Digital Protection of Power System
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Lecture 26
Coordination of Overcurrent Relays for Distribution Network - VI

Hello friends. So, in the previous lecture, we have discussed regarding the coordination among various devices particularly in distribution network.

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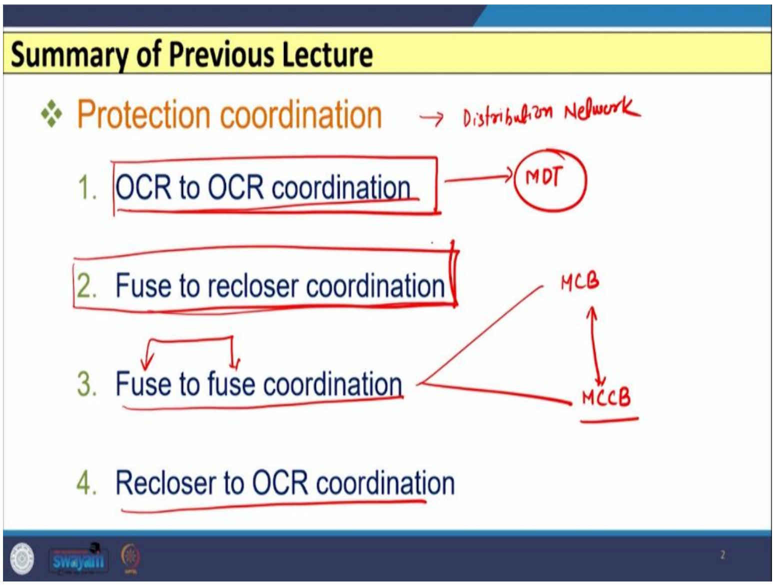

So, this coordination is carried out for distribution network and we have discussed that four possibilities are there. So, at four levels coordination is required. The first level is the coordination between two overcurrent relays or multiple overcurrent relays. Then the second is the coordination between fuse and recloser.

The third is the coordination between fuse to fuses or sometimes, if I consider domestic consumers, which utilizes MCB and maybe at a higher 415 Volt three phase level utility is using MCCB. Then coordination between this or coordination between these two devices, that is also required. And last that is coordination between recloser and overcurrent relays that is also required.

We have already discussed in the previous class, what is the important issue, which we need to consider, when we talk about the coordination between two overcurrent relays. And we have discussed that when we incorporate DG then this coordination becomes more difficult, particularly, with reference to the minimum discrimination time available between two characteristic of the relays. Now, in this case, let us consider the second point, that is the coordination between fuse and recloser.

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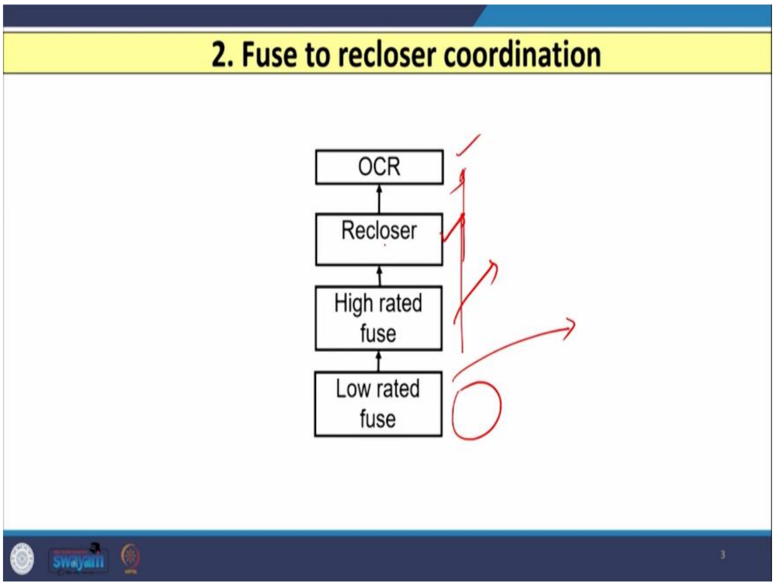

So, before we start this coordination, the hierarchy of this coordination is very important. So, the first comes that is the low rated fuse. Let us say its rating is very small. Then we have high rated fuse and then we have the recloser and the last comes that is the overcurrent relays.

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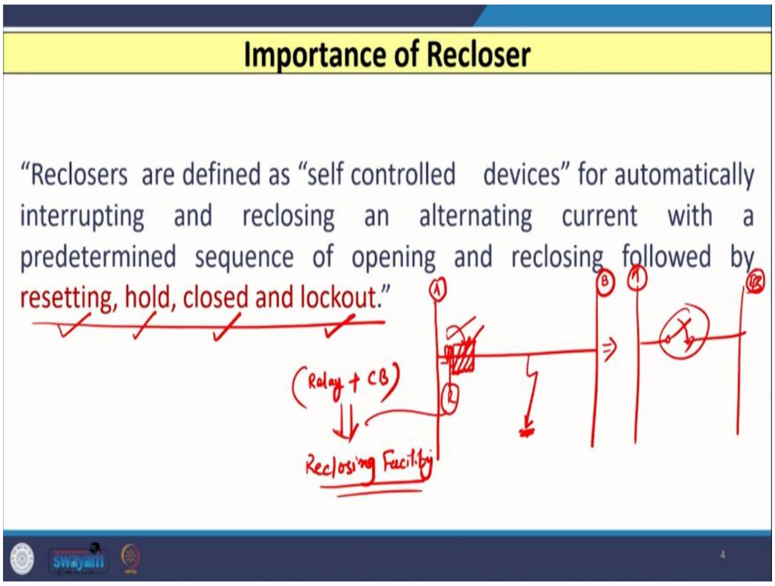

Before we start, let us understand, what is recloser. So, recloser is nothing but a device, which is self-controlled and which operates automatically for any AC system and which is meant for interruption of the current. And at the same time it is also having and reclosing attempt with some predetermined or predefined sequence of opening and reclosing. This is followed by four things, that is, first is resetting, second is hold, third is closed and fourth is the lockout.

So, if I just tell you how the recloser works. So, let us consider a bus A and here (as shown in above slide) we have one feeder connected between another bus B, and let us consider that one relay is available here with circuit breaker. And this relay is equipped with reclosing facility. These relay and breakers relay plus circuit breakers both are equipped with reclosing facility. So, when we have the relay and breakers capable of having reclosing attempt.

So, now, let us understand, what is the function of recloser. So, whenever any fault occurs here, then this relay senses this fault assuming that this fault within the zone of this relay and this relay senses the fault and it gives signal to this circuit breaker. So, here the pole of circuit breaker that becomes open. So, once the pole of circuit breaker, if I draw further, the same diagram here, then you can see (as shown in above slide) that the pole of circuit breaker, I am drawing single line diagram, so, pole of circuit breaker that is going to become open.

Now, the meaning of recloser is after opening of certain time period the pole of the circuit breaker recloses. And this reclosing attempt is carried out depending upon certain specified sequence. And this is valid for AC system only. So, this is nothing but the function of reclosers. So, now, the question comes, why reclosers are required? Why we need to carry out reclosing attempt of recloser, when fault occurs? So, the reason is majority of faults, which are going to occur on the overhead distribution network, they are transient in nature.

