Power System Protection
Professor. A.K. Pradhan

Department of Electrical Engineering

Indian Institute of Technology, Kharagpur

Lecture No. 21

Distance Relay Implementation

Welcome to NPTEL course on Power System Protection. In this lecture we will continue with distance relaying and the implementation issue.

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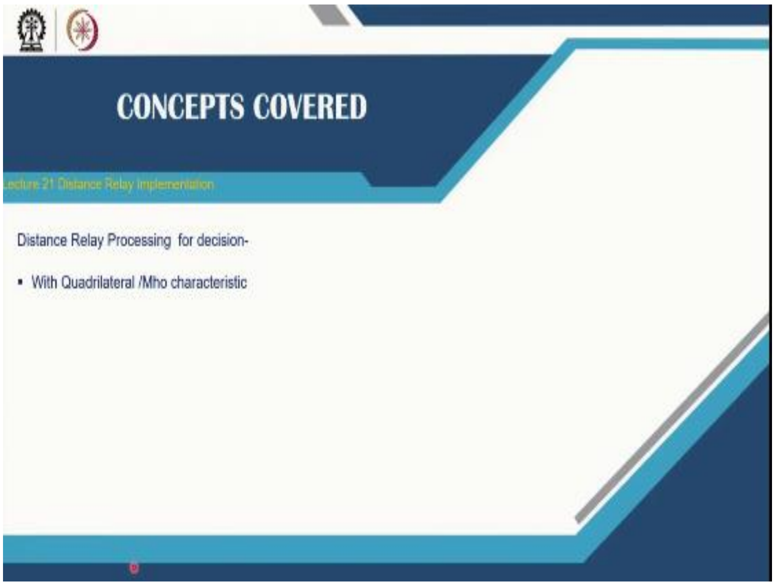

Our focus will be on the processing of different states in a distance relay for the final decision and specifically quadrilateral and Mho relay characteristics.

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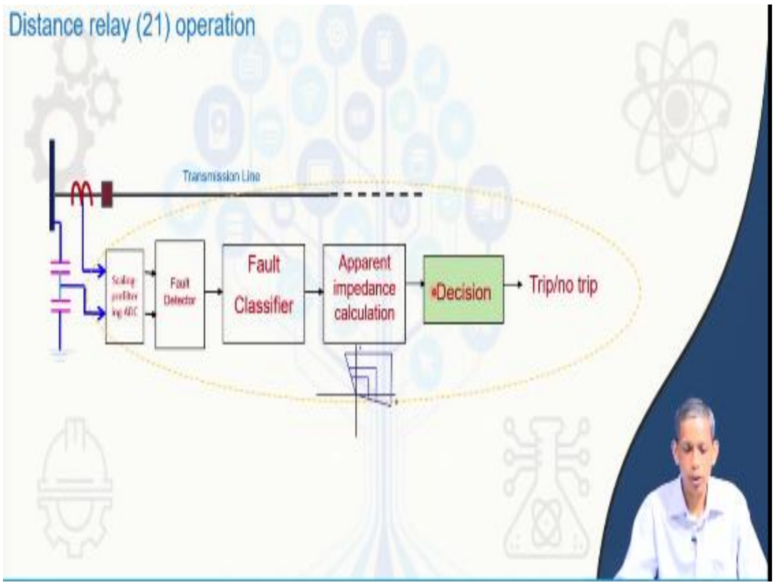

We have already discussed this different steps associated with distance relay. Last lecture we discuss about apparent impedance calculation with different examples. Now in today's lecture, we will talk about how the decision is being derived.

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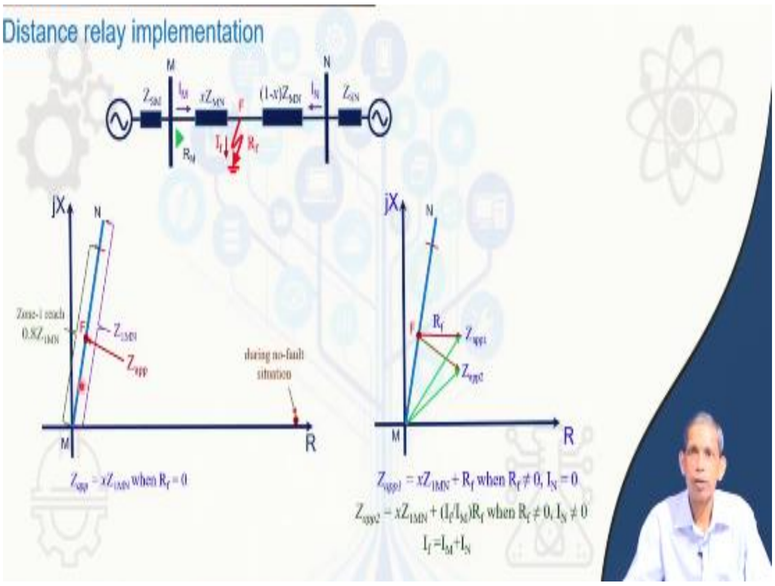

So, let us go to a 2 bus system interconnected one both side sources. So, on the R-X plane this relay R_M let us throughout this lecture we will talk about only zone 1. We can extend this idea to zone 2 and zone 3 also. So, an internal fault F here and we have 3 kilometers of this and rest of the kilometer this side. So, consider that this is a zone 1 fault. So, for this the corresponding impedance line positive sequence impedance of this line becomes M to N.

So, we know that distance relay computes the positive sequence impedance up to the fault point Z apparent. So, therefore our setting here is based on the positive sequence impedance of the line. Zone 1 setting typically from 80% to 90% of the line section here M and N and corresponding positive sequence component. So, this is MN line so the corresponding angle is R/X ratio of the impedance of the line.

