Power System Protection
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Lecture – 26
Effect of Fault Resistance

Welcome to Power System Protection Course NPTEL. We are continuing with distance relaying.

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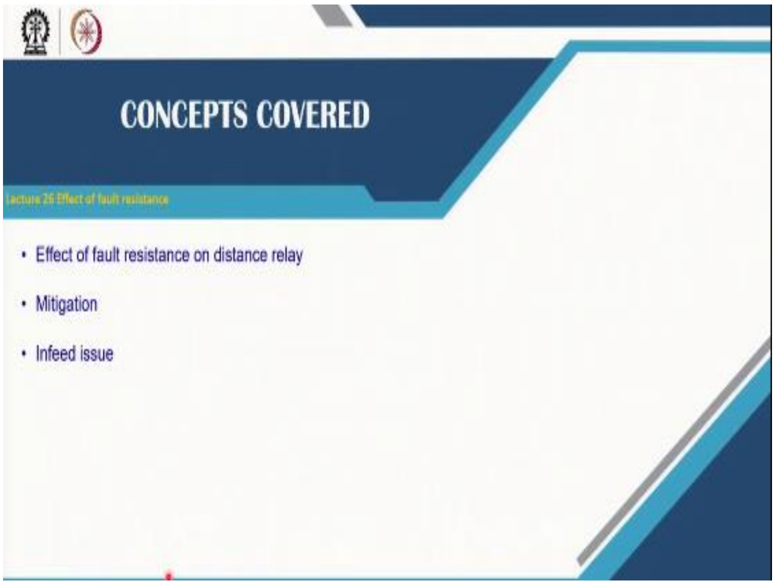

In this lecture we will see the effect of fault resistance on distance relaying. How to overcome this and then at the end we will discuss on the infeed issue with distance relay.

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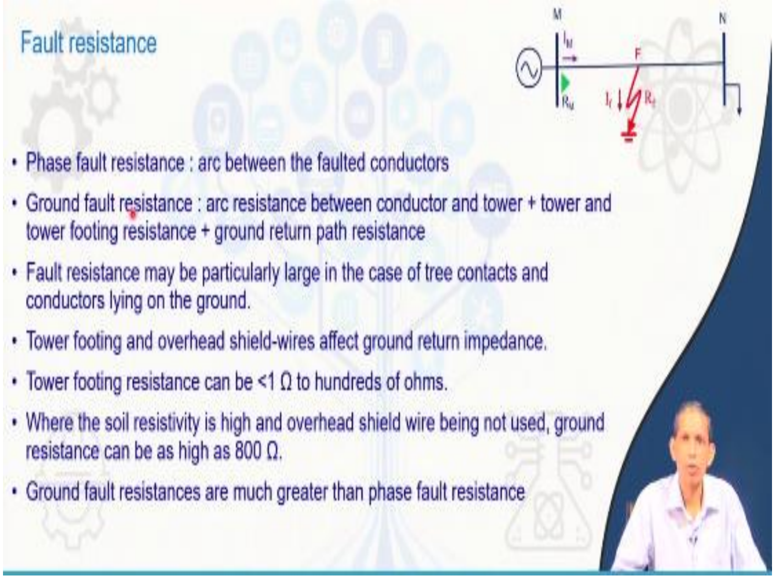

So, come to this first point that is the fault resistance issue with distance relay. We have come across the fault resistance in several lectures. So, we know something about this, but we will have more elaboration on this and then the issue with distance relay will be discussed. We know that whenever in a transmission line a fault happens to be there then we show a diagram like this.

And the fault current passes through the fault path if it is a ground it goes to the ground if it is between two phases so it is confined to them and like that. So, we say that these before the physical contact happens to be there between the phase conductor or another phase conductor or the ground because of the large voltage arcing will be established. So, we have phase fault resistance mean to say that when the fault happens to be between two phase conductors.

So, the arc is between the faulted conductors. In case of ground fault resistance the arc resistance between the conductor and tower. So, the towers carries the conductor so conductor and tower. Tower and tower footing resistance. So, we have the fault current will pass through the phase conductor, tower and the tower footing resistance and then the ground path and the ground return path resistance.

So, we see that in case of fault involving with ground the path encounters not only the arc resistance also tower footing resistance and the ground path resistance. Furthermore, fault resistance may be particularly large in case of tree contacts and conductors lying on ground so this is involved with the ground fault. One more point tower footing and overhead shield wires effect also observe on the ground return impedance.

