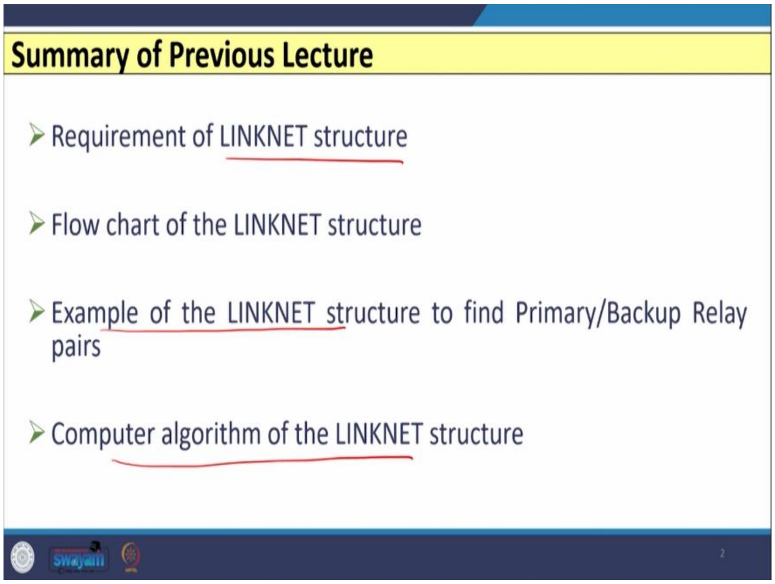
Digital Protection of Power System
Professor Bhaveshkumar Bhalja
Department of Electrical Engineering
Indian Institute of Technology Roorkee
Lecture 25
Coordination of Overcurrent Relays for Distribution Network - V

(Refer Slide Time: 00:28)

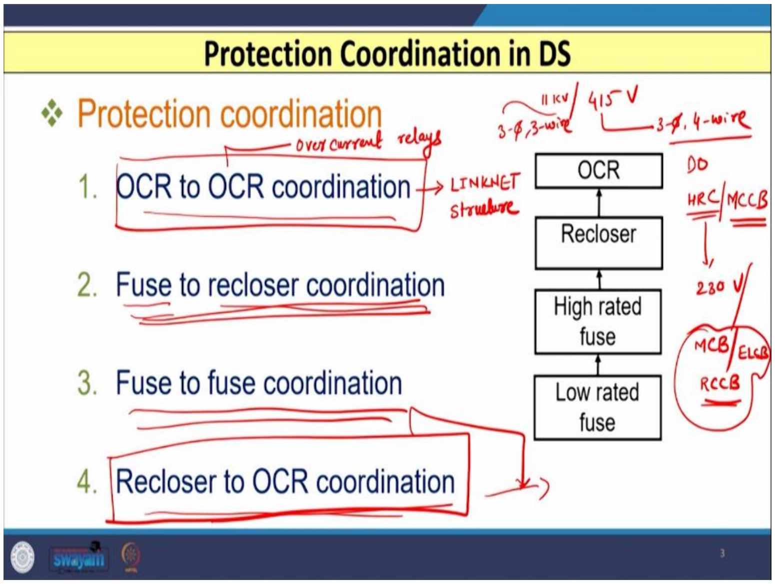


Hello friends. So, in the previous lecture we have discussed regarding the requirement of LINKNET structure. And we have discussed that two algorithms are used in LINKNET structure, in which, algorithm 1 is used to prepare the table which shows the various parameters like the next and far. And the algorithm 2 is used for the determination of primary backup relay pairs. And after that we have discussed one example on LINKNET structure and in that we have considered one network, which contains four branches and eight relays.

And we have discussed that if we consider this algorithm, then using the algorithm 1 of LINKNET structure, the whole table that is prepared, which is known as the branch network table and that can be prepared for this network. And after preparation of that and utilizing that table, we can also go for the determination of primary backup relay pairs, using algorithm 2 mentioned in the LINKNET structure.

After that we have discussed that if we want to carry out the, let us say, we want to discuss or we want to find out the primary backup relay pairs for a large network, which contains more number of branches and more relays, then we have to write some code and for that we need some algorithm. And we have discussed that if we go for different IEEE larger bus network systems then we can write down the code efficiently, using these two algorithm. And we can determine the primary backup relay pairs.

(Refer Slide Time: 02:03)



So, till now, what we have discussed is, that coordination of protection, in terms of four different aspects. The first is the coordination between two relays. So, OCR-to-OCR coordination, where OCR indicates the Overcurrent Relay. So, we have the coordination between overcurrent relays, that is one relay and the other relay.

So, LINKNET structure indicates that, that if we have, let us say, 10 or 20 number of relays available in a particular network, then how the coordination among these relays that is to be carried out. And we have already discussed, this is done by LINKNET structure. The second type of coordination is required, in case of distribution network that is between fuse and recloser.

So, we know that fuse are widely used in distribution network, at transformer level also, let us say, we have 11 KV by 415 Volt transformer is there, where 11 KV is your three phase, three wire system and your 415 Volt is your three phase four wire system. There also we can use the DO or dropout fuses at 415 Volt level, we can use the fuses known as HRC high rupturing capacity type of fuse.

