Power System Protection
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Lecture 12
Overcurrent Relay Coordination

Welcome to the NPTEL course on power system protection. This lecture is on overcurrent relay coordination.

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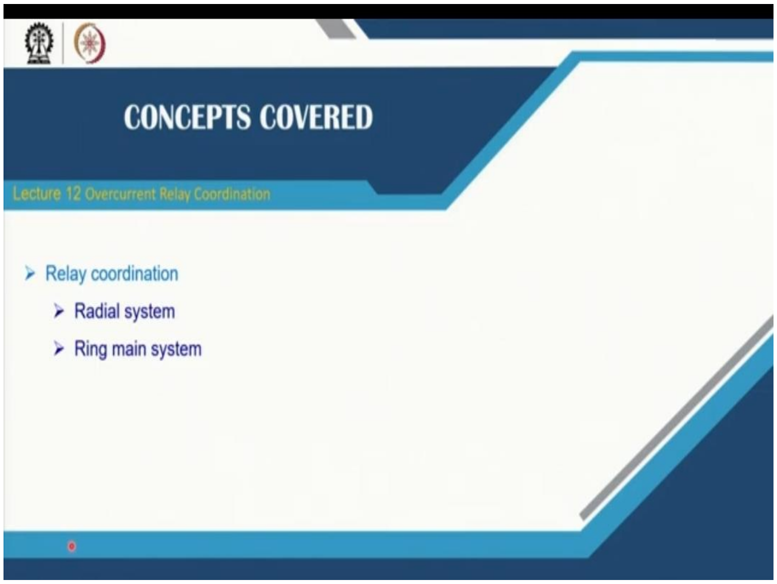

CONCEPTS COVERED

Lecture 12 Overcurrent Relay Coordination

- Relay coordination
  - Radial system
  - Ring main system

So, in this lecture we will see how we can coordinate different overcurrent relays for radial system and also to ring main system. Coordination of overcurrent relays is how one relay is related to the other relays that you have to see and then in a power system protection scheme for a feeder how can I apply this concept we will see.

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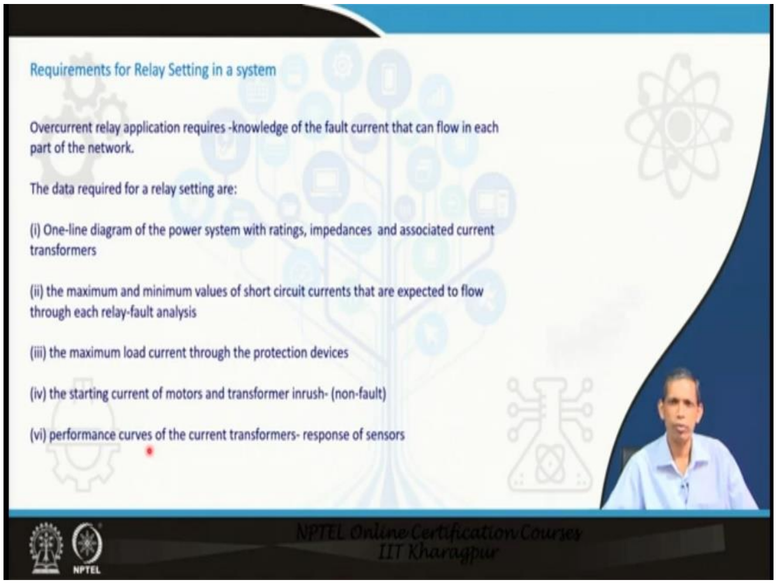

Requirements for Relay Setting in a system

Overcurrent relay application requires -knowledge of the fault current that can flow in each part of the network.

