Power System Protection
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Lecture No. 22
Application to Double Circuit Line

Welcome to NPTEL course on Power System Protection on distance relaying. In today's lecture we will go to application on double circuit line.

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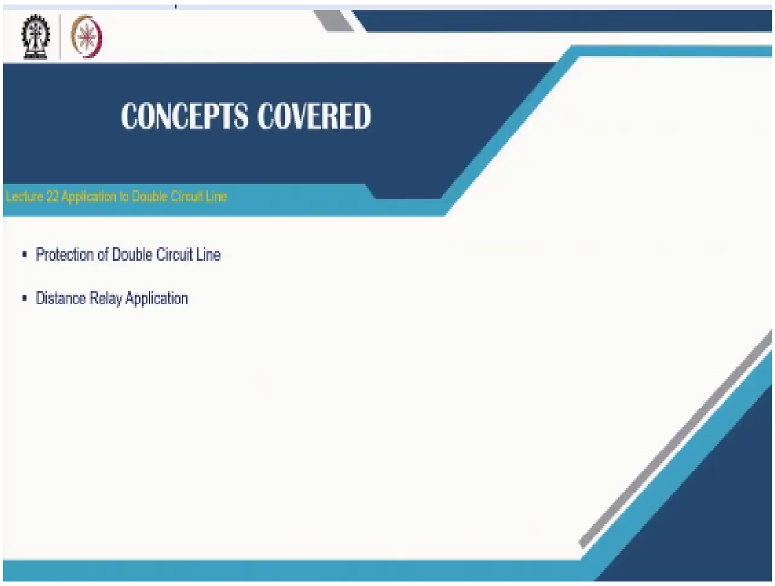

Our focus will be on protection aspects on double circuit line and then we will see how a distance relay can be applied for such a transmission system protection.

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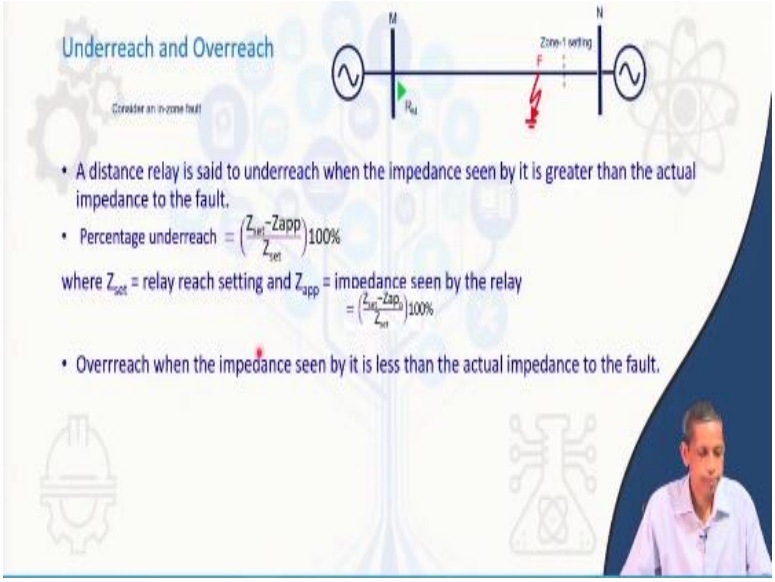

Now before going to that let us be clear on two terms, the underreach and overreach of a relay. So, what we see let us consider this transmission system and we have relay at the bus M. So, consider distance relay in zone fault at F. So, it is inside the zone 1. Now if the relay now finds the apparent impedance to be greater than the actual fault impedance, positive sequence fault impedance then we call we consider this situation as underreach.

Once again a distance relay is said to be underreach when the impedance seen by it that is the apparent impedance is greater than the actual impedance to the fault. The percentage of underreach is calculated in terms of the $\left(\frac{Z_{set}-Zapp}{Z_{set}}\right)100\%$. So, this you can say that when we say this remain that at the reach of the relay what the corresponding apparent impedance is seen by that.

So, if we use this one then we can see that what is the percentage of underreach. Here what we like to see is that underreach implies that the relay we will see because of the apparent impedance being higher values for the fault point so it will not reach up to the zone 1 setting of this point. So, before that it will be observing the required impedance setting. In case of overreach when the impedance seen by it is less than the actual impedance.

So whatever the actual impedance, if it see the lesser value than the corresponding situation is called overreach situation. So, in that case this relay will see even the zone 1 beyond this also. So again, the corresponding relation for overreach will be similar to that.

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Now we will go in this lecture on double circuit line protection, application of distance relay. Many lines in transmission level are being of double circuit in nature. We have discussed something in the directional relaying application also. Now if you see the structure here in this tower when we see the left hand side we have 3 bunch of conductors but they are each bundle conductors and in the right hand side also we can consider that 3 a set of 3 conductors.