So, HRC fuse are very widely used, 415 Volt. And may be at 230 Volt also, that is our residential purpose or for domestic consumers. We can also go for the conventional KitKat type of fuse or maybe MCB also, because nowadays most of the domestic consumers, they use MCB along with the ELCB. So, it is Miniature Circuit Breaker or Earth Leakage Circuit Breaker. Sometimes, it is also known as the RCCB, Residual Current Circuit Breakers. So, when our relay is connected or recloser is also another device, which is used at 11 KV substation and this reclosers are, we will discuss further also as we proceed in this lecture.

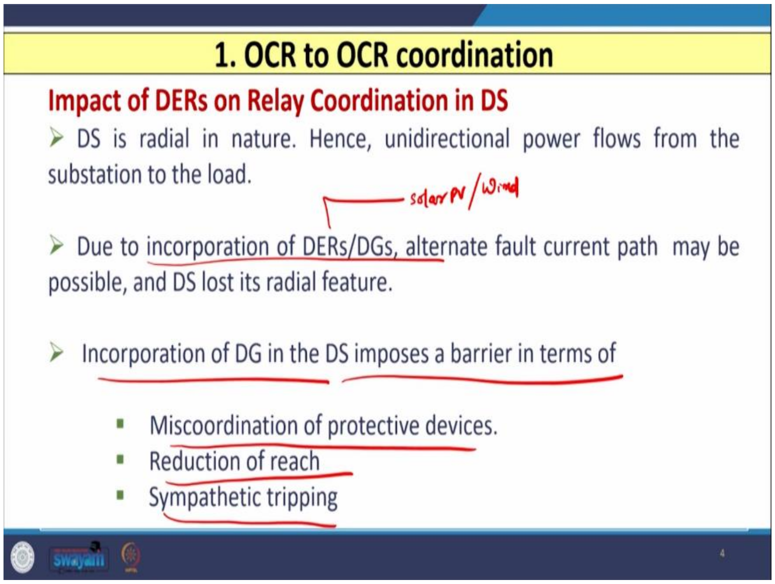
So, the coordination among these different types and categories of fuses, which we are using at different voltage levels, starting from 230 Volt to 415 Volt to 11 KV with recloser and relay that is also required. So, that second type of fuse-recloser coordination is very important as far as distribution network is concerned. And this also we will discuss here.

Then coordination between two fuses, because we know that at 230 level, we use fuse or MCB and at 415 Volt also, we use, let us say, high rupturing capacity type of fuse. So, between two fuses coordination is also required. Nowadays, most of the domestic consumers they use MCB and even at 415 Volt also instead of utilizing high rupturing capacity type of fuses, most of the utility, they will also go for MCCB that is Molded Case Circuit Breakers.

So, coordination between two fuses, if we go for fuse, or coordination between MCB and MCCB that is also very important, when we talk about distribution network. And fourth that is coordination between recloser and overcurrent relay that is also required. But, I think, this is not that much important because the overcurrent relay, whatever digital relay available, it has a feature inbuilt that it can also work as a recloser. So, I think this fourth option is not important, but second and third option is very important. And we will discuss further more about the second option.

So, first option that is coordination between overcurrent relays, we have discussed using LINKNET structure. And we have seen that if interconnected network is there, where multiple sources are present, then how the coordination that is achieved. Now, before we go into second part, the first part, which we have discussed, in that one more point is very important is, we know that nowadays, the most of the utilities are encouraging the placement or interconnection of distributed energy resources.

(Refer Slide Time: 6:43)



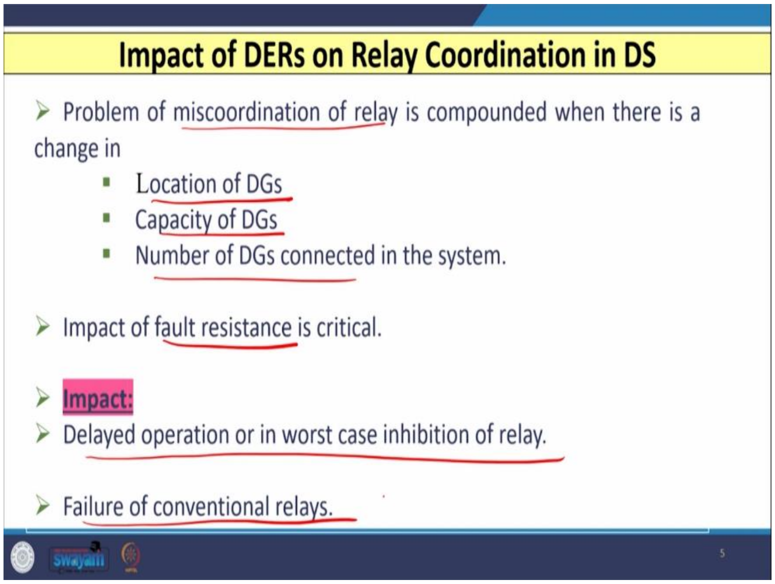
So, when we talk about the distributed energy resources or we can call it distributed generators, maybe in terms of solar, wind and some others, then this play also an important role. So, distribution system at present, normally, it is radial in nature and hence normally, whatever is the power flow that is unidirectional in nature, from substation to the load or maybe from right hand side to left hand side or maybe left hand side to right hand side, whatever it is.