This corresponding this point corresponds to the reach of zone 1 see here you have considered 80% , $0.8Z_{1MN}$. So, M to N is 100 % of Z_{1MN} and M to this point the reach of the zone 1 is 80% we have considered here and that is $0.8Z_{1MN}$. Now in this R-X plane if we see the corresponding loading condition no fault situation, then the corresponding impedance seen by the relay will be much, much higher than any characteristics.

Because if you compare with the fault with the loop impedance as seen by the relay is only a portion of the line whereas in case of load condition the impedance which will be seen by the relay depends upon the voltage and current and that will be the line impedance plus if we have load here the load impedance or the equivalent impedance here. In case of a radial system if load will be connected.

So, the corresponding line impedance for the load impedance that we have already discussed in earlier classes also. So, the point here is that load impedance as typically in a transmission system the power factor is close to unity. So, the impedance seen by the relay at that time will be close to the real axis that is the R axis and it will be much, much higher value. So, let us consider this operating point during no fault condition is this one.

Now when a fault happens to be there then suddenly, corresponding current becomes significant as seen by the relay and the voltage becomes down and the corresponding V/I ratio proper V and proper I for the fault then the corresponding point is expected to lie on line section portion I can say that of the reach of the relay. So, what you see here that from the no load condition the point travels and then finally settles on to the we can say that fault point which we have already discuss in earlier lecture about the Z apparent computed by the relay.

The Z apparent as seen during no fault condition becomes a point close to the real axis far away from this impedance line. Whereas, you can say that at the time of fault we expect that a corresponding fault point lies on the impedance line and as in this case if it happens to be on the line section within this reach of the relay then the relay can declare that this is a zone 1 fault.

Now let us say this is a condition when you consider the corresponding $R_f = 0$ there is no arc resistance, fault resistance associated in this part, but see now what happens in case of when the fault resistance we considered a fault resistance. First condition the system to be radial no current flowing from this side only current is flowing from this side. So, the current through this fault path is only the current which is seen by the relay I_M.

So, the impedance of this slope a corresponding voltage divided by this total impedance in this part that impedance also includes R_f, but we know this line is the impedance impedance of the line. Now if we include this R_f so this you have to include this R_f at all point here. Any fault we can say happens to be here for this corresponding considered point we have to include an R_f.

So, R_f is resistive we consider so then we can say that it will be a horizontal line. So, for this fault point if we include R_f then that becomes $Z_{apparent}$ at that time with inclusion of R_f. In this case we consider a situation of without R_f, $R_f = 0$ now with R_f the corresponding impedance becomes this. So, let us consider that becomes equals to Z_{app1} , first condition with R_f.

Now another condition in an interconnected system with a fault resistance if we see here the fault current here with phasor sum of current from M side and also from the N side. So, therefore $I_f = I_M + I_N$,. In that scenario when $R_f \neq 0$ and we have a contribution of I_N from right hand side source also $I_N \neq 0$, then we see that the Z apparent becomes equals to what the voltage here will be no more you can say that only controlled by this side current.

The voltage here considered here V_f will be governed by the current from right hand side also $V_f = I_f .R_f$ but $I_f = I_M + I_N$, $V_f = (I_M + I_N)R_f$. So, the V_f here will be also is a function of corresponding current I_N that leads to situation of the Z apparent in the second case with infeed consider from the right hand side. The $Z_{app2} = xZ_{1MN} + (I_f / I_M) R_f$.

So, we see here we can say that however the I_f is a function of I_N also and in that case the corresponding if you go for the considered corresponding voltage by current the Z apparent may be modulated from this you can say that horizontal line inclined this way or that way depending upon the corresponding infeed from source from the N bus. So, that leads to a situation that the corresponding R_f value here will be in terms of this or that.

And that leads to the Z_{app2} to be this way. So, that means that from this you can say that two pictures we concluded that in case of R_f to be included which is more practical then only that impedance line cannot be the required characteristics for trip decision. So, to include R_f we have to have a characteristics which can include the R_f also.

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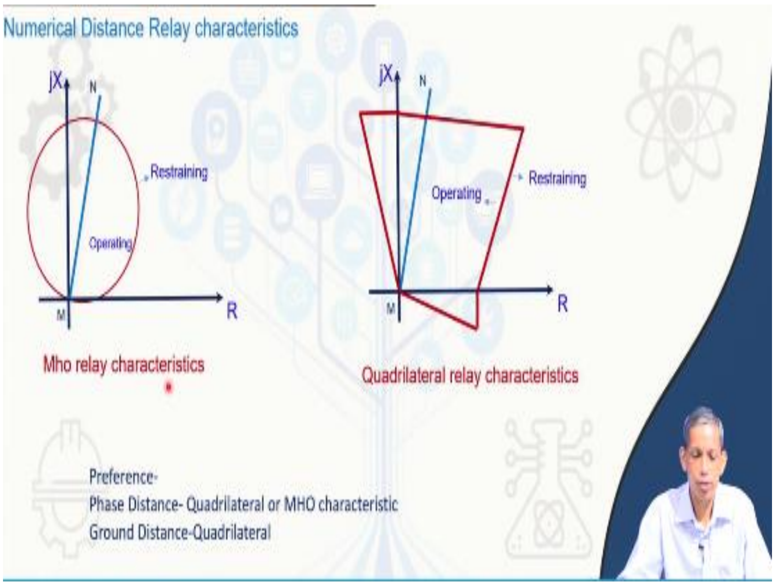

In that respect we have already discussed two characteristics which are being used in numerical relays mostly. Others are also there in transmission and applications and all these things these two characteristics are more common. So, on the R-X plane we have already discussed Mho characteristics in the Mho characteristics we can say that this is the line, transmission line M to N the corresponding impedance line and we talk about 80 %.