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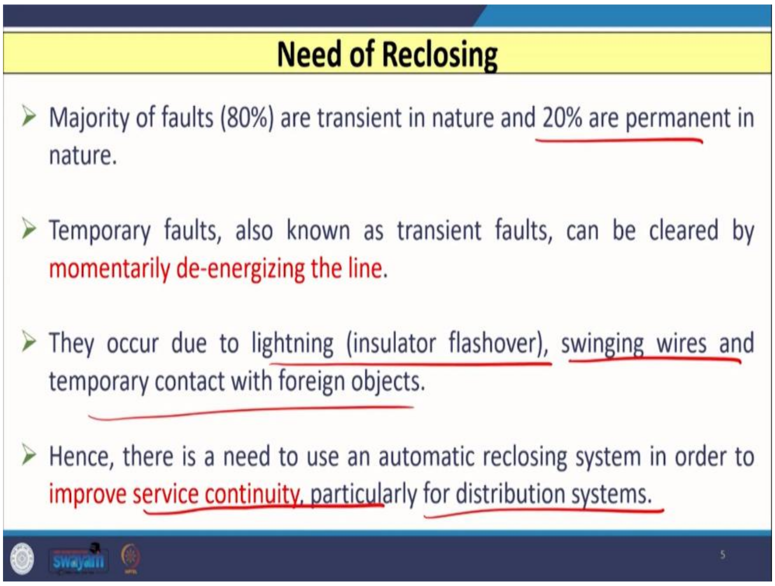

So, almost 80 to 90 percent faults are transient in nature and only 10 to 20 percent faults are permanent in nature. So, this transient faults also known as temporary faults that can be cleared momentarily, if we de-energize the line. So, that de-energization of line that is to be carried out with the help of reclosers or reclosing attempt of the circuit breaker pole.

If we go for reclosing attempt of the one of the pole or of the circuit breaker then we are going to deliberately de-energize the line and for the time period, if fault is not there, if it vanishes and when we reclose it then the line is working in perfect or healthy condition or normal condition. So, such type of transient faults are going to occur because of many reasons.

The very important and prominent reason is the lightening surge, may be because of insulator flashover or some other reason, maybe because of swinging wires or when any temporary contact touches with foreign bodies, then also such type of fault occurs. And those faults are transient or temporary faults and they are going to die out, maybe after one or maybe two cycles or three cycles. And in that case, there is no need to again carry out tripping of circuit breakers and manual interruption is not required.

Hence there is a need to use auto-reclosing system in order to improve service continuity, particularly for distribution system. So, we know that for in case of distribution system, if we want to improve continuity of service then we must go for the reclosers, which are equipped or which are associated with the relays and circuit breakers that is installed on the distribution network or feeder.

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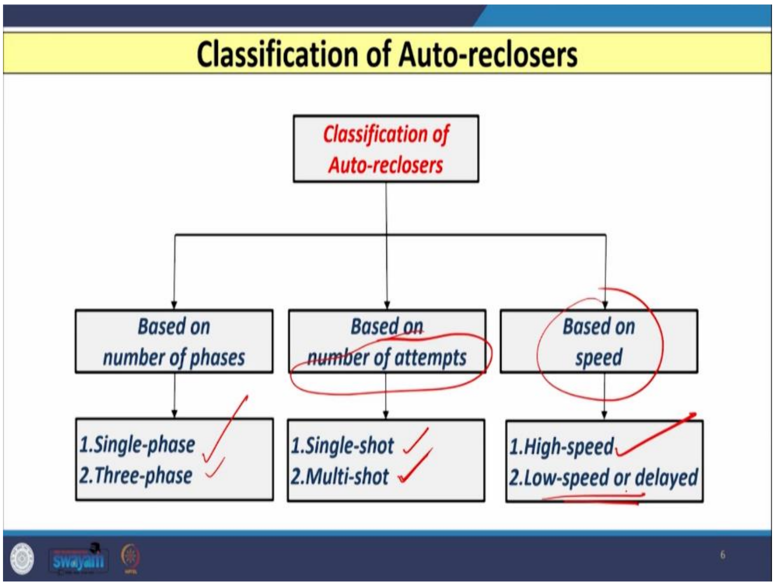

Now, if we consider the classification of reclosers then reclosers can be classified based on number of phases. So, either we can use it for single phase or three phase because we know that in distribution network, some of the single phase feeders are also there, two phase feeders are also there, three phase feeders are also there. So, based on number of phases, we can classify based on number of attempts, we can classify whether we want single reclosing attempt or we want multiple reclosing attempt.

So, that is known as multi shot reclosing relay and the previous one is known as single shot reclosing relay. And the classification can also be done based on the speed. So, high-speed reclosers are also there, low speed reclosers are also there. For transmission system, we need high-speed reclosers, whereas for distribution system we need low speed reclosers.

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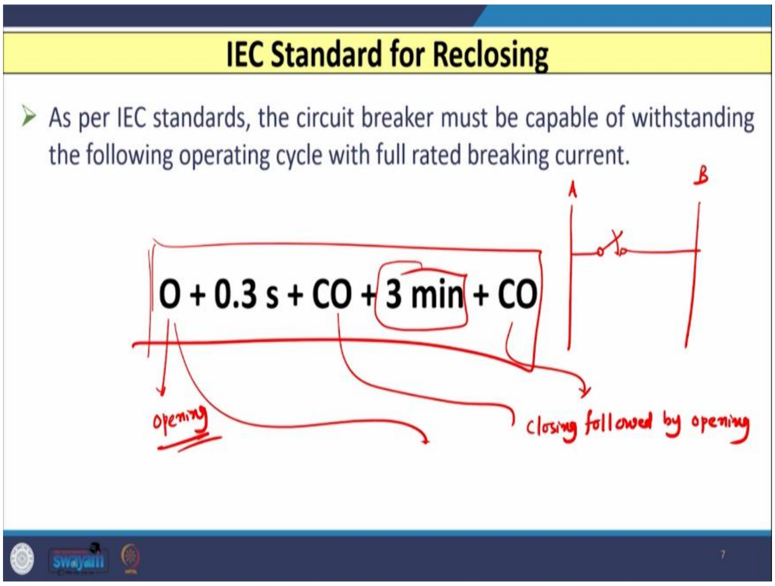

Now, when we go for this reclosing attempt, as I told you that the first point when we talk about the reclosers that is nothing but, how or what sequence we are going to follow for the circuit breaker which is associated with the relay and reclosers. So, here when we talk about reclosing attempt as per IEC standards, this circuit breaker must be capable of withstanding certain operating cycles at rated breaking current.

So, this cycle is given here, O + 0.3 s + CO + 3 min + CO, where the meaning of O that is nothing but opening. So, opening of the pole of the circuit breaker. So, this is nothing but the opening of the pole of the circuit breaker then there is a waiting period of 0.3 second or 300 millisecond, then the period is closing followed by opening.

So, this is nothing but the closing followed by opening. So, this is going to close and again it is going to open and again there is a waiting period of 3 minutes and then again the same sequence closing followed by opening is carried out. So, this sequence need to be followed by any circuit breaker which is installed in the actual field.