Due to incorporation of this distributed generators or distributed energy resources, this R in terms of solar PV or wind or any other, like fuel cell or so on, so, alternate current path exists and whatever distribution network or structure radial structure is there, that may lost. So, now, our conventional distribution network that does not remain radial in nature.

So, when we incorporate the distributed generators in terms of solar PV wind then distribution system imposes barriers, in terms of, we observed mis-coordination among various protective devices, if proper care that is not taken. Sometimes, it is also observed that the reach of overcurrent relay also reduces.

And sometimes it is also observed that sympathetic tripping is also there. Sympathetic tripping means it is nothing but phenomena, where if fault occurs in one particular section and the relay located in other section operates, then those operation of relays that is known as sympathetic tripping. So, these three phenomena are the impact of incorporation of distributed generators, when we talk about the coordination among the relays, using LINKNET structure

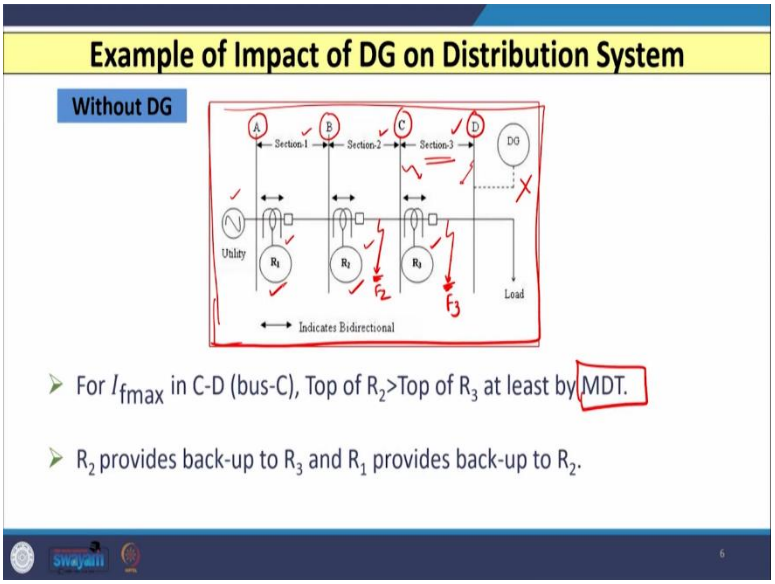
(Refer Slide Time: 8:36)



Now, when we talk about the coordination of relay and we know that the relay may mal-operate, which we called as mis-coordination among various relays. This is increased when the location of DG changes, when the capacity of DG changes and when the number of DG is connected in the distribution network that also changes. So, more number of DGs are connected into the network, the mis coordination among relays that is observed. Even when we consider the impact of fault resistance then this problem becomes more compounded.

So, the overall impact, when we talk about incorporation of DG in the distribution network with reference to the coordination among overcurrent relays, then the main two impacts are delayed operation or sometimes, in worst case, relay may not operate. And failure of our conventional relays that is also observed.

(Refer Slide Time: 9:34)



So, let us understand this thing. How the relay mis-coordinate, when we incorporate distributed generators in a radial distribution network with some example. So, here let us consider this system (as shown in above slide), in which the three sections are shown, section 1, section 2 and section 3. And these three feeders are connected between the four buses, bus A, bus B bus C and bus D.

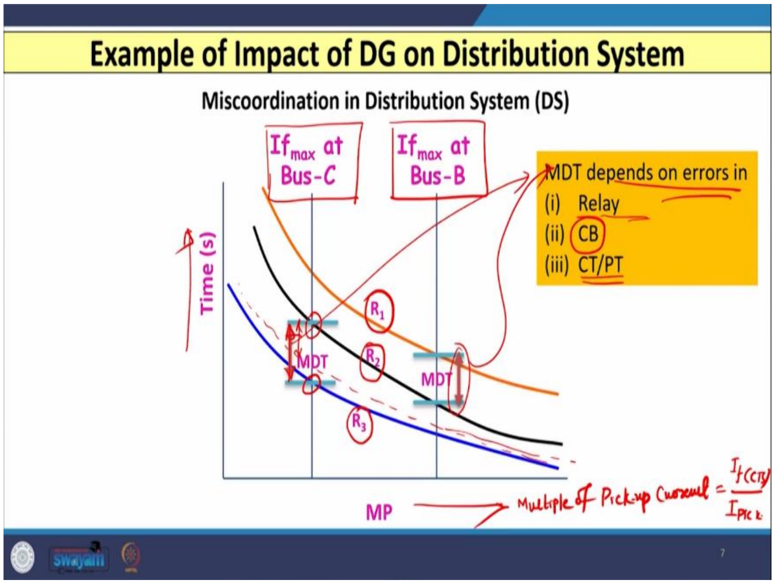
We have a source connected near bus A and the loads are connected at each bus starting from D C B and so on. And at present only three relays are connected. Let us say at R_1 R_2 and R_3. All three relays are bi-directional in nature. You can also consider directional relays also. And at present no such DG is connected with this radial distribution network.

