Digital Protection of Power System
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Lecture 21
Coordination of Overcurrent Relays for Distribution Network - I

Hello friends. So, in this lecture, we are going to discuss about the coordination of overcurrent relays that is used for distribution network. So, we know that overcurrent relays are widely used in distribution network as a primary protection, because they are very cheap as well as their protection is very simple. And these relays are sometimes also used at maybe medium transmission or high voltage transmission line protection as a backup.

And this relay operates when the value of current or magnitude of fault current exceeds the pickup value or threshold value and then relay operates and it gives signal or command to the circuit breaker.

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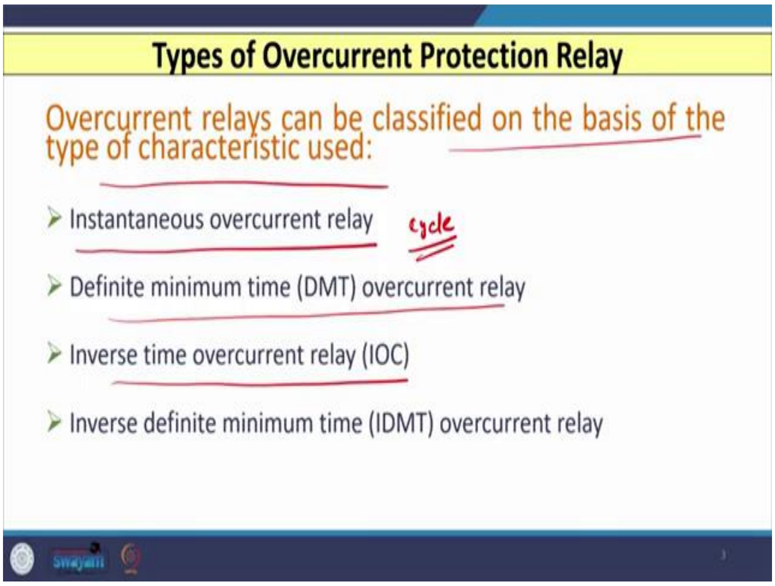

Now, we know that overcurrent relays can be classified on the basis of type of characteristic that is used by overcurrent relay itself and basically four classifications are available. The first is the classification based on the time of operation, so instantaneous overcurrent relays are there, which operates instantaneously. However, we know that no such relay exists in actual field which operates instantaneously.

So, any relay which operates in let us say in a cycle, then those relays are treated as instantaneous overcurrent relays. The second type of characteristic that is definite minimum time overcurrent relay, the third is the inverse time overcurrent relay and fourth is the inverse definite minimum time overcurrent relays. So, basically these four categories of overcurrent relays are used based on the what characteristic that is utilized by a particular relay.

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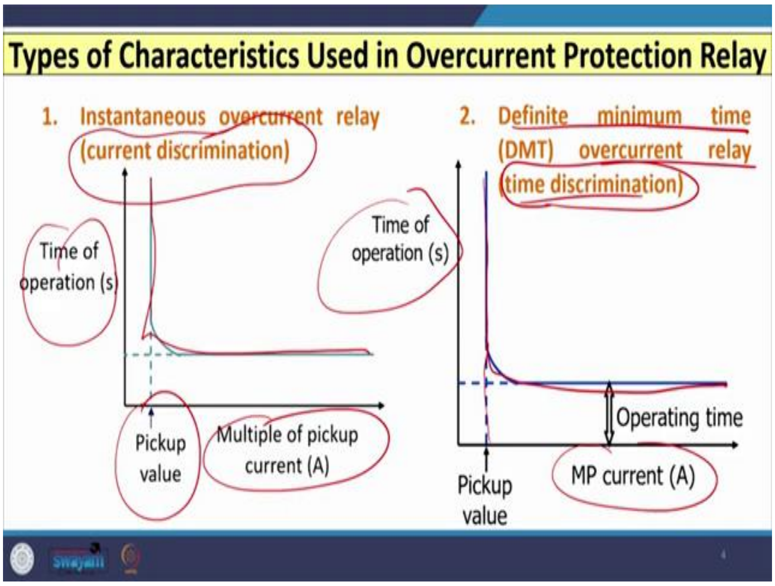

Now, if I consider instantaneous overcurrent relay, which is usually works based on current discrimination, then if I draw a graph of multiple of pickup current versus time of operation, then you will have a graph like this (as shown in above slide). So, whenever the current exceeds this pick up value relay operates instantaneously. However, on the other hand, in case of definite minimum time overcurrent relay, which operates on the time discrimination.

So, here, if I draw a characteristic of multiple of pickup currents versus time of operation, then we will have the same graph as we have in case of instantaneous overcurrent relays (as shown in above slide), but the difference is when the current exceeds this pickup value, then the operating time of relays remain constant which is set by the user. So, here time discrimination is important. Whereas in case of instantaneous overcurrent relay, current discrimination is important.

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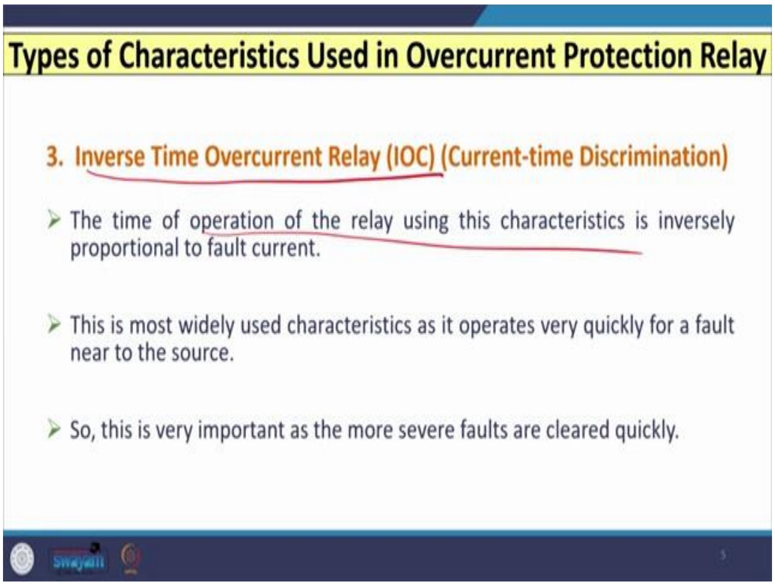

If we combine both current discrimination and time discrimination philosophy, then that is going to give us the third type of characteristic which is known as inverse time overcurrent characteristic. Now, in this case, the time of operation of relay is inversely proportional to the magnitude of fault current, higher the magnitude of fault current lower is the time of operation of relay and vice versa.

So, the most widely used characteristic or that covers under inverse time overcurrent relays, it has different characteristics like normal inverse, very inverse, extremely inverse. And as we move from normal inverse to very inverse and very inverse to extremely inverse, the curve of this characteristic or slope of this characteristic that becomes more and more steeper. So, it is very important for the user to select which characteristic is most suitable as far as the application is concerned.