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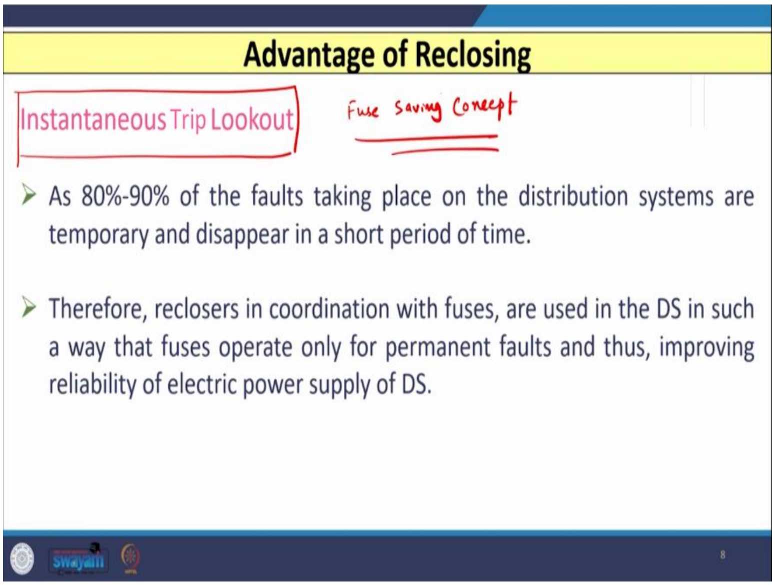

Now, let us understand, why reclosers are very important as far as the distribution network is concerned and why we are more concerned about the coordination between reclosers and fuse, particularly for distribution network. So, to understand this concept, we need to understand one of the important phenomena which is known as instantaneous trip lookout or sometimes it is also known as the fuse saving concept. So, we will see this two concept.

So, we have already discussed that almost 80 to 90 percent faults which are going to take place on overhead distribution conductors, they are temporary or transient in nature and they disappear after, let us say two cycles or three cycles. So, therefore if we installed the reclosers in the distribution network then obviously by de-energizing the line temporarily, we are removing this transient or temporary fault and we are improving the service continuity of the distribution network or system.

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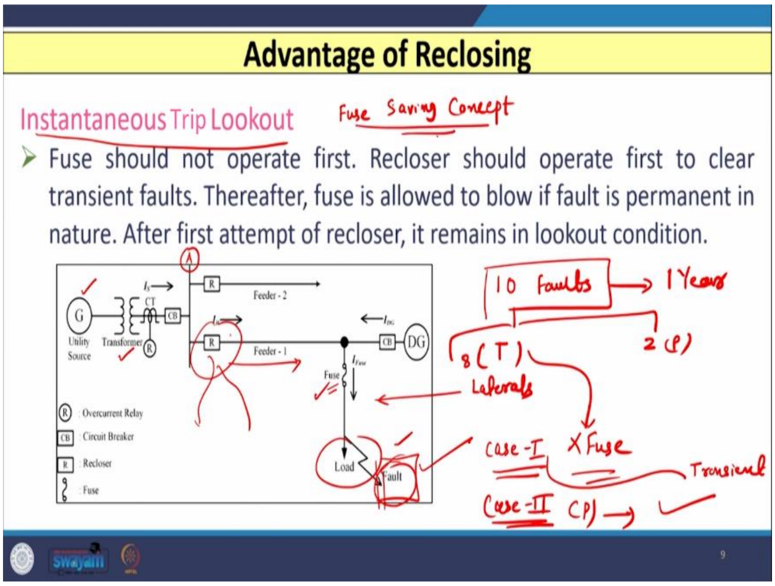

However, when we adopt these things, some issues are faced. Let us say to understand this issue, let us consider one example of one network. So, here you can see (as shown in above slide) we considered one utility which is again connected to the transformer and on the other LV side of the transformer, we have the bus connected, let us say this is bus A and then we have several feeders are there, HT consumers are there.

Let us say feeder 1, feeder 2 feeder N, and if we consider one of the feeder, let us say, feeder 1, then from this feeder 1, one of the connections are taken these are known as laterals. So, these connections are known as the laterals. So, on these laterals, let us say some load that is connected may be in some domestic or residential load or some induction motors like that and this load is protected by this fuse. And on this feeder we have the relay with the reclosing facility.

So, now, the point is, if fault occurs on these laterals, as shown here (as shown in above slide), on these laterals then obviously the first device which is going to sense the fault that is fuse and fuse is going to operate. So, as an in charge of the substation we have to send the lineman to rewire the fuse and again that will involve manual intervention and the continuity of the electric supply that is affected. Because, why we want to avoid this?

The first reason is that for every time, we know that if any fault occurs on these laterals let us say 10 faults are going to occur in a span of 1 year on this laterals, out of 10 faults 8 faults are transient or temporary in nature. We have discussed. So, for these 8 faults, we do not want to rewire the fuse, because these faults are transient or temporary in nature and we do not want to operate the fuse.

Because, if fuse operates for this let us say 10 faults are going to occur in a span of 1 year and out of this 10 faults, only 2 faults are permanent in nature, whereas 8 faults are transient in nature or temporary in nature. And we do not want for these 8 faults, operation of fuse we do not want.

So, how to avoid this? So, in that case what we do is, we put it here the recloser and characteristic of recloser should be coordinated with the characteristic of fuse in such a way that the recloser should operate first for any fault on these laterals and fuse is not going to operate.

So, whenever any fault occurs on these laterals, let us say these 10 faults are going to occur, for these faults, recloser is going to operate first. So, any fault occurs here, recloser should detect it, it will operate. So, obviously pole of the breaker becomes open and then recloser operates.

So, pole of the breaker recloses and if these 8 faults are transient or temporary in nature then again the system becomes normal as and when we reclose the pole of the circuit breaker. So, there is no unnecessary disconnection of this feeder by the operation of fuse and there is no question of rewiring of use, there is no involvement of human, if we avoid this then we have to coordinate the characteristic of recloser with the characteristic of fuse in such a way that, for all faults that those are going to occur on the laterals, recloser should operate first. This concept is known as fuse saving concept, because we do not want to operate the fuse.

We want to operate the fuse only when the permanent fault is there. So, if suppose for example, there are two cases. Let us say case 1, is like this that there is a transient fault on the lateral. So, obviously recloser will sense this fault, recloser will operate, it will again reclose this and fault is transient, so system becomes healthy. So, this is the nothing but the transient or temporary fault, no issue.

The second case we consider, let us say, that is the permanent fault on the feeder. So, if there is a permanent fault on this lateral here, there is a permanent fault on the lateral then recloser will operate but still fault is permanent in nature. So, again it becomes open and it remains in open condition. It is also known as instantaneous trip lookout.

So, after one operation the pole of the circuit breaker will go in lockout condition, it will not operate and then fuse will operate and fuse is going to disconnect. This fault because it is a permanent fault. And in both the cases, we want this operation and this concept is known as the fuse saving concept and this is widely used in distribution network.

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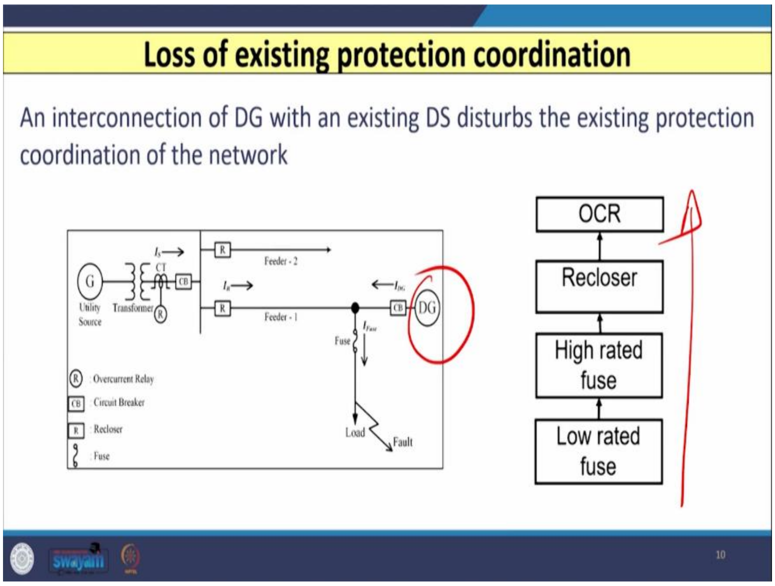

So, when we consider the same network, again we need to follow the hierarchy that is of the low rated fuse to high rated fuse to reclosers and to the overcurrent relays. But, this is only possible when there is no interconnection of distributed generators or distributed energy resources into the distribution network as and when there is a inter correction of distributed generators into the radial network then this whole fuse saving concept that is disturbed. Let us see how this is disturbed and how it is going to work.