So, we make a circle with center you can say that with this being the diameter. Now the inside one is the operating region outside the restrain region. So, if we see here as we are discussing on R_f issue so at each point you can say that some R_f values can be included, the Mho characteristics as such includes we can say that some R_f values from the line impedance. So, it accommodates some R_f value.

So, therefore any fault happens to be there with some value of R_f also can be taken care by the relay correctly. Now when you see the quadrilateral characteristics if this is the corresponding impedance of the line, then the quadrilateral characteristics can be like this. So in that case, in that case the inside one is operating and the outside one is the restraining region then we say that with respect to this impedance of the line the characteristics can accommodate R_f.

One flexibility with the numerical relay with quadrilateral characteristics is that you can include more you can say that R_f if we receive the corresponding line more towards the right. So, this accommodative thing of R_f of the quadrilateral characteristics is more beneficial for the protection schemes whereas the R_f which we see from this Mho characteristics is having a limited value.

So, as per the application is concerned the phase distance relay like our phase-to- phase fault quadrilateral or Mho can be there both can be good at because in such conditions the corresponding R_f value is not high, but for ground distance relay in many applications it is required this R_f value to be significant. So, there the quadrilateral has an advantage. As far as the application is concerned many countries they only refer to for all you can say that transmission line with protection application with distance relay using quadrilateral characteristics. Countries also use both Mho and quadrilateral characteristics in the distance relay applications.

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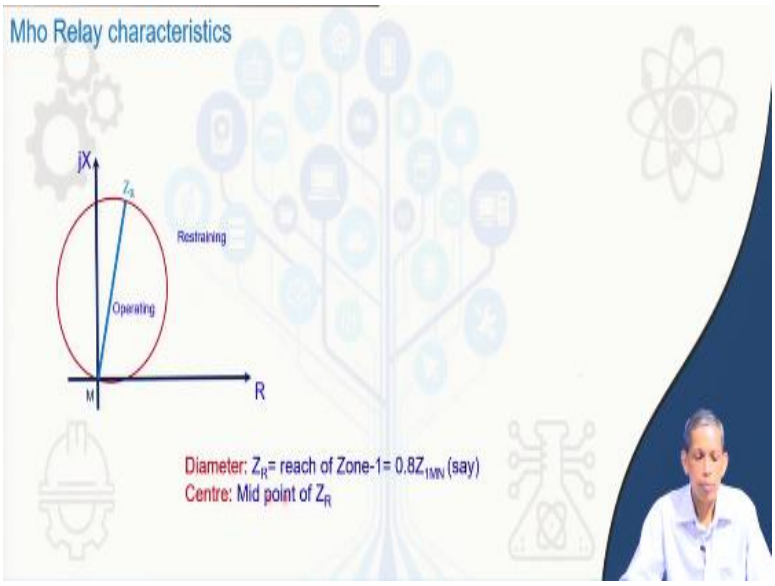

Now going to this how Mho characteristics can be applied in the distance relay. First we will see that we have already mentioned this circle corresponds to the corresponding Z_R the reach of zone 1 let us say we are discussing only zone 1 in this lecture. So, reach of zone 1 we can consider here let us say 80% of the line from M to N in our example. So, 80%, $0.8Z_{1MN}$. Center of this line is a midpoint of Z_R and then we have the circle. So, any Z apparent inside the circle is a fault point as we have already discussed that is accommodating some R_f. So, this is all about we can say that Mho characteristics which is passing through the origin.

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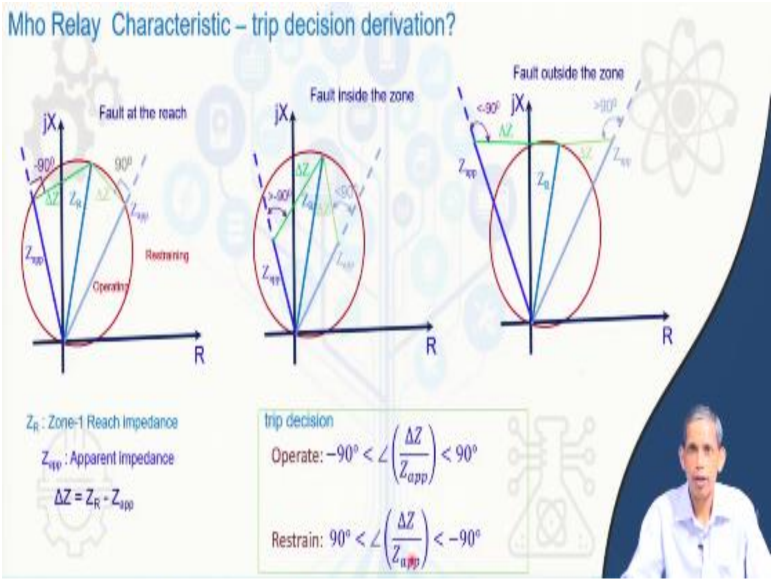

Now let us see now how a distance relay considering Mho characteristics takes the trip decision. So, for that decision it put some logic and how that logic is being used that we like to see. So, let us see this first picture here if you see this is our Z_R up to the reach point the impedance of the line with 80% setting let us say. Now let us say for a fault on the boundary of the reach at the boundary at the reach point if the fault happens to be there fault at reach.

At the remote point in zone 1 remote point at zone 1 so that is about this point because this circle refers to circle point refers to the reach point. So, it happens to be some R_f at this point. So, this is your Z apparent calculated by the relay. From this Z apparent if we put this one so we define $\Delta Z = Z_R - Z_{app}$. So, we are defining a term $\Delta Z = Z_R - Z_{app}$.