So, if you remember inductance calculation, capacitance calculation we use set of conductors, multi conductor system AA', BB' and Cc'. Suppose this becomes A of one circuit, this become A' of another circuit, B, B' and C, C'. So, this kind of transmission system having two circuits we consider in terms of that and that we can say that not only gives us more power to be sent.

And also other advantages in terms of inductance reduction and so on. Now in such a case, we see that on the same tower both circuit 1 and circuit 2 are available and that is we consider the issue which arises and it need special attention on protection perspective we will see.

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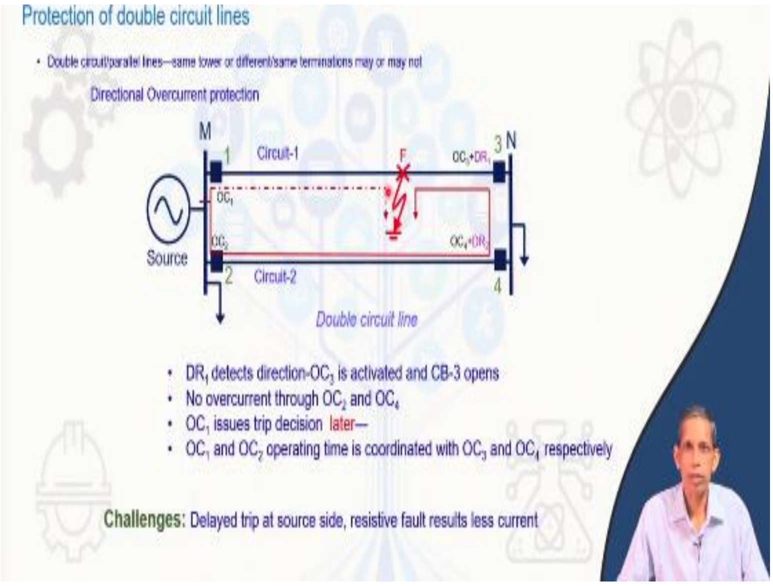

Now let us we will consider a simple double circuit system however, double circuit or otherwise called also parallel lines can be can run on same tower, can be running on different towers and the same nearby right up way they can be terminated at different nodes, they can have a common bus also and the other bus may not be common. So, there can be different configurations on double circuit line in a power system.

We will consider a simple such a structure where we have the 2 bus M and N and in between them we have 2 parallel lines or 2 circuits like the tower I showed you where we have two circuits on the same tower. So, let us say fault happens to be there at F which is internal fault in circuit 1. Now what is the issue with overcurrent and directional relay approach we will first see and then we will proceed for the requirement of distance relay protection.

So, when a fall happens to be there we see there is a radial system. So, current fault current will flow from this path and also fault current will flow from this path. So, in the directional relaying lecture we mention that the where we essentially require a directional relay here in addition to overcurrent relay and here for this breaker also we require additional directional relay with overcurrent relay.

We have overcurrent relay this side and at for both the circuits breakers. So, the objective is that for an internal fault in any of the line that line should be only out the other line scheme should be functional this is from the selectivity point of view. So, for that in this case what will happen whenever a fault happens to be there this side these directional relays sees forward direction in the DR1.

And then the OC3 also we will see large amount of current so therefore this combination will open the breaker at 3. Now, therefore the fault current path from this route now is no more there. So, this OC2 at breaker 2 and OC4 at breaker 4 they will not see no more fault current. So, therefore this circuit will remain intact because they will not operate the corresponding breakers.

Now from this side at breaker 1 this fault is still we can say that continuing so this overcurrent 1 here we will see the large current and there is a coordination between OC1 and OC3 and OC2 and OC4 respectively. So, therefore in a delayed time OC1 will operate after the clearance from the circuit breaker 3 side. So, this is what the parallel line linkage is being protected by overcurrent and directional relaying combination.

But what we see from here that the breaker which is closer to this four sides substation side otherwise is having we can say that a delayed operation so which is not a good thing from protection point of view. So, therefore that is one perspective of the demerits of such a protection philosophy. The second thing is that if the corresponding fault happens to be resistive fault higher and higher resistive fault.

Then the current amount decreases and therefore, the overcurrent may find limitations in terms of that or it may be delayed operation and so further delayed operation and so. So, with such limitations of overcurrent principles here, there is alternative and the alternative we are talking about here today is on distance relaying application.