What I mean to say here the overhead shield wires for lightening purpose they are grounded through the towers. They connect all towers. So, therefore the corresponding ground path is also affected by the shield wires. Tower footing resistance typically can be small less than 1 ohm to hundreds of ohms depending upon the arrangement and the soil resistivity and so on. When soil resistivity is high and overhead shield wires being not used special cases.

Ground resistance can be as high as 800 ohms this is worst situation, but can be typically it can high voltage line can be confined to 5 ohm, 10 ohm, 20 ohm, 30 ohm also, but situation says also that there can be hundreds of ohm also. Ground fault resistance are much greater than phase fault resistance we have already elaborated on this that phase fault resistance is only confined to the arc. Whereas ground fault resistance is having other components a tower footing resistance and the return path.

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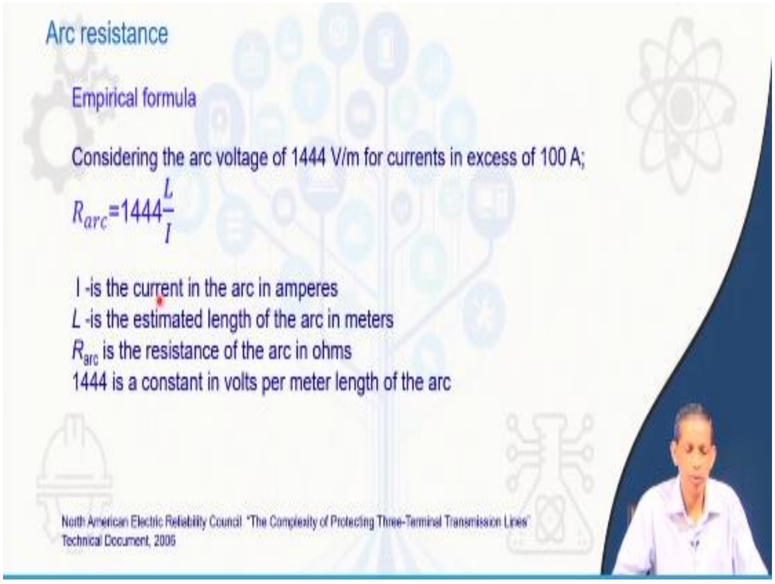

The arc has its own resistance and that depends on different components particularly the length of the arc and the current associated. There are empirical formula one of them we can say that is like this that considering the arc voltage to be 1444 volt per meter sometimes expressed in 440 volt per meter also. For current exceeding 100 amperes so the arc resistance happens to be $1444\frac{L}{I}$.

Where L is the length of the arc estimated on and I is the current in the arc in amperes and this 1444 is a constant that constant has a unit of volts per meter length of the arc. So this formula gives us you can say that what will be the expected arc portion resistance associated with a fault. There are other formula like Warrington formula and so someone can have look on that also. These formulae differ in different aspects so these are empirical formula. This L also it will find descriptions the length of this one also depends upon the velocity of air because that depend upon that the arc will be so a day also.

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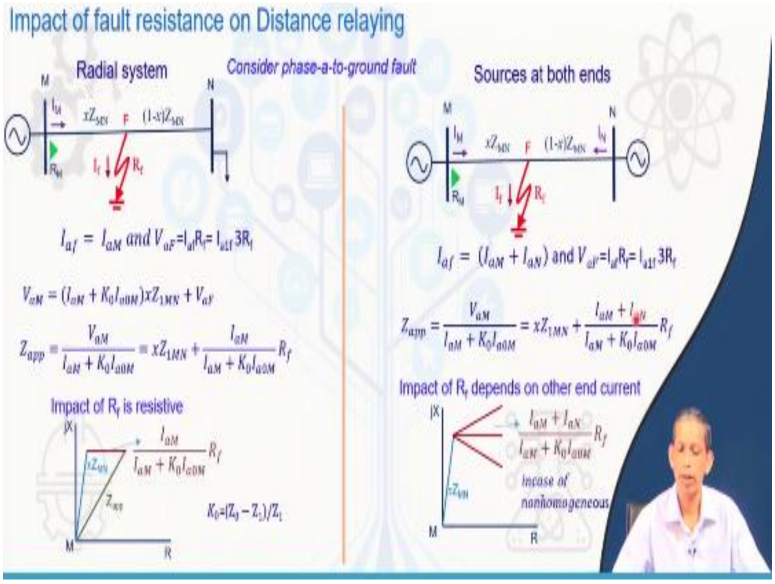

So, going further on this we will see how the effect of the fault resistance in different situations affect the distance relay. We see that this fault resistance is of significant value or phase-to-ground fault compared to phase-to-phase fault. So we will analyze the phase-to-ground fault. Let us consider phase a-to-ground fault for this simple 2 bus system. So this is a radial system power is flowing from bus M to N.

