay current also. Therefore this voltage is zero. So, to calculate this voltage so we are going against the current. So, therefore relation between V_{1M} is and I_{1MN} can be written as

$$\frac{I_{1MN}}{V_{1M}} = \frac{1}{Z_{MF1}}$$

So defining ϕ_1 for the positive sequence, the angle between the corresponding current I_{1M} and that which is flowing through the relay minus the angle of this relay voltage that equals to

$$\emptyset_1 = \angle I_{1MN} - \angle V_{1M} = -\angle Z_{MF1}$$

Where Z_{MF1} is the impedance of this portion from fault to the relay. So, that is what nothing but the impedance of the line. So, we say that the impedance of the line being positive, if you see that for this forward fault which we are considering the ϕ_1 will come to be a negative value. It means that for forward fault because this is the equivalent for all types of fault, for forward fault we can say that the ϕ_1, which is nothing but the angle of positive sequence current seen by the relay minus the angle of the positive sequence voltage seen by the relay R_{MN} will be equals to a negative value because this is a forward fault. This is the conclusion we see from here.

Now, one point here in practical R_F may not be zero, but different faults, for line to ground fault it may be higher value. So, in that case, what we say that if R_F becomes higher, if this becomes the fault path current. So, this path becomes more and more resistive with higher and higher R_F. That means that the corresponding angle which will talk about angle of this will go on decreasing. But typically here, if we see the corresponding impedance angle will be 80^0 and so for the over head transmission line and so maybe more also.

Therefore, even you can say that with R_F value the corresponding angle decreases. But still we see that the corresponding ϕ_1 will be negative in general. That is what we say that. So, in general we can say that for a forward fault the ϕ_1, which is the angle between the corresponding positive sequence current and the positive sequence voltage will be negative.

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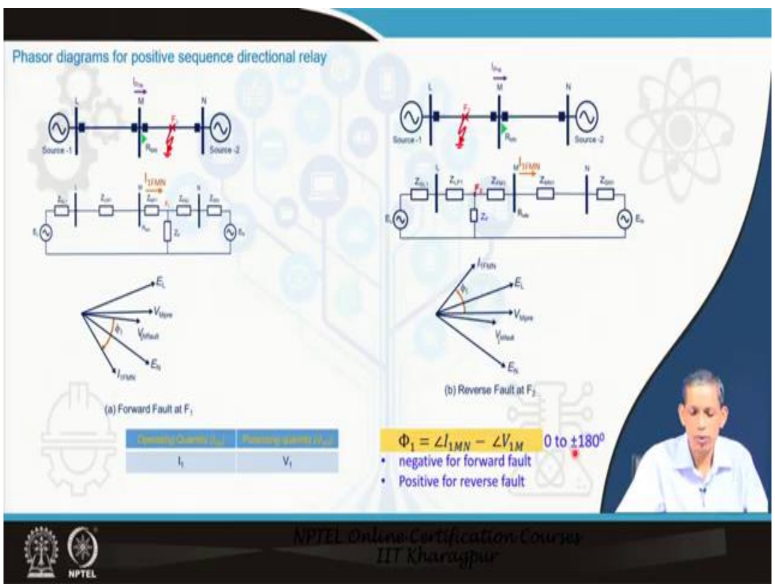

Now, let us come to in terms of phasor diagram how we can interpret this. So, let us this is our same 3 bus system. Forward fault, we got the equivalent diagram to be like this. So, we have L bus voltage E_L, current is flowing from left to right, N bus voltage E_N and in between we have M bus voltage let us say V_M before the fault V_{Mpre}. Now what happens if fault happens to be there, equivalent network becomes like this.

So, now the corresponding V_{fault} or at that bus decreases. So, this is decrement. Now we compute from this V_A, V_B, V_C the corresponding $V_{M1fault}$, positive sequence fault voltage. Note that when we are computing the $V_{M1fault}$. So, V_A, V_B, V_C will be available and we orient V_B , V_c towards A phase that is $1+ \alpha V_B + \alpha^2 V_C$ one third of that. So, that results in your positive sequence voltage.

So at that time the corresponding voltage will be to the pre voltage, it will close to that and somewhat lower depending upon the deep in the voltage. So, this leads to this corresponding situation like this. Note that the corresponding fault current will lag the corresponding V_{Mpre} or V_{Mfault}. Therefore, it is lagging and this is you can say that the corresponding current and this current whatever type consider from this perspective V_C that this current will lagging in this path. So, therefore we see that the current I_{1FMN} lags the $V_{MNfault}$.