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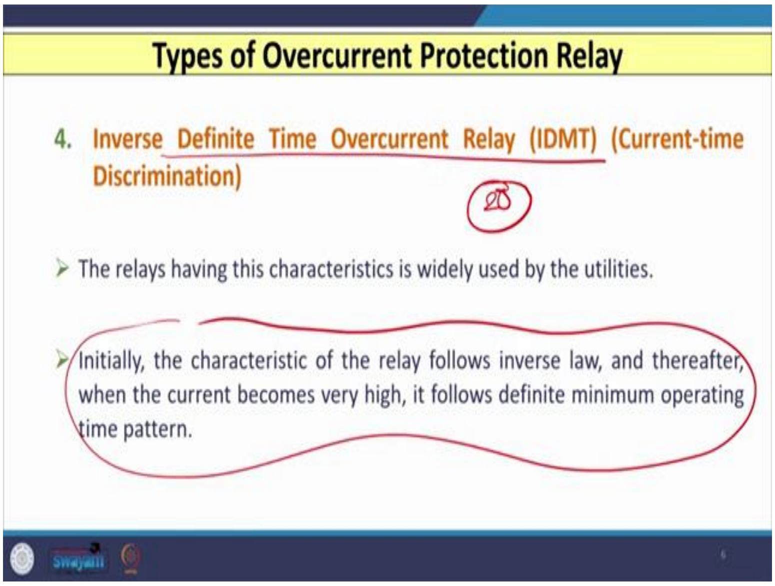

The fourth type of characteristic which is known as IDMT characteristic or inverse definite minimum time characteristic and in this again the discrimination philosophy is current time. The only difference is this relay or this characteristic of relay follows inverse relationship that means magnitude of fault current increases, time of operation reduces up to a particular value of plug setting multiplier, that is multiple of pickup current let us say 20.

And if your multiple of pickup current or PSM exceeds 20, then the characteristic of this relays follows some different curve let us say definite minimum time curve. So, that the torque or the flux produced inside the disk of the relay that saturates and relay operating time remains constant.

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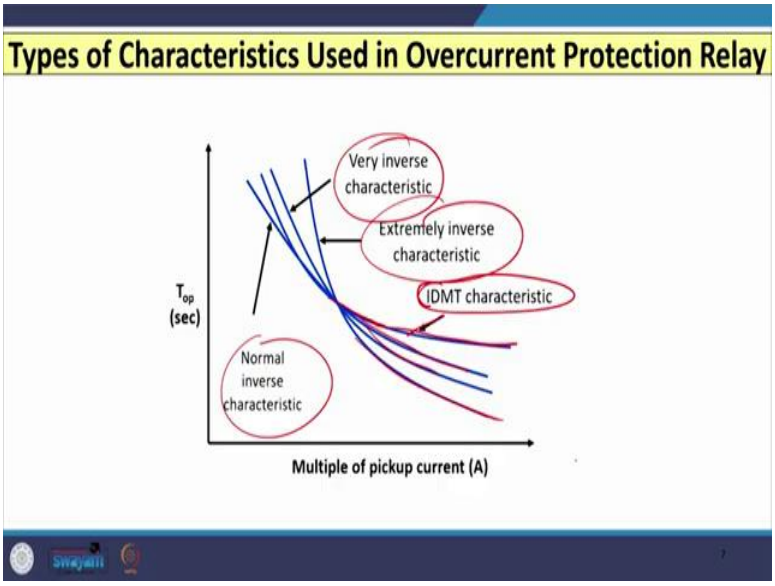

So, if I see the characteristic of all these, then you can see (as shown in above slide) I have shown the very inverse, extremely inverse and normal inverse characteristic in multiple of pickup current versus time of operation of relays in second. Along with that, I have also shown the IDMT characteristic which is here (as shown in above slide) as you move ahead the characteristic becomes more and more steeper.

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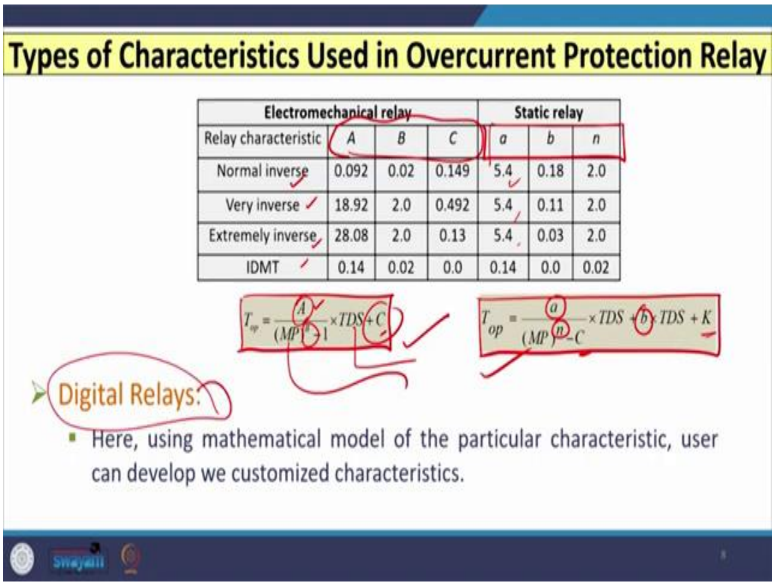

Now, for all this characteristic if I want to use electromechanical or static relays, then for electromechanical relays, I have to use this equation to calculate the time of operation of relay.

$$T_{op} = \frac{A}{(MP)^B - 1} \times TDS + C$$

So, here A, B and C, these three are the constant and depending upon what value of constant you select, you will have the normal inverse characteristic, very inverse characteristic, extremely inverse characteristic and IDMT characteristic. The value of multiple of pickup current depends on the magnitude of fault current referred on CT secondary side and pick up current of the relay. TDS value is already given.

Similarly, if I use static relay, then for static relay to calculate the time of operation of relay, we will use this equation,

$$T_{op} = \frac{a}{(MP)^n - C} \times TDS + b \times TDS + K$$

in which a, n and b; these are the constants and these constants are different for different characteristic you can see here the value of K and value of this C are also different, but we can keep it constant in this case. Now, what is the difference in case of digital relay?

So, here in digital relay, we can go for the mathematical model of particular characteristic and user can develop its own customized characteristic however, that customized characteristic development is not possible in case of electromechanical or static relays. So, in electromechanical and static relays, we have some fixed characteristic whereas in digital relays, we can develop our own characteristic depending upon what constant we want.