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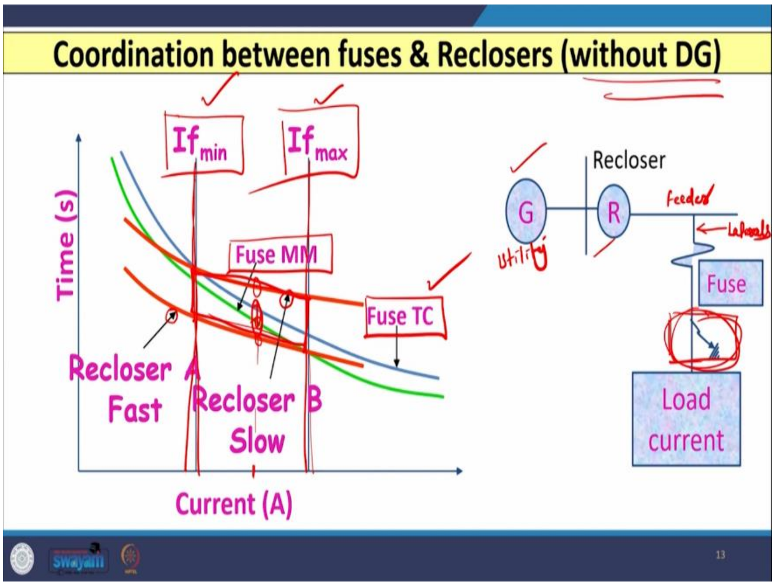

So, let us consider with this diagram. So, I have shown one utility (as shown in above slide). Let us say this is my utility and this is my recloser, this is my laterals, this is my feeder and one of the laterals let us say some loads are connected and it is protected by fuse. So, any fault which is going to occur on the lateral, we want that recloser should operate first.

So, recloser has two characteristic, recloser fast characteristic normally denoted by A and recloser slow characteristic normally denoted by B. So, you can see (as shown in above slide) that I have shown here, recloser fast characteristic and recloser slow characteristic by same color. So, recloser first characteristic is at the bottom side because what we want whenever any fault that is going to occur we do not know whether it is permanent or transient. So, any fault that is going to occur on this laterals recloser should operate first.

So, recloser has two characteristic, recloser fast and recloser slow. So, recloser fast characteristic is the at the bottom side then the characteristic of fuse comes. So, you can see the characteristic of fuse, I have denoted by green and blue color (as shown in above slide), where the green characteristic I have mentioned as fuse MM characteristic. So, it is fuse a minimum melting characteristic and blue characteristic I have shown with the nomenclature fuse total clearing characteristic.

Now, these two characteristics are normally provided by fuse manufacturer and the difference only between these two characteristics is that fuse minimum melting characteristic arcing resistance is not considered. So, whenever the filament of fuse melt then there is an arc for a fraction of second between the two points and if we eliminate, if we do not consider that, that characteristic is known as fuse minimum melting characteristic.

And when we consider the arc resistance in that characteristic it is known as fuse total clearing characteristic. So, fuse total clearing characteristic is always above the fuse MM characteristic because of the incorporation of arc resistance. So, you can see that I have considered here on vertical two bars, one is the minimum fault current and another is the maximum fault current (as shown in above slide).

So, we have to coordinate this recloser and fuse characteristic between this minimum current and maximum current. Minimum current is decided by the feeders or laterals full load current. What maximum full load current laterals or feeder can withstand with percentage of overload? That is my IF minimum, above that whatever current I consider that is minimum fault current it can detect and also there is a maximum fault current, which is detected by this recloser and fuse depending upon the capacity.

So, between this two vertical bar If_{min} and If_{max}, this characteristic should be coordinated and you can see that this point in this section, the characteristic between recloser and fuse that is well coordinated. The question comes, what is the need of recloser slow characteristics? So, it is, basically, just required to provide additional protection. If fuse fails, recloser slow characteristic will detect the fault and it will operate.

Let us say this fault is going to occur and its current is somewhere here then first it is detected by reclosers using recloser fast characteristic, it will operate reclosing attempt, that is done, if it is transient then it remains connected, so system becomes healthy, if it is permanent then it will becomes open and remain in open condition and then the fuse minimum melting and total clearing characteristic is there. So, it is detected by fuse, if by some means, if fuse fails then also it is detected by the recloser by its slow characteristic.

So, this is how the coordination is carried out between recloser and fuse. But, here one very important point is we have not connected any distributed generators or any distributed energy resources. Now, the question comes, as and when I connect the distributed generators, the scenario will be different.

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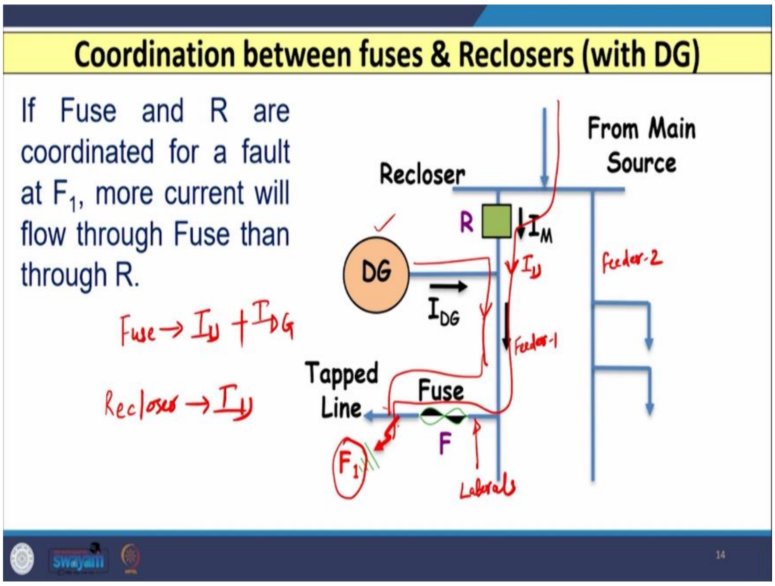

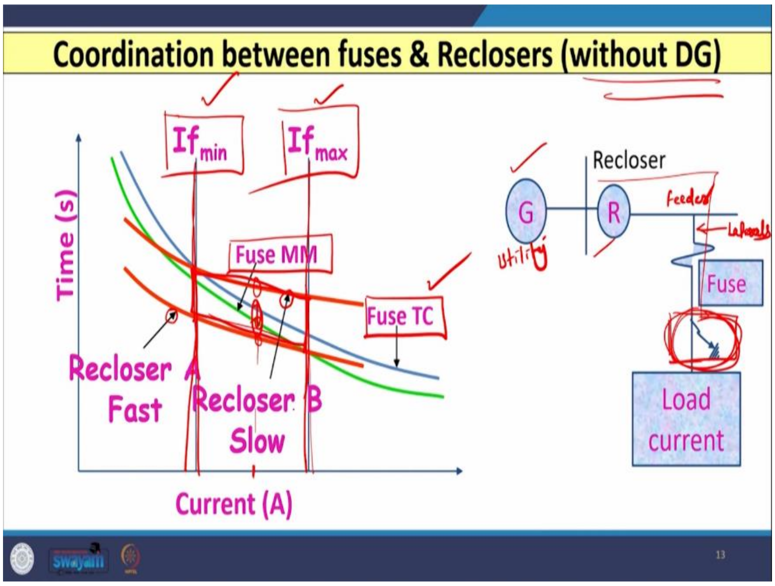

So, here you can see (as shown in above slide) I have connected this DG, where I have considered the same feeder, my laterals is here, this is my laterals and this is my feeder, feeder 1 and this is my feeder 2. So, here you can see for any fault on laterals, you can see that whenever fault occurs at F_1 in this laterals, now, when DG is connected the current that flows through the fuse that is different (as shown in above slide).