And the fault is there at F, x per unit distance from bus M and the relay R_M is a distance relay and how does it see. So we have derived this apparent impedance calculations for different kinds of faults, types of fault including phase-a-to-ground fault so this is extension of that. In those derivations we only consider R_f to be equals to zero solid fault. So in that case the fault point voltage V_F happens to be 0.

But now because of the presence of this R_f which consists of in this case the arc resistance, the tower footing resistance and the ground fault resistance. In that case this corresponding I_{af} flows through this one. So the drop V_{aF} becomes equals to I_{af} into R_f. Now for earlier one we are discussing V_{aF} equals to 0 and the V_F equals to particularly V_{aF} in this case equals to 0.

And we are talking about a positive sequence, negative sequence and zero sequence components of that summation of that were 0. Now here V_{aF} equals to this I_{af} R_f and if we remember the corresponding sequence diagram that becomes equals to I_{a1f} $3R_f$ where I_{a1f} is the positive sequence current through the faulted path and that equals to the zero sequence equals to the negative sequence component of the fault current for the phase-a-to-ground fault.

We can write this V_{aM} in a similar fashion to what we have discussed earlier in apparent impedance calculation like this $(I_{aM} + K_0 I_{a0M})xZ_{1MN}$ for this portion plus this V_{aF} this V_{aF} earlier was having 0 now you can say that substituted by this I_{a1f} $3R_f$ or that equals to I_{af} R_f. So substituting this and then Z apparent $Z_{app} = \frac{V_{aM}}{I_{aM}+K_0 I_{a0M}}$ as usual we do that this becomes to be xZ_{1MN} plus an additional term what we have discussed earlier.

This additional term is coming because we can say that this the corresponding R_f part where earlier you are considering Rf to be 0. So, if we consider this Rf only this xZ_{1MN} will come which we have derived earlier. So that results we can say that a plot on the RX plane so earlier you can say that our value line impedance you can say that happens to be this up to this xZ_{1MN}.

And then we can say that if we add the corresponding this part then this become we consider this red part we consider this is nothing, but the additional term. So that becomes we can say that now the apparent impedance happens to be larger than what we can say the corresponding line impedance up to x per unit was being observed by the relay. Note that this factor is having K naught and the zero sequence current plus the phase-a current.

So, it is a function of this you can say that three terms multiplied to the Rf. Now note that K_0=$(Z0 - Z1)/Z1$. Now in this Z_0 and Z_1 are having the same impedance angle then this we can say that K_0 becomes a real number and this I_{a0M} only considering the fault current that becomes equals to one third of I_{aM}. So, therefore this K_0 is a real number and I_{a0M} and I_{aM} they are being same angle along this I_{aM}.

So the angle cancels out and this become a real number with R_f. So, therefore what happens that if we add this value to this impedance value to a real number this total so that you can say that we just simply I can say that only X axis along the r axis you can say that will add value for this component, but if that is not so like this K naught becomes an imaginary and may be complex number which is having imaginary part also.

Then this you can say that addition will consider we will be having certain angle with respect to this horizontal line, but typically if you see that the imaginary value may be small and therefore you can say that the corresponding line will be very close to this horizontal line. Now we will see more generic form in a high voltage systems where an interconnected line will be considered. So source will be both the sides.

So we have M bus that we have seen now N side also we are having source so this we consider will be having now in this case for the same fault position what we have discussed earlier same line then what happens the only difference that current flows from this side also, current high value flow from right hand side to this fault path also. So, this I_f current fault path current becomes a summation of left hand side current plus the right hand side current.

So therefore I_{af} becomes because we are talking about phase-a-to-ground fault $I_M + I_N$ and then consider the V_{aF} that becomes equals to I_{af}, faulted path current in phase a equals to I_{a1f} $3R_f$ the way we considered we have seen in this side also and that comes from your sequence network diagram. So, we see that as compared to this radial system and additional current flows through this path that is the difference between this.

Now, if you proceed for you can say the apparent impedance seen by this R_M for this case then we will have $\frac{V_{aM}}{I_{aM}+K_0 I_{a0M}}$. These V_{aM} we can say that will having expression from like this with V_{aF} and all these things, but the V_{aF} we can say that is having now this in case of this perspective, but this Iaf we can say that only difference is that I_{af} that becomes an additional current IaN created from the remote end.

