Power System Protection
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Lecture 17
Superimposed Component Based Directional Relaying

Welcome to a NPTEL course on Power System Protection. We are on module four on Directional Relaying, Lecture 17 on Superimposed Component based Directional Relaying principle.

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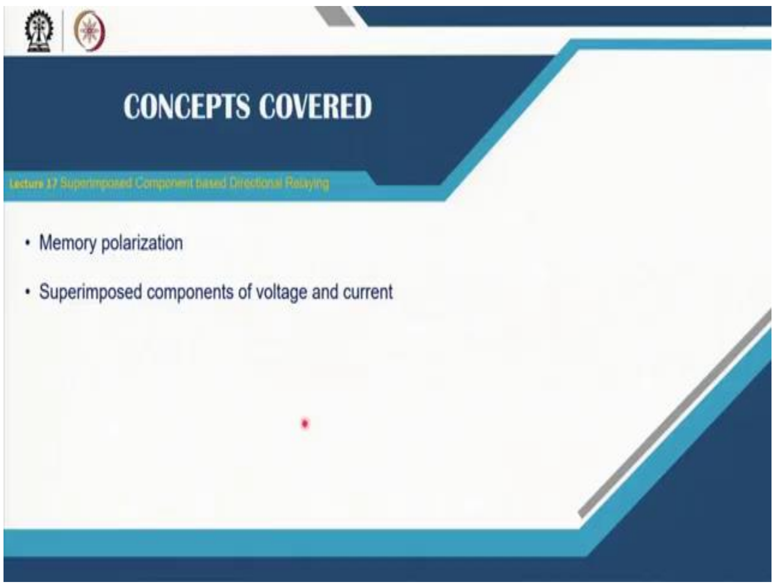

Here we will see a how we can exploit the memory polarisation aspect and then we will come to superimposed component voltage and current. How they can be useful for Directional relaying principle.

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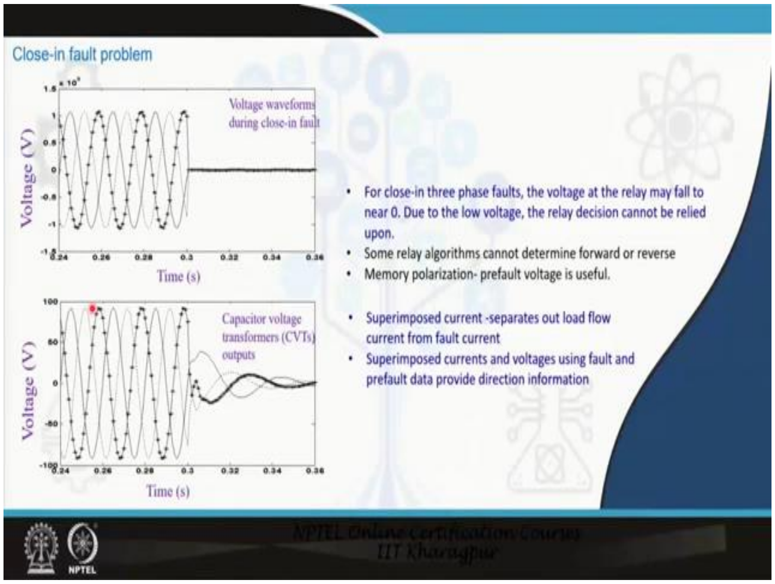

Moving further let us first appreciate an issue. Now suppose, in a system we have already explained that a fault happens to be closed to the relay bus, in that case all the voltages V_a, V_b, V_c will collapse if the fault happens to be a voltage three phase fault. Once again if the fault is close to the relay bus and happens to be a voltage three phase type then all the voltages will collapse simultaneously.

In that case neither positive sequence nor negative sequence nor zero sequence components will be available, nor the phase quantities also available. That means that like you can see here the voltages arise normal, fault happens to be there, all the three voltages collapses. This is a simulated data.

However, if the corresponding system in high voltage level then as usual there will be capacitor voltage transformers and the output of the capacitor voltage transformer for this step jump in voltage will be going through a subsequent transient and their response will be like this. Note that this voltage, represent this voltage, so this is also erroneous. So with this kind of input the relay if it goes for the decisions then that will be erroneous.