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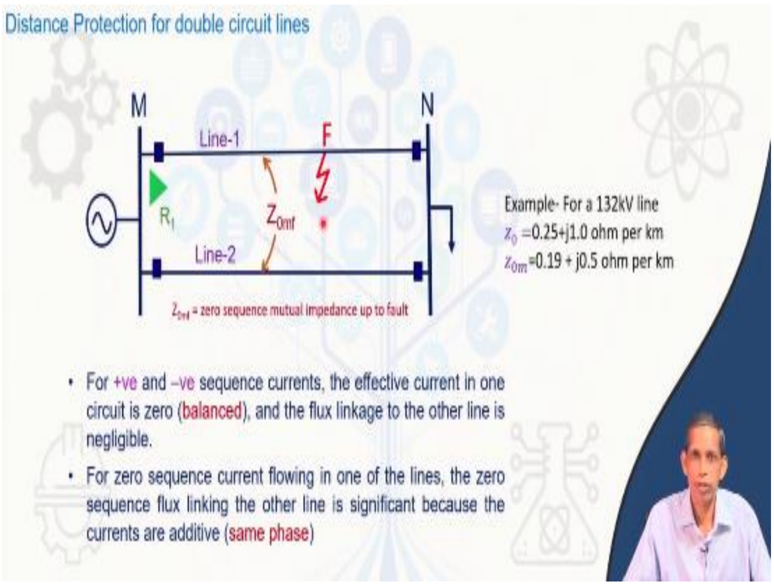

How the distance relay can be applied to double circuit line more efficiently that we will like to see, but before going to that there are issues so let us see that issue. We have circuit 1 circuit 2 or line 1, line 2. Fault happens to be there in one of the line then we have already analyzed that this circuits fault analysis can be for this circuit can be analyzed in terms of positive sequence, negative sequence and 0 sequence component and are associated impedances.

Now let us consider only the current part so when we say positive sequence current or negative sequence current they are balanced. So, therefore in that faulted phase the positive sequence current and the negative sequence current may be balanced. The associated current I_{a1} + I_{b1} + I_{c1} all the three phasors summation will be 0. So, therefore the corresponding flux which should be out of this 3 lines, I am circling that one if you remember the inductance calculation. So that becomes 0 because that circle and encircles summation of these 3 currents which happens to be 0 for positive sequence current.

So, therefore the flux linkage from one circuit to the other one that becomes negligible. Similarly, for negative sequence also that being balanced the associated flux linkage to the other one also becomes negligible. That means that the positive and negative sequence components of currents they have negligible mutual inductance, mutual impedance between these two lines. Come to the 0 sequence component, 0 sequence as we have already seen 0 sequence component is I_{A0}, I_{B0} and I_{C0} they lie in the same phase, same direction.

So, therefore the associated flux of any line or any circuit the corresponding contributed by the 0 sequence components they become additive. And that results in that the flux become significant to link the other line conductors. So, therefore the corresponding associated 0 sequence mutual impedance become significant as compared to positive sequence and negative sequence aspects. So, that cannot be neglected for different lines. And for example for a 132 kV line the data says that the 0 sequence component as you have already seen for the line individual line becomes 0.25+j1 Ω/km.

Where the Z0m the mutual impedance per kilometer between these two lines that becomes equal to 0.19+j0.5 Ω/km. So, we see here we can say that as compared to the 0 sequence component of the line the mutual part is also significant. So, this says that from this that the 0 sequence current has a mutual impedance with the other circuit whereas the other sequence component positive and negative they do not have and they are negligible such impedances.

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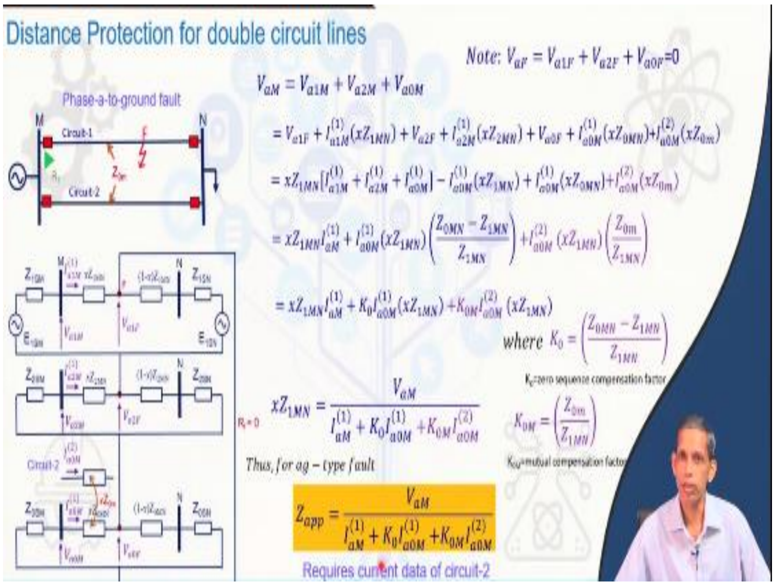

So, this leads to our analysis for double circuit line little bit different then what we have derived the apparent impedance calculation for single circuit analysis. Now, let us consider the double circuit line here phase a-to-ground fault we have analyzed for other fault also similarly you can analyze fault in circuit 1 and we have a zero sequence mutual impedance between these two lines Z_{0m}.