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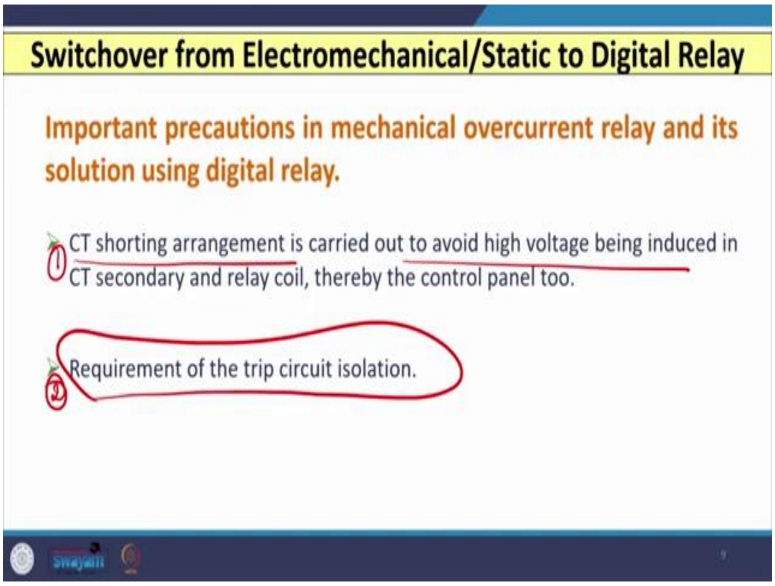

Now, the reason is why people are most of the researchers or utility personnel switch over from electromechanical or static relates to digital relays. There are mainly two reasons; the first reason is the CT shorting arrangement, which is required if we go for electromechanical or static relay, because when we have connected the relay coil, then CT shorting arrangement is required otherwise high voltage that is produced across the secondary of CT or in the relay coil, so if any control personnel is working in the control circuit and doing some maintenance, then he may get an electric shock.

The second reason that why we switch over from electromechanical or static relay to digital relay, that is the requirement of trip circuit isolation. So, trip circuit isolation is normally used during the periodic maintenance. So, when we carry out the periodic maintenance of electromechanical or static relays, then what we do is we activate the trip circuit isolation thing or a particular logic whenever we test the relay, relay operates and it gives signal to the circuit breaker and circuit breaker may trip.

Because this is not an actual trip we are testing the relay for periodic maintenance. So, for that trip circuit isolation is required. However, in case of digital relay, this is not required. So, because of these main two advantages, we will switch over from electromechanical or static to digital relay.

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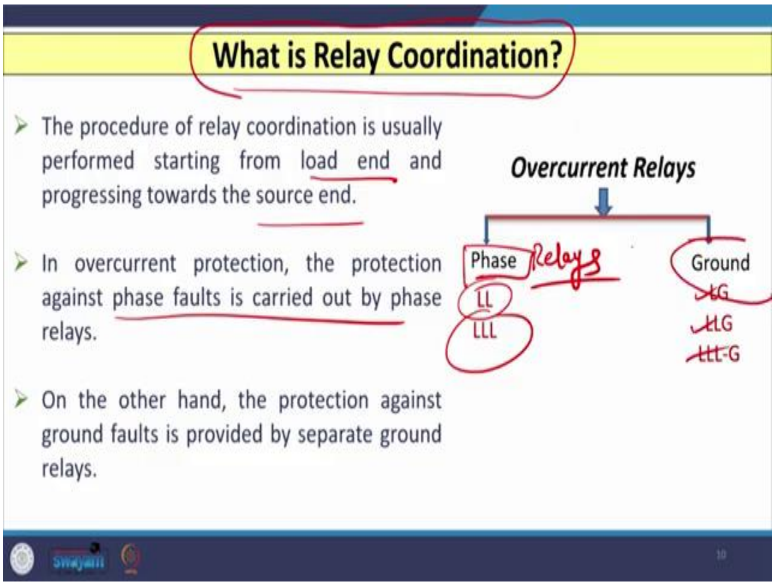

Now the question comes what is relay coordination and why it is required? So, the relay coordination is nothing but a procedure using which we can calculate the plug setting and time dial setting of all the relays available in a particular network. And wherever we follow or wherever we have the relay coordination of a particular network with available relays, then we have to always start from the load end relay and we have to progressively move towards the source end relays. This is a normal thing we consider.

So, if we consider the overcurrent relays then the protection against phase faults, those do not involve ground like line to line and triple line faults that is carried out or obtained by phase relays. So, we have phase relays and again protection against the ground faults which involve ground like line to ground, double line to ground and triple line to ground that is achieved by ground relays separately.

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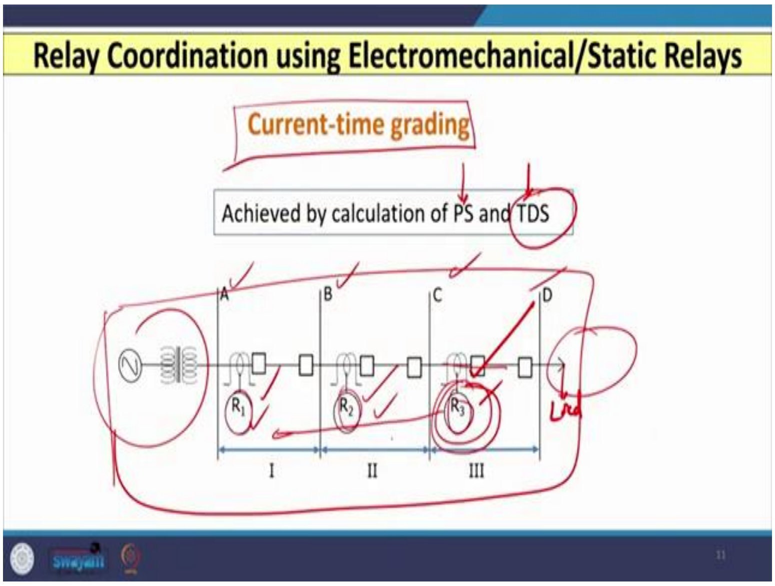

So, if we talk about the relay coordination then, if I consider the current time grading in that case usually the relay coordination or calculation of settings of all the relays and when I say settings that means, we are talking about plug setting and time dial setting of all the relays that we need to calculate. And if I go for current time grading, then let us consider this example, where we have four substations, ABCD and feeders are connected between AB, BC and CD and three relays R_1, R_2, R_3 in three sections are connected.

So, whenever we want to calculate the plug setting and time dial setting of this relays, R_1, R_2, R_3, this is a radial network or structure of the distribution network. So, we have to start with the relay which is connected near the load. So, we have to start first the calculation of plug setting and time dial setting of relay R_3 plug setting is normally calculated based on the full load current of this feeder with some percentage overload it can take.

And time dial settings are calculated based on the fault MVA or the breaking capacity of a particular circuit breaker. Once we have the value of R_3, we have to move towards the relays located at source end, so then we can calculate the plug setting and time dial setting of R_2 and then we can calculate the plug setting and time dial setting of R_1. So, in this way, we can carry out the relay coordination. However, this is a simple radial network where source is connected at one end and the other side loads are connected. So, this is very simple.