For Z_R it is the set point for the reach as we have already mentioned here $Z_R - Z_{app}$. Z_{app} is calculated by the relay using the corresponding voltage current ratio. Now see a condition when the fault happens to be inside the zone, zone 1 here then suppose find a point we consider Z apparent here inside the line, inside the zone 1, Z apparent here. So, this is the Z apparent line this is our Z_R line the line impedance line up to the reach of the relay and this one is ΔZ here $Z_R - Z_{app}$.

Third case fault outside the zone. So, let us outside the zone so therefore the Z apparent happens to be outside a point here. So, this is Z apparent so this is our Z reach so this is ΔZ this one is ΔZ for the case. Now if we see this 3 pictures 3 situations fault at the reach point, fault inside the zone, fault outside the zone 1 here. So, if you see this from the circle geometry of the circle this angle becomes 90^0.

So, the ΔZ subtends an angle of 90^0 with respect to Z_{app}. In this case with in zone fault zone 1 fault inside zone 1 the corresponding angle becomes less than 90^0 when the fault becomes out of the zone out of zone fault beyond the reach then the angle becomes greater than 90^0. So, which angle the $\angle\Delta Z$ subtends with $\angle Z_{app}$. So, we say that here from that if the corresponding such angle becomes less than equals to 90^0 then we say, it is zone 1 fault else if it is greater than 90^0 then this is beyond zone 1.

So, we see here the decision process now can be derived from the angle relations between ΔZ and Z_{app}. Now we will make it more generalized. This is the region of Mho relay so we expect considered a fault during a fault the corresponding Z apparent can take a position in this side of this impedance line or can be this side also. Now, if the corresponding fault point happens to be in the left hand side of the Z_R.

Let us say the reach point then this angle becomes again 90^0, but note that in this case the corresponding ΔZ, this angle becomes -90^0. So, here if we say this becomes this and this become this. So, if you see here you can say that as compared to ΔZ line this line you can say that each advancement if you put a parallel line here ΔZ here. So, on the complex we can say that advancement of 90^0 , Z apparent will be there. Whereas in the first case Z apparent ΔZ this side so Z apparent was lagging to this delta Z with a 90^0 case.

Now ΔZ is lagging to this Z apparent by 90^0 so that is why the -90^0. Fault inside the zone again if the Z apparent point happens to be left of this Z_R. So, we can say that this angle becomes greater than -90^0. So, that is the point and when the fault is outside this one so this you can say that becomes less than $- 90^0$ because of this minus sign.

So, the angle becomes larger and it is beyond we can say that 90^0 then it is in a negative side. So, these 90^0 , -90^0 , $< 90^0$ and $> - 90^0$; $> 90^0$ and $< - 90^0$. These are the 3 clear conditions for we can say that the angle between ΔZ and Z apparent which reveals the corresponding decision process.

So, therefore a trip decision can we say that the inside of the zone is an operating region, inside of this boundary is an operating region so the relay should operate for a trip decision if the corresponding $-90^0 < \angle (\Delta Z/ Z_{app}) < 90^0$. But it should restrain in case of $90^0 < \angle(\Delta Z/ Z_{app}) < -90^0$ (anticlockwise).

So, from this we can conclude that the Mho relay can go for a trip decision by computing such an angle.

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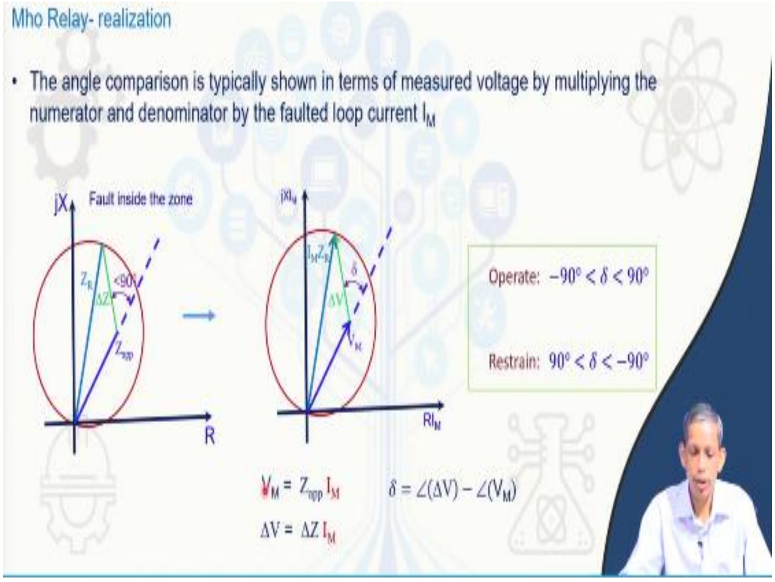

More easier things can be achieved in the realization of this steps. So, what we do here this diagram we have already seen in the earlier slide these are all based on the impedances we multiplied to each impedance and the reactance and resistance to all with I_M. For example, Z apparent we multiple with I_M phasor so that becomes equals to VM= $Z_{app}I_M$ the corresponding voltage of the relay.

$\Delta V = \Delta Z.\ I_M$. So, we multiply to these $\Delta Z.\ I_M$ that becomes ΔV and we have $Z_R.\ I_M$. We have jX .I_M (())(23:04) and R. I_M. So, we multiply with all we can say that R,X and Z component by IM. So, we can say that this so therefore what we see that the corresponding VM and this and then we consider $\Delta V = \Delta Z.\ I_M$. So, by computing this we can say that we can use directly corresponding the voltage of the relay and this ΔV if we compute like this whatever Z apparent seen and then Z_R - Z_{app} that gives you ZI and then multiply with IM so those are all voltage.