Note: this is a phase-a-to-ground fault. So, therefore, $V_{aF} = V_{a1F} + V_{a2F} + V_{a0F} = 0$. Now voltage in phase-a at bus M the common bus for circuit 1 and circuit 2 relay bus. So, $V_{aM} = V_{a1M} + V_{a2M} + V_{a0M}$, but this individually we go to the sequence component the way we did in the earlier lecture on apparent impedance calculation.

So this V_{a1M} equals to V_{a1F} plus this drop. So that is what this part and we are only looking at circuit 1 now. So, therefore V_{a1F} and I_{a1M} of circuit 1 and the corresponding impedance of that part here to here it is xZ_{1MN}, for Z_{1MN} in the impedance of this line positive sequence impedance of the line and x corresponds to the per unit fault point distance. Similarly, for the negative sequence component V_{a2F} plus this part. So, V_{a2F} plus this drop.

Now you come to the zero sequence component V_{a0F} plus this drop, but now consider that we have in 0 sequence we have a mutual component. So, therefore for the circuit 2 the corresponding line has a mutual component of xZ_{0m} and then you can say that this xZ_{0m} and the corresponding current associated with the circuit in the second line. So, therefore this corresponding relations becomes $V_{a0F} + I_{a0M}^{(1)}(xZ_{0MN})$. So this is the common like the earlier positive and negative part, but there will be an additional component for the 0 sequence mutual part $I_{a0M}^{(2)}(xZ_{0m})$ of the circuit 2.

So, we are analyzing for the circuit 1 fault so relay at R1 for the circuit 1. So, for that the corresponding mutual part has the other circuit 0 sequence current. So, this is the expression for the voltage for bus M at the relay location for the phase a-to-ground fault and we are analyzing the fault at phase voltage relation. This we see $V_{a1F} + V_{a2F} + V_{a0F} = 0$. So this one this and this three becomes 0. Now we have all the other current components 1, 2, 3, 4 terms.

So, now similar to the earlier single circuit aspect, if we take the xZ_{1MN} and we know Z_{1MN} and Z_{2MN} they become same. So, therefore we can say that I_{1M} and I_{2M} and I_{0M} similar to the earlier expression this becomes that and this is nothing but your I_a component of I_{aM} component phase a current component during fault. Now if you go to the other components if we see here we can say that we have added and subtracted this part $I_{a0M}^{(1)}$ and $I_{a0M}^{(1)}$ this part like we did earlier case.

So, this gives us $I_{a0M}^{(1)}(xZ_{1MN})\left(\frac{Z_{0MN}-Z_{1MN}}{Z_{1MN}}\right)$, but there is another additional term for this component. So this is what we consider $+I_{a0M}^{(2)}\left(\frac{Z_{0m}}{Z_{1MN}}\right)$. So this Z_{1MN} that we can say that we will cancel out. So now we see here we can say that from this relation so that xZ_{IMN} I_{aM} this part remains this and we define we can say that $K_0 = \left(\frac{Z_{0MN}-Z_{1MN}}{Z_{1MN}}\right) I_{a0M}^{(1)}(xZ_{1MN})$.

Now we can say that for this part we defined we can say $K_{0M} I_{a0M}^{(2)}(xZ_{1MN})$ term we are putting and we are putting we can say another factor $K_{0M} = \left(\frac{Z_{0m}}{Z_{1MN}}\right)$ where K_{0M} is called the mutual compensation factor mutual compensation factor and the reason behind that we have the 0 sequence mutual impedance between these two lines Z_{0m} and that we can say that with respect Z_{1MN} that factor is called mutual compensation factor.

Note that to remember you that this K_0 in the last lecture also we discuss about 0 sequence compensation factor in some of the literature we will find this we can say that a factor of 3 in the denominator and that is due to because the corresponding current that is being considered is the neutral current or the Earth current. So, that becomes three times of Ia0 so therefore they remain same you can say in terms of that.

Here we are considering Ia0 zero sequence current and that is why I can say that three term is not here. So, from this one from this relations we say that the corresponding xZ_{1MN} is a common term in all the three term. So xZ_{1MN} you can take it outside and then this becomes equals to $\frac{V_{aM}}{I_{aM}^{(1)}+K_0 I_{a0M}^{(1)}+K_{0M} I_{a0M}^{(2)}}$. So, in general we can conclude from this relation that these xZ_{MN} is nothing but the impedance up to the fault point positive sequence impedance up to the fault point that is what we say here.