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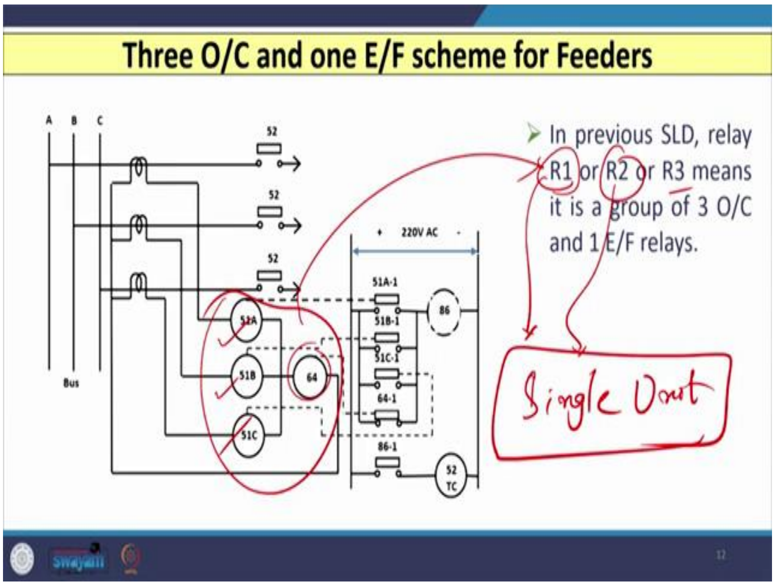

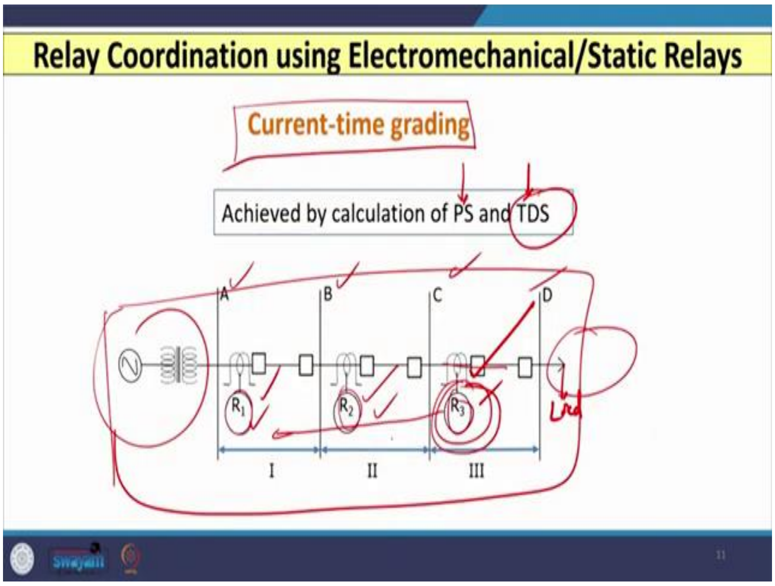

Here one more important point is whenever I say R_1, R_2 and R_3; this R_1, R_2 and R_3 are group of relays and I told you, for phase faults phase relays are used, for ground faults ground relays are used. So, when I say R_1 that means R_1 contains a group of relays total four relays, three phase relays and one ground relays. So, when I say R_1, R_1 means four relays, three phase relays, one ground relays; R_2 means another four relays, three phase relays, one ground relays and so on.

However, this is possible if I consider electromechanical or static relays, if I use digital relays, then all these four relays which is equivalent to R_1 those are replaced by single unit, because in digital relay contains both ground protection and phase protection, both are possible in single unit.

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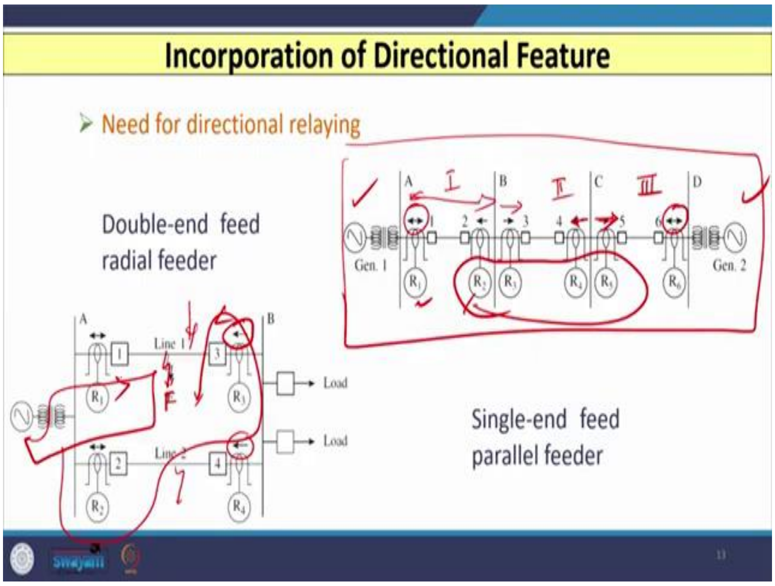

Now, if I consider another feature, which is the addition of directional feature, then you can see (as shown in above slide) that I have shown the same radial feeder, but now this radial feeder is fed from both the ends. So, source is connected at both side, compared to the earlier feeder or network in which source is connected only on left hand side. So, as you can see in each section, section1, section2 and section3, you can see I have connected two relays R_1, R_2, R_3, R_4 and R_5, R_6 (as shown in above slide).

So, here when you have the feeder or the radial network connected or fed from both side source, then you first thing is you have to decide which relay is directional and which relay is bi-directional. So, these two relays you can see which are located near the source R_1 and R_6 these two are bi-directional, whereas other four relays R_1 to R_5 these are directional because how to decide the directional relay or bi-directional relay?

We can decide assuming that a particular point or location where the value or magnitude of fault current reverses those relay we can treat as directional relay and direction we can take it always away from the bus. So, you can see that R_2, R_3, R_4, R_5 are directional relays and the direction is like this. So, what is the difference between simple overcurrent relay and directional relay?

Simple overcurrent relay operates when current exceeds pick up value, whereas directional overcurrent relay operates when current exceeds pickup value or plug setting and the direction which is like this (as shown in above slide) that is also satisfied. So, END logic of two things are there. Now directional relays are very important when we consider the parallel feeder like this, where there are fair chances of reversal of fault.

For example, if I consider a fault here at point number f, one of the way to flow the fault current is like this, the other way to flow the fault current is like this (as shown in above slide). So, obviously, there are fair chances of reversal of fault. That is why this relay I have considered as directional. Similarly, when fault occurs here this relay (as shown in above slide), I have to consider as directional.

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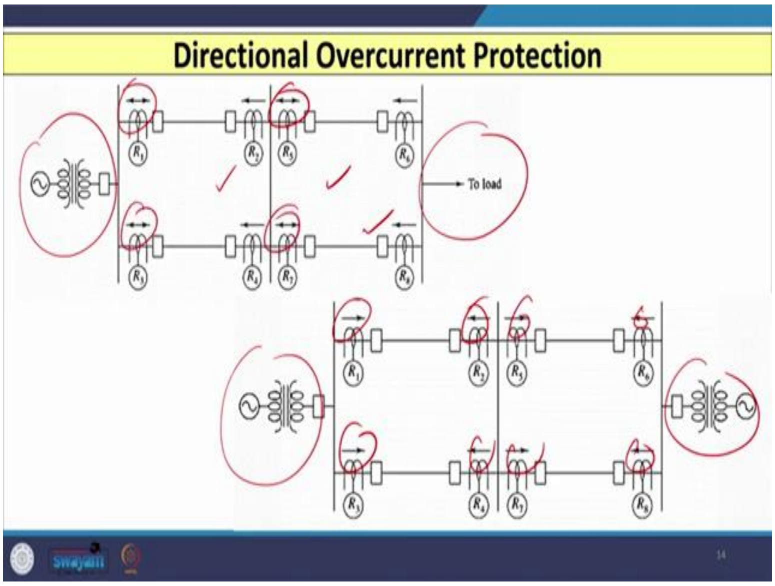

Same way, this is a single parallel feeder, I can go for cascaded parallel feeder two parallel feeders are cascaded, and this cascaded parallel feeder is connected at one end source other end is load. However, you can also modify where this cascaded parallel feeder are connected from both the sides with the source. So, in this case, all the relays you can see are directional in nature. Whereas, in earlier case, this case, you can see (as shown in above slide) that these relays are bi-directional, whereas other relays are directional in nature.