So, these two voltages now we will compare when we (())(23:49) we can say angle that $\pm 90^0$ angle between ΔZ and Z_{app} that becomes suppose (())(23:55) we can say that the delta here showing. So, this delta follows the same angle because this phasor and this impedance triangle are same. So, therefore the relay will operate in case the delta becomes lies in this (-90^0 , 90^0) and it has to restrain in case it lies between $+90^0$ to -90^0.

So, this concludes that we can implement the Mho relay characteristics by computing the V_M and ΔV_M and finding out this angle between them. As we see here $\angle \Delta V_M$ - $\angle V_M$ as reference and that angle if it implies between this range it operates otherwise remains silent.

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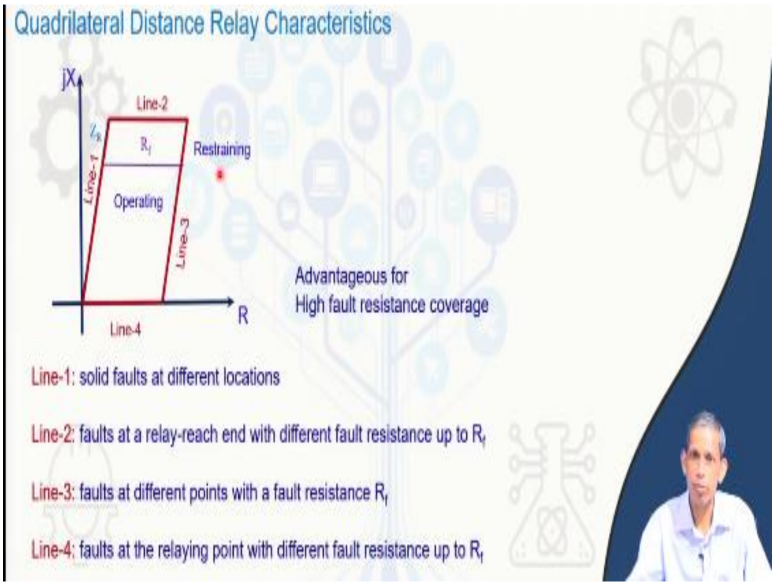

Now going to the quadrilateral characteristics more important one. So, if we consider this line 1 corresponds to the Z_R the impedance of the line there is Z_1 setting so let us say 80% or 90% setting up to this point. Line 2 is the coverage for R_f line 2 faults at reach relay and we consider different fault resistance up to R_f we can add from R_f. So, each point if we add R_f and R_f and R_f so then we can say that we get a region like this and that is where the line 3. And then we can say that this is at the origin means M bus the relay bus so this is about the coverage.

So, that leads to situation that from the impedance of the line if you have a coverage for the R_f then you get a characteristics like this and this is what we approximate a quadrilateral characteristics. So, this is the operating region inside this quadrilateral and outside this is the restraining region. So, as already mentioned depending upon the requirement of this R_f, the engineers can set the corresponding R_f value and it can extend the corresponding region more and more. Only problem is that if we include more R_f value it is approaching towards the load in case of zone 3 also because zone 3 region will be more and more.

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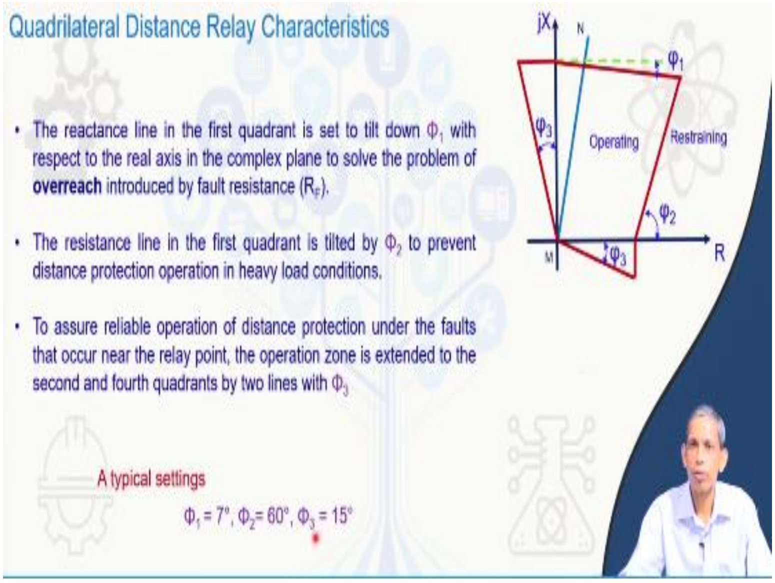

Now, a typical quadrilateral characteristics in a relay it is further more refined and shown we consider as shown earlier also shown here we can say that more details. So, we will see here that quadrilateral the corresponding lines are being modulated. Why these lines are being modulated and how the corresponding angles are being set we will explain here in this slide. So, we have this line having to this horizontal line it subtends an angle ϕ_1 little bit smaller to avoid overreach condition because the relay has infeed from the right hand side also.

So, there is a chance of overreach condition and that is not desirable because it may extend you can say that to the other zones, other lines and so. So, therefore we can say that we include an angle with respect to the horizontal line which earlier in the earlier slide we are considering to accommodate Rf and then we consider we say this corresponding ϕ_1 angle with that one. So, this is to overcome to overreach issue.

Now the ϕ_2 angle we see here what happens that this region becomes the load region. We expect the load to be on the R axis because a unity power factor close to unit power factor load for the transmission system. So, to prevent the distance relay operations for heavy loading heavily loaded conditions, we make the corresponding ϕ_2 to be squeeze we incline like this not like a vertical line to reduce this portion we expect this portion to be the load region typically for zone 3 case.