So all the techniques which we have till now narrated they are clueless, what to do? So what we say that for close in faults such issues are there. So in this case you can say that the solution is that the less would use memory polarized the stored prefault data, prefault voltage to substitute the corresponding fault voltage there.

In that case that becomes good at, like we know that the fault voltage phasor does not deviate more in terms of angular position with respect to prefault voltage. So considering that assumption, if we use the prefault voltage instead of the fault voltage in that situation in such situations, then the relay can properly decide the directional relaying.

Because in directional relaying we saw that we have very large angle margin and in that case the prefault voltage can be a good substitute and in numerical relaying we have that scope because the relay continuously store data and in case of an event which is to be recorded, the relay stores the data permanently. Therefore, prefault voltage can be employed in such situation for correct relaying decision that is what we talk about memory polarization and so. In addition to that because we are able to do, handle prefault voltages and currents in a numerical platform.

The superimposed current called, which you can see that separates the load flow current or load current from the fault current because we see that in case of positive sequence perspective prefault current was affecting the performance of the relay. So if we can subtract the prefault current from the fault component current then that is called superimposed current. So that has other advantage. Superimposed current and voltages can provide directional information that we will see.

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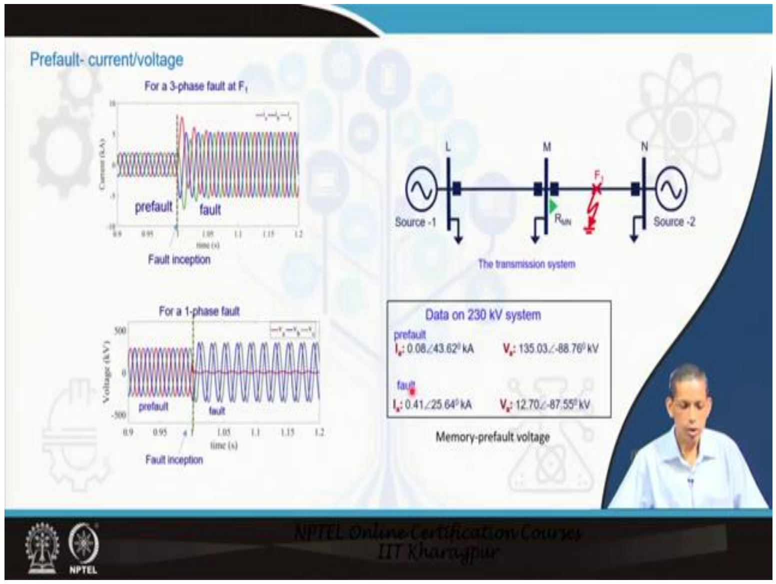

So before going to that perspective let us first have clarity on the prefault, fault and so. This is the same system three bus system fault for this relay R_{MN} forward fault. A three phase fault so a normal current, three phase fault, all the three phases current increase. This is the fault inception. So from the fault inception once again in this case similarity data this is prefault this is fault. So we designed it like this. Before the fault is the prefault data and this is during the fault, so this is fault data. Now note that in the sequence component diagrams also we discussed also that if a fault happens to be there and the fault is associated with R_F and so, so that the fault current flows like this. In addition to that current also will flow from left to right that the load current perspective.

So the point is that the relay shifts the current during fault that is combination of both fault current, fault component of current and the load component of current. Now in case of voltage also let us this is a single line to ground fault case and you see that one of the phase, phases having a substantial low voltage other phases remain some more higher voltage then the normal voltage depending upon the system grounding and so. So for this case fault inception one at one second this is the prefault voltage data, this is the fault during fault the corresponding of voltage data. So in case of superposition both fault and prefault are being used. In case of memory polarizations voltage you can say that prefault data substitute the corresponding fault can say that during fault you can say that the corresponding data perspective.

Now let us for a system, 230 kV system prefault current at one instant is 0.08 like this and the corresponding voltage is 135.0 and this. During fault the corresponding current is $0.41\angle 25.64^0$, and V_a is $12.7\angle 87^0$ this. The substantial lower voltage. So now this is the prefault dataset for that phase and this is the fault dataset for this case. So, we can this voltage substantial low means this voltage can substitute. This voltage can be substituted by this one. You see here the angle deviation between prefault voltage to fault is pretty low and that is what we are mentioning that if you substitute with this in case of requirement then the decision some directional relaying can be still be good at.