The data required for a relay setting are:

(i) One-line diagram of the power system with ratings, impedances and associated current transformers

(ii) the maximum and minimum values of short circuit currents that are expected to flow through each relay-fault analysis

(iii) the maximum load current through the protection devices

(iv) the starting current of motors and transformer inrush- (non-fault)

(vi) performance curves of the current transformers- response of sensors

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So, what are the different requirements for this overcurrent relay setting let us see first. This overcurrent relay applications requires knowledge on fault current in different branches, what level of current flows during different faults that we have to see for the setting because you are going for fault analysis, we require essentially single line diagram of the power systems with different ratings of different elements in the system, like transformer, feeders and so impedances and the CT ratings and its you can say that, dynamic performance and so on.

The maximum and minimum values of short circuit currents that are expected to flow through each relay that can be obtained from fault analysis, the maximum load current through the protection device that in the relay we have consulted, that how much maximum load current is expected. The relay we will see during the process of operation. The starting current of motors and transformers inrush, so these leads to that significant amount of current much higher than the even the full load current and thereby overcurrent which is based on the amount of current is expected to operate but this is not fault situation. Therefore, the relay must not operate for this and that is why I can say that the data sheet for that also should be available. Performance curves of current transformers that is the response of the sensors is important because the input signal to the relay numerical platform will be through this. So therefore, how good the sensor during this fault or the transition process, that is also important.

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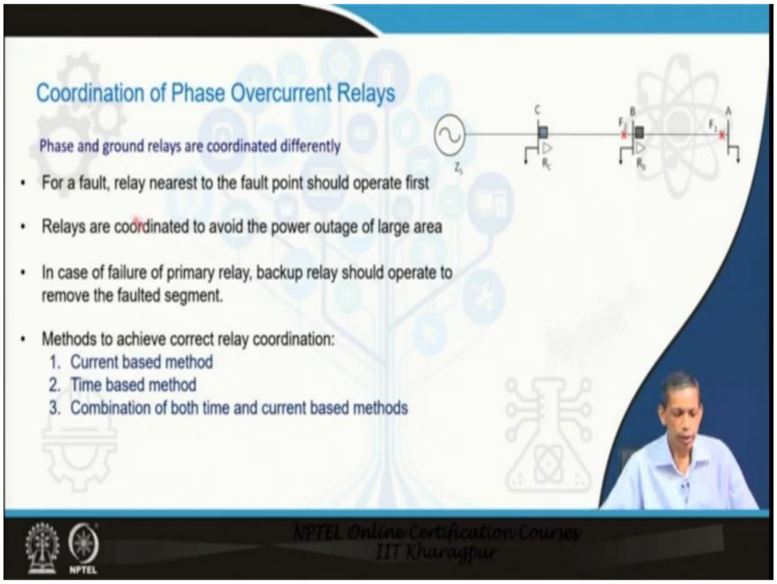

Coordination of Phase Overcurrent Relays

Phase and ground relays are coordinated differently

- For a fault, relay nearest to the fault point should operate first
- Relays are coordinated to avoid the power outage of large area
- In case of failure of primary relay, backup relay should operate to remove the faulted segment.
- Methods to achieve correct relay coordination:
  1. Current based method
  2. Time based method
  3. Combination of both time and current based methods

Now, we go to the coordination and what the coordination means and what is it requirement and how that is being accomplished that we will like to elaborate. For any system we have already defined that overcurrent current relay can be divided into two: phase and ground. Note that overcurrent relay coordination for phase and ground relays are differently done, but they have in the process of designing there are similarities. We will address on that. Relay for a fault nearest to the fault point should operate first. So, let us say consider this system, bus C, B and A. So, we have relay and circuit breaker here requirement and relay and circuit breaker combination required here also.

So, we say that for any fault nearest, you can see that arrangement, protection arrangement is at bus B. So this breaker should be open. If for fault F_1, the breaker at C opens, then this section and this section, both the sections will be out. So therefore, this load will not be fed even though we can maintain a supply if breaker at B opens. Once again, for a fault at F_1, if instead of B at C the breaker opens, then this load will not be solved. So, that is not good for power system operation point of view, reliability point of view and that is what we see here, for a fault, relay nearest to the fault point should operate first. Relays are coordinated to avoid the power outage of large area. These relays in the system should be designed in a coordinated way so that we can avoid larger, area for the power outage during a fault or so. That means to say that for fault in this section, this relay must not operate.

