Power System Protection and Switchgear

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Lecture 18

Protection of Transmission Lines Using Distance Relays-V

Okay. So, let us start our discussion. Let us continue our discussion. So, let us consider the one important impact of fault resistance on the performance of distance relay.

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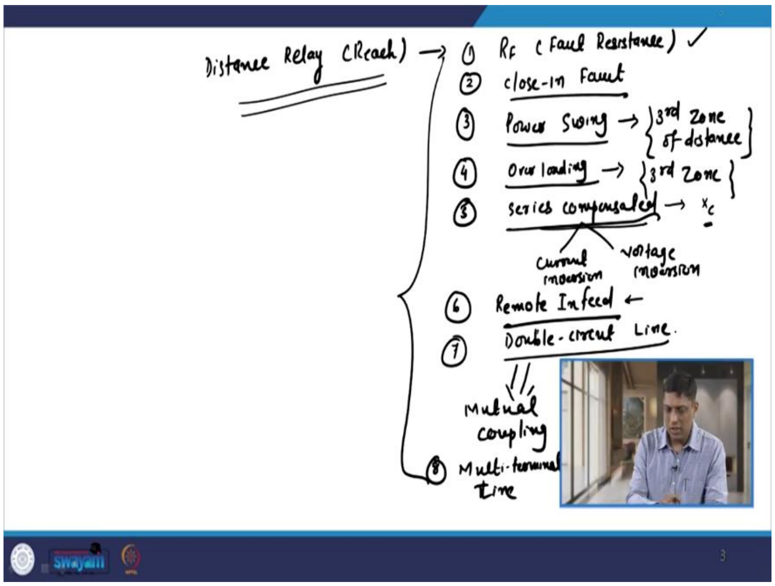

So, if I consider what are the different impacts of distance relay, then the performance of distance relay, we can say the reach of distance relay, that is affected by many parameters. The first that is known as the fault resistance RF. So, that is fault resistance, because whenever we consider the performance of the distance relay, we consider the solid fault. But whenever fault involves some resistance, then it's a reach that is affected.

The second is the reach of distance relay is also affected when we consider closing fault. So, when we consider the closing fault, then also, as I told you in case of overcurrent relay also that whenever fault occurs very near to the bus or relay, then the whatever the voltage given to the relay in case of directional relay that is not sufficient and if triple L fault occurs, then the voltage of all the three phases that reduces to very low value and that voltage is not sufficient because some polarizing quantity or voltage is required for directional relay. So, distance relay is also affected by close-in fault.

The third problem that is known as, because of the power swing, so whenever the power swing, we will discuss later on that whenever the power swing comes, then there is a problem of mall operation of distance relay and this is specifically in third zone of distance relay. So, which is backup, so third zone of distance relay. In that case, the distance relay may mall operate. So, in the actual field, some blocking feature is provided. So, whenever power swing is detected, then the third zone of distance relay that is blocked, means operation of third zone of distance relay that is blocked by some blocking feature.

The fourth problem that occurs that is because of the overloading condition. So, whenever the overloading on the transmission line that is carried out, then the reach of again in this case also the third zone of distance relay that is affected because of this overloading. The fifth problem is when we consider the series compensated transmission line. Then, also the reach of distance relay that is affected. And specifically, in this case, the current inversion and the voltage inversion takes place.

So, in this case, relay sees the impedance in third quadrant, so negative impedance and relay is not capable to measure, sometimes relay may also under reach, because here, when we use compensated lines. So, we have to compensate the line, line inductive reactance with the sum value of xe. So, some case maybe fault occurs after this capacitor. Then, the reach of distance relay that is affected.

The other case is the remote infeed. So, whenever we have the current or source corrected at the receiving end or the remote end, then because of the presence of that source or current, the reach of the distance relay that is also affected. The another problem is double circuit line. So, whenever we consider the double circuit transmission line, then also because of one specific phenomenon known as mutual coupling.

The reach of distance relay that is affected. The other cases of distance relay, that is the some spatial type of line that is the multi-terminal line. So, in this case also the reach of distance relay multi-terminal line. So, in this case also the reach of distance relay that is affected.

So, in all these conditions, means all these situations which we have listed of course, some other situations are also there. So, in all these cases, the reach of distance relay is affected. So, let us start our discussion with the first that is what is the impact of fault resistance on the reach of distance relay.

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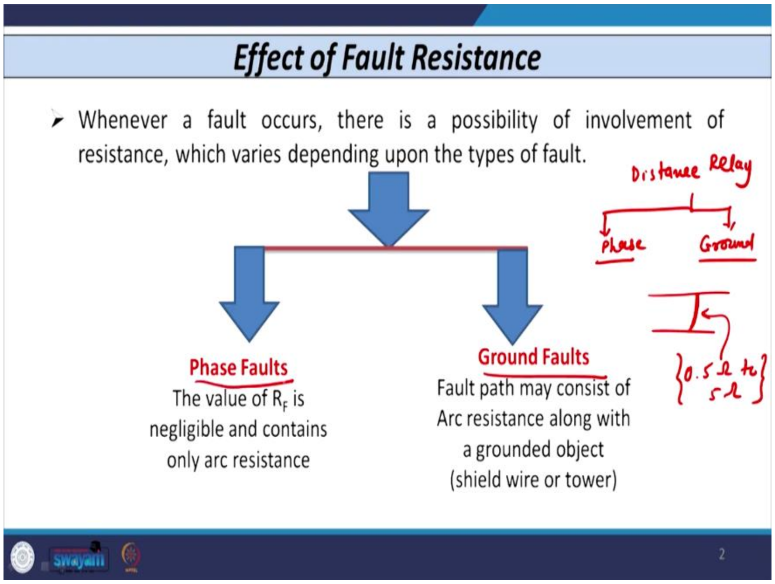