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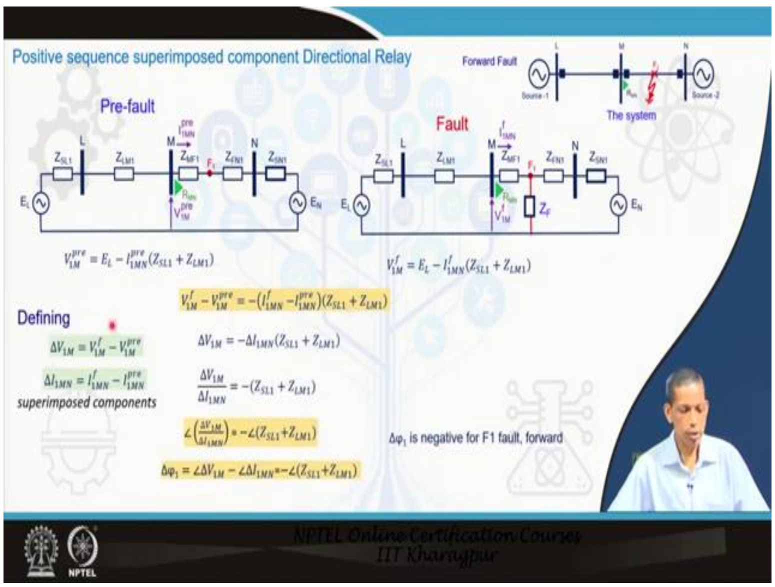

Now we will go to how the superimposed component can be advantageous for directional principle. So we will use positive sequence superimposed component. As already mentioned superimpose component, superimpose current is that the fault current minus the prefault current that gives us you can say that the corresponding superimpose component. Let us consider this system.

So we have faulted F_1 for this relay forward fault, so this is prefault sequence diagram balanced condition positive sequence diagram only. This is the relay bus. Prefault current to the observer the relay, V_1 and pre prefault voltage as relay positive sequence. I_1 and pre positive sequence current. Now fault happens to be now at F_1, forward fault. So equivalent positive sequence diagram with Z_F becomes like this. This we have already discussed in earlier lecture.

So, Z_F consist of the negative sequence and zero sequence if they are present and the corresponding $3R_F$. The series parallel combination of that gives you the equivalent Z_F. During fault we have this V_{1MN} and the corresponding I_{1MNF} the corresponding relay current with the fault component. So we can write down for this circuit

$$V_{1M}^{pre} = E_L - I_{1MN}^{pre}(Z_{sL1} + Z_{LM1})$$

Z_{SL1} plus Z_{LM1} is the impedance source impedance plus line impedance behind the relay. During fault

$$V_{1M}^{f} = E_L - I_{1MN}^{f}(Z_{sL1} + Z_{LM1})$$

So these are the two equations for this diagram one is for prefault for this system and this is for fault. If you subtract this V_{1M}^{pre} from V_{1M}^{f},. Then this side, this equation minus this equation that leads to

$$V_{1M}^{f} - V_{1M}^{pre} = -(I_{1MN}^{f} - I_{1MN}^{pre})(Z_{sL1} + Z_{LM1})$$

So then we get that suppose we define this corresponding this voltage difference to be a ΔV_{1M} positive sequence, change in positive sequence voltage and this current change in current in the positive sequence current seen by the relay that we called the superimposed components. So this ΔV_{1M} and ΔI_{1MN} positive sequence voltage and positive sequence current change define as the superimposed components.

$$\Delta V_{1M} = V_{1M}^{f} - V_{1M}^{pre}$$

$$\Delta I_{1M} = I_{1MN}^{f} - I_{1MN}^{pre}$$

With ΔV_{1M} ands ΔI_{1M} above relation can be expressed as

$$\Delta V_{1M} = -\Delta I_{1M}(Z_{sL1} + Z_{LM1})$$

$$\Delta\varphi_1 = \angle\frac{\Delta V_{1M}}{\Delta I_{1M}} = -\angle(Z_{sL1} + Z_{LM1})$$

This angle difference $\Delta\phi_1$ equals to the angle of this negation of the angle of the impedance behind the relay. So this impedance is always around 80^0 or about that. So, therefore this is negative. So that means that the corresponding $\Delta\phi_1$ is negative for forward fault for designing forward direction.