So that leads to we can say that situation of the corresponding apparent impedance seen by the relay without any Rf consideration when Rf becomes 0. xZ_{1MN} as usual plus $I_{aM} + K_0 I_{a0M}$. Now you see that this I_{af} this V_{aF} we can say that consider I_{af} so this I_{af} divided by this $I_{aM} + K_0 I_{a0M}$ coming from here. So, that leads to we can say that situation.

And therefore plus I_{aN} in the numerator is an additional term what we have seen for the radial system. So this infeed current from the remote end becomes a new factor here for the influencing to this additional term associated with the R_f. So, what we have seen here is that because of this we can say that modulating factor by this infeed current. So, this we can say that part will be having can be modulated in different angles.

That depends upon one perspective is that if the corresponding infeed side is not matching with the corresponding impedance angle of this side that is non homogenous situation then also we can say that the corresponding angle becomes modulated in this case and therefore we can say that it may be that horizontal line what we discuss here it may be modulating this side or that side depending upon the situation.

In addition this contributes we can say that factor now. So, therefore this part becomes may be a larger perspective because of this current and the current infeed become significant then this also will be significant and then this you can say that component becomes larger.

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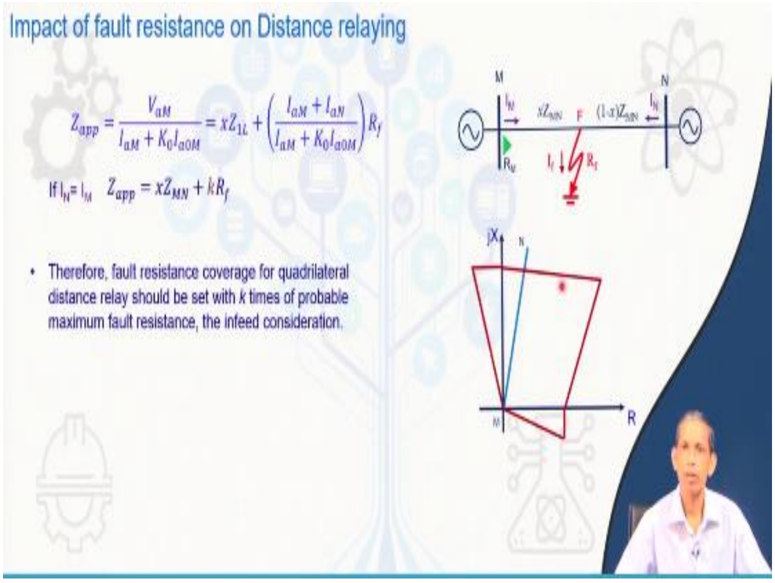

So, now we see that for the relations for the infeed case we have this expression. Now, if the amount of we can say current infeed becomes significant this side current or so. So, then we can say that we can have a factor of let us say consider this to be a factor of K. So, this K factor becomes we can say that may be significant as compared to this. So, if we that can be close to two times also depending upon both we consider infeed current becomes as far as the relay side current.

So, this leads to situation that if this factor becomes greater than 1 note that in a quadrilateral characteristic using numerical relay for ground fault. The corresponding fault resistance coverage which we are only thinking about we can say that only R_F we are considering to this impedance line from R_f. Now because of this we can say this these factor greater than 1 that must be considered we can say that there is a strong infeed situation for a line.

Once again so the fault resistance coverage for this kind of situations where infeed is higher must be this factor also must be taken into consideration for constructing the quadrilateral characteristics.

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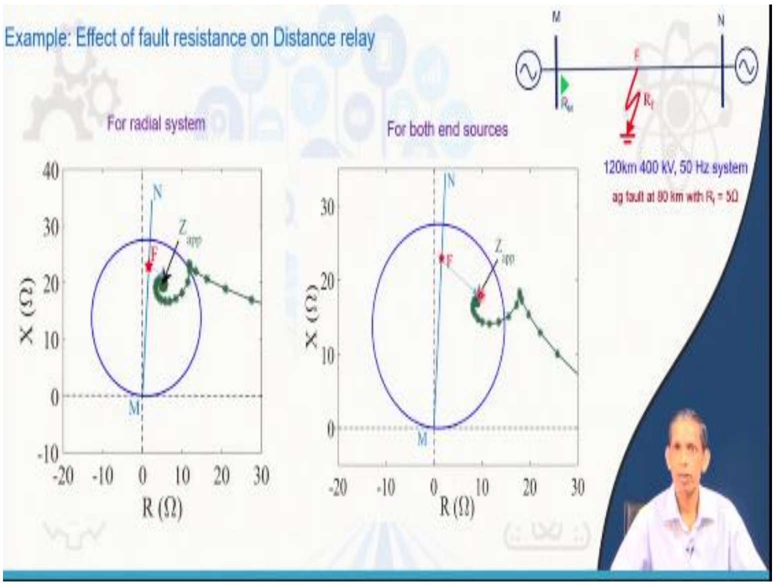