So, as I told you earlier, whenever fault occurs, the possibility of involvement of resistance varies depending upon the type of fault. So, as I told you, the distance relay, if I consider the distance relay, then the distance relay that is of two types, one is phase type distance relay, that means, distance relay as phase unit and another is it has the ground unit. This, we have already discussed.

So, whenever the fault occurs if phase fault occurs, may be line to line or triple line RY, YB, BR or RYB, then the value of RF is very negligible and that contains only the arc resistance, because there is a power arc between the two conductors. So, its involves only the arc resistance. Its value is very small, roughly it can be from 0.5 ohm to 5 ohm, this is very small.

Now, but on the other hand, a fault whenever fault occurs and if it involves ground, may be in case of line to ground or double line to ground or triple line to ground, then the fault path consists of arc resistance. Along with that, it also consist some ground object and that can be because of shield wire or tower, tower itself. So, tower has certain resistance, plus we need to consider the resistivity of soil also.

Whenever the tower is involved, when there is ground is involved, we need to consider the 0 sequence network. So, 0 sequence impedance of the system or network that also we need to consider. So, whenever the ground fault occurs, then the value of fault resistance that is very significant we cannot neglect, as we have neglected in case of phase fault.

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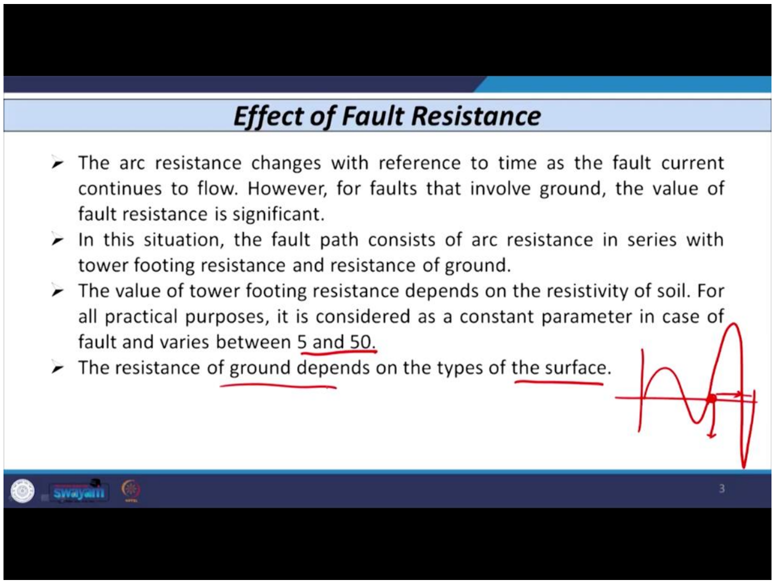

So, the arc resistance changes with reference to time as the fault current continues to flow. So, whenever, if I consider, say fault occurs from this instant. This is the instant when fault occur so magnitude of current that becomes very high. So, from this incident, if you just take one cycle or one and a half cycle, then the value of arc resistance is very small.

And as the fault current continues, its value also changes. Now, in this situation, the fault path consists of arc resistance along with some tower resistance and resistance of ground. Now, for all cases, the tower resistance that is fixed and it varies from 5 to 15 Ohm. It is proved and some empirical formula is also available that the value of tower resistance varies from five to 50 Ohm, so that we can consider.

The resistance of ground that depends on what type of surface we are using, whether we use RCC surface, whether we use plain surface, whether we use the asphalt surface or some other types of surface, then the value of the ground resistance also changes. So, we need to consider all these point into account when we consider the impact of fault resistance.

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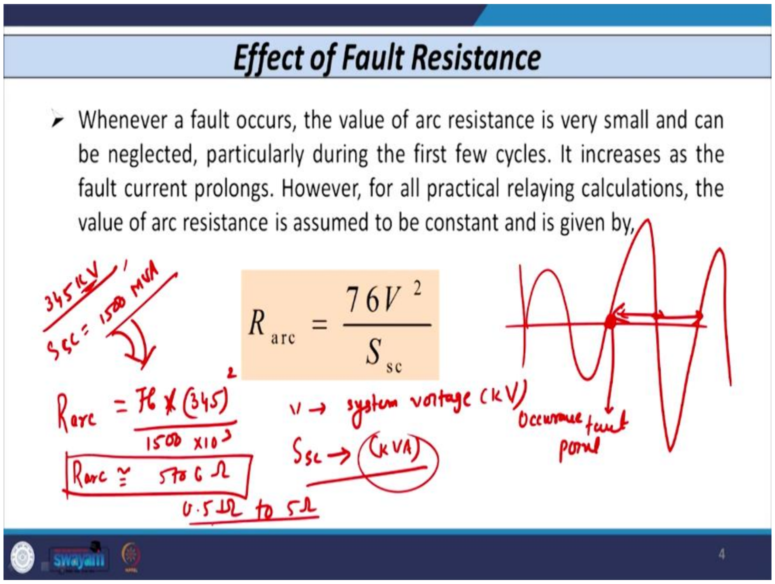

Now, wherever fault occurs, the value of arc resistance is very small. And so, generally we neglect it, particularly during first few cycles, after the inception of fault, we can neglect it and it increases as the fault current prolongs. So, if I consider again, this point which is the fault occurs at this instant. So, this is the occurrence of fault point.