So similar to the earlier sequence component based we have seen that in case of positive sequence superimposed component ΔV_{1M} and ΔI_{1M} the angle difference gives us similar logic for the directional relaying using superimposed component. $\Delta\phi_1$ is negative for forward fault. Now another thing you see here only difference is that we are not taking current angle minus voltage angle, we are taking now voltage angle minus current angle that is the only difference.

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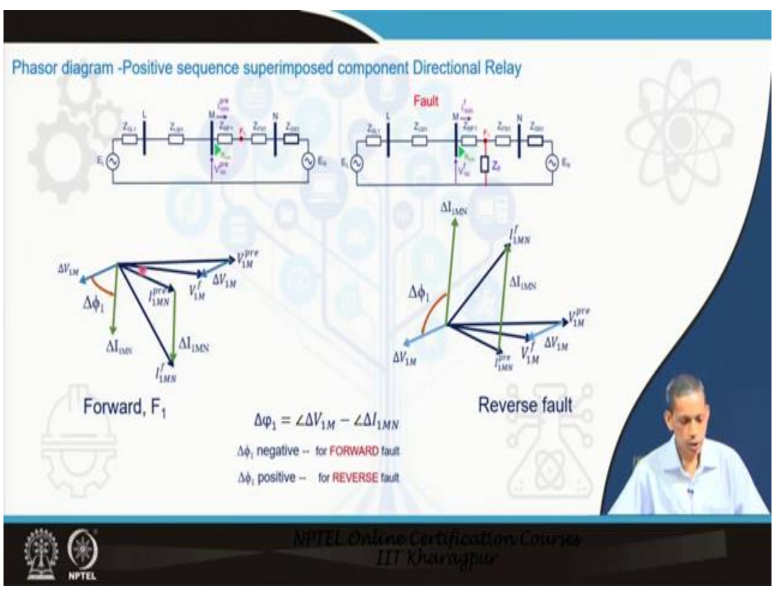

Now going to the phasor diagrams like we did for the sequence component also so we have prefault and we have fault sequence diagram, positive sequence diagram. Now let us first go for the forward fault like what we have seen here. So, we have V_{1M}^{pre}, we have V_{1M}^{F} so this is ΔV_{1M}. We have current lagging to this voltage I_{1M}, I_{1M} we have I_{1pre} so this is ΔI_1. So, this ΔI_1 we plot here at the origin and this ΔV_1 we plot here at the origin.

So, we see that ΔI_1 is leading to this ΔV_1. So our logic here is angle ΔV_1, ΔV_1 of ΔV_1 minus angle of ΔI_6 so this becomes a negative. So, we say that the $\Delta\phi_1$ is negative for this forward fault. Now come to the reverse fault. So, current direction changes now we see here same V_{1M}^{pre}, V_{1M}^{F} ΔV_1, now we see here I_{1MN}^{pre}, I_{1MN}^{f} reverse fault, so current is reverse as compared to this.

So this is ΔI_1, this is ΔV_1, we plotted at the origin ΔV_1 and ΔI_1. We see here now the current is lagging. But we are taking the delta Phi 1 angle of delta V1 minus angle of I1, so again same conclusion $\Delta\phi_1$ is positive for reverse fault. So this is what we say for forward fault $\Delta\phi_1$ is negative for reverse fault $\Delta\phi_1$ is negative similar to the sequence components of phase quantity based approach.

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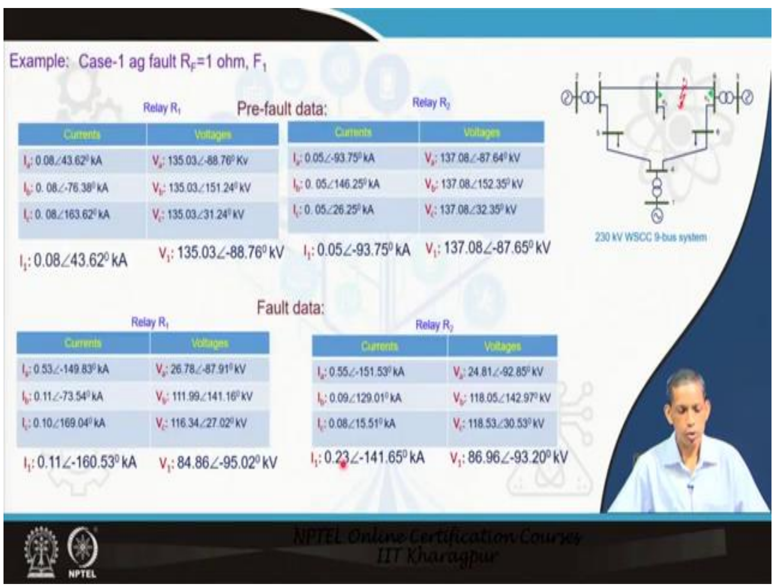