And then we consider this is the vertical line then you have ϕ_3 both the sides this ϕ_3 what it does that when a fault happens to be near the relay bus. So, to accommodate all the faults near to this relay bus both these sides the corresponding characteristics is being extended with an angle of ϕ_3 because of all uncertainties and so. So, this is in total is about the quadrilateral characteristics.

We say from the earlier simple quadrilateral characteristics we modulate the things with ϕ_1 ,ϕ_2 and ϕ_3. A typical relay shaped design a corresponding ϕ_1 becomes 7^0, $\phi_2 = 60^0$ and $\phi_3 = 15^0$ kind of thing.

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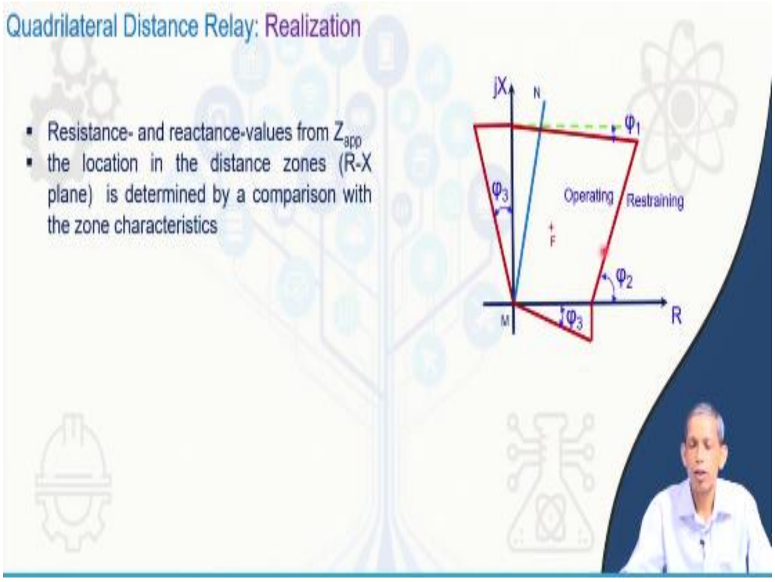

How the relay with quadrilateral characteristics does the decision if that we say in case of a fault in the zone 1 let us say this is zone 1 characteristics. The fault point is expected to inside the operating region then what the relay does that the Z apparent being calculated using the corresponding relations for voltage and current. So, the real part of the apparent impedance is resistance and the imaginary part is the reactance. So, resistance and reactance are calculated and in the RX plane with the quadrilateral characteristics the point the point is fixed with the Z apparent calculated and thereby you can say that the relay now finds whether it is inside the different limits upper, lower and this high limits are now and accordingly makes decision on the protection.

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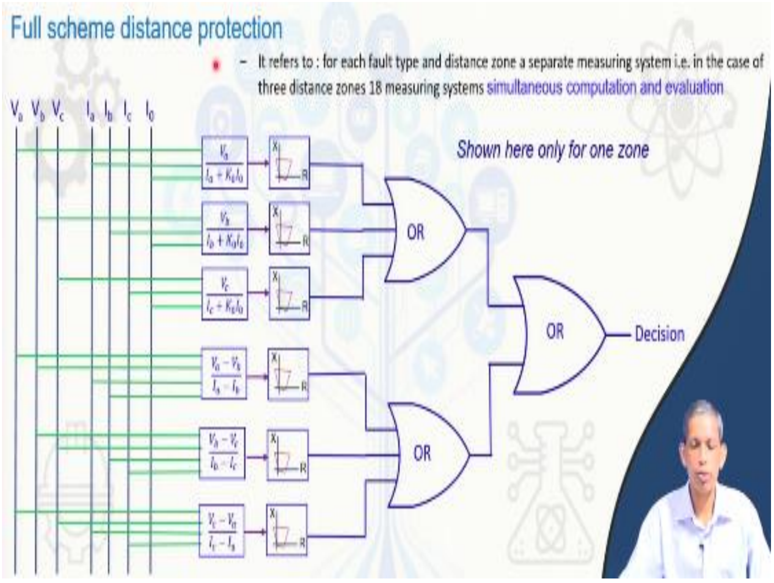

There are different schemes which the relay uses in numerical relay. Present newer versions of the relays, numerical relays accommodate full scheme distance protection and let us see what do you mean by that in realization of the distance protection schemes. It refers to that for each type of fault and for each zone the relay uses a separate measuring system. So, thereby we have let us say 3 zones. Each zone we have 6 measurement process. Why 6? We have Ag, Bg, Cg type 3 phase-to-ground faults.

We have Ca and Cag, Bc and Bcg and Ab and Abg these 3 sets they have the corresponding apparent impedance relation same. So, phase-to-ground and phase-to-phase or phase-to-phase-to-ground. We have 6 loop equations and from there we have the corresponding voltage current relations to calculate the Z apparent. So, this each zone requires 6 relations to calculate the Z apparent. To realize that relations each zone uses 6 calculations, 6 into 3, 3 zones 18.

So, therefore, 18 measuring systems and related calculations simultaneously being computed and evaluated in a distance relay. Here for simplicity we shown only for one zone we can extend this for other zones also. So, what you see here that the set of voltages and currents including 0 sequence current (Ia+ Ib + Ic)/ 3. So, what we see here we have Va/(Ia + K_0I_0) so this relation is for phase-to-ground fault. Checks inside the characteristics if it is inside then it goes to the trip decision.