So, therefore that we can say we consider that in terms of the refer it as a Z apparent as calculated by the relay. So, $Z_{app} = \frac{V_{aM}}{I_{aM}^{(1)}+K_0 I_{a0M}^{(1)}+K_{0M} I_{a0M}^{(2)}}$. The circuit where the relay is looking at $+K_0 I_{a0M}^{(1)}+K_{0M} I_{a0M}^{(2)}$. So, this term becomes an additional term and note that this requires zero sequence current of the circuit 2.

So, for that the corresponding I_a, I_b, I_c of circuit 2 are required to obtain the corresponding zero sequence current aspect. So, these derivation for the phase-a-to-ground fault reveals such that for a double circuit line the corresponding expression for Z_{app} the first and these difference we can say that is by this factor the additional factor here we can say that this perspective.

Now note that this Z_{app} now for this reason becomes modulated one as compared to this perspective. What the modulation is being done by this double circuit line is that the zero sequence current in the other line during that fault and this factor of K_{0M}. So, this part with regard to this part may be additive or subtractive depending upon the corresponding phase relation after the I_{0M} with respect to this part of the currents these two currents.

So, that means that we can say that the corresponding denominator becomes larger or smaller depending upon the phase position of this I_{0M} in terms of this two currents. So, that leads to that if these value total value becomes smaller than this value than the corresponding impedance will be larger and impedance is larger means that the corresponding situation will be underreach situation.

And if this factor becomes additive and then this total impedance becomes larger as compared to this value then the larger impedance means the corresponding value will be smaller and that leads to an overreach issue. So, that we consider the consideration we can say that if we consider only this part as usual which we have considered for the single circuit line.

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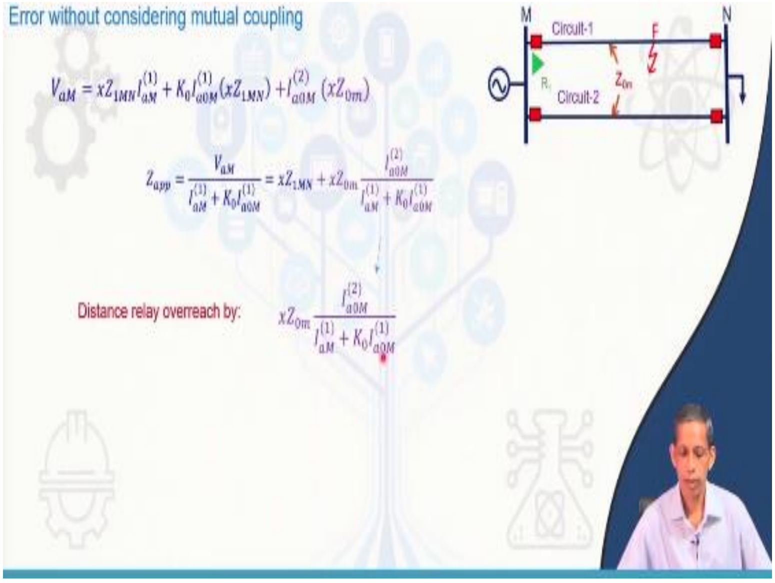

Now, I will you can say that see this perspective of for the same circuit so if we consider the 0 sequence current of the other line and considering the mutual aspect we derive the equations as you see the last slide. Now from these relation voltage relation and current relation now suppose we do not take the corresponding current in the denominator the expression if the corresponding current this part to get the corresponding xZ_{1MN}.

And if we take only that the single circuit line what we have seen earlier we take the expression of $\frac{V_{aM}}{I_{aM}^{(1)}+K_0 I_{a0M}^{(1)}}$ then what happens you see here then dividing with this current these relation becomes xZ_{1MN} which is the fault distance actual one plus there is another term $xZ_{0m}\frac{I_{a0M}^{(2)}}{I_{aM}^{(1)}+K_0 I_{a0M}^{(1)}}$. So, this is additional term which you are getting for the double circuit line.

If we use the same current relation and voltage relation for line-to-ground, phase-to-ground fault in phasor-to-ground fault as you have seen in the single circuit case. So, this additional term we can say that is if these becomes additive as I already say we can say that so that becomes overreach or underreach depending upon the phasor position of I_{a0} in the second line or fault in first line.