So, applying this concept of superimposed components we say that for same 9 bus system relaying to ground fault, same set of ΔI_1 this and the ΔV_1 this, this is the prefault data R_2, for R_2 I_1 is this and from the set of voltages V_1 is this. Note that this F_1 fault for both relays are forward fault. Now fault data available relay R_1 computed I_1 computed V_1 for R_2 computed this I_1 and computed the V_1 as you did in earlier example.

Now prefault datasets, fault datasets note that we require now additional datasets that is prefault data. What is prefault data? Just before the corresponding fault data. And note that the prefault data, these are phasors so these phasors are computed using the prefault waveform current samples and voltage samples available either in the DFT, cosine filters, earliest square and so.

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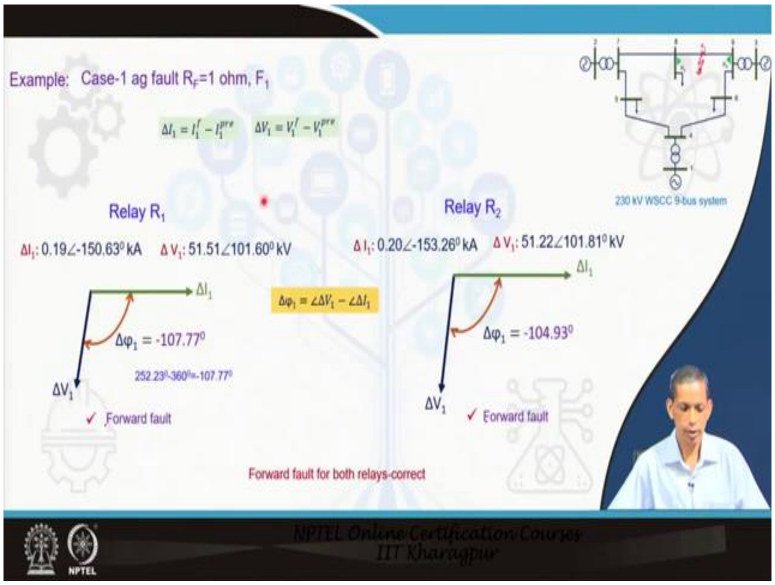

Now we will imply the principles so for this case we will first find out the delta I1 will compute ΔI_1 is I_{1F} minus I_{1pre} and ΔV_1 is V_{1F} minus V_{1pre}. So for relay R_1 we have already computed this positive sequence current and voltages, so ΔI_1 compute $0.29\angle- 150.63^0$ kA, ΔV_1 is $.51.51\angle 101.6^0$. So compute the $\Delta\phi_1$ using the relations ΔV_1 minus ΔI_1. Note that the change as I already mentioned.

So this is angle of voltage first then the angle of current. So this $\Delta\phi_1$ for this case happens to be minus 107.77 degree. So this how do you obtain this, if you see this the ΔV_1 is 101 minus 150, so 101 plus 150 gives you this is 251 degree, so this 252 degree is greater than 180 degree, so subtract this 360 degree then you get minus 107.77 degree.

Because already mentioned that this angles should be from the phasors, angles should we plus minus 180 degree so to get the corresponding angle proper one we get to consider this. Otherwise also with respect to the corresponding voltage, in this case the current leads, so how much is the leading angle. That matters to us and that leading angle is nothing but minus 107.77 degree.

So this is a case of minus angle means forward fault, so which is being correctly identified varies superimposed quantity is directional relaying. Now going to the R_2 side the corresponding ΔI_1 from this I_{1pre} and the I_{1fault}, ΔV_1 from the V_{1fault} and V_{1pre} happens to be like this, so similar to this implying this relation we can find out $\Delta\phi_1$ to be minus 104.93 degree which is having negative angle implied forward fault which is also correct.

So, we see that for this case the superimposed component occurs both relays find the direction properly. For F_2 side this is a forward for R_2 and reverse for R_1 we have prefault datasets and we have fault datasets then compute the I_1 and V_1 for each set. For the fault data also like that I_1 and V_1 and I_1 and V_1.