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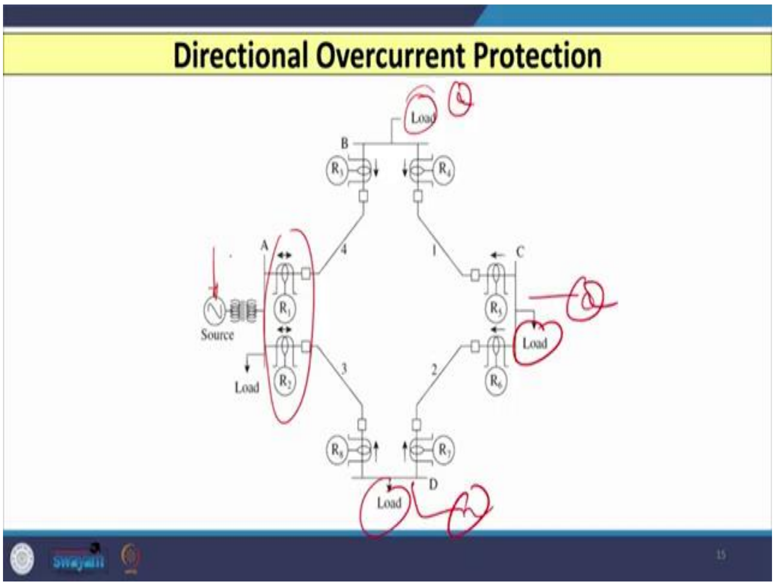

Similarly, if we go for ring main network, assuming that let us say loads are connected at this point and source is connected only here, then you can see (as shown in above slide) that total eight relays are shown and except these two relays, all other relays are directional relays. And if I connect source here also, then you can see that all the relays, all eight relays must be directional in nature (as shown in above slide).

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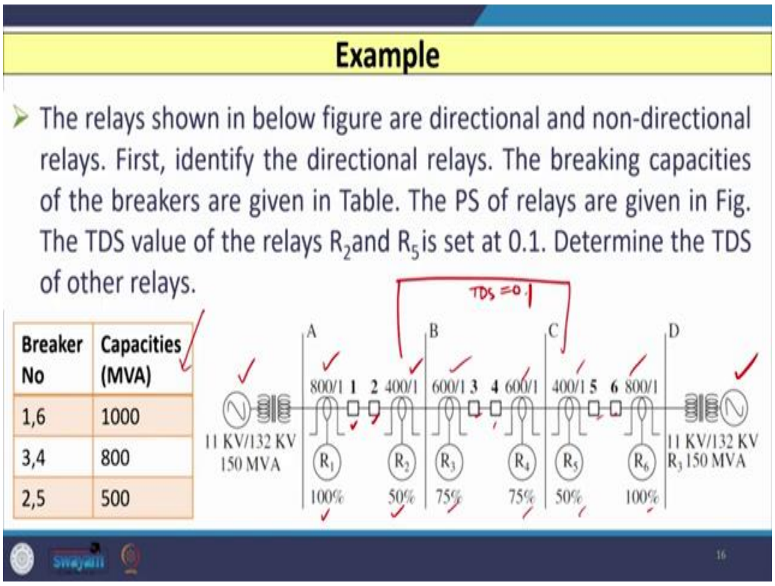

Now, to understand all these things, and why we need coordination, let us consider one simple example. So, what I have done, I have considered the same radial feeder or same radial network, but it is fed from both ends. So, sources connected on left hand side as well as right hand side, the CT ratio of each relay is shown. The plug setting of each relays R_1, R_2, R_3, R_4, R_5, R_6 are given.

Moreover, the breaking capacity in MVA for each circuit breakers are also given in this table as shown in above slide). So, you can see breaker 1, 2, 3, 4, 5, 6 their breaking capacity in MVA that is also given. And the time dial setting of relay R_2 and R_5 this is also given. So, for relay R_2 and for relay R_5 the TDS value that is also given. And you need to determine the TDS value of other relays, let us say R_1, R_3, R_4 and R_6. So, let us see how we can calculate it.

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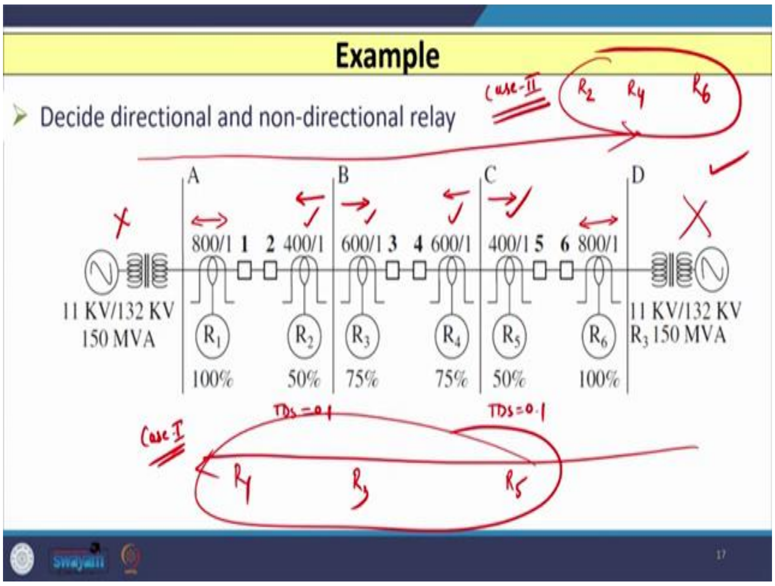

So, here the first thing is we have to decide which relays are directional and which are bi-directional. So, obviously, these two relays which are located near the source, these two are again bi-directional in nature, whereas, these relays are directional in nature (as shown in above slide). So, R_2, R_3, R_4 and R_5 are directional in nature and their direction of current is like this. Now, with this background, let us see how we can calculate the time dial settings of relay R_1, R_3, R_4 and R_6. Time dial setting of this R_2 that is given us 0.1 and R_5 that is also given as 0.1.

So, obviously, what we have to do in this case, we assume that this source is not connected and then we have to move from load end to source end this is case number 1. So, in that case, what we have to do we have to consider relay R_5, relay R_3 and relay R_1 and we have to carry out coordination of these three relays. This is for case number 1.

In case number 2, what you have to do is we have to consider that this source is not connected and this is connected and then we have to move from this side to this side (as shown in above slide). And here we have to consider the relay R_2, then relay R_4 and then relay R_6 and then we have to coordinate these relays so that we can easily obtain the time dial setting of whatever relays that is calculated.