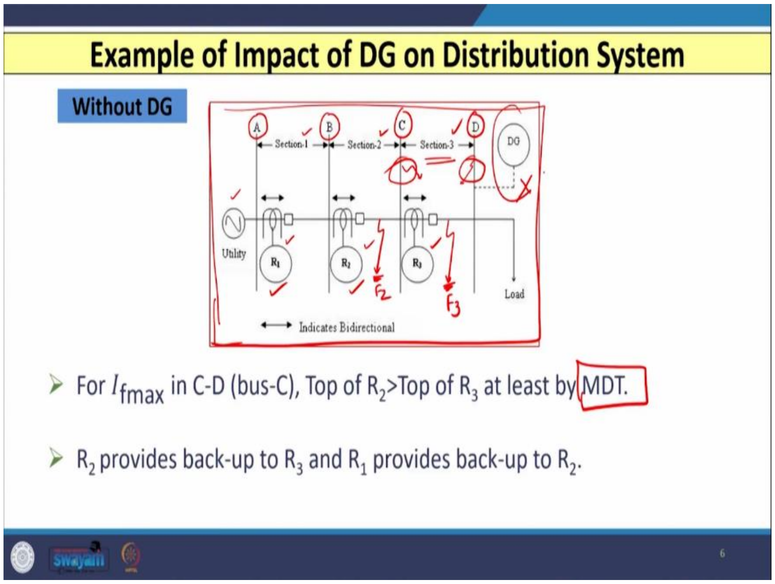
So, when we talk about the fault in this third section C-D section, then obviously, whenever fault occurs at bus C the fault current is maximum, compared to the occurrence of fault at bus D. So, when we talk about the section C-D then what we want is, that the time of operation of relay R_2 should be greater than the time of operation of relay R_3 by some margin. And that margin we can call it as minimum discrimination time or sometimes it is also known as Coordination Time Interval, CTI.

So, the meaning is that if fault occurs in this section, let us say, at F_3 then relay R_3 must operate as a primary relay. So, R_3 has to operate first. If R_3 fails to operate then R_2 has to provide backup.

Similarly, so on. If fault occurs in section 2 at F_2 then R_2 must operate first and if R_2 fails because of some reason, then R_1 will provide backup.

(Refer Slide Time: 11:47)





So, if we understand this, by plotting the characteristic of R_3, R_2 and R_1 relays, because all 3 are inverse definite minimum time relays. So, if we talk in terms of the characteristic of these three relays, then we can plot the characteristic of three relays, considering on X-axis the multiple of pick up currents. So, this is nothing but the multiple of pickup currents or MP is nothing but fault current referred to CT secondary divided by relay pickup current or plug setting of the relay.

And if I consider the time in second on Y-axis then we can plot the characteristic of relay R_3, relay R_2 and relay R_1 like this. I have shown R_1, R_2 and R_3 relay characteristic by different three colors (as shown in above slide). And you can see that characteristic of R_3 comes first, because we want that relay R_3 should operate first because it is connected near to the load. And as we progressively move towards the source, the further the R_2 characteristic comes and then R_1 characteristic comes.

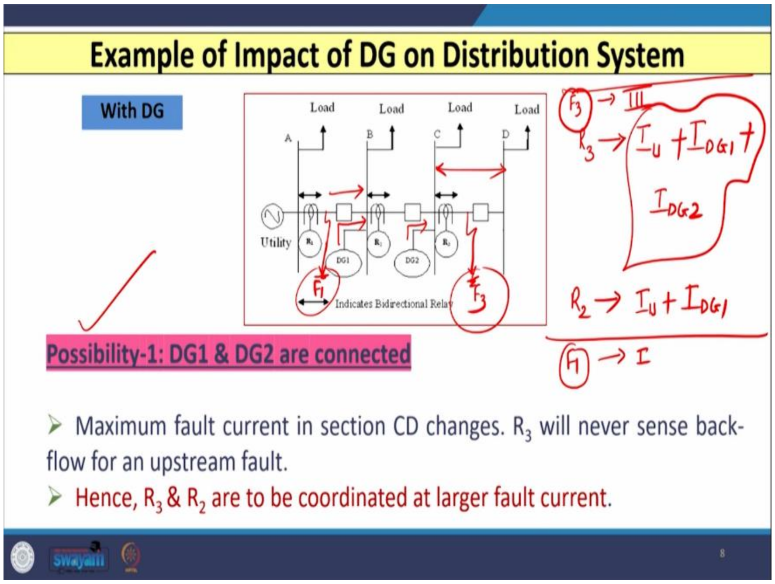
Now, we are talking about the minimum discrimination time between two relays, let us say R_2 and R_3. So, you can see that this is the point and this is the point (as shown in above slide). So, these two points are decided by considering the maximum fault current at bus C. So, if I consider maximum fault current at this bus and maximum fault current at this bus, at bus C and bus D, then I have seen here, the maximum fault current at bus C and may be maximum fault current at bus B or bus D, whatever you consider. So, based on that you can plot the characteristic and you can see that this much margin is available between R_2 and R_3 (as shown in above slide). This is the margin, and between R_2 and R_1, this is the margin available and this margin is known as the minimum discrimination time. So, this margin between the characteristic of two relays, depends on errors available in the relay. So, let us say for example, how the errors in relay changes the value of MDT. So, it may possible that my relay R_3, which is following this blue curve, it may possible that this relay will operate with slight delayed.