Therefore, to ensure that we require a proper coordination between relay at R_B and R_C. Note for fault at F_1 whatever current flows through this, fall current amount, whatever flows through this relay same amount of fault current will be there, because this source is same. They are connected in a series path. So that leads to that if the same amount of current is flowing for this fault, then relay at this point should operate, not at this point. So, there you need an essentially coordination.

In case of failure of primary relay, for fault F_1 primary relay is this. This should operate that is what we say. Backup relay should operate to remove the faulted segment. Further, there is a chance that the breaker here is a mechanical device may fail, the relay here may fail to pick up for this fault. If a failure of here, that means that the fault continues. Therefore, at that time the upstream level, the breaker here, this C must operate and that is what we call a backup protection for section BA. For section BA, the protective devices are this breaker and this relay. Any failure here will lead to the continuation of this fault. So, therefore to avoid that situation a backup protection scheme is available here. Note, this provides backup protection for these. In addition, this relay at this point provides primary protections to the section C to B. So, that is what you say that the coordination becomes more purposeful, meaningful to address all the aspects in overcurrent relaying applications. To achieve such an objective, there are 3 basic methods available and they are called current based method only using the current magnitude, time based method only using the time information, higher time lower time we have seen earlier different time characteristics curves so how to use that we will see and then again we will see that the third is the combination of time and current both. We will elaborate more on these 3 techniques. You can see that how that can be applied for coordination perspective.

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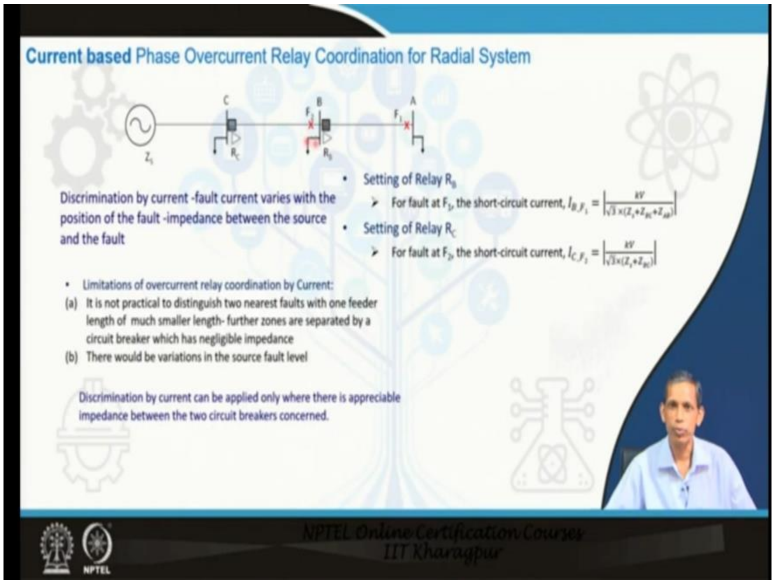

Current based Phase Overcurrent Relay Coordination for Radial System

Discrimination by current -fault current varies with the position of the fault -impedance between the source and the fault

- Setting of Relay R_B
  - For fault at F_1, the short-circuit current, $I_{B\_F_1} = \left|\frac{kV}{\sqrt{3}\times(Z_s+Z_{BC}+Z_{AB})}\right|$
- Setting of Relay R_C
  - For fault at F_2, the short-circuit current, $I_{C\_F_2} = \left|\frac{kV}{\sqrt{3}\times(Z_s+Z_{BC})}\right|$

- Limitations of overcurrent relay coordination by Current:

(a) It is not practical to distinguish two nearest faults with one feeder length of much smaller length- further zones are separated by a circuit breaker which has negligible impedance

(b) There would be variations in the source fault level

Discrimination by current can be applied only where there is appreciable impedance between the two circuit breakers concerned.