This show that the ϕ_1 the angle of I_1 minus the angle of V_1 for the relay becomes negative because current is lagging the voltage corresponding current is lagging the voltage. Now come to the reverse fault. This was reversed fault F_2 for this situation the corresponding equivalent diagram based on the positive sequence network will be like this with the Z_F corresponding thing.

It depends upon the type of fault and the R_F here in this case, again, E_L, E_N and V_M the pre fault voltage. So, now the corresponding $V_{M1fault}$ somewhat lower so obtain from V_A, V_B, V_C at the current at this relay is fair we can say from the E_N source and there is a reversal of current. So this current will be reversed that we have already seen in case of the phase quantity based directional relaying. So, current will be reversed. So, current will upward. That means that these I_{1FMN} leads the corresponding $V_{1Mfault}$ and therefore, we can say that the corresponding ϕ_1 will be positive in case in case of here that is angle of I_1 minus angle of V_1. So, we say that as compared to this, this is a lagging current, this is a leading current. So, ϕ_1 will be positive in this case.

So, we conclude from this that for forward fault ϕ_1 computed in this manner will be negative and for reverse fault the ϕ_1 computed in this way will be positive. Note that based on these phasor diagrams, these angle ϕ_1 is limited to 0 to $\pm 180^0$. That has to be seen in case of the calculation.

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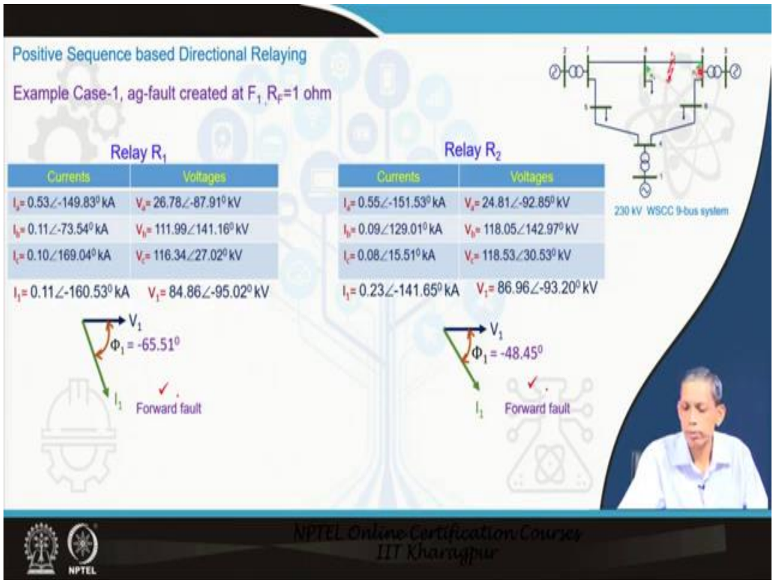

So, this we say that positive sequence based directional relay can be obtained from the angle ϕ_1, which is equal to angle of I_1 minus angle of V_1 at the relay bus. So, let us see an example for the 9 bus systems, which we have already discuss in case of phase quantity based directional relaying. So, the relay R_1 and R_2 are therefore at bus 8 and bus 9 for the line section 8 and 9, voltage at F_1, for relay R_1 this is the forward fault point.

For relay R_2 also this is the forward fault. Now let us see from the data. So, this case is for the phasor to ground fault, *ag*-fault created at this point with a fault resistance of R_F equals to 1 Ω. So, what the relay finds currents I_a, I_b, I_c. I_a 8.53, I_b 0.11, I_c 0.10. It means these are pre fault currents and this is the fault current.

So, there is a load here that is why these currents are in other phases, see the voltages now. V_a voltage, now 26.78 V_b and V_c are much higher than the these are the close to the rated voltage. This is substantially low. It means that the fault is in phase *a*. Based on this I_a, I_b, I_c, I_1 and using V_a, V_b , V_c, V_1 computed. So, we got the corresponding angle here.