So, you can see that this characteristic of relay R_3, which is shown in blue color (as shown in above slide) that is shifted slightly upward. So, then obviously, you can see this margin, which is MDT that is going to reduce. So, errors in relay means your whatever relay, which is prescribed for particular operation, relay may operate earlier or it may operate slightly slower also. And same is the situation for relay R_2 and for relay R_3 (as shown in above slide).

Similarly, errors in circuit breaker is also there, because relay once operates, senses the fault, it gives signal to the breaker. So, there has to be some time delay in the operation of circuit breaker. As the circuit breaker installed and as the time progresses then obviously the breaker operation that is also affected.

And the third thing is the ratio and phase angle error in the CT and PT. That is also is another factor which is going to affect the value of MDT. And why we are stressing more on MDT? Because, minimum discrimination time is the sum margin available between two relays. If this margin is not available then for a particular fault, maybe two relays or more than two relays may operate simultaneously, which is against this selectivity criteria of the protective system. So, that is why this margin is very important. Now, this margin is okay, when we do not connect any DG in the radial distribution network, then we have this sufficient margin.

(Refer Slide Time: 16:03)



Now, let us consider same radial network but we have connected or we have incorporated distributed generators or distributed energy resources, maybe in terms of solar, wind and so on at different buses. So, when we connect the DG, let us consider different possibilities, so, first possibilities I am taking that 2 DGs, DG1 and DG2, are connected at bus B and bus C respectively, as shown in the figure.

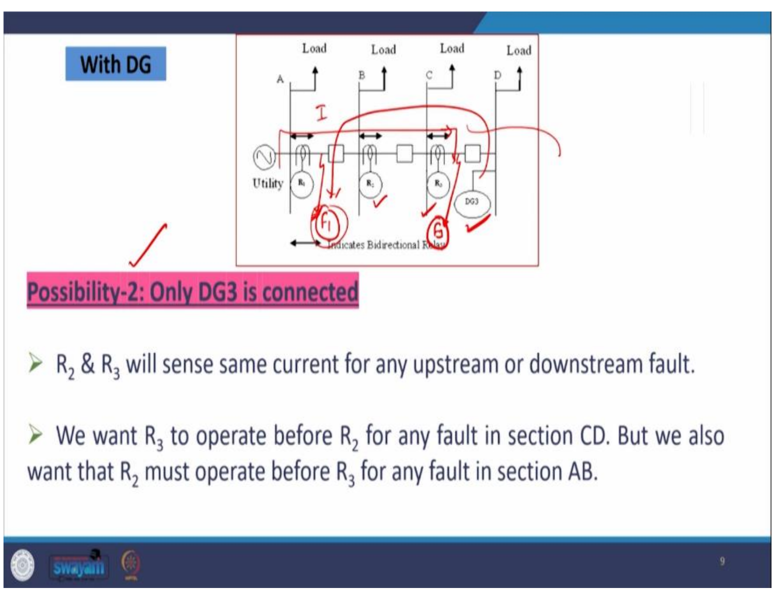
So, if this is the case then we know that, if I consider now, this third section that is section connected between C and D, and if fault occurs in this section, somewhere here at F_3, then the current that flows through relay R_3, what is the current that flows through relay R_3? So, that current is the current from the utility, I utility (I_U), plus the current that is available from or fed by this DG1. So, I_{DG1}, it is also there plus the current fed by this I_{DG2}. So, this is the addition of all these three currents that will flow through relay R_3, whereas, from relay R_2 the currents that flows that is the $I_U + I_{DG1}$.

So, now, you can see that in earlier case, when no DGs are connected, the current flows through the relay R_1, R_2, R_3 are same, whereas when we connect the DG at two buses, let us say B and C the current that flows through the R_3 and relay R_2 changes, and obviously this current, which flows through relay R_3 and R_2 that increases because of the additional fault current fed by these two DGs, DG1 and DG2. So, this two relays, R_3 and R_2 need to be coordinated at larger magnitude of fault current. So, this is very important.

Now, on the other hand, if I consider let us say the fault in section 1, let us say F_1, this first case we have considered, where we consider the fault at F_3 in section 3. Now, here I am considering fault at F_1 in section 1, between A B. So, here now, you can see (as shown in above slide) that when fault occurs in section A-B, then the current flows through relay R_2 that is again fed by this DG 2 only, whereas, from relay R_3, no current flows because no DG is connected.

So, now, when the reverse flow is there. So, whenever fault occurs at F3, this faults because it is near the load, we can call it as downstream fault, and whenever any fault occurs, let us say, at F1, which is near the source we can call it as upstream fault. So, this is very important, where we consider the two DGs then the current flows through the relay increase because of additional fed of the current by the DGs and these two relays are coordinated at larger magnitude of fault current and even current flows through R_3 and R_2 that is also entirely different.