Now, let us take an example now. We have a 2 bus system 400 kV line 120 kilometer and we created a fault 80 kilometer from the RM phase-a-to-ground fault with R_f equals to 5 ohm only. In real situations it may be much more also. So, what we say that for a radial system we see the corresponding fault deviating from the line you can say that impedance line this much settling here with that 5 ohm.

So, if we have we can say that infeed then we can say that for the same case without changing anything here. Infeed we can say will be there first cases with radial no infeed in second case it is with infeed then we see that the corresponding R_f is increased and that is what in the earlier discussions we had that the corresponding K factor becomes may be larger and also the angle of modulation also may be larger and this way or that way depending upon the homogeneity of the situations.

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So now if the fault resistance becomes a prominent thing particularly for the phase-to-ground fault then the modulus apparent impedance then what is the solution for that? So, one is that the quadrilateral characteristics can be extended with high value of R_f so that the area coverage becomes more, but if we consider for this larger zone having, we can say that characteristics larger radial like zone 3 or so.

Then we will see consider in subsequent lecture on the load encroachment issue that one we can say that reach to the load area and that might consider create problem. So there is a limitations to increasing the fault resistance coverage with quadrilateral characteristics or so. So that limits the corresponding distance relay sensitivity for high fault resistance situation. So that gives us a scope and the solution we can say what is being used in industry is the sensitivity or ground overcurrent relay.

So, the ground overcurrent relay is being used in conjunction with the distance relay which we can say that can have better sensitivity as compared to distance relay in this kind of situations.

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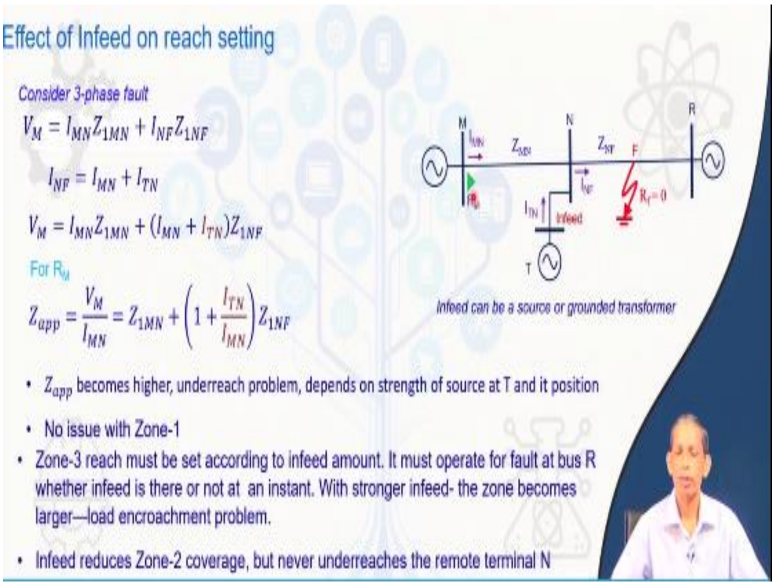

Now, we will go to another issue on distance relay on the infeed issue. So, consider a system like this 3 bus system and then at the intermediate bus we have another source connected so this source consider infeed's power to the grid. Now, what happens we can say that to this RM we would like to evaluate. This RM has three relays minimum that we are talking about zone 1, zone 2 and zone 3 characteristics.

So, in this kind of infeed situation this infeed can be a source and also can be a grounded transformer then it becomes a zero-sequence current close for the phase-to-ground fault also and that gives also considered a scope of infeed current zero sequence infeed current at that situation. So, in that kind of situations what happens for the relay M bus we would like to evaluate and then it concludes the effect on resetting perspective.

Now, for simplicity consider here three phase fault so this V_M becomes equals to for this fault in the let us say second line. This can be in zone 2 or zone 3 depending upon the distance from this one. So, the corresponding V_M becomes equals to $V_M = I_{MN}Z_{1MN} + I_{NF}Z_{1NF}$. So, you can say that drop here the voltage you can say that at plus M the corresponding INF through this path that becomes equals to the current $I_{MN} + I_{TN}$.