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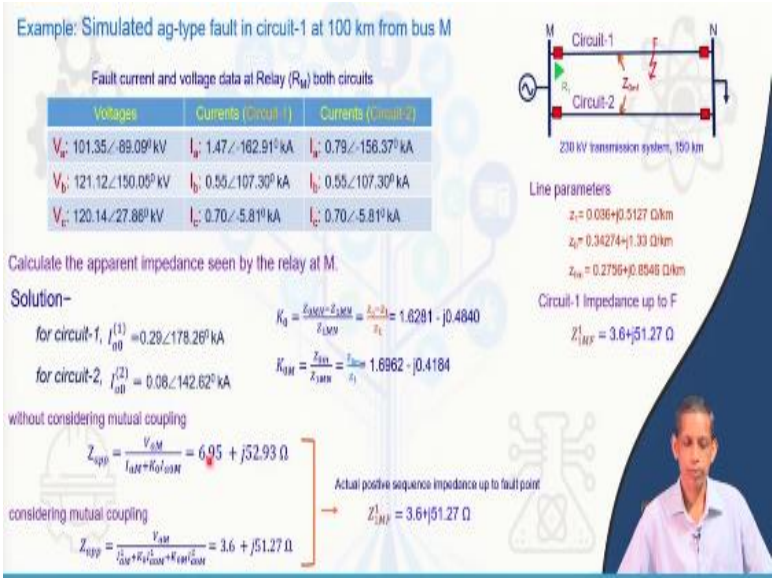

Now let us go to an example so we have a double circuit line as shown radial systems and we have Z_{0MF} corresponds to the 0 sequence mutual impedance up to the fault point for this circuit with the circuit 2. There is a 230 kV system 150 kilometer and we have line parameters z1, z0 and z0m the mutual 0 sequence impedance and the fault considered is being created at 100 kilometer.

So, therefore the corresponding Z_1 positive sequence impedance of the fault point which the relay is expected to obtain from the Z apparent becomes 100 into this per kilometer impedance so that gives us 3.6+j51.27 Ω. Now we will calculate for this phasor-to-ground fault a simulation was drawn for this circuit at 100 kilometer from this point and we will observe the relay voltage and currents.

So, this is the set of voltage phasors during fault and this is set of current I_{abc} for circuit 1 and this is set of current I_{abc} for circuit 2. In circuit 1 the phasor current is significant as compared to the other two phases in circuit 2 the corresponding phase current we see here there, there is no significant change like in case of circuit 1 for this case. Now we see here we require not only this first circuit currents we require second circuit current to calculate the zero sequence current of the second line.

So this task is to calculate the apparent impedance seen by the relay at M. Now two approaches we will see as already we discussed earlier that only using the circuit 1 current and voltage and also using the circuit 2 currents also. So, the simple relations of $\frac{V_{aM}}{I_{aM}+K_0 I_{a0M}}$ and the other one we can say that $\frac{V_{aM}}{I_{aM}^1+K_0 I_{a0M}^1+K_{0M} I_{a0M}^2}$.

So, for the solutions we will find the corresponding zero sequence current for circuit 1 from this relation Ia, Ib plus Ic upon 3 and we got the corresponding of this for the circuit 2 also we got like this. Note that the 0 sequence current here they are close to each other then the corresponding they are almost in phase kind of thing that results in an additive factor in the denominator as we have discussed earlier.

The $K_0 = \frac{Z_{0MN} - Z_{1MN}}{Z_{1MN}}$, already in this single circuit we have analyzed this, this becomes equals to if we divide by the kilometer distance length of the line 150 kilometer then we got the $\frac{z0 - z_1}{z_1}$. This small perspective is nothing, but in terms of the per kilometer basis this values which are provided here. So, K_0 is considered as a complex number obtained.

Now, K_{0M} for the mutual perspective is $\frac{Z_{0m}}{Z_{1MN}}$ so that can be also $\frac{z0m}{z_1}$ divided by the length of the line so that comes out to be complex numbers. So, these two factors are having complex terms. Now, we will apply the two approaches without considering mutual coupling means without considering the second line currents. So, this considering a single circuit approach $\frac{V_{aM}}{I_{aM} + K_0 I_{a0M}}$.

So, this becomes equals to substituting the value we got this to be $6.95 + j52.93\ \Omega$. So these says that this value is higher than this actual positive sequence fault impedance up to the fault point from the relay that is what our comparison $3.6 + j51.27\ \Omega$ so this should be higher value. So, that means that if we use this formula like the single circuit approach, then this relay will underreach this relay will underreach.

Now, if we consider the mutual coupling between these two and use the second circuit current to obtain the 0 sequence current for that circuit and use the formula like which you have derived so then V_{aM} upon this then this becomes $3.6 + j51.27\ \Omega$ which happens to be exactly equal to Z_{1MF} the positive sequence impedance up to the fault point from the relocation. So, that means that this relations which we have derived is an agreement with the corresponding positive sequence impedance actual one and if we use this relations using the current from the second line then we will be getting more accurate apparent impedance.