Now, what we need you can say that now that angle of I_1 minus angle of V_1 will be the corresponding ϕ_1 angle. So, angle of I_1 is -160.5^0. And angle of V_1 is - 95^0. So, angle of I_1 minus angle of V_1. So, - 160.5^0 + 95^0, so that gives us - 65.51^0. So, this is the angle ϕ1. These angle is negative implies the fault is in the forward direction. So, therefore from this computation as seen by the relay R_1 here, then the corresponding ϕ_1, angle indicates that default in forward direction, which is correct. Now let us see what the relay R_2 sees. There are two kinds of measurements I_a, I_b, I_c like this. We compute I_1 using these three. Similarly, from V_a, V_c compute one and then we got the I_1 to V_1 an angle of - 141.65^0 and V_1 - 93.2^0. So, angle of I_1 - 141.65^0 minus this angle means 93.20^0. That gives us minus 48.45^0.

So, this also says that the angle is negative implies the fault is in forward direction as seen by the relay R_2. So, R_2 also see the fault in forward and this is correct as per our logic, we can say that in the last slide. So, the conclusion for these two relays from the sets of measurements either the fault is in forward for both relays. So we can conclude that it is inside the line 8 and 9.

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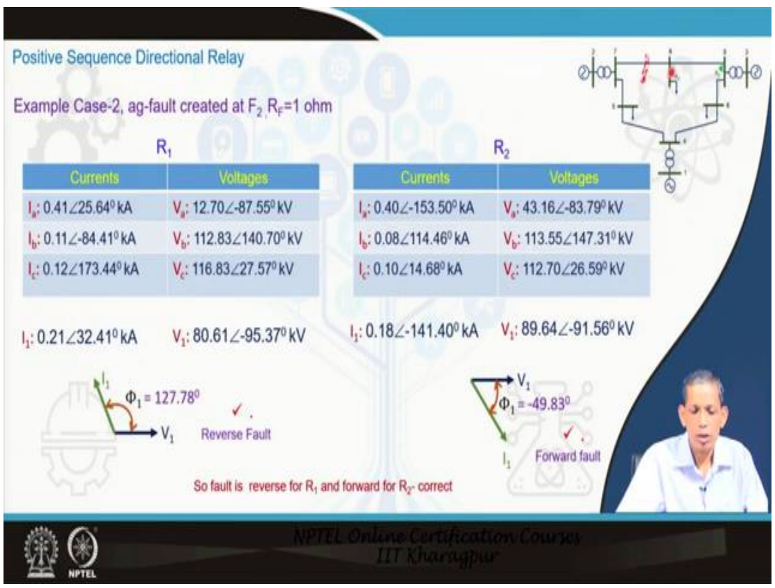

Now will go to another case. Fault is beyond line 8, 9 it is so R_2 will see still it is in forward direction. But R_1 will see in a reverse direction. Now let us see how they evaluate the corresponding fault situation. So, for R_1 the corresponding currents set is like this and the corresponding voltage sets available here. We see V_a phase voltage is substantially low. Now, if you compute the corresponding I_1, this becomes having a magnitude of 0.21 and angle of 32.41^0, a positive angle.

Now V_1 80.61 with a negative angle of 95.37^0, so angle of I_1 minus angle of V_1; 32.41^0 plus 95.37^0 gives you 127.78^0. Positive angle, positive angle of I_1 means reverse fault that we have seen because this is less than 180^0. Now coming to the R_2 relay for the same case set of currents and we have set up voltages computed the I_1, the I_1 has an angle of -141.4^0 and the corresponding positive sequence voltage angle of $- 91.96^0$. So angle of I_1 $-141.4^0 + 91.56^0$ gives you $- 49.83^0$, minus angle means this a forward fault case. So, for R_2 this is a forward fault case this is also correct. So, we conclude that the R_1 and R_2 correctly identified the fault, R_1 finds reverse fault and R_2 finds it as forward fault.

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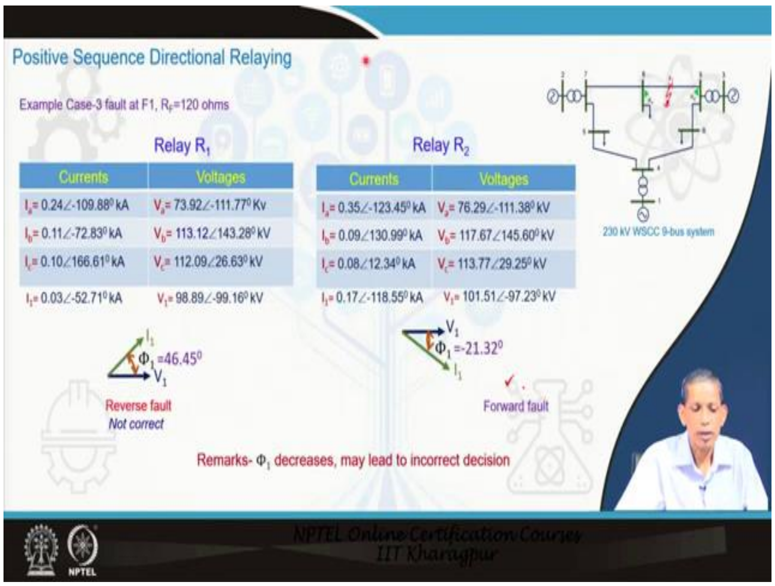