The corresponding infeed which is going from this source or the corresponding transformer path. So, now we can say that this additional current as compared to the earlier discussion is now the issue that leads to this V_M substituting this corresponding I_{NF} that becomes equals to $I_{MN}Z_{1MN} + (I_{MN} + I_{TN})Z_{1NF}$. So, without this become equals to only I_{MN}. So, this additional term is the concern.

So, for R_M this Z apparent for 3 phase fault $\frac{V_M}{I_{MN}}$ any phase voltage any phase current so that equals to Z_{1MN} visually, but now with infeed this term we considered is coming to picture. So, this you can say that becomes equals to Z_{1NF} that is this one this portion Z_{1MN} from N to F and the corresponding factor 1 plus I_{TN}/ I_{MN}, the infeed by this I_{MN}.

So, this you can say that the additional term is the corresponding apparent impedance seen which is having more as compared to what we have seen for earlier case. So, what we see here that the Zapp becomes higher because of this infeed. So, we can say issues with the corresponding apparent impedance seen by zone 2 from here will be smaller, but note that we can say that this does not create any problem to the zone 1 protection perspective.

So, because the infeed does not have any effect on the zone 1 side to this line side create problem to this side. Now, the point we can say that is that for the zone 3 reach must be considered if we think about the zone 3 that will be significantly affected because this portion will be coverage, but the zone 3 must we can say that cover up to bus R. So, for that one because this one we can say that underreach kind of situation kind of things.

So, therefore the coverage must be extended such that the corresponding R bus also seen within zone 3. So, the zone 3 has to be extended as compared to the without infeed situation and that we can say that case depending upon the infeed amount the corresponding zone 3 should be said accordingly. Furthermore, the zone 2 because of this underreaching kind of problem the zone 2 coverage on this portion reduces.

And thereby we can say that that the only difference we can say that with the infield. The other issue is that infeed may be there at times and infeed may not be there. So, therefore the relay what will be there for zone 1, zone 2 and zone 3 they should not have any problem we can say that in both the situations. So, that must be addressed for the reach setting or the relay setting.

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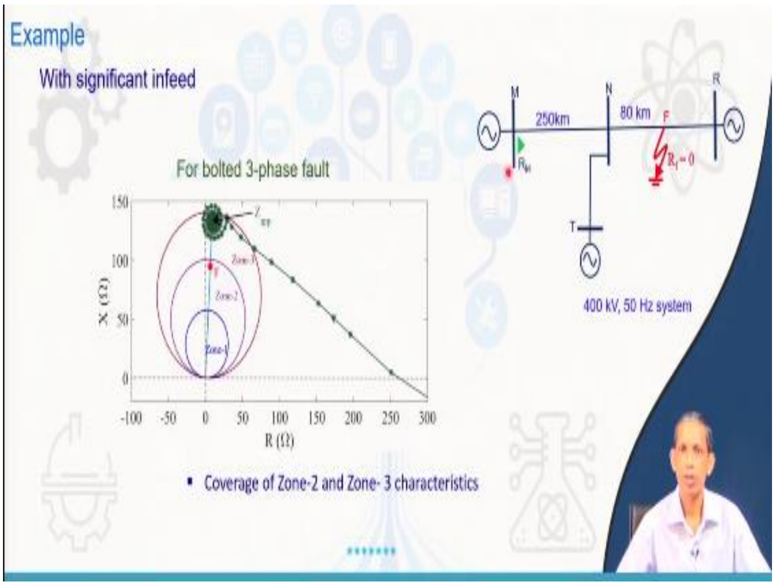

As an example this is a case to 250 kilometre first line, in the second line at 80 kilometre 3 phase fault is created and what you see that this is 80 kilometre in zone 2 of this relay, but if you see the corresponding fault to be beyond zone 2 it settles in zone 3. So, this clearly says that we can say that the apparent impedance seen by the relay is higher than expected we can say that it should be F point.

And this is nothing, but due to the even though R_F is 0 here no fault resistance like what we discussed earlier. The infeed creates problem and the apparent impedance seen by the relay becomes more. So, that says that the coverage of zone 2 and zone 3 are affected. So, considering the maximum infeed at this bus the corresponding relay here has to be set. So, we discuss the effect of fault resistance and the infeed on impedance on the distance relay perspective. Thank you.