So, this is the point from which the fault occurs. And so, from this, if you consider one cycle, then the value of arc resistance in this period is very small. And hence, for all relaying calculations, the its value is given by this formula that is R arc is equal to this 76 v square by SSC. This is an empirical formula. And in this formula, the V that is the system voltage. And this system voltage is usually considered in kV for this formula. And the SSC that is the short circuit mVA or power at that fault point. So, this is also usefully considered in kVA.

So, for example, if I consider a simple 345 kV transmission line with short circuit capacity of let us say, 1500 mVA. Then, in this case, the value of arc resistance, that is nothing but R arc that is 76 into V square. So, V we have to consider kV, it is already in kV. So, 345 square divided by the SSC, that is the short circuit power at the fault point, so that is given in mVA. So, we need to convert it in kVA. So, it is 1500 into 10 raise to 3. So, if you solve this, then, that comes out to be roughly around 5 to 6 ohm. So, arc distance that normally varies from 0.5 ohm to maybe 5 ohm or 6 ohm, so this is fixed.

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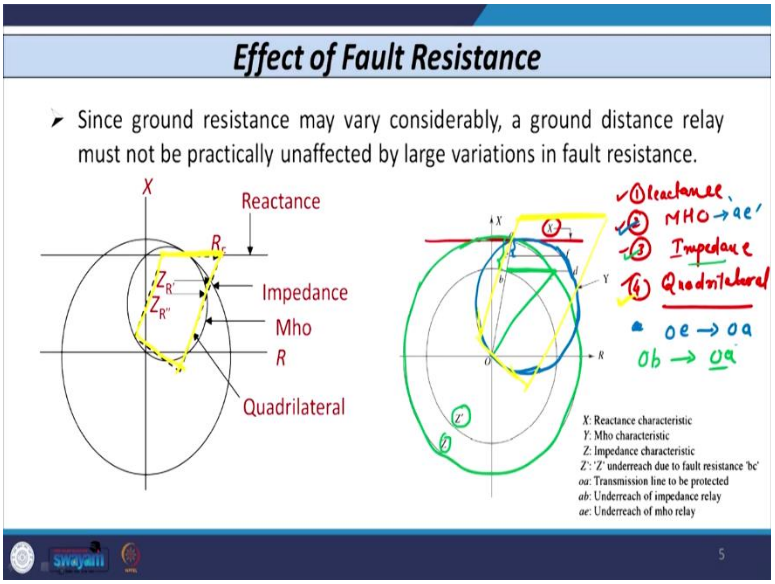

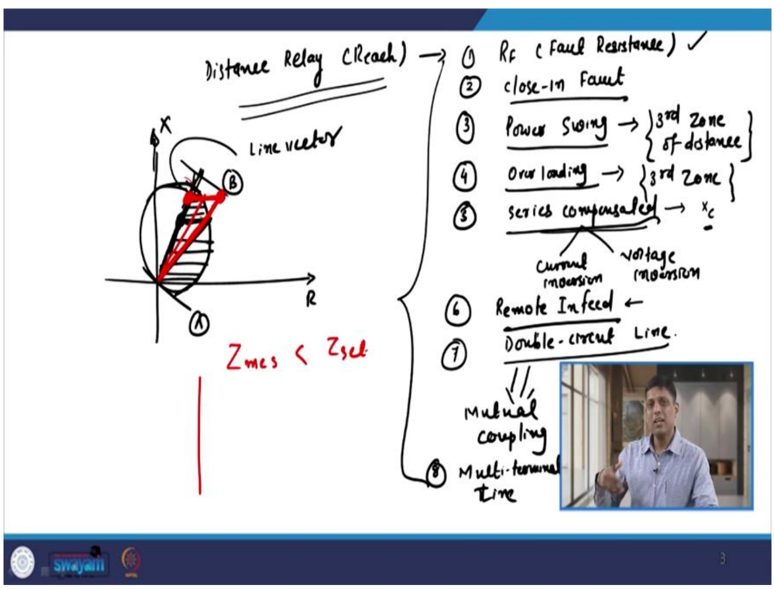

Now, let us see what is the impact of fault resistance on different characteristics of distance relay. So, we have studied the various characteristics. Mainly, we have studied the reactance characteristic first. Then we have studied the MHO characteristic and then we have studied the impedance characteristic. And we have also studied the quadrilateral characteristic. So, if I consider this characteristic, you can see here in figure that, if I consider simple the RX plain for this, then, if I just draw RX plain, the real and imaginary part. And this is the line which you have to be protected between two bus let us say A and B.