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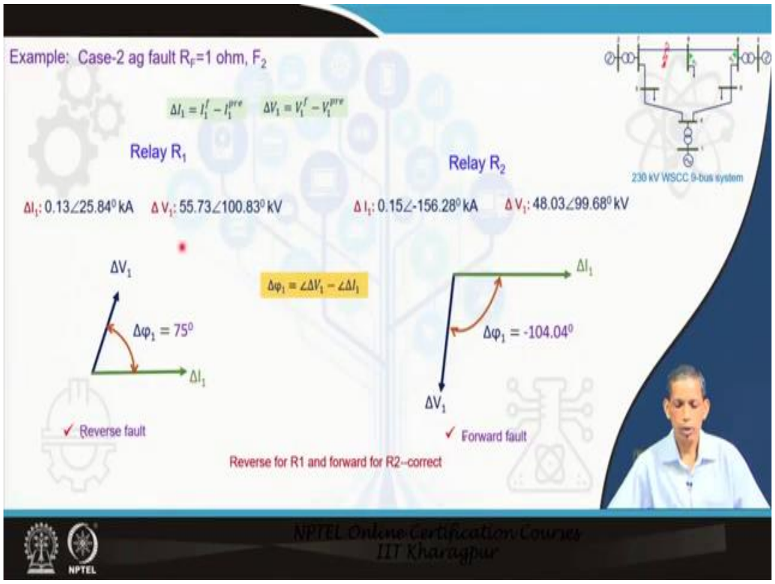

Now we will compute for this case for relay 1 using this relation delta I1 and delta V1 so delta I1 is this and ΔV_1 is this for relay R_1. So also ΔI_1 and $\Delta V_1$for relay R_2. Using the relations for phase angle $\Delta\phi_1$ equals to angle of ΔV_1minus angle of ΔI_1 $\Delta\phi_1$ equals to 75 degree which happens to be positive means this is reverse fault so for R_1 this is reverse fault which is correct. And we say can this is $\Delta\phi_1$ equals to minus 104.04 degree this also minus angle means forward fault so for R_2 this is forward fault which is also correct. So, both relay R_1 find its relay R1 find its a reverse fault and relay R_2 finds it forward fault which is correct. As per as you see from this simulation.

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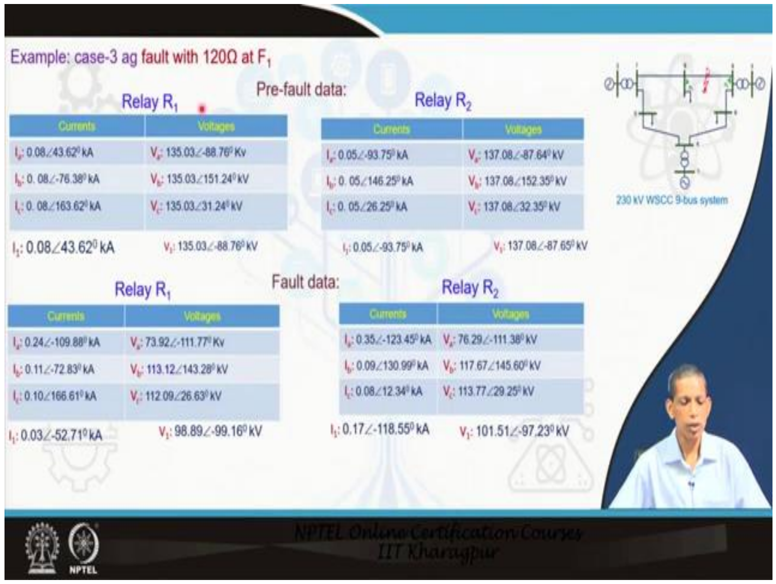

With high fault resistance 120 Ω case as you have seen earlier also pre fault data using we find the I_1 and V_1 for both the relays. Fault data I_1 V_1 and I_1 V_1 for both the relays this is the separate data available for the relay.