Let us first come to the current based phase overcurrent relay coordination for radial system. This is radial system. Source or the substation in this side and then we have, you can see that 3 buses and they are feeding to different loads. So, this is the current base, the discrimination is achieved by only the current magnitude.

The fault current, note that the fault current varies with the position of the fault. Further the fault, we have already mentioned earlier lectures also, farther the fault, the amount of current will be lesser because the fault loop considered will encounter an impedance. Source impedance here, line impedance here and line impedance here for this for fault F_1. For fault F_2, we can say that source impedance and the corresponding line impedance. So therefore, for different positions of the fault, the impedance of the fault loop varies and therefore accordingly the current also changes.

In addition to that there are types of fault also is a factor for designing the amount of current. Now for setting up relay R_B when you think about then the, for fault F_1 this short-circuit current can be obtained from

$$I_{B\_F_1} = \left|\frac{kV}{\sqrt{3}(Z_{BC}+Z_{AB}+Z_s)}\right|$$

Where kV is the system voltage and Z_{BC}, Z_{AB} are the corresponding impedance of this path, Z_S the source impedance of this path. You can say that for extension of fault very close to A point. For setting relay R_C at this point, the corresponding fault you can that, suppose considered is F_2. So, 3 phase short-circuit current will be nothing but

$$I_{C\_F_1} = \left| \frac{kV}{\sqrt{3}(Z_{BC} + Z_s)} \right|$$

So that implies that you can say that, the corresponding amount of current changes as you have seen from this theory but there is a limitation to this. Say for example, if the corresponding length, you can say that, is 5 km and length of this portion is only 500 m. Then this impedance is much smaller than this part and thereby consider the current difference for fault at F_1 and F_2 may not be appreciable. So, that means that we can say that the distinction of fault current to set these two relays maybe challenging because we require coordination based on the magnitude of current.

So, that is what we see here limitation of overcurrent relay coordination is not practical to distinguish two nearest faults with one feeder of much smaller length, further zones are separated by a circuit breaker only. So, we see here you can see that from for this relay, the corresponding zones is up to this and we have a circuit breaker and then the other zone starts. So, this between, you can see that for a fault at F_2 and very close to here between these you can say that points, the corresponding impedance only consider these circuit breaker.

So, the circuit breaker has very little impedance compared to the line impedance and therefore to distinguish fault close to this just before, you can say, that the bus B and just after bus B will be very difficult. So that discrimination is difficult to achieve by considering these kind of principle only based on current and source. There would be variations in the source fault level and the corresponding this part you can see that connected to a system which have a parallel lines. Then one line is out means the corresponding impedance of this path you can say that will be different and therefore for these fault you can say that during that time will be a different level and that is what you say, that there will be variations in source fault level and you can say that whether the corresponding relays will be able to distinguish that is a question in that perspective because the current level now changes. So thus we see the discrimination by current can be applied only where there is a appreciable impedance between two circuit breakers if you have appreciable impedance, otherwise, you can say that it may be difficult for this case though it seems to be simple in nature.

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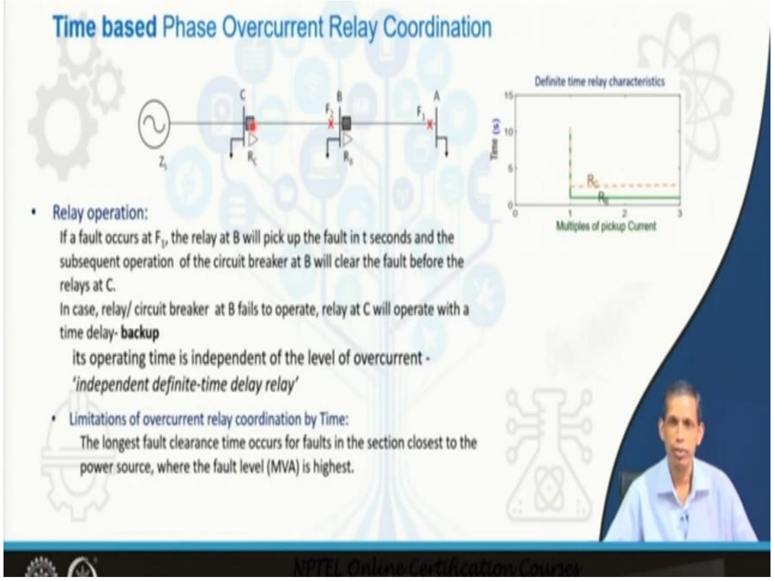