So, there will be no issue of underreach or overreach whereas we neglect that part then there will be in this case we observe that this will underreach, but again the corresponding this current becomes its phasor position with respect to this becomes deviate significantly then we can find we consider this also the other way considered overreach phenomena overreach issue also.

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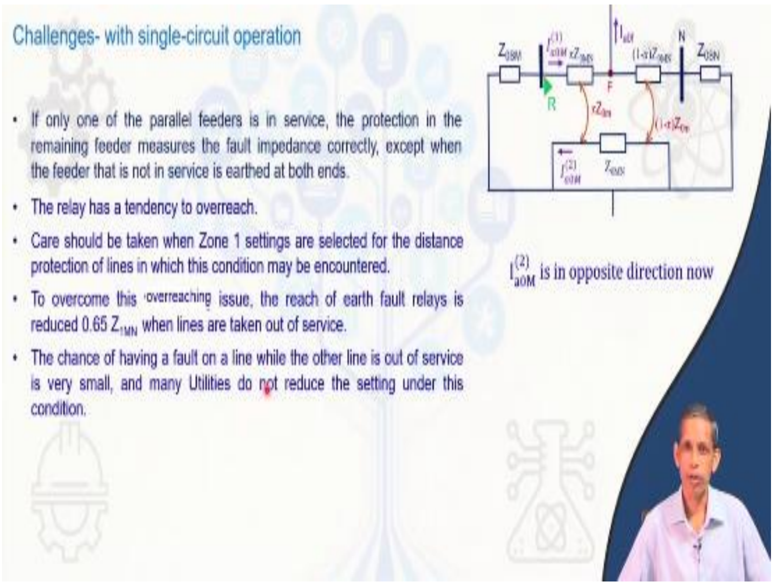

So, with these we see we can say that zero sequence mutual coupling is of significance to distance relay apparent impedance calculation also. Now we will see consider what are the different challenges associated with the circuit operation. One is that a double circuit line what you have seen in the earlier diagrams that at times if these line may be out of service due to maintenance and so.

So, generally what is being done that the line at the both end both ends they are being grounded, but with that grounding what happens that the corresponding if the faults happens to be in this circuit 1 if a faults happens to be in the circuit 1 and circuit 2 is grounded non operational then this point will look like this through ground. So, therefore there will be zero sequence induced voltage in this circuit and that zero sequence induced voltage we circulate current in this one.

And that current will be in the opposite direction that what we have seen in the earlier case. So, in that case it is being said that the relay has a tendency to overreach. So, therefore care should be taken for the zone 1 setting for this kind of situations to overcome this many recommend we can say that not 80% of zone 1, 65% of the positive sequence impedance of zone 1 for such condition only.

So, in case of only single circuit is operation for a double circuit line because of this mutual effect. However, such a fault for a single circuit operation during the other line not being analyzed is very rare. So, many utilities they do not consider this lower setting of positive sequence, lower setting of the zone 1. They continue they consider the normal setting of 0.8 to 0.9 we consider that of the Z1MN.

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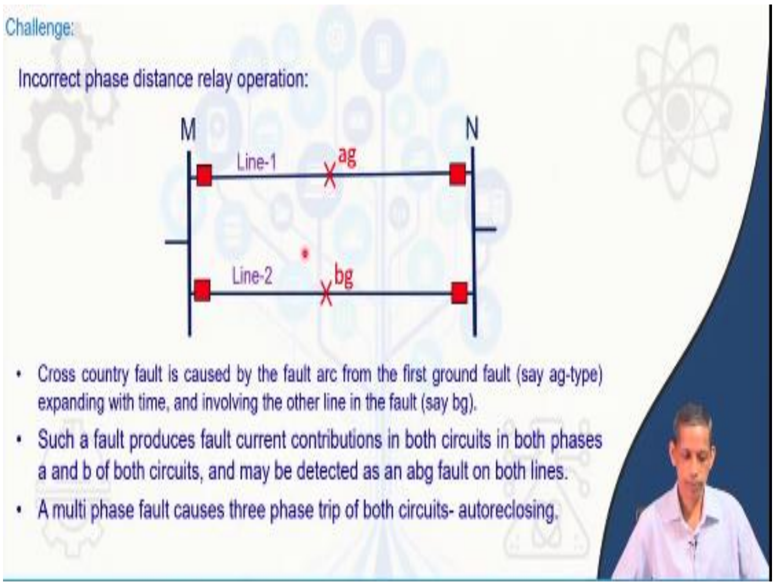

Another challenge is the cross country fault so what do you mean is that suppose line 1 as you can say that phasor-to-ground fault and associated with this arcing and so. A fault may be triggered in the other line or circuit in another phase like here in this case we have shown phase b-to-ground. So, what will happen that both we consider distance relay at this point and this point or from the other side also in the network that they will see significant current in phase A and phase B.