Because, what is the current that flows through the fuse, that is the utility current, which is provided from this side, that is your I utility plus. So, this is my I utility and plus the another current that is provided by this DG. So, I_{DG} that will also flow through the fuse, whereas the current that flows through the recloser that is only the I_U. So, now, you see that in earlier case, when there is no DG, for any fault here on the lateral, current flows through the recloser and fuse both are same.

So, there will not be any issue of the coordination between recloser and fuse. And within these two vertical bars we can easily manage to coordinate both recloser and fuse. But, as and when we connect the DG at particular location then the coordination between the recloser and the fuse that is lost. Because now, the current flows through the recloser and fuse both are different.

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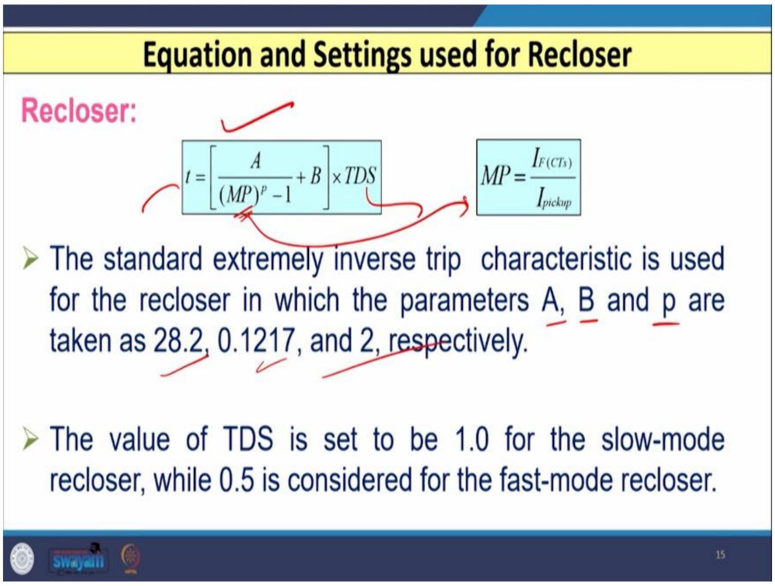

Normally, recloser characteristic is achieved by this equation,

$$t = \left[\frac{A}{(MP)^p - 1} + B\right] \times TDS$$

$$MP = \frac{IF(CTs)}{Ipickup}$$

Where t is nothing but the time of operation of the relay, MP is the multiple of pickup current, and A B and p, these three are the constants; A B and p and this normally we consider the extremely inverse characteristic, because we have to coordinate this characteristic with the load which is connected at the last end or tail end from the source side.

So, if we consider the extremely inverse characteristic then it has the steepest curve as we move from source to the load. So, based on that the value of A B and p, you can consider, that is this value, TDS value, you can consider as 1 for slow, recloser and half that is 0.5 for fast preclosure.

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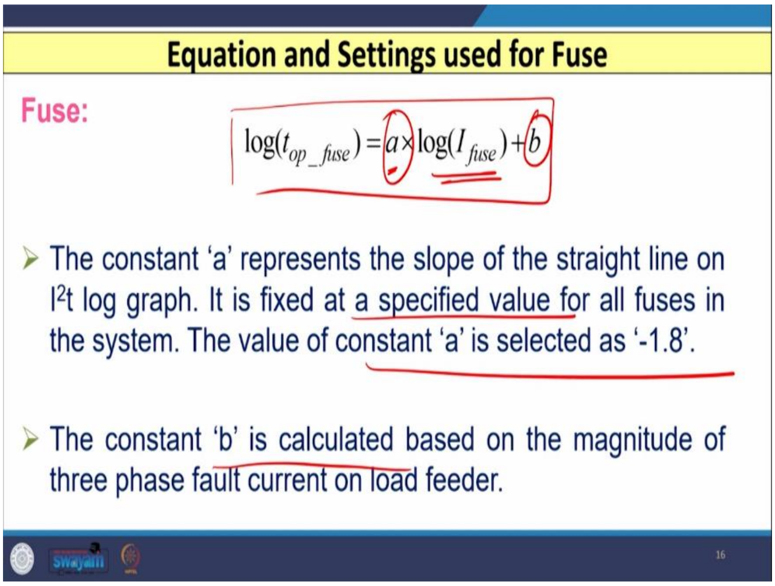

Fuse characteristic that is normally given on log-log curve. So, it is given by this equation $\log(t_{op\_fuse}) = a \times \log(I_{fuse}) + b$

Where, a represents the slope of the straight line on the I square t log graph and it is fixed at specified value for all fuses of a particular system and its value is normally considered as minus 1.8. The constant b that is normally calculated by considering the three phase fault and based on that three phase fault on the feeder you can have the value of b.

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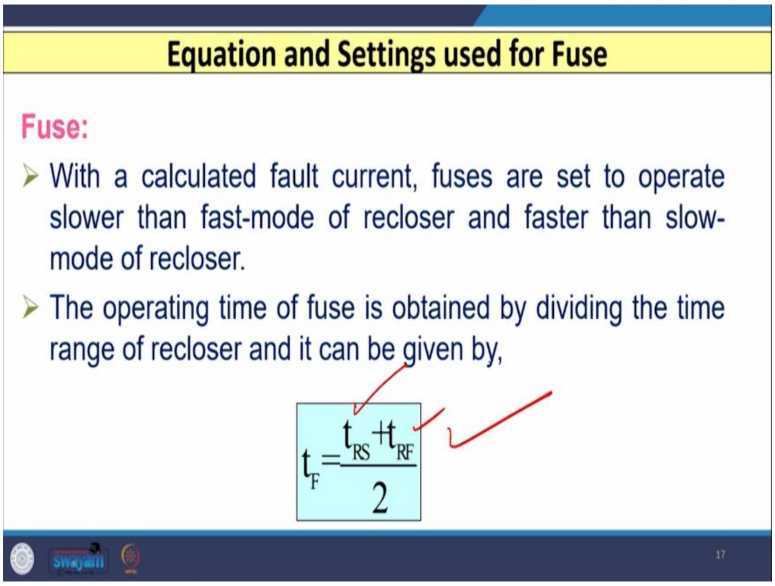

Fuse normally when you consider the time of operation of fuse that is given by this equation $t_F = \frac{t_{RS}+t_{RF}}{2}$, where t_{RS} is the time of operation of recloser in slow mode and t_{RF} is the time of operation of recloser in fast mode.