Now, when you consider this and this is let us say, this is protected by some relay, let us say more relay, in first zone 80 percent of this line. Now, when you consider the any point on this line vector, this is the line to be protected. This is your line vector. So, when you consider any point on this line and when I add fault resistance, obviously, it comes parallel with this R, so you can add somewhere here. So, you can see, as you move from this point on line vector towards the 80 percent first zone complete, this value is higher, maximum somewhere here near the origin. And as you move towards this point, the value of RF, which the characteristic can take or you can include that reduces.

So, that means the move, if fault occurs somewhere here with some specific value let us say this, the measured impedance of the line is like this. If fault occurs suppose somewhere here is let us say on this point, somewhere here and if measure value fault, if you accommodate the fault resistance like this, the measured impedance is like this.

So, you can see that, if I include more value of fault resistance, the impedance measured by relay, that falls outside this circle. That means, the relay is not able to operate because we know that when the measured impedance is less than the set value then and then relay operates, that means, when the locus that is fall on this area, then and then relay operates, otherwise relay blocks.

So, with this fact, let us consider the four different characteristic of distance relay. So, if I consider the reactance characteristic, you can see that the reactance characteristic is this one. You can see here, this is the reactance characteristic and reactance relay, as it measures the reactance, so it is immune to the fault resistance effect.

There is no effect of fault resistance. Let us consider the second characteristic, that is the second characteristic is let us say the impedance characteristic, this one. So, if I consider the impedance characteristic, impedance characteristic I have shown here, that is with this circle. So, you can see that, if I consider this circle here, then if I consider one point let us say point B somewhere here, then it can accommodate only some this much value of resistance.

So, relay can measure from this point only up to this impedance somewhere here. If value of RF is more than this value, this value then the impedance characteristic is not able to measure it. So, we can say that, if OA that is the transmission line to be protected, then this much is the underreaching of distance relay, if I use the impedance characteristics, that is why I have shown the modified characteristic as Z dash. That means, it can even though we have Z impedance characteristic is shown by green circle. But because of modification of this, its impedance due to involvement or incorporation of fault resistance, it can measure only up to OB instead of OA. So, AB is the underreaching in case of impedance relay.

What is underreach, I told you if fault occurs within the zone of relay. And if relay is not able to operate, then, that is known is underreaching of relay. And this is quite possible because of involvement of fault resistance. As I told you in this case also, if I consider the characteristic somewhere here and if fault resistance is this much, then relay measured impedance is this much and this point as it is outside this circle. So, relay does not operate. So, even though, fault is within the zone of the relay, but relay measures this much impedance, because of incorporation of fault resistance, so relay does not operate. So, that is known as underreaching of the relay.

If I consider another characteristic, that is the MHO characteristic. Then, you can see that in case of MHO characteristic, that is shown here by blue circle. So, if I just draw this characteristic, MHO characteristic, then you can see that the MHO characteristic is capable to incorporate more fault resistance compared to impedance characteristic. So, underreaching of MHO relay is only if this is the characteristic and it is going to protect line OA, then it can protect only up to OE. So, AE that is the underreaching of the MHO relay, in case of involvement of fault resistance.

So, it can measure only up to OE instead of OA, whereas, in previous case that is, in case of the impedance characteristic, we can see that it can measure only from OB instead of OA. So, OA is the line which needs to be protected. So, this is all about the impedance.

Now, if I consider the another one, that is the quadrilateral characteristic, then for quadrilateral characteristics, you can see here that if I just draw the quadrilateral characteristic on this ground only, then you can see that quadrilateral characteristic that is somewhere like this. So, it can incorporate MHO value of fault resistance.

So, that means its characteristic is small. You can see on left hand side of this figure, its characteristic area that is small, smaller than the MHO relay. But at the same time, it can incorporate MHO value of RF that is in parallel with R. So, if I consider the quadrilateral characteristic, then, underreaching of distance relay compared to MHO and impedance relay reduces, but still, the effect is already there.

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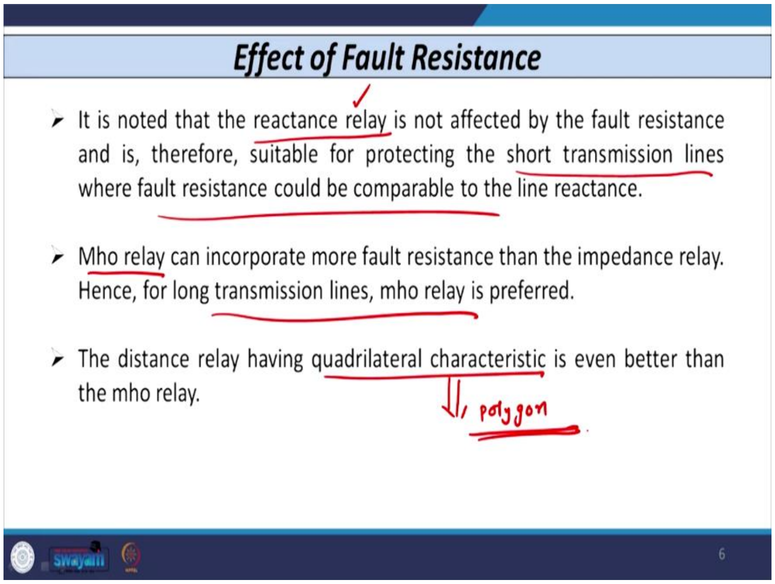

So, we have discussed that reactance relay is not affected by fault resistance. So, basically it is suitable for the protection of the small transmission line or short transmission line, because in that case fault resistance that is already comparable with line reactance. One more point is that we cannot use reactance relay for the protection of long EHV and UHV line, because in case of power swing this relay may mall operate compared to other type of distance relay characteristic, that is why reactance relay is not used for protection of long lines.