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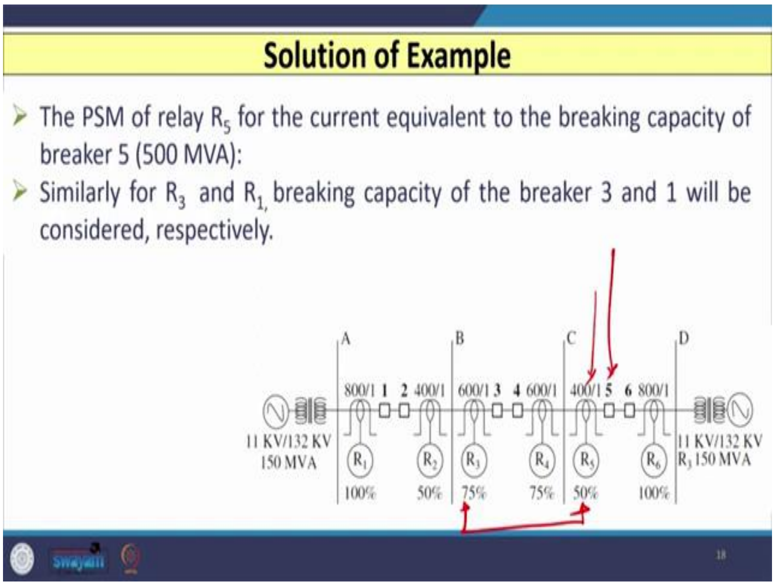

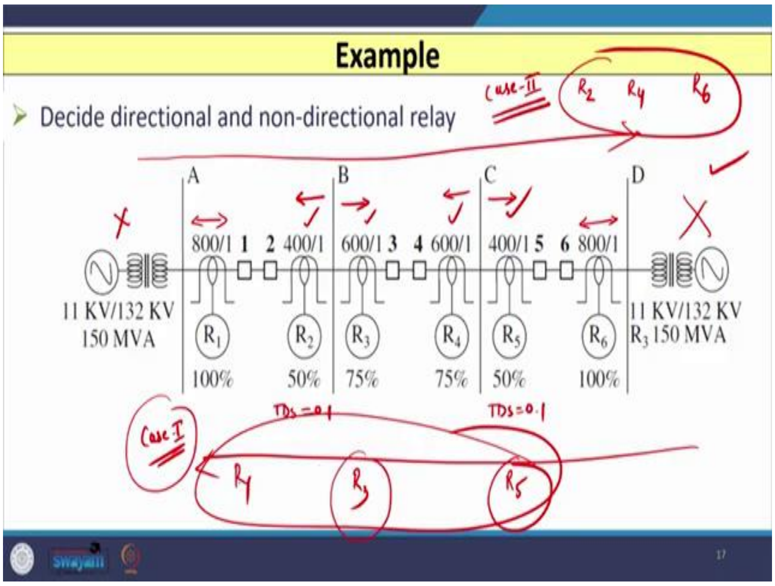

Now with this let us first calculate the time dial setting of relay R_4 or R_3 let us say R_3. So, we are considering this case, case number 1 where the plug setting and time dial setting of relay R_5 both are given and we need to calculate the plug setting and time dial setting of R_3 and R_1. Although plug setting are given, so we need to calculate the time dial setting. So, let us coordinate first relay R_5 with relay R_3. So, here plug setting multiplier of relay R_5 we need to calculate first, assuming that breaker capacity of this circuit breaker 5 that is given as 500 MVA.

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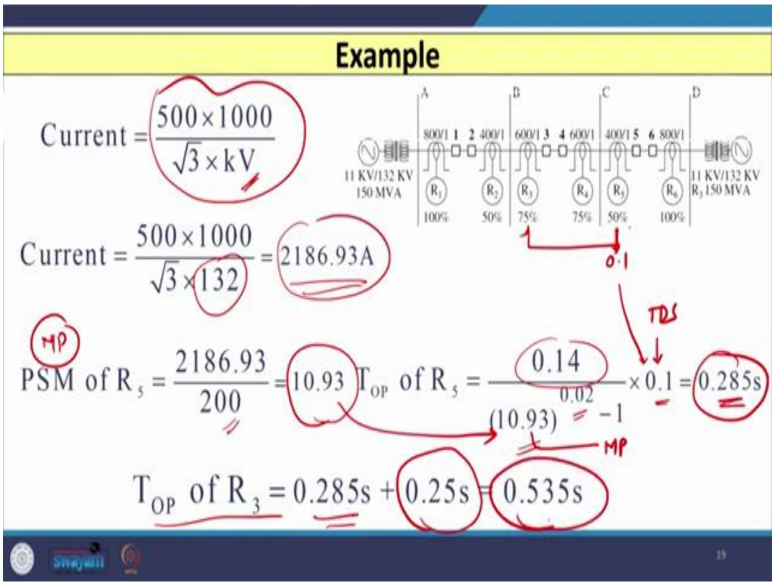

So, we can easily calculate the current using this 500 MVA.

$$\text{Current} = \frac{500 \times 1000}{\sqrt{3} \times \text{kV}}$$

$$\text{Current} = \frac{500 \times 1000}{\sqrt{3} \times 132} = 2186.93\text{A}$$

So, for relay R5, we can calculate the plug setting multiplier or multiple of pickup current,

$$\text{PSM of } R_5 = \frac{2186.93}{200} = 10.93.$$

So, TOP of relay R5 you can easily calculate using this characteristic,

$$T_{OP} \text{ of } R_5 = \frac{0.14}{(10.93)0.02^{-1}} \times 0.1 = 0.285s$$

Now, once the time of operation of relay R5 is available, now, you are coordinating relay R5 with relay R3. So, required time of operation of relay R3 that should be time of operation of relay R5. So, this is available, but we need to calculate TDS of relay R3.

$$T_{OP} \text{ of } R_3 = 0.285\text{s} + 0.25\text{s} = 0.535\text{s}.$$

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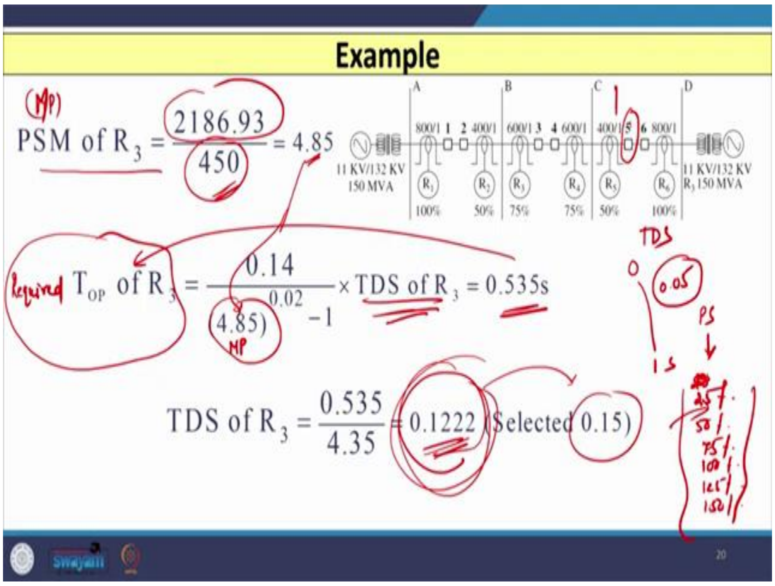