Time based Phase Overcurrent Relay Coordination

- Relay operation:
  If a fault occurs at F_1, the relay at B will pick up the fault in t seconds and the subsequent operation of the circuit breaker at B will clear the fault before the relays at C.
  In case, relay/ circuit breaker at B fails to operate, relay at C will operate with a time delay- **backup**
  its operating time is independent of the level of overcurrent - *'independent definite-time delay relay'*
- Limitations of overcurrent relay coordination by Time:
  The longest fault clearance time occurs for faults in the section closest to the power source, where the fault level (MVA) is highest.

The other option is time based phase overcurrent relay coordination. Here, we are talking about the time is the basis not the current. So, we have already seen earlier different characteristics for overcurrent relay and one of them it is nothing but definite time relay characteristics. So, we talk about definite time for this, any current more than the pickup current, relay trip immediately and that you can say that the corresponding setting is adjustable in this case.

So what we do here in this case for fault at F_1, we said we consider R_B relay is the lower one and for fault at F_2 the corresponding relay at C is above the time because we have already mentioned earlier that if fault at F_1 is not taken care at this point then the back up will be operating at a later time means the corresponding breaker and the corresponding relay should decide at a delayed time.

That is why I can say that R_C relay is above R_B relay at the time coordination. So this principle uses only time information in the setting and only you have to check if the current is greater than the pickup current. Then they will go for the trip decision. So, what we say here that its operating time is independent of the level of current. So, level of current is immaterial, only it has to check whether it is greater than threshold or not. After that, you say that, it does not matter. So it is called independent definite time delay relay. This principle which we are talking about the coordination based on a time independent of current magnitude and then it goes definite time delay for the applications.

The limitations of such overcurrent relay coordination between relays is there the longest fault clearance occurs for faults in the section closest to the power source. So, when you go towards the source here, we are showing a simple system but in a practical systems, there may be several such branches and so and they may be connected like this.

So, if you go from right to the extreme and you can see feeder towards the source. Then if you go for coordination like this, then the closest to the source the corresponding fault is F1, it means that fault will be cleared at a later time, though towards the source the corresponding fault level goes on increasing. So that becomes a critical point for that perspective. Even though current amount is high, but the decision time is more and that is what the limitation of time based coordination for phase overcurrent relays.

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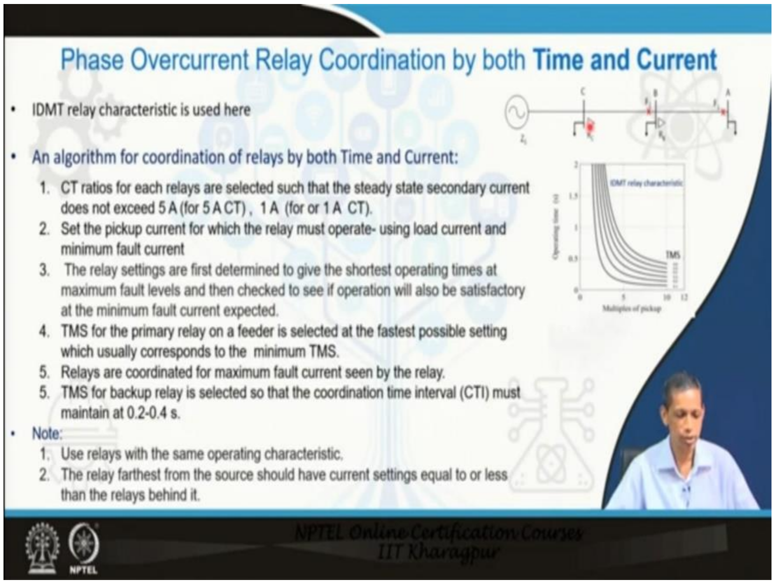