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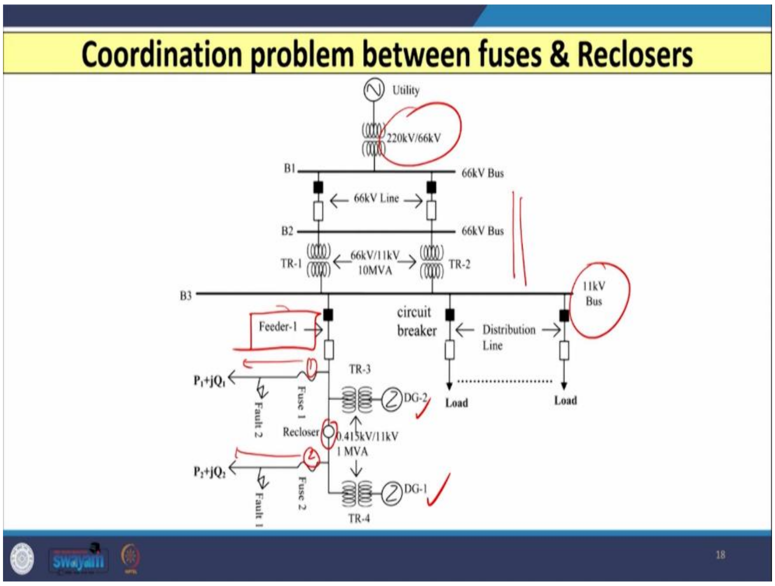

Now, let us consider one big system (as shown in above slide), where we have the utility with 220 kV by 66 kV voltage, which is stepped down and we have 66 kV line available and which is further shafts down using transformer and we have 11 kV bus available from which HT consumers or distribution feeders are emanating.

And let us consider one of the feeder that is feeder 1 and on that let us consider the two laterals, lateral 1 and lateral 2, where we have the two fuse are connected fuse 1 and fuse 2. These two laterals are protected by fuse 1 and fuse 2 and I am considering one recloser here (as shown in above slide) and I am also considering two DGs are connected at these two positions. So, now, let us see what is the current seen by recloser and what is the current seen by the fuse.

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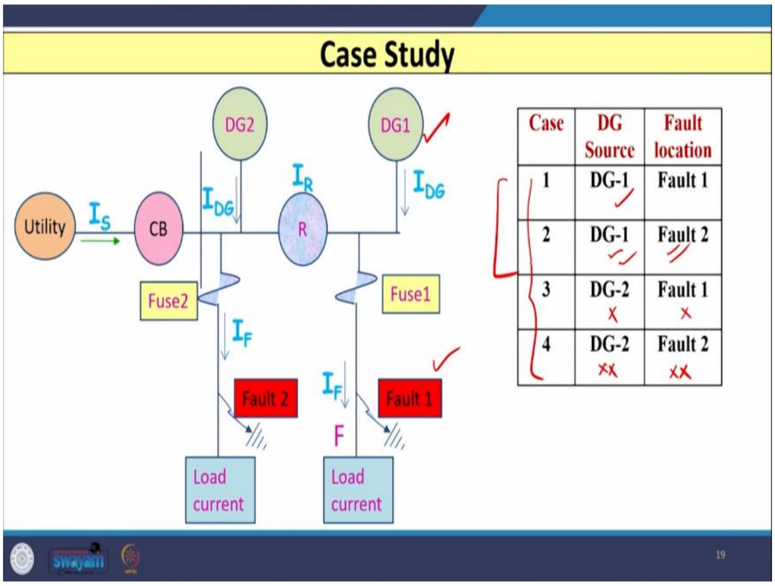

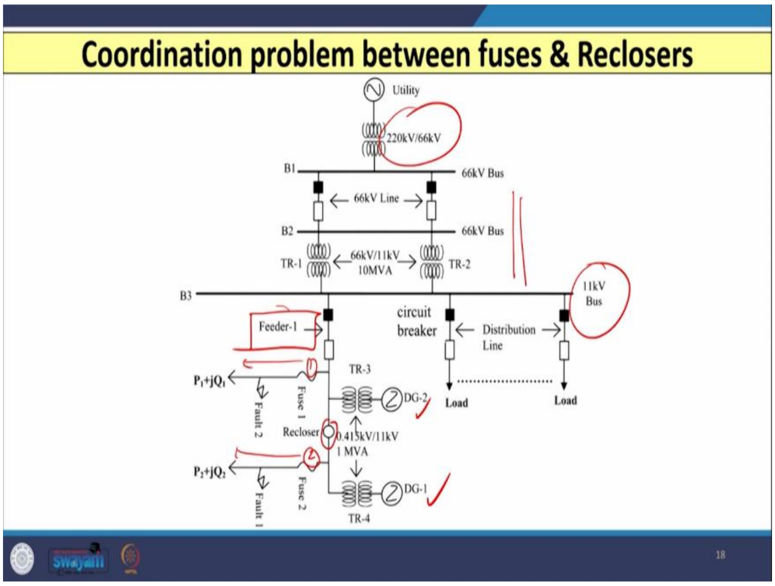

So, normally when I consider this if I just take the diagram small portion of this in a large fashion then we have the system like this (as shown in above slide) and four cases are possible let us say these four cases are depend on, which DG we are considering, let us say, we are considering DG 1 and we are considering fault 1, we are considering DG 1, but we are considering fault on another lateral. So, DG 1 and fault 2.

The third we are considering case that is DG 2 we are considering and fault 1. And we are considering fourth case, where DG 2 is we are considering but we are considering fault on another lateral that is fault 2. Out of these four cases, I think these first two cases are very important.

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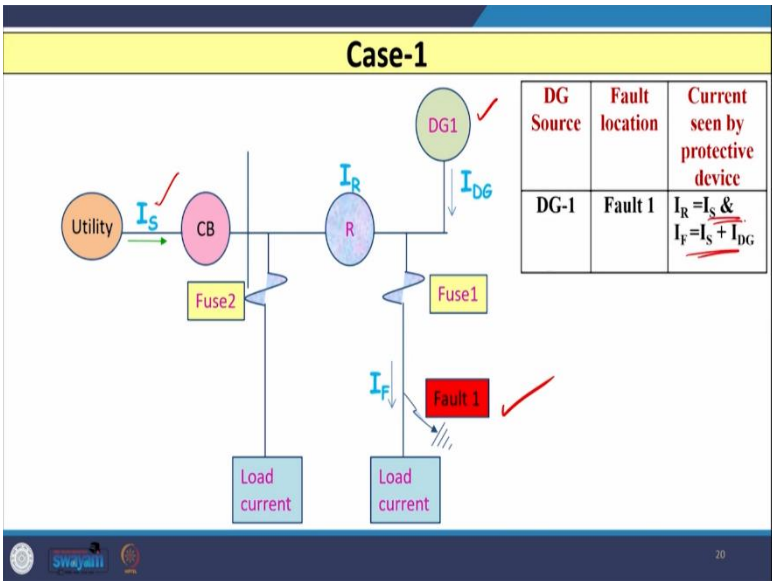

So, if I consider the first two cases, case number 1, where we are considering DG 1 and we are also considering the fault 1. So, now, you can see (as shown in above slide) if there is a fault on these laterals. So, recloser is connected here. So, if any fault is there current through the recloser is only the current flows from the utility that I_S, whereas current that flows through the fuse that is nothing but the summation of the I_S that is current from utility and current from the I_{DG}. So, you can see the current through the recloser and fuse both are different.