What I mean to say is that a fault is there in ag and therefore we can say that phase a current will be significant. Now a fault again falling again it trigger in phase B of the other circuit. So therefore from this we can say a part considered from the phase B part we can say that goes to this. So, in phase B current also at this we can say relay position also will become significant. So, that results in the corresponding relay at this point distance relay at this point will see the fault as not easy fault.

We will see the fault as abg fault. Now if the relay sees this abg fault then it will use the corresponding relay we can say that $(V_a – V_b)/(I_a – I_b)$ not $V_a/ (I_a + K_0I_0^1 + K_0I_0^2)$. So, that means what do we see that this is a situation of cross country fault and such a fault produced fault current contribution in both the circuits for phase and this. A multiple phase consider fault causes phase tripping what I mean to say that if this corresponding relays is the corresponding fault to be the phase abg fault, then the autoreclosing business it will be considered as a three phase tripping aspect.

Whereas only a single phase to ground fault is happens to be there. If single phase can be removed and here also single phase can be removed in phase b they also we can say that the system can run and then I can say again we can revoke the systems after sometimes. So, this is what we consider about parallel line brings issues you can say that to distance relay based protection scheme.

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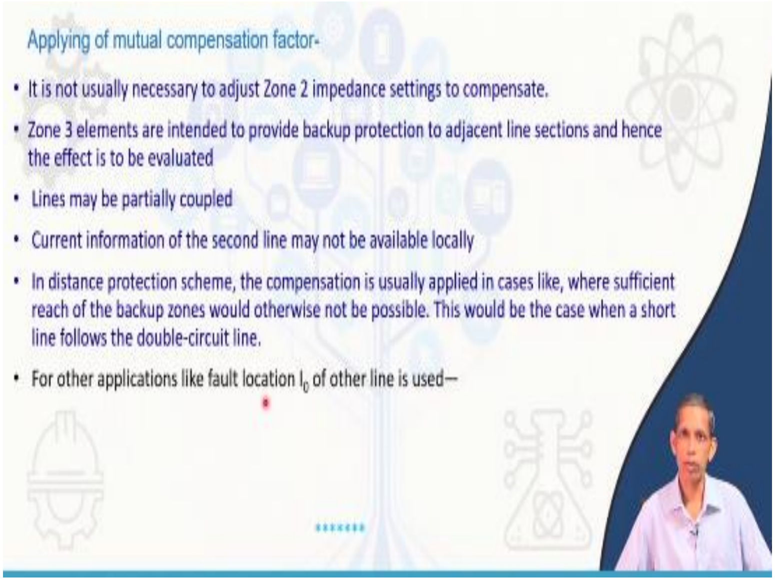

Now we discuss on the issues on compensation factor the zero sequence compensation factor contributed by the other line, other circuit. So, we discussed mostly on zone 1, but in many aspects for zone 2 we can say that the corresponding impedance setting is not being taken care in general because zone 2 setting we have extended is there from 120 percent to 150 percent of the corresponding line being protected.

So, that factor of larger value of we can say that zone 2 to take care of the whole line of zone 1 gives having sufficient safety margin. So therefore we can say that on this perspective that the zone 2 may not be in trouble. Zone 3 however is a breaker protection for the subsequent line, for the remote bus. So, therefore there must be a check whether this mutual factor is of significance in terms of that.

And that may be that zone 3 setting should be of concern and so therefore, a mutual aspect must be considered for the double circuit line. Note that as already mentioned in the earlier the lines may be partially coupled. It means that they may have a common person and the right of way for the part of the line then that becomes we can say that more introduced as more complexity in the system depending upon the fault position and so.

Current information of the second line may not be available because they may not be having a common bus at the relay side. So, if the corresponding two buses are of distance apart, then we cannot get the corresponding currents from the second line. In distance what we have seen the compensation for the mutual compensation is applied in case like for sufficient reach of the break up zone would otherwise not be possible.

Like if we say a short line followed by long double circuit line. So, short line we know issue considered its breaker protection zone 2 of the first line may be double circuit line longer line make go beyond the zone 2 of the subsequent short line. So, that may be issue so that is why we can say that it may be critical in that perspective and if that is important from that perspective as a backup protection then this may be followed.

Otherwise using the relation for the apparent impedance calculation using the compensation factor, the zero sequence compensation factor considering the other line current is not quite they being used in the industry because of this complexity of so many issues, configuration issues and single circuit operation and so and so. However, for other applications like fault location and so, the zero sequence current of the other circuit becomes useful to proper impedance calculation and so. So, in that case that can be successively used.

So, this is what we learn on how for the double circuit line the distance relaying can be applied and the associated issues and the corresponding practice in the industry. Thank you.