Phase Overcurrent Relay Coordination by both **Time and Current**

- IDMT relay characteristic is used here
- An algorithm for coordination of relays by both Time and Current:
  1. CT ratios for each relays are selected such that the steady state secondary current does not exceed 5 A (for 5 A CT) , 1 A (for or 1 A CT).
  2. Set the pickup current for which the relay must operate- using load current and minimum fault current
  3. The relay settings are first determined to give the shortest operating times at maximum fault levels and then checked to see if operation will also be satisfactory at the minimum fault current expected.
  4. TMS for the primary relay on a feeder is selected at the fastest possible setting which usually corresponds to the minimum TMS.
  5. Relays are coordinated for maximum fault current seen by the relay.
  5. TMS for backup relay is selected so that the coordination time interval (CTI) must maintain at 0.2-0.4 s.
- Note:
  1. Use relays with the same operating characteristic.
  2. The relay farthest from the source should have current settings equal to or less than the relays behind it.

Now, we will go to the better approach of doing this. Phase overcurrent relay coordination by both time and current. So, we have seen individually current and time and now we will see how we can combine them for a better coordination. So, we have seen the limitations of both also. Current, its limitations if the feeder length is small then it has a problem and time the problem is that more time it requires when it goes towards the source relay.

So, what we say here that we will use the IDMT relay characteristic like this curve here, which we have already seen for these different IDMT curve, IEEE, IEC and very inverse, extremely inverse, moderate inverse and so this IDMT is fully considered in this coordination perspective.

An algorithm for coordination of relays using both time and current requires following things to be addressed. CT ratios for each relays are selected such that the steady state secondary current does not exceed 5 A or 1 A in CTs. 5 A means 5 A CT and 1 A means ampere CT. Set the pickup current for which the relay must operate using load current and minimum fault current. We will set the pickup current with adjustment based on the load current and we consider minimum fault current in that feeder.

So, that should be our pickup current selection. These are guiding factors. The relay settings are first determined to give the shortest operating time at maximum fault levels and in this case you can say that for this relay the corresponding maximum fault current will be here close to this and for that the corresponding time required should be shortest that principle you have to follow and then check if the operation is also satisfactory at the minimum fault current expected. So, the minimum fault current is expected here.

So, for that also whatever characteristic we have picked up for the maximum current that set is applied to C. Why we talk about maximum fault current because maximum fault current is more detrimental and it take less time for protection decision. Time will play a setting in this kind of curves of the primary relay on a feeder is selected in the fastest possible setting which usually corresponds to minimum TMS. So that is why we should pick up something which will give as minimum TMS as possible. If we go to the higher TMS, then the time relation will be more which is not desirable from protection perspective.

Relays are coordinated for maximum fault current. The coordination between two relays that is relay R_B and R_C are based on maximum fault current seen by relay. Now, the coordination is obtained from the maximum fault current for R_B is at this point close to this where B bus and that is based on that maximum fault current there is coordination between R_B relays and R_C relays are obtained. That is what this statement says. TMS time multiplier setting for the backup relay is selected so that the coordination time interval must maintain 0.2 to 0.4 second. So, the backup R_C for this section B to A is selected such that the coordination time interval is maintained.