(Refer Slide Time: 19:22)

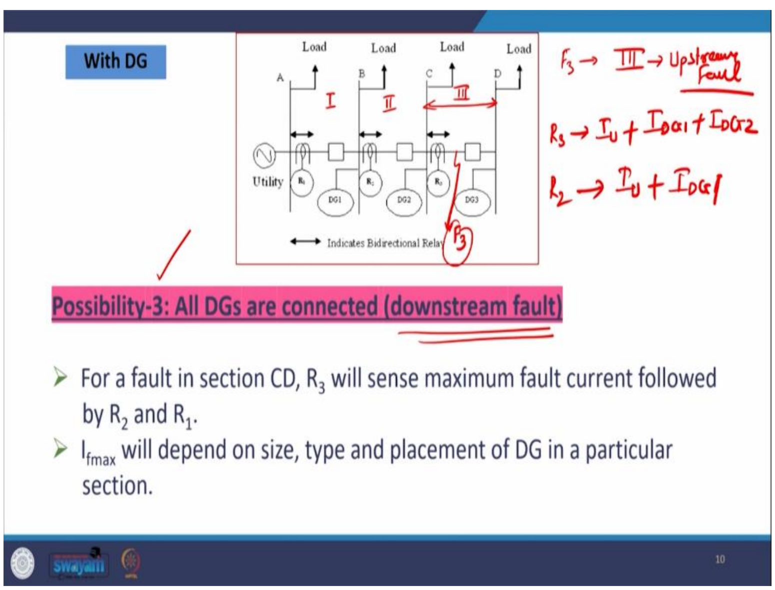


Now, let us consider the another possibility 2 in which I have connected only DG3 at bus D. So, when this is the case, you can see (as shown in above slide) that both relay R_2 and R_3 will sense same current for any upstream or downstream fault. So, if fault occurs, let us say, at downstream side here, then the current flows through relay R_2 and R_3 that is only from the utility side.

So, utility will feed the current and if fault occurs, let us say, somewhere here at the upstream side at F_1 (as shown in above slide) then also you can see the current fed by this DG that will again like this. So, current flows through the R_2 and R_3 that will remain same it is fed by DG 3 only. So, what we want now?

So, in this case we want that relay R_3 should operate before relay R_2 for any fault in section C-D. So, any downstream fault somewhere here between section C-D at F_3, we want that R_3 must operate before R_2. But, what we want on the other side? If there is a fault on upstream side at say in section 1 at F_1 then we want the reverse operation, we want that R_2 must operate and R_3 should operate after that.

(Refer Slide Time: 20:45)

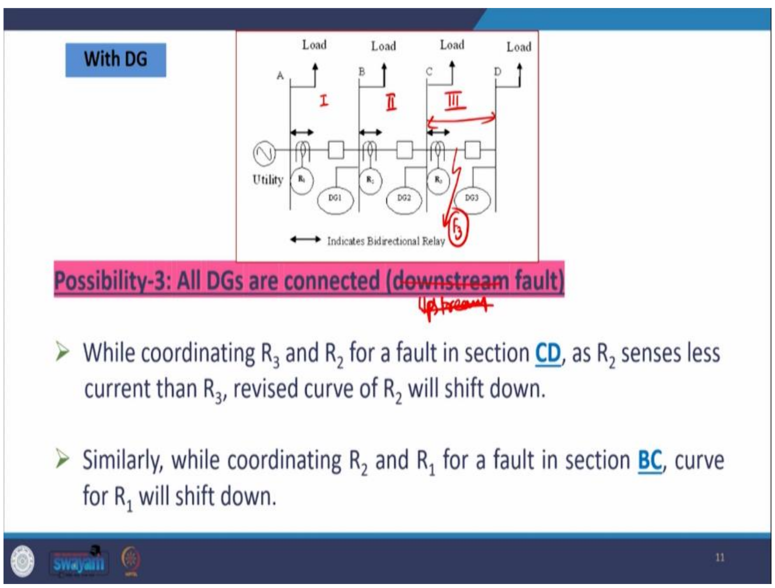


Now, let us consider the third possibility, where all the DGs are connected. So, DG1 is connected at bus B, DG2 is connected at substation C and DG3 is connected at substation D. So, now, in this case, for any fault in section C-D, let us say, this is our section 3, section 2 and section 1, any downstream fault in section C-D, because we are discussing for this third possibility where all DGs are connected.

Let us consider first that fault occurs on the downstream side (as shown in above slide). So, at F_3 in section 3. So, for a fault in section C-D, R_3 will sense maximum fault current followed by the current sense by R_2 and then current sense by R_1. So, maximum fault current will depend on size of the DG, type of the DG and placement of the DG in a particular section. So, if I consider, let us say, fault at F_3 here in section 3, this is known as downstream fault.