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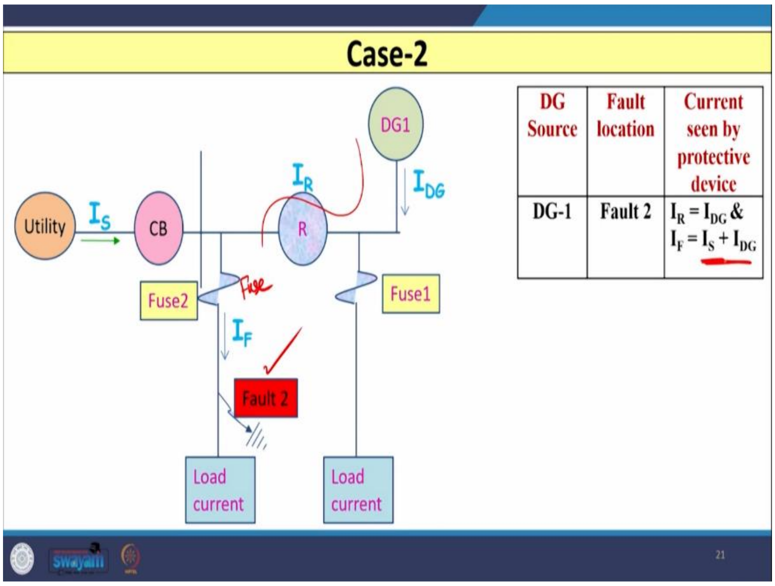

Similarly, for second case, where we consider DG1 and fault at second lateral then also the current through the recloser, you can see (as shown in above slide) that is the current that flows through the DG 1. So, I_{DG} and current that flows through the fuse, that is this fuse that is nothing but again the current that flow available from the utility I_S and current from the DG that is I_{DG}.

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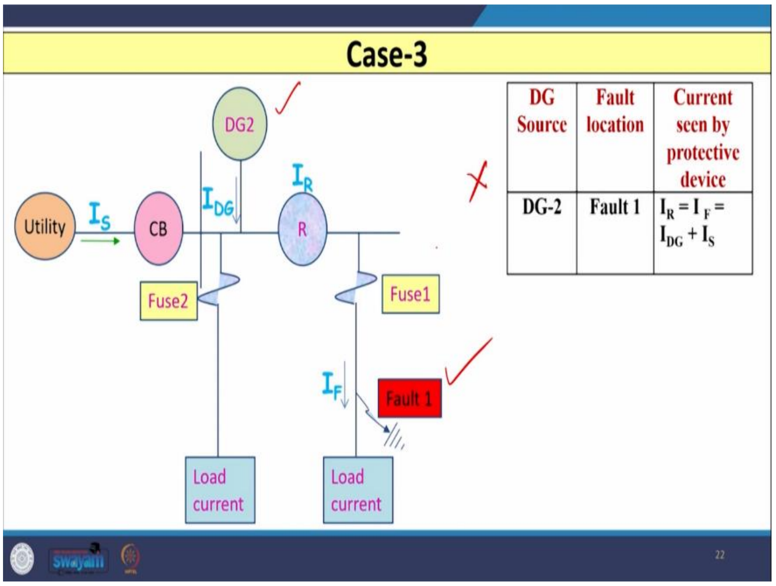

If I consider the third case, where the DG 2, I am considering and I am considering the fault 1. So, in that case current flows through the recloser that is current flows through the fuse both are same and that is I_{DG} + I_S. So, you can see here (as shown in above slide), if I consider this fault then the current flows through this that is both are same and current flows through the fuse that is also same thing. So, this case is not important for us.

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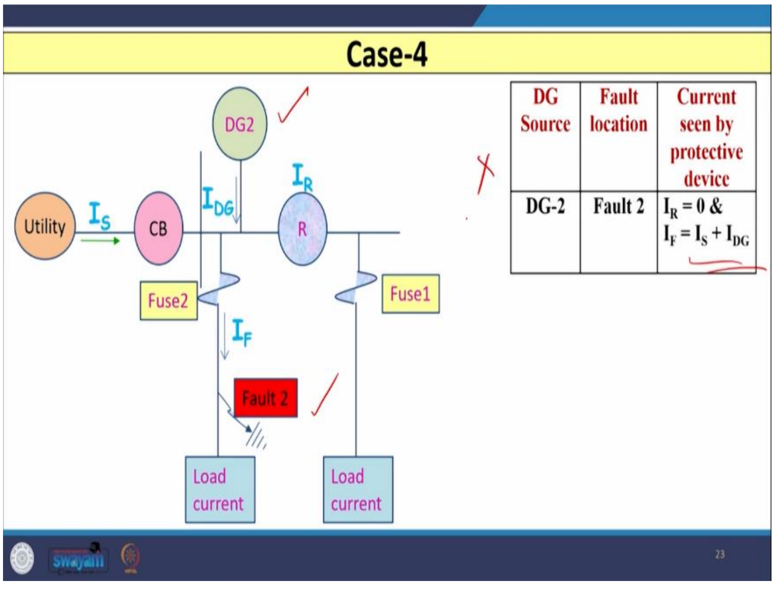

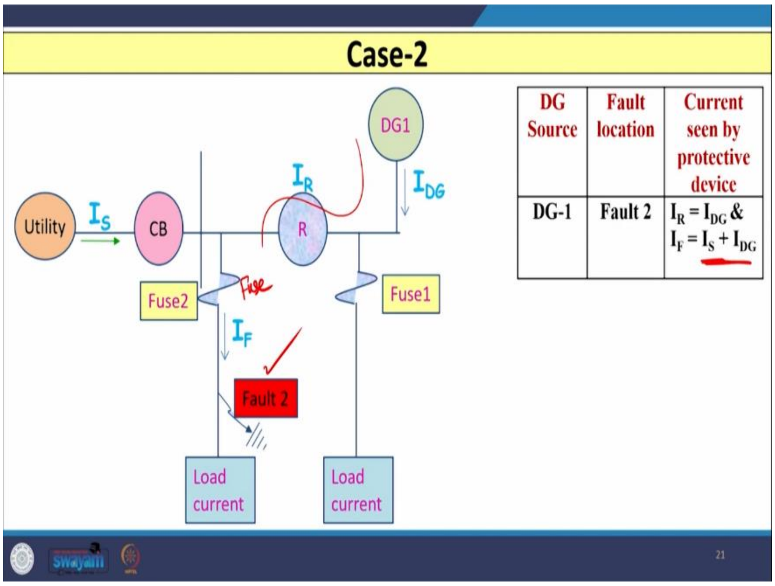

Similarly, if I consider the fourth case, then in this case, when I consider DG 2 and fault 2 then the current that is through the recloser that is 0 that is not there and current through the fuse that is both from utility as well as the DG. So, this case is also not important.

So, only case what is important with us that is case 1 and case 2, in which current through the recloser and current through the fuse, both are entirely different. And that is going to create a problem. If we consider or if we refer the fuse saving concept, then what we want is that recloser should operate first then the fuse.

Because we want that recloser should operate and avoid all transient or temporary fault and fuse should operate only for a permanent fault. But, this is possible only when we consider there is no DG connected. But, as and when DG is connected then the situation becomes different.

Because, when no DG is connected, current through the recloser and fuse both are same, but as and when we connect the DG, current through the recloser and fuse both are different. So, now, what, how much different current is available when we connect the DG which are going to flow through the recloser and fuse that depends on the type of DG, placement of DG and capacity of DG.

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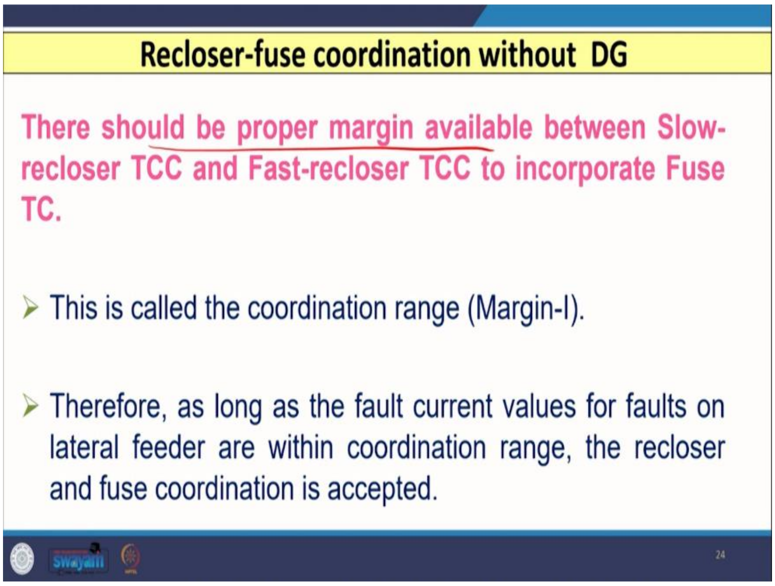

So, what we want is there should be some proper margin available between the slow recloser characteristic and fast recloser characteristic to incorporate the fuse characteristic. And this is known as margin. Therefore, as long as the fault current values for faults on the lateral feeder are within the coordination range, the recloser fuse coordination is accepted, that is without DG even when you connect DG then even that margin is satisfied.