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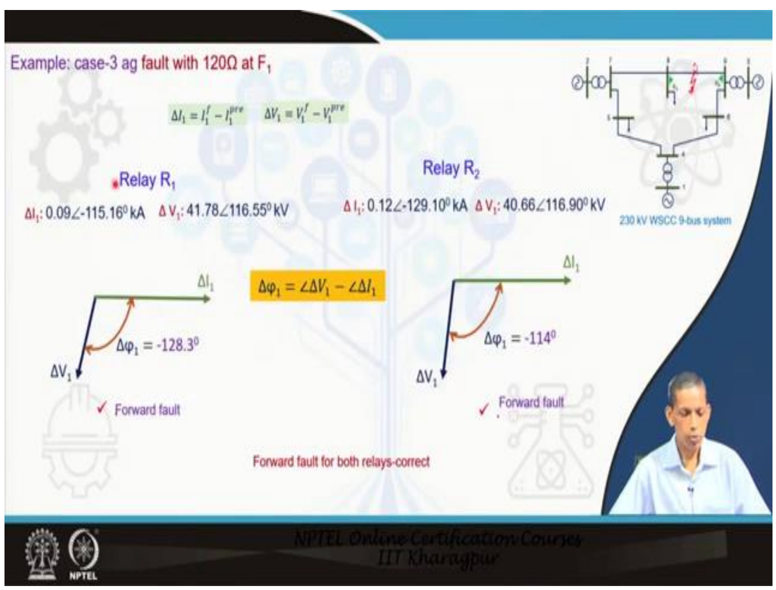

Now if you see this performance of the R_1 you got the delta Phi 1 to be negative, negative even though the fault resistance is very high, it is correct. And the $\Delta\phi_1$ minus 114 degree is R_2 that is also correct. So, we consider that both the relay correctly identifies the direction of fault using the principle of superimposition quantities. And so we see that the corresponding superimposed quantity also not affected by the fault resistance and also this is not affected by the prefault current because this is already subtracted from the fault quantity also.

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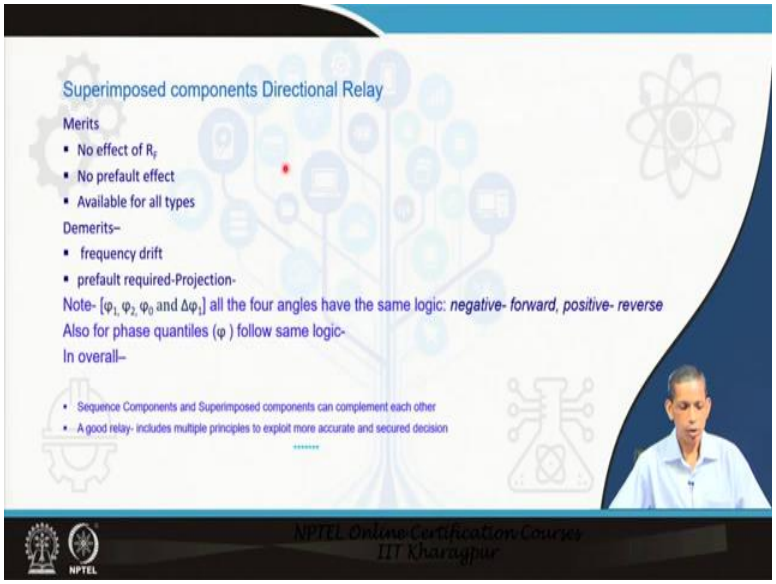

So, we say that the merits of superimposed components of directional relaying that this is a not affect by R_F, not affected by the prefault as already mentioned. Being positive sequence based this is available for all types unlike negative sequence and zero sequence components. But the demerits is that because it deviates the prefault components, the prefault samples are being projected to the all side to find the corresponding ΔI_1 and the ΔV_1. If the frequency deviates during the fault, then the frequency accordingly the corresponding drift angle has to be compensated. This prefault required projections that has to be done correctly. Further note that we have learned through this directional relaying principles using positive sequence, negative sequence, zero sequence and the superimposed component, positive sequence, negative sequence, zero sequence and this is superimposed component. Positive sequence superimposed component $\Delta\phi_1$. In all four angles we have the same logic, negative angle means forward fault, positive angle means reverse fault, also same thing logic we applied in case of the phase quantities also whether it is 90^0 connections or normal phase quantities. So, in overall the sequence component and the superimposed components can complement each other. A good relay includes multiple principles to exploit more accurate and secured decisions. And that is why the modern relays are using today to obtain the proper direction of fault at numerous challenging condition also. Thank you.