If I consider on the other hand MHO relay, then, MHO relay can incorporate some significant value of fault resistance compared to the impedance characteristic and reactance. So, it can be used for protection of long transmission lines. On the other hand, if I consider quadrilateral characteristic, then it is even better than the MHO relay. If I consider some other characteristic like lenticular or quadramo, then those characteristics are still better than the quadrilateral characteristic.

Nowadays, they are using some characteristic known as polygon. So, this is also one of the application of this type of characteristic for protection of long lines.

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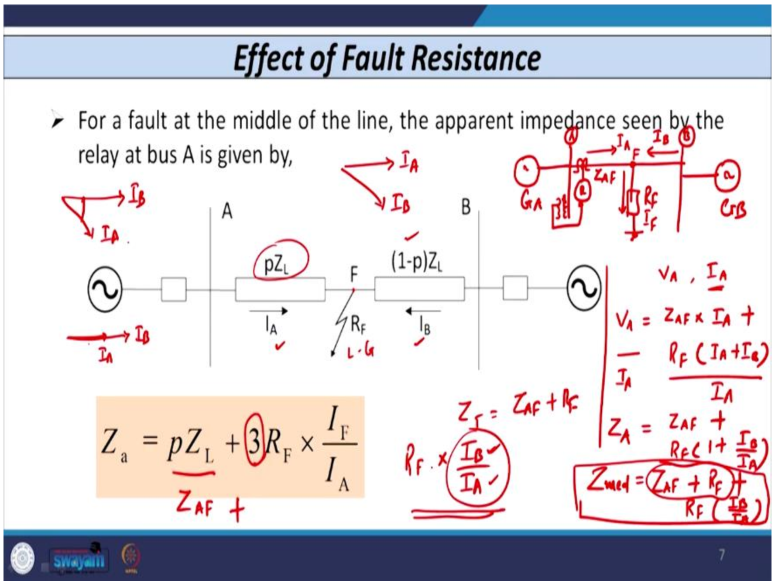

Now, to understand the effect of fault resistance, let us consider one example. So, before that, let us, let me consider one simple example. Let us consider a generator and let us say bus A and let us consider the another bus B. From there also, we have the another generator let us say GB and GA. The line is connected between these two bus and we have a relay placed here, let us say the relay R distance relay. It is also fed by the PT also.

Now, if I consider the fault point somewhere here, say RF. The current from bus A let us consider that is IA and the current from bus B let us consider that is IB. The voltage measured at bus A that is let us say VA and the current measured that is IA, because the current from A bus is IA. The total fault current through this fault let us say that is IF, which is nothing but the summation of IA and IB.

So, now if I consider from A point to this let us say this point is F, the impedance from A point to F point is let us say ZAF. So, what is the voltage measured by relay R at bus A? So, if I consider this, voltage measured by relay R at bus A that is given by the impedance from A to F. So, that is ZAF, into current through that part, so that is IA.

So, basically it is nothing but the voltage drop between point A and point F, plus the value of RF into the current that is IF, what is IF? That is nothing but IA plus IB. And what is the current seen by relay R that is IA. So, if I just divide it by IA, whole this, then the impedance measured by relay R at bus A that is nothing but ZAF plus RF into one plus IB by IA. If I again solve it, it is ZAF plus RF plus RF into IB by IA. This is the impedance measured by relay R at bus A, this is very important. What is the true impedance, correct value of impedance that is nothing but ZAF from A to F plus RF. Now, you can see the relay will measure ZAF plus RF along with that there is an additional factor that is RF into IB plus IB divided by IA. Same equation, if I use as shown in this.

So, instead of ZAF, I have considered the PZL, where P is the location of fault, IA is there, IB is there, RF is there, point F is there. The remaining part from this point F on right hand side that is 1 minus P into that ZL. So, that is nothing but the P is the fault location. And if you add this PZL is nothing but your ZAF.

So, this is your ZAF. And the 3 part this point, 3 factor comes because as you, when you draw the sequence network of single line to ground fault, then the 3 factor comes in the sequence network when you join positive negative and 0 sequence impedance. So, this is also we consider LG fault with value, some value of fault resistance that is RF.

Now, you can look at it here, the factor which is included is RF into IB divided by IA. Now, this IB by IA what is this? IB is the current from bus B and IA is the current from bus A. These two if IB and IR in phase, let us say if this two, if this is your IB and this is your IA, if both are in phase, then the whatever additional term which is incorporated in measured value that has only effect on real part.

So, the measured impedance because of involvement of RF only the real part of measured impedance changes. But this IB and IA, both are not in phase. It may possible that the voltage or angle at bus A and bus B are different. So, because of that, the IB and IA both are not in phase. It may possible that your IB leads IA by some angle or it may possible that that your IB, it may lacks the IA by some angle, depending upon in which direction power flows whether it is from A to B or whether it is from B to A before in pre-fault condition.

So, that means depending upon the phase ship or whatever is the angle exist between the two currents IB and IA relay may overreach or relay may underreach.