For any fault if from these relations which we have already studied in Z apparent calculations. If any point any apparent impedance calculated during a continuous process of Z apparent calculation any point fault inside any characteristics the relay with an OR operation makes a decision. So, what the relay does here that without going for the detection, without going for the classification it continuously calculates the corresponding Z apparent from this voltage and current measurements.

Using this all these 6 relations for each zone and if any of the zones is the corresponding apparent impedance inside any point the relay makes a decision. So, this is about the simultaneous computation in evaluation approach called full scheme distance protection approach.

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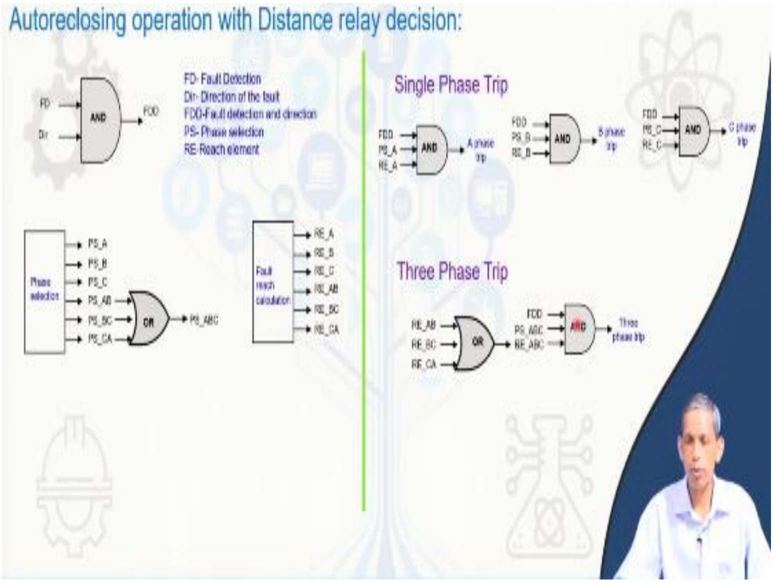

Note that distance relay does other aspects also. One of the important aspect is auto-reclosing. So, in many applications it is advantageous to have single phase tripping so that this stability can be maintained in a better way. So, in that also 3 phase auto-reclosing for different applications. Now how that can be applied how that can be realized with the distance relay we would like to see that.

So, we have fault detection, directional relay, combined this, fault plus directional relay. If it is in forward directions so this becomes it is fault and it is a forward direction this becomes forwarded signal is output obtained otherwise no signal output. Now come to the second module, phase selection we have this classification phase A, phase B, phase C, AB, BC, CA or ABG, BCG, CAG.

And we can OR circuit for this and we can say this to be a ABC kind of thing. Why will see other perspective later on. Fault reach calculation so following this for a phase selection, fault type we know the corresponding relation and then we go for the reach calculation. Reach A, reach B, reach for C, reach for AB, BC, CA. Now how we will realize the trip business for the auto-reclosing.

Single phase trip or 3-phase trip so a single phase trip options. So, if you find any of these 3 any of the 3 phases only not here then what you do with that. The fault is detected, direction is in forward a FDD is certifying, Phase A certifying here phase you consider this selection is certifying it is Phase A reach is certifying that yes it is inside then we make an AND operation and then trip the phase A only with the single phase tripping option.

Similarly, for phase B and phase C and using the 3 phase tripping case note that if the fault is not of this category or first three phase-to-ground, then the fault is in this category then it has to go for 3 phase trip decision. So, therefore what is being done if any of the reach lower phase-to-phase or double phase-to-ground find the corresponding reach inside then this will be there we make it OR so therefore reach ABC.

And this phase ABC, ABC here corresponds to the 3 phase tripping. So, 3 phase tripping for 3-phase tripping ABC this is okay, we combine all these 3 reach any of the reach you can say satisfy that this is fault then RE ABC becomes okay. So, this input PS ABC from this input and fault detection and direction is okay. So, if this is okay, this is okay, this is okay to make an AND operation and go for the 3-phase tripping business.

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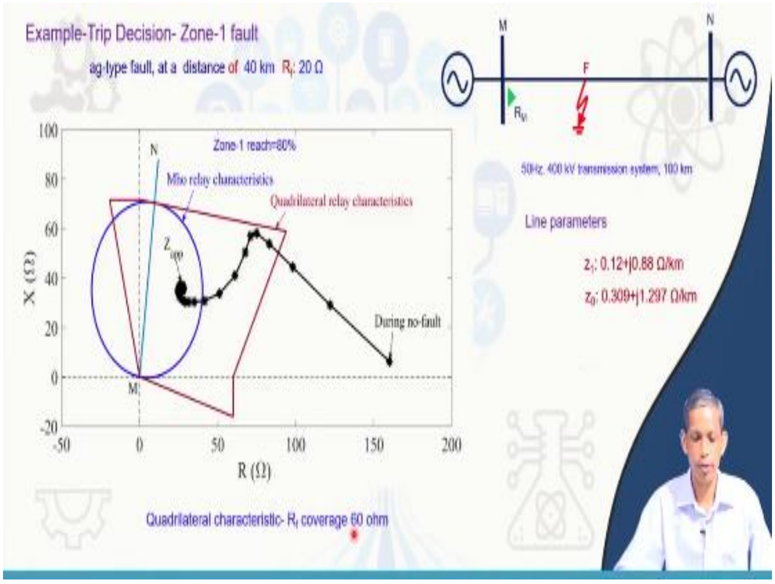

Now we will see some examples how the corresponding zone 1 faults happens to be there and how the zone 1 fault is being realize or seen in Mho relay characteristics and in the quadrilateral relay characteristics. This is a transmission system 400 kV, 100 kilometer length, interconnected system, line parameters z_1 per kilometer and z_0 per kilometer given here, ag type fault, phase a-to-ground fault.