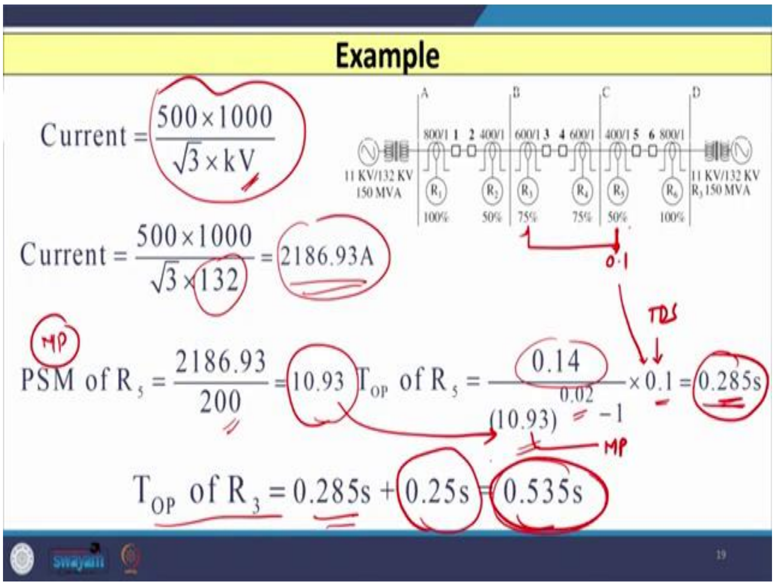

So, for that we will first calculate the plug setting multiplier or multiple of pickup current of relay R_3. So, same current what we have considered using this breaker 5, we can have the value that is $\text{PSM of } R_3 = \frac{2186.93}{450} = 4.85$. So, we have the required we need to write required time of operation of relay R_3 that is this value.

So, we have MP we have calculated So, you can put it here TDS we need to find out required time of operation of relay R_3 that is available that is 0.535 second. So, you can put it this value here and you can calculate the TDS of relay R_3 $\text{TDS of } R_3 = \frac{0.535}{4.35} = 0.1222$ (Selected 0.15)

However, in electromechanical or static relay, the time dial setting dial range is given from 0 to 1 second in steps of 0.05. So, if this value is available, you have to go for higher step and you can select 0.15.

Now, here the fundamental difference comes between electromechanical and static or digital relays. In digital relays, you can see this limitation is not there in electromechanical relay plug settings are given from, let us say 25 percent, 50 percent ,75, 100, 125, 150 like this in steps of 25 percent and TDS is given from 0 to 1 second in steps of 0.05.

So, if value comes in between in plug setting or time dial setting like this, then you have to go for higher value. In case of digital relay, these limitations are not there, you can select whatever value if you want 0.12, you are free to select that value. So, this is the main advantage of digital relays compared to the previous generation relays.

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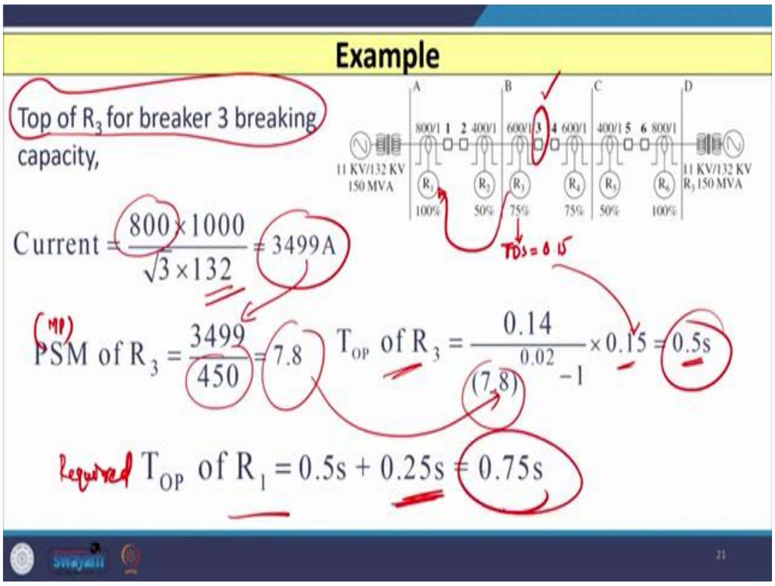

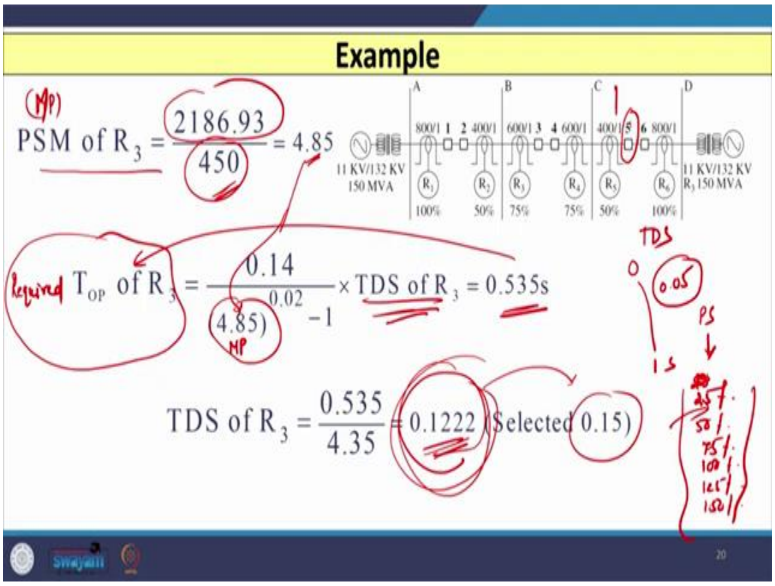

Now, we know the time of operation of relay R_3 because TDS of R_3 we have already calculated 0.15. So, if I consider TDS of R_3 that is 0.15 then you can easily calculate the plug setting multiplier or multiple of pickup current of relay R_3 considering this as the MVA capacity of this breaker. So, for that, if I consider breaker 3 with 800, MVA is the capacity and 132 KV is the voltage this is the current you can calculate. $\text{Current} = \frac{800\times1000}{\sqrt{3}\times132} = 3499\text{A}$

And multiple pickup current of relay R_3 you can calculate $\text{PSM of } R_3 = \frac{3499}{450} = 7.8$, and then you can calculate the value of time of operation of R_3 for this fault current, that is this value by putting TDS is equal to 0.15 and multiple pickup current is 7.8 you will have 0.5 seconds. Now, we are coordinating relay R_3 with relay R_1. So, the required time of operation of relay R_1 $T_{op\ of\ R_1} = 0.5\text{s} + 0.25\text{s} = 0.75\text{s}$