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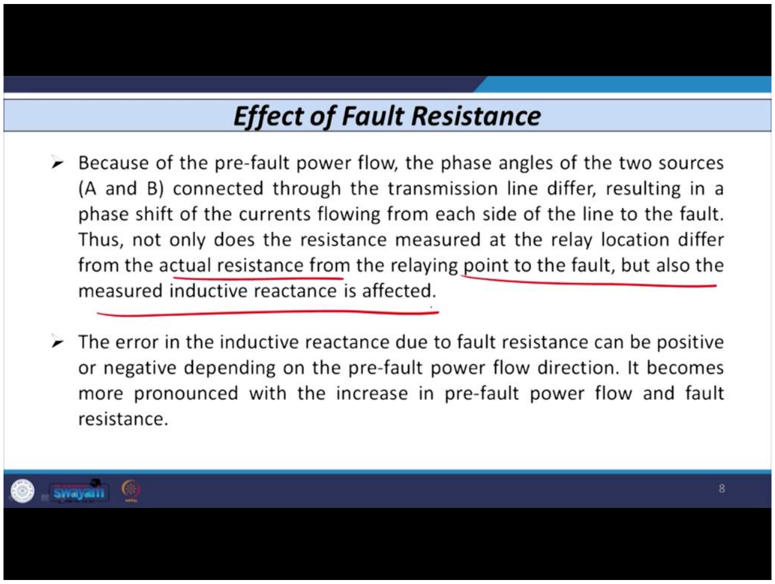

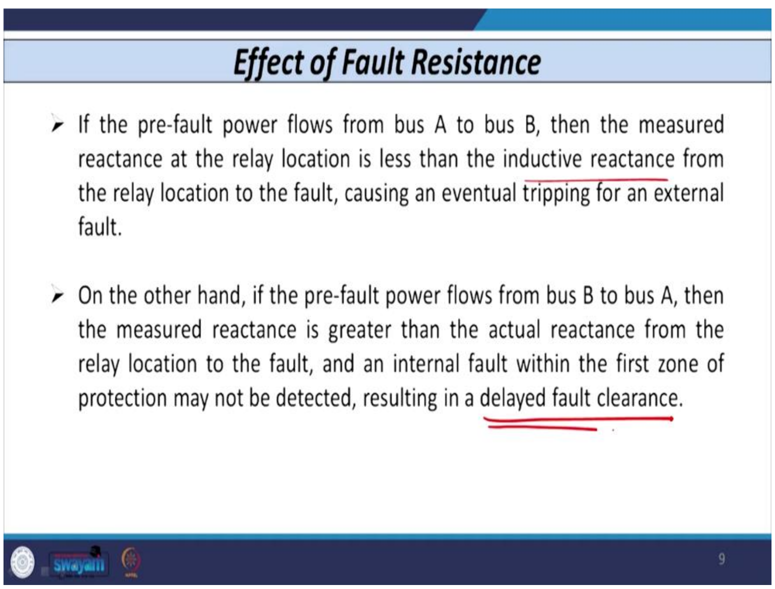

So, this is very important that when we consider the pre-fault power flow, the phase angle of because as I told you phase angle of the two sources connected at bus A and bus B are different. So, that is why both the current IB and IA are not in phase. So, that means because of that, what will happen, not only the real part of the measured value, but the imaginary part of the measured impedance that is also affected because of the impact of fault resistance. So, that means, we can say that the actual resistance from relaying point to the fault point but also the measured inductive reactance that is imaginary part that is also affected because of fault resistance impact.

So, the error in the inductive reactance part, that is due to the fault resistance that can be, now see whatever error comes whether that is in real part or imaginary part, whenever error comes in imaginary part, that error can be positive or it can be negative. So, that depends on whether the power, in which direction power flow is there, before the fault, whether power flow is from A to B or from B to A.

So, this is very important. If I consider the pre-fault power flow is from bus A to bus B, then the measured reactance at the relay location is less than the inductive reactance from relaying point to the fault point. So, because of that, the relay may mall operate even though the fault is beyond the zone of relay that is an external fault. So, that is nothing but the overreaching of relay and that is because of the reduction of this inductive reactance or imaginary part.

The second case if pre-fault power flow is from bus B to A, then the measured reactance is greater than the actual reactance from relaying point to the fault point, if any fault occurs within the zone of relay, the relay is not able to detect that fault. So, that is known as underreaching of relay and that may cause the delayed fault clearance, because that fault is looped in second zone by some other relay and that relay will operate after some time delay. So, this is very important point.