Distance from 40 kilometer from the relay, R_f consider 20 Ω , fault resistance this part considered to be 20 Ω. So, therefore what you say that during no fault situation for this relay the relays sees a point far away from the characteristics. So, we have Mho relay characteristics 80% set zone 1 depending upon the positive sequence impedance and this is about the quadrilateral characteristics as we have defined with ϕ_1, ϕ_2, ϕ_3 and this $0.8Z_{1MN}$.

Now you see that for this case the final point Z apparent is computed by this relay settles at this point, this is inside the Mho and also this is inside the quadrilateral characteristics. This implies that the quadrilateral characteristics and the Mho characteristics they are able to see this fault correctly with a fault resistance of R_M. Note that for the quadrilateral characteristics we have a R_f coverage of 60 Ω in this case.

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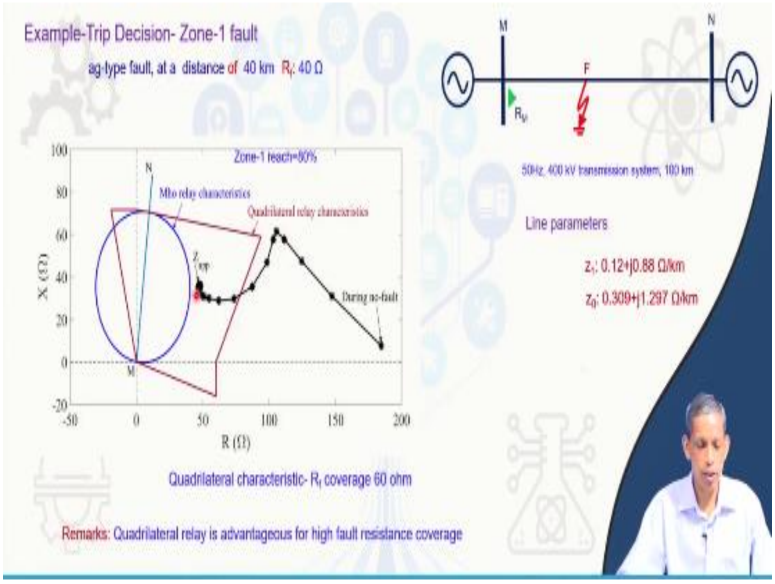

Now we go to the second example with the same 40 kilometer fault only have changed the fault resistance with 40 Ω, the fault resistance in now increased. Now you see here the Z apparent computed now settles finally at this point which is outside the Mho means more relay we will not be able to see this fault which is inside the quadrilateral. So, quadrilateral characteristics for zone 1 we will be able to see the fault.

Fault is in 40 kilometer out of this 100 kilometer line so it is in zone 1 only we have increased the fault resistance to 40 Ω. Now notice that with a coverage of 60 Ω this quadrilateral characteristic is able to find the fault inside the zone, inside the quadrilateral characteristics. So, the quadrilateral is okay and Mho relays fails here and we have already told from the beginning that Mho relay have limited R_f coverage. This is the strength of quadrilateral characteristics in high fault resistance coverage.

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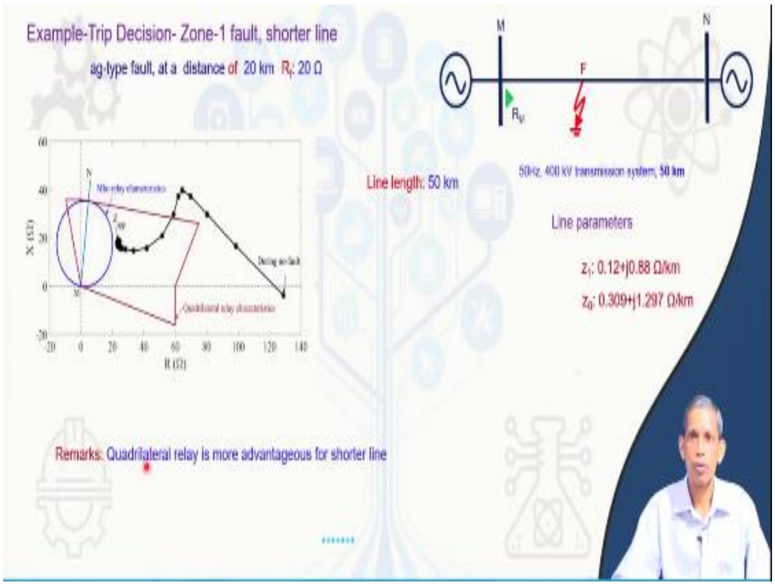

Another example this line section is smaller now see the situation line is now 50 kilometer, fault is at 20 kilometer, 20% earlier it was 40% out of the 100 kilometer fault resistance 20 Ω. So, line is now shorter. So, in a shorter line what happens that we will like to see and fault resistance just like the first example is only 20 Ω. So, the corresponding quadrilateral characteristics and the Mho characteristics are shown here for with 80% coverage for the quadrilateral characteristics 60 Ω coverage.

Now what do you see that only for R_f equals to 20 Ω the fault at 20 kilometer settles outside the Mho characteristics, but inside the quadrilateral characteristics. Again here the Mho characteristics fails to find the fault inside the zone. The reason behind that because the corresponding Mho characteristics the line length is small. So, therefore the corresponding R_f coverage for the Mho relay with shorter line becomes much smaller because of the smaller radius.

And therefore, with R_f equals to 20 Ω, it fails to find the fault inside the characteristics. So, thus the quadrilateral characteristics has advantages for shorter line application also. So this is on how the different characteristics are being realize in distance relay applications. Thank you.