Now we have another case on this evolution of the directional relay using positive sequence components. So, we increase the corresponding R_F below to be higher, and we already mentioned when R_F below becomes higher the corresponding path in the positive sequence diagram, we see that becomes more resistive. So, that is why the angle is expected to go down that from the angle of the impedance angle of the line.

So, let us see for this F_1 fault, which is forward to both R_1 and R_2 how the corresponding relaying principal perform. Current sets are set is available here, corresponding positive sequence current with $- 52.71^0$ corresponding voltage V_a, V_b, V_c, V1 and it is $– 99,16^0$ this. So, we see that -52.71^0 plus 99.16^0 gives you 46.45^0 so the angle is positive angle. Positive angle means reverse fault, but this is not correct. R_1 sees here forward fault, so this reverse fault because ϕ_1 is positive is incorrect, erroneous.

The reason for this, now we have only increased the fault resistance and that is the reason we can say it is coming out with positive value and then there is pre fault currents and in the system. Now relay R_2. We have a set of currents, set of voltages, positive sequence current and positive sequence voltage computed as

$$(-188.55^0 + - 97.23^0) = - 21.32^0.$$

This is positive means forward. So, relay R_2 sees the fault in forward direction relay. Note that as compared to the earlier case the corresponding angle for R_2 also has come down and this is due to only because of this R_F. So, this means that the ϕ_1 is affected by these R_F we have already mentioned and we found that substantially high value of R_F may lead incorrect basis on that is what the conclusion from this observation table.

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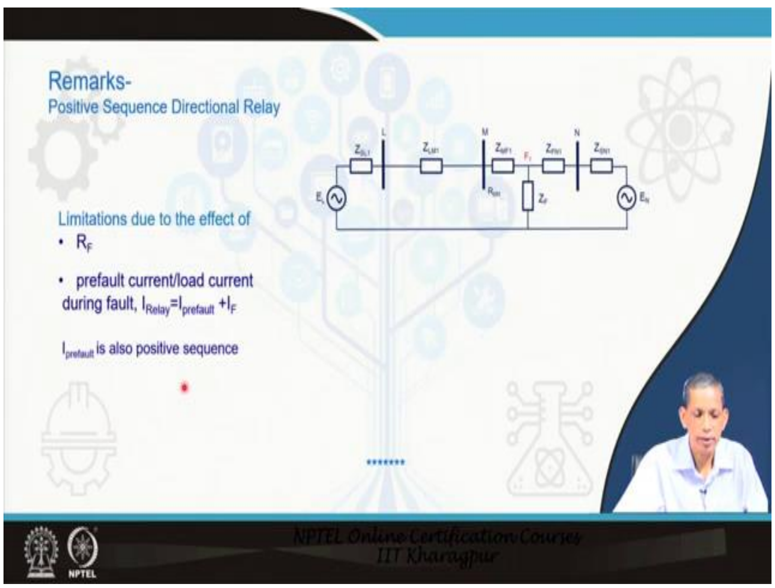

So, we see that positive sequence based directional relaying can be obtain and this is based on these kind of equivalence sequence diagram, positive sequence diagram. But we observe that due to the, when the R_F value become significant, then the corresponding decision why the relay may be affected. This happens particularly for the land to ground fault involving grounds. Furthermore, because the fault current, which will be going through this Z_F path.

In addition to that there is pre fault current in the systems, the current which will be observe by the relay is a combination of the pre fault current or the load component of current plus the fault component. So, therefore the corresponding current is seen by the relay during fault is being modulated by the load component of current. So, when this load component of current becomes significant as compared to the fault component, then also the modulation to the current phasor and the corresponding angle may be significant and sometimes that also may affect significantly. So, that is the relay, $I_{relay} = I_{prefault} + I_{fault}$ and if the pre fault becomes significant, that may also affect the directional relaying performance using the positive sequence component. Thank you.