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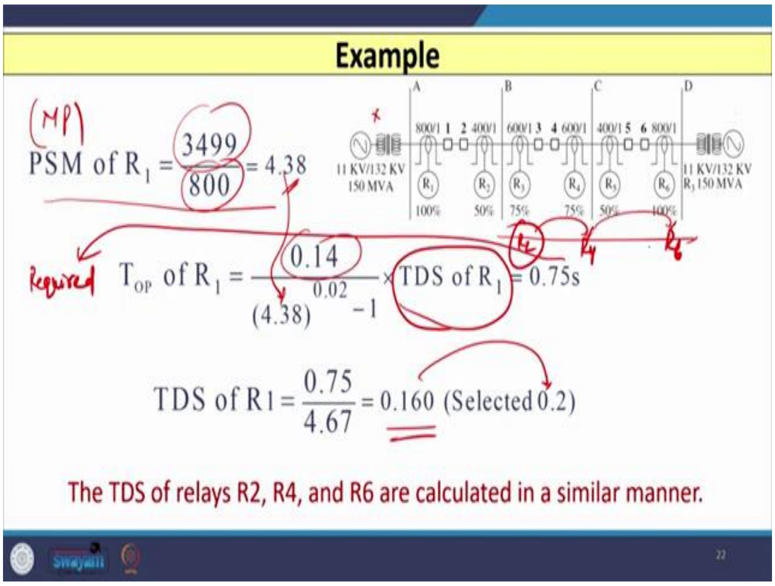

And once you have that, you can have the multiple of pickup current of relay R_1 for same value of current. PSM of $R_1 = \frac{3499}{800} = 4.38$

So, require TOP of relay R_1 that is known, that is this value 0.75 second you can have this equation you can put this value of MP here and you can have the calculation of TDS. So, TDS available or calculated is 0.16.

However, the availability is either 0.15 or 0.2. So, you can go for higher value that is 0.2. Similarly, if you consider the second case, assuming that this is not there, and you can move from relay R_2 to relay R_4 to relay R_6 and you start with relay R_2 then coordinate with R_4 then coordinate with R_6 and you can calculate the TDS of these relays.

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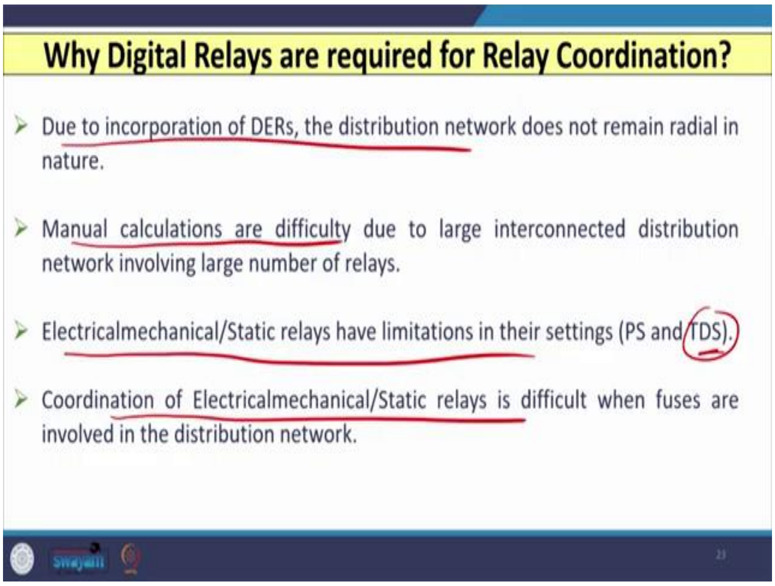

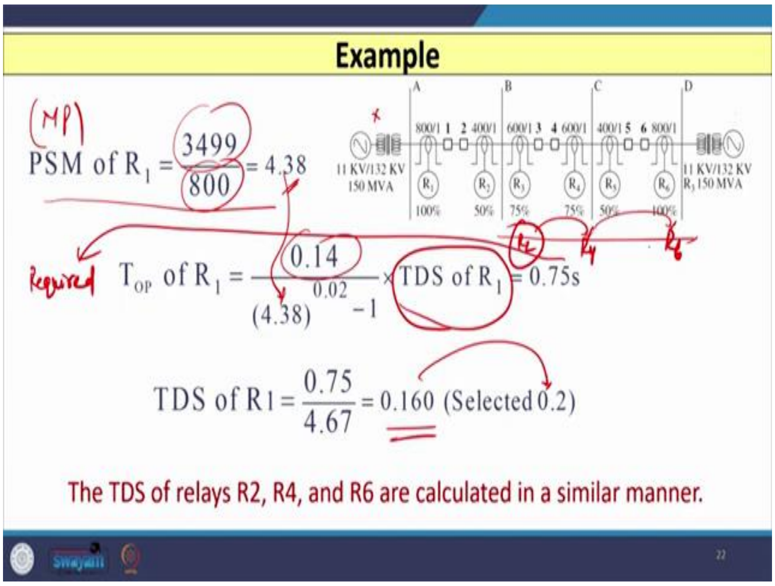

So, you see that, why digital relays are required for this coordination. So, the important point is because of interconnection of different distributed energy resources like solar wind, etc, the distribution network which was earlier radial in nature now, it is not radial in nature. So, bi-directional sources are connected and that is why we have to rethink about the coordination of relays.

Manual calculations are very difficult I show you the example, this is a very simple network, but if I have ring main network or even larger network with large number of relays, then it is very difficult to carry out these calculations manually, it is very complex and hence, we have to go for some interconnected relay coordination procedure which can be obtained using some algorithm.

The third point is electromechanical and static relays have limitations in their settings in terms of settings limitation for plug setting and settings limitations are also there for time dial setting as I told you, it is from 25 percent to 200 percent in steps of 25 percent, whereas TDS is from 0 to 1 second in steps of 0.05. However, in case of digital relay no such restrictions are there. And coordination of electromechanical and static relays are difficult particularly when fuses are involved in the distribution network.

And we know that HRC type of fuses are widely used in distribution networks, we wish to coordinate fuse characteristic with the relay characteristic with assuming that the distributed energy resources are present in the radial network, then this coordination is difficult. So, for that case, we have to go for digital relays and we have to go for some interconnected algorithm we need to develop so that it can automatically calculates this plug setting and time dial setting of this relays all the digital relays.

So, in this lecture, we started our discussion with what are the different time coordination philosophies available for overcurrent relays. And we have discussed that instantaneous overcurrent relays are there, definite minimum time delay relays are there, inverse time overcurrent relays are there and inverse the finite minimum time relays are also there.

Then we have discussed that if I wish to go for relay coordination, then we need to add directional feature also. Because the net current or magnitude of current that reverses at several instant or locations. So, we have to incorporate the directional feature and then we have discussed that if we go for simple network, then the manual calculations if we do then the whole procedure is very complex. So, we have also discussed there are several advantages of digital relays compared to electromechanical and static relays.

So, we need to design or we need to develop some algorithm that we can write down the code in the maybe in some other languages. And then that code will give you the input in terms of plug setting and time dial setting of relays. And of course, those relays are digital relays in nature. So, the rest of the things we will cover in the next class. Thank you.