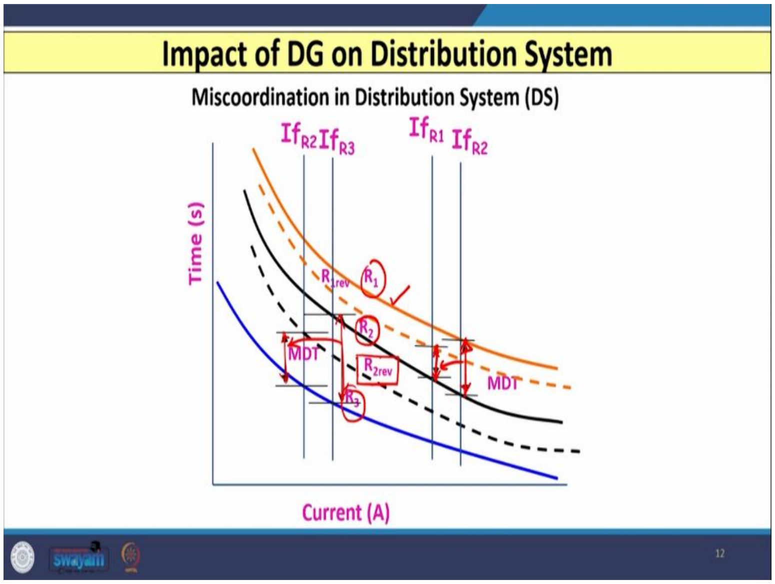
Then in this case, obviously, the current that is sensed by relay R_3 is again the same as I told you, it is $I_U + I_{DG1} + I_{DG2}$. And whereas the current through R_2 that is only $I_U + I_{DG1}$. So, again there is a difference in the current flows through the relay R_3 and relay R_2, for any downstream fault let us say at section 3 at F_3.

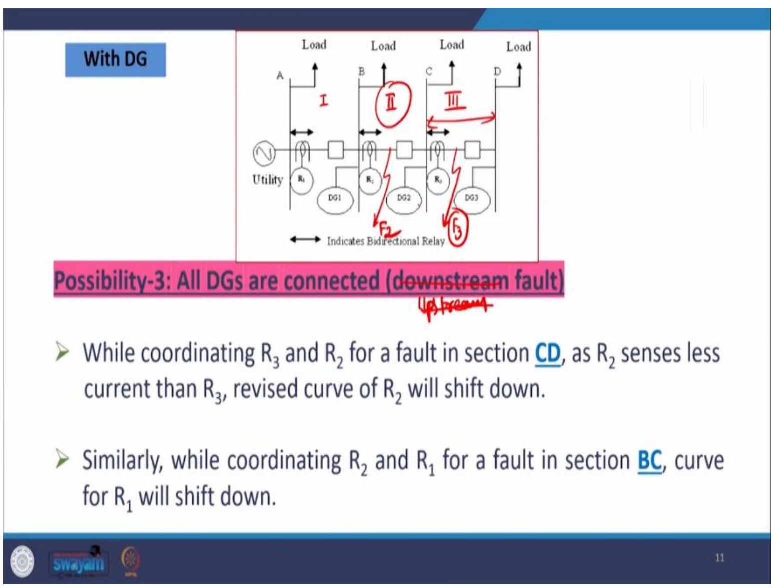
(Refer Slide Time: 22:28)



So, again let us consider the same third section here (as shown in above slide). This is our section 2. So, this is my section 1. Now, let us say, we are coordinating relay R_3 with relay R_2 and we are coordinating relay R_2 with relay R_1 and the fault is going to occur in section C-D, let us say at F_3. So, in this case, for this fault as R_2 senses less current than R_3. Why? Because through R_3 the current that flows is $I_U + I_{DG1} + I_{DG2}$, whereas from R_2 current flows that is $I_U + I_{DG1}$. So, as R_2 senses the less current than the R_3.

(Refer Slide Time: 23:18)