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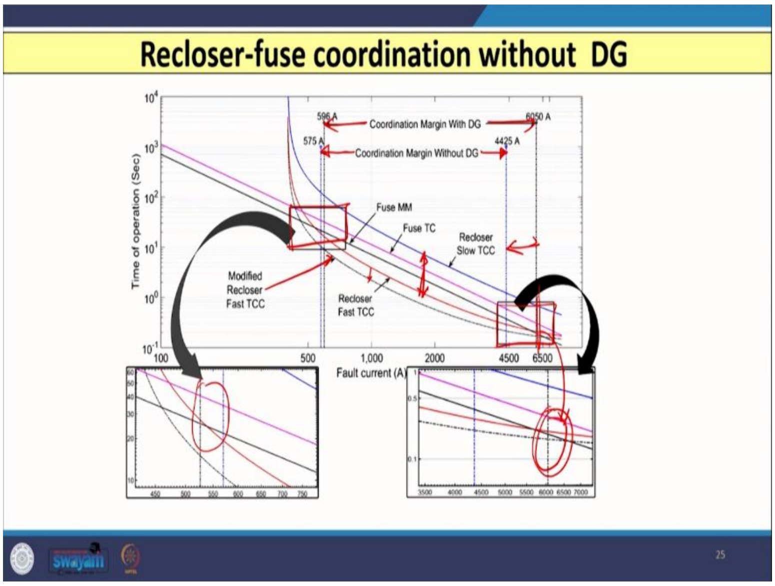

Let us say for example here (as shown in above slide) I have shown the coordination margin with two vertical blue lines you can see here. So, here you can see that coordination margin without DG that is shown by two vertical blue lines and here you can see that the characteristic

I have shown that is, this red color is recloser fast, the blue color is recloser slow and in between I have the fuse TC and fuse MM characteristic (as shown in above slide).

Now, you can see that outside this range, if I take the zoom portion of this, then you can see that here, there is a mismatch in the characteristic, two characteristic overlaps (as shown in above slide). So, this characteristic, you can see this region, that is perfectly working when there is coordination margin available between these two vertical blue lines.

If I connect the DG and if my coordination margin increases then you can see (as shown in above slide) at this point I have shown here, this point, then two characteristic either fuse TC or fuse MM that is going to overlap with the recloser fast TCC. So, what will happen that whatever fuse saving concept we want, that is violated and for any fault, somewhere in this region, because that is the extended portion, in that case, fuse and recloser both will operate simultaneously. Even in this region also you can see that the characteristic of this, that is overlapping.

So, if we want solution for that then what we have to do is, we have to reduce the characteristic of the recloser fast TCC, slightly below which I have shown here and I have mentioned as modified recloser fast TCC curve. If I do this, then sufficient margin is available, but again that is only for sufficient value of the DG which you have connected. After once it exceeds that then also this is not possible, means if I reduce the characteristics slightly below then it is possible only up to certain extent. So, what extent we need to consider.

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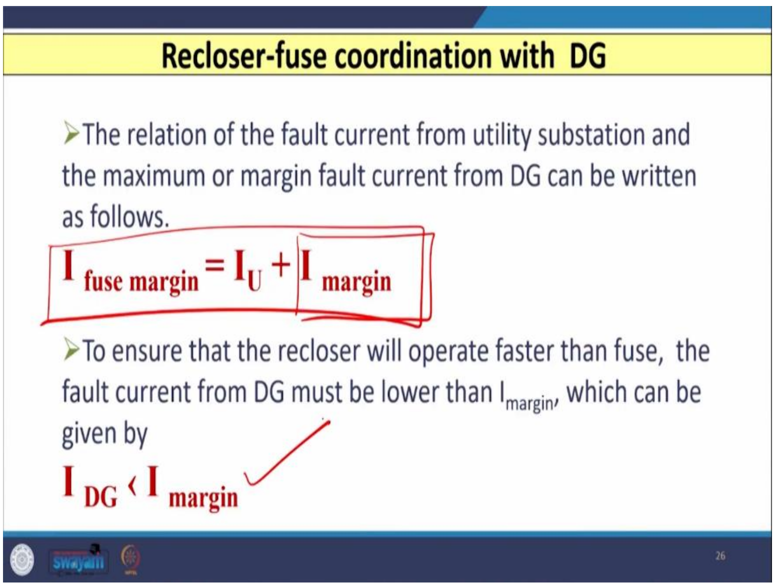

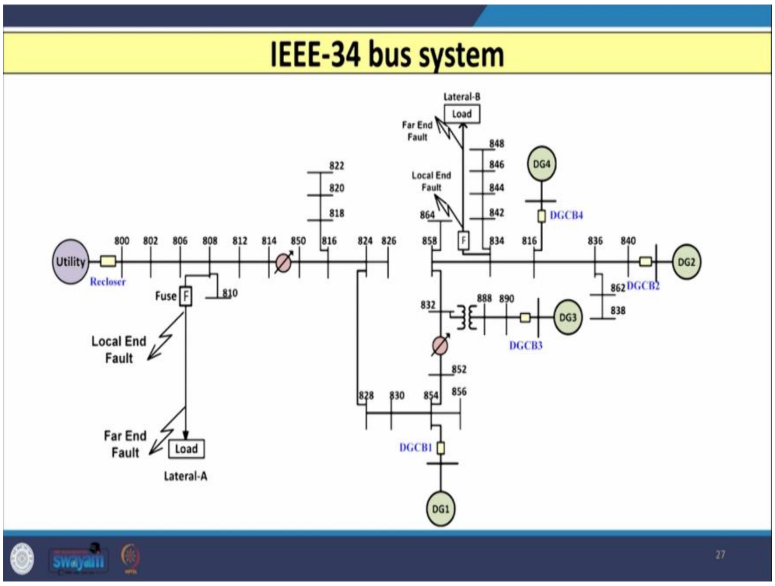

So, for that what is possible is that we have to consider this equation $I_{fuse\ margin} = I_U + I_{margin}$.

So, that DG current we are considering as margin and that DG current should be always less than some margin current. So, that coordination between all these four curves are maintained.

If it is not satisfied, if this is not satisfied then coordination is lost and this can be also this problem becomes very complex when you consider larger network like IEEE-34 bus network, there, you see that the system becomes very complex and it is very difficult to achieve this coordination between recloser and fuse.

So, in this lecture what we have considered is, we started our discussion with the coordination between fuse and recloser and we have seen that considering the different cases, initially, we have discussed that we will go for fuse saving concept and that is the concept used by most of the utility. And in that we have discussed that when no DG is connected recloser should operate first.

So, that all the transient or temporary faults are die out and there is no unnecessary disconnection of laterals because of operation of fuse. But this is not possible when DG is connected and this solution of this is partially achieved, if we reduce the characteristic, fast characteristic of recloser then up to certain extent that problem can be resolved. Thank you.