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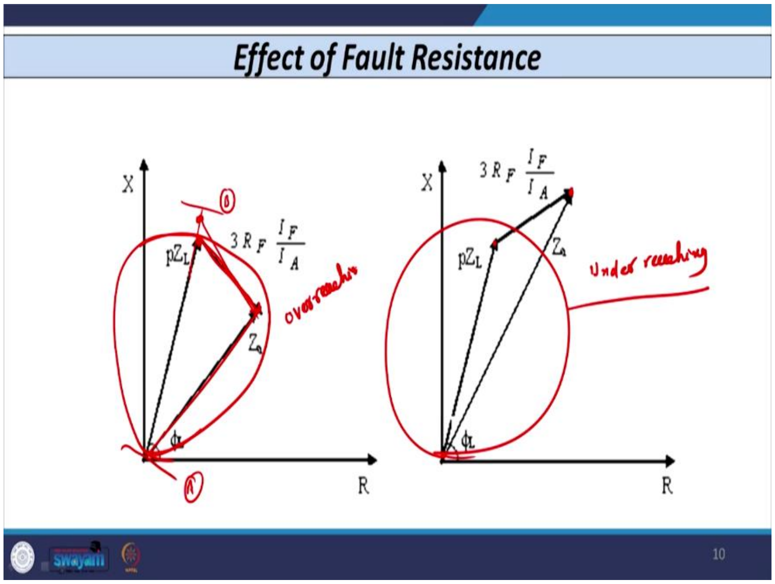

So, as I told you, because of the power flow if it is from A to B, then the relay will show the value of that part that reduces, so the measured impedance is only this, so, that is within the zone of the circle. So, if I just draw this circle from here this point this is your B and this is your A, then this point comes inside the circle. So, even though the fault is somewhere here, relay may overreaches. And it may be possible that in this case, the relay may underreaches, because the fault is within the zone of relay, but relay will measure this value because of increase of this factor, three RFIF by IA. So, the relay will measure higher impedance, which is greater than the set value, so relay underreaches. So, in this case, underreaching of distance relay is there and in this case the overreaching of the distance relay that is there.

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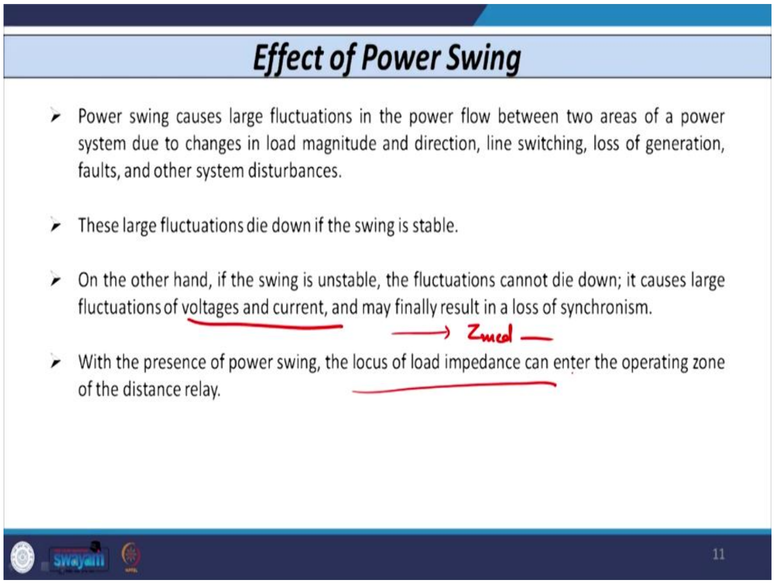

So, now, let us see the another effect, what is power swing. So, power swing causes the large fluctuation in the power flow, that is between two areas. And this fluctuation is maybe because of the change in magnitude of load or direction, switching off line, very big line, loss of generator maybe because of fault or maybe because of some other the system disturbance.

Now, whenever such type of disturbance occur, if that those disturbances are stable then the fluctuations may die down after some time and relay may not be mal operate. But if seeing its unstable, then in the fluctuations may take long time, then the fluctuations may not be die down and it cause the change in large fluctuation in the voltages and current and because of that the measured impedance by the relay that is also affected. So, because of power swing the locus of impedance that can enter in the third zone of distance relay and distance relay may mal operate.

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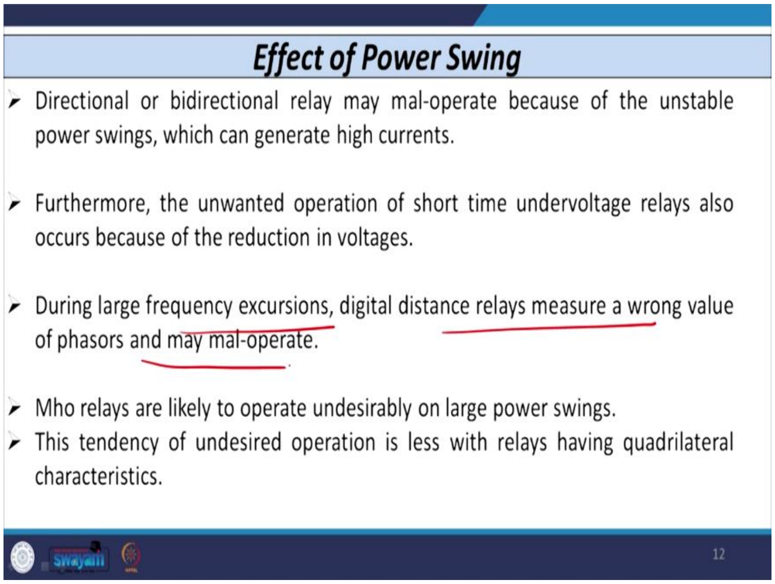

So, whenever power swing phenomena occurs, the current increases. So, any overcurrent relay that is not able to operate correctly. In this case, in case of power swing, voltage also reduces. So, any voltage-based relay that is also not operate correctly. In case of frequency accessors, digital distance relay that also measures the wrong value, because it is based on the phasor calculation.