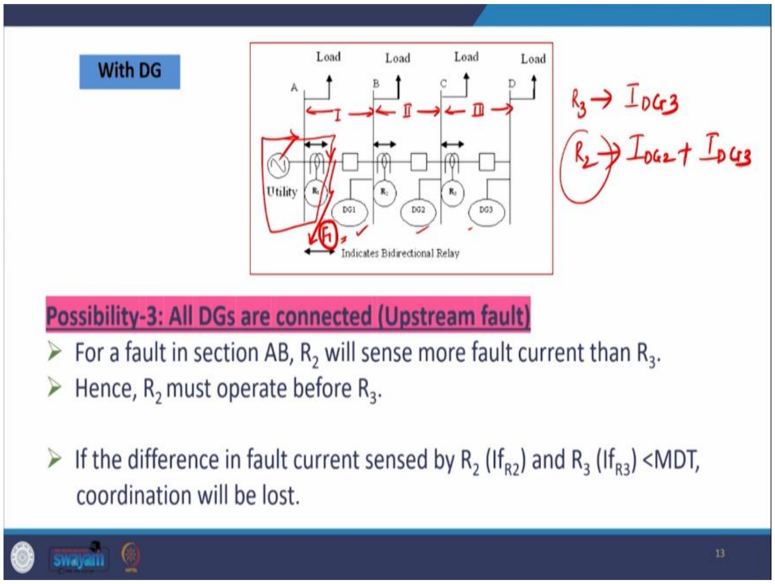


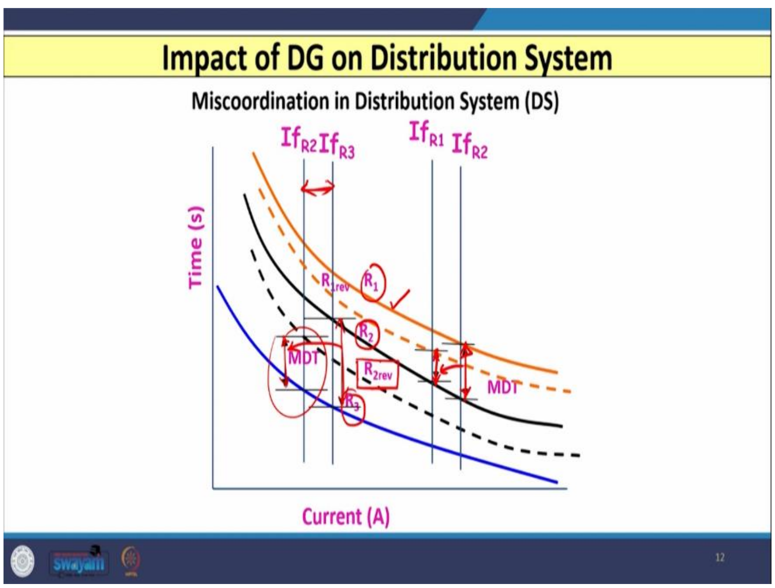
So, the R_2 curve has to shift down, and you can see (as shown in above slide) that I have shown the characteristic of R_1 with this color, R_2 with black color and R_3 with this original blue color. Now, the characteristic of R_2 has to shift below. So, you can see I have mentioned here I R_2 revised. So, which is shown by dotted black color. So, now, you can see in earlier case between R_2 and R_3, this much margin is available (as shown in above slide).

But, now, because of shifting of this characteristic curve of R_2, the margin available that is going to be reduced. And that depends on placement of DG, type of DG and the capacity of DG. So, this is very important. Similarly, when we coordinate relay R_2 with relay R_1 then also for a fault in another section, let us say, in this case also curve of R_1 will shift.

And again my minimum discrimination time which is available between R_2 and R_1 is like this, which is going to reduce from this to this (as shown in above slide). So, this is very important point as far as the margin between two relays is concerned. And this margin is going to reduce, when we connect the more number of DGs at different location and with different capacity.

(Refer Slide Time: 24:42)





Now, let us consider the third possibility, where all the DGs are connected that is DG1, DG2 and DG3 are connected at bus B, C and D and the fault we are considering that is the upstream fault means those faults which are going to occur near the source. So, let us say, we have this is our section 1, this is our section 2 and let us say this is our section 3 (as shown in above slide). And fault that is going to occur let us say, at F_1 in section 1. So, this is nothing but the upstream fault.

In this fault at F_1, relay R_2 will sense more fault then the relay R_3. So, obviously when fault occurs at F_1, one of the flow of the current from the utility side is like this (as shown in above slide). And the second side, if you consider the relay R_2 and R_3 then relay R_3 the current flows that is only by I_{DG3} and through relay R_2 the current flows that is because of $I_{DG2} + I_{DG3}$.

So, more current will flow from R_2 then relay R_3 for a fault at F_1. So, in this case, what we want is that obviously as more current will flow from relay R_2, so, R_2 should operate first then relay R_3 will operate. And because of this obviously, the margin between the two relays that is going to reduce, as I told you, when this difference of this margin that is MDT and difference of these two fault currents, let us say, IF R_2 and IF R_3. So, when difference of these two fault currents is less than the minimum discrimination time margin.

So, this margin is let us say reduce because of placement of DG and when this value, this difference, is less than MDT then mis-coordination of relays will be definitely there and we cannot avoid that. And for that we need to use some other philosophy or algorithm, if we wish to avoid mis-coordination among different overcurrent relays.

So, what we have discussed in this class is that, initially, we started our discussion with the four categories or four possibilities that is the coordination between two relays OCR to OCR, overcurrent relays to overcurrent relays. Second we have considered the coordination between fuse and recloser. Third we have considered the coordination between fuse and fuse or may be MCB and MCCB. And fourth we are considering coordination between the overcurrent relay and the recloser.

And then we have discussed that the fourth possibility is very important. So, the first possibility, when we consider the overcurrent relay coordination with other overcurrent relays available in the network then when we connect or when we penetrate more number of DGs that is renewable energy sources into the radial distribution network then the radial structure of the distribution network is lost and it becomes multi-source system.

And in that case minimum discrimination time between the two relay characteristic that is very important and when the difference in fault current between two adjacent relays, if that is lower than the minimum discrimination time between the two consecutive relays or adjacent relays then the mis-coordination or the coordination between two relays that is lost and that is very important.

Because, when we connect more number of DGs into the network then depending upon the location, capacity and size of the DGs, the current flows through the relay that is different when we consider the downstream fault compared to when we consider the upstream fault in the network. So, this is very important as far as the coordination between two relays are concerned. So, in the next class, we will discuss more about the coordination between fuse and reclosers. Thank you.