So, the phasor calculation may not be correct and hence a digital relay may also mal operate. So, to avoid this, we need to add either some power swing blocking function or we need to use some other different philosophy.

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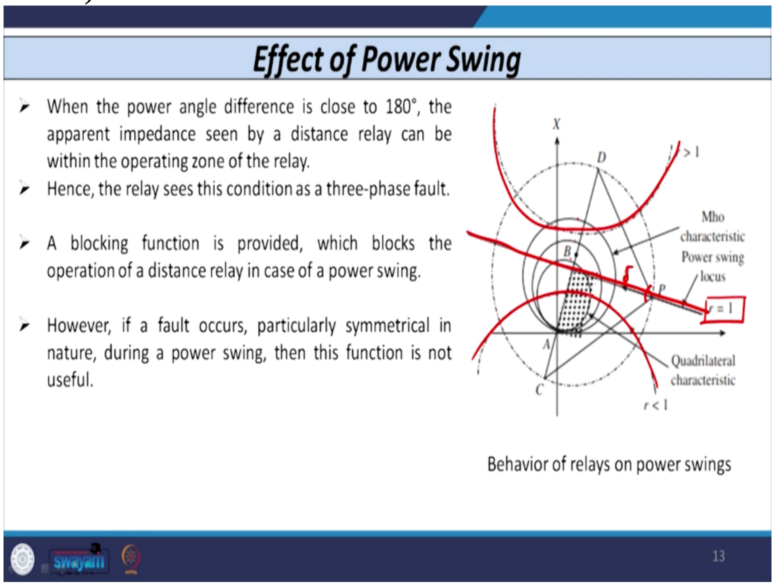

Now, to understand the power swing phenomenon, you can look in this figure. I have shown the 3 zone characteristic of MOH relay. So, this is first zone, second zone and third zone of MOH relay. And I have also shown with dotted line, the quadrilateral characteristic. And I have shown the Locus of Power swing, that is shown by the value R, this R is nothing but the ratio of sending an voltage to the receiving end voltage magnitude.

If this ratio is exactly unity, the Locus of Power swing that is like this and your delta that is this delta. If the ratio is greater than one, the locus is like this. It is like this. And if the ratio is less than 1, the locus that is like this. So, in any case, you can see the locus always pass through the 3 zone characteristic of distance relay, whether it is the quadrilateral or whether it is the MOH type characteristic.

And you can see that if I consider quadrilateral relay, then any of this characteristic first enters in the third zone of MOH relay and then it enters the quadrilateral relay third zone. So, this, because of this, maloperation of distance relay may possible, particularly in third zone. So, we need to again take corrective measure and that is we normally in terms of power swing blocking function.

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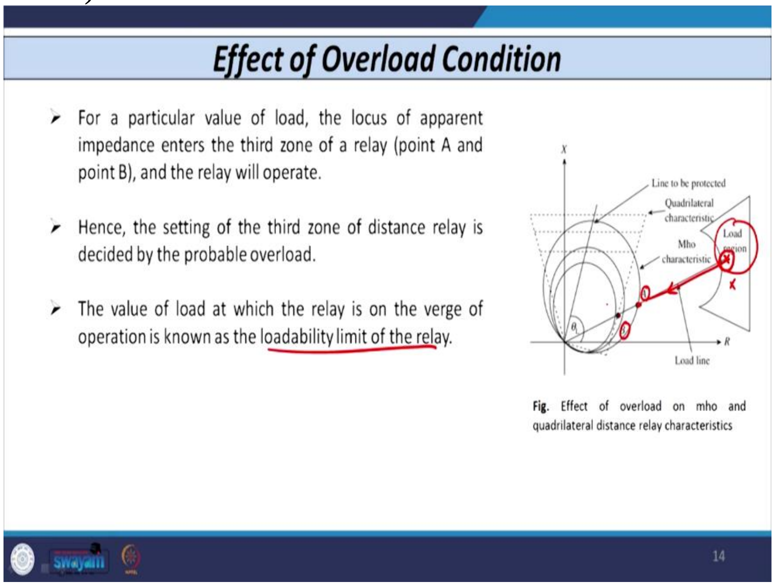

Let us discuss the last point, what is the effect of overload on the distance relay? So, I have shown here the characteristic of three zones of MOH relay and the quadrilateral relay. You can see that I have also shown the load region. So, in normal condition or pre-fault condition, the locus is somewhere here at this point. Whenever fault occurs or disturbance occurs, locus move from this point to here like this in this direction. So, you can see it, first I have shown the point A. So, the locus enters the third zone off the MOH relay.

And after some time, it enters the third zone of the quadrilateral relay at point B. We can say that the value of particular load on the relay at which the relay is just on the verge of operation that is for MOH relay, point A and for quadrilateral relay, it is point B so, that is known as load ability limit of the relay.

And if I use quadrilateral relay, then it has better load ability limit, because it, the point comes after this point A and it can accommodate MOH value or fault resistance. So, quadrilateral characteristic is better as far as power swing is concerned, as far as the overloading condition is concerned or as far as the incorporation of fault resistance is concerned.

So, in this lecture, we have discussed the various important parameters, due to which the reach of the distance relay is affected. The remaining parameters we have not discussed, because it is not possible to incorporate all those discussion in this lecture. So, I just stop here. Thank you.