So the coordination between R_B and R_C, we require a coordination time interval (CTI) that the R_C relay should operate at a later time. How much? By this CTI and should be between 0.2 to 0.4 second. So 0.2 to 0.4 second, it means that for a 50 Hz systems, 1 cycle corresponds to 20 milliseconds. So this corresponds to 0.2 means 10 cycles and 0.4 means 20 cycles. This seems to be much larger number of cycle wise but why that is larger we will see in the next slide. So, note that, from the above use relays with the same operating characteristic. We can say that using for a system when we are going for a design coordinating for different relays in a system like this, radial system, we will be using same operating characteristics. Either IDMT, very inverse or moderate inverse, anyone you pick up and then you can see the different TMS for different relays. That is what is being suggested. The relay farthest from the source should have current settings equal to or less than the relays behind it. The relay farthest means this should have current settings equal to or less than the relays behind it. The current setting of this one should be considered lesser or equal to the behind means that for the R_C. So, R_B is current setting should be less than the R_C current setting. That is what you get in this perspective. This is the general guidelines for coordination business for phase overcurrent relay.

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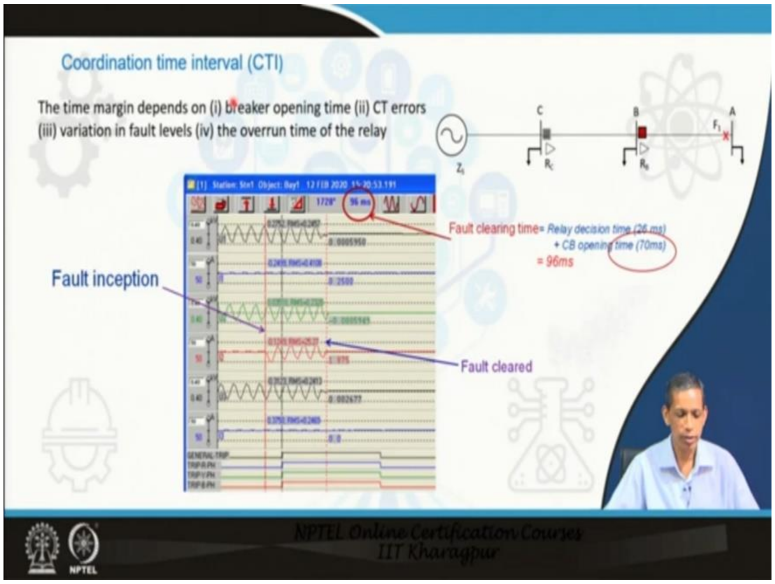

Coordination time interval (CTI)

The time margin depends on (i) breaker opening time (ii) CT errors (iii) variation in fault levels (iv) the overrun time of the relay

Fault clearing time = Relay decision time (26 ms) + CB opening time (70ms) = 96ms

Now, we talk about coordination time interval that happens to be 0.2 to 0.4 s, 10 cycles to 20 cycles for a 50 Hz system. These depends upon a number of factors. Important are breaker opening time. The breaker opens see the relay commands, let us say the fault is at F_1, the relay picks up, commands the breaker and the breaker opens. Fault is clear so this section is out. This load and the rest of the system remains intact. That is what is being expected.

Therefore, even after the relay has picked up, identified the fault, and decided it commanded the breaker; the breaker takes time. Like in earlier slide we have seen. This are our lab experimental results. So, what we see here is that, this is you can see the fault and this is a phase and the pre fault current is small and now the fault current becomes significant and now again the current becomes 0. So, this shows that the corresponding command issued by the fault triggered, the relay detects here, commands the circuit breaker and the circuit breaker still opens, tries to open, arcing goes on and the corresponding fault is being cleared at this moment. This is nothing but this portion is the circuit breaker opening time. In this case, it comes out to be more than 3 cycles in the system. So that means that the relay takes around 1 s here, the decision time and the circuit breaker opens around at 3 cycles or so. So, in a practical system, the circuit breaker opening time typically maybe 1.5 cycles and more than that, but not necessary that the fault can be cleared by the circuit breaker in a 1 cycle or 2 cycles period. It may sometimes take longer time and the relay may also take sometimes longer time. Furthermore, it depends upon the corresponding current, the decaying DC and the decaying DC is being not handled by the corresponding relay. CT has some saturation issue. Then error will be creeping into the relation process because the signal is now distorted.

Variation in fault levels. Therefore, that I say that source capacity increment and decrement and so and the overrun time of the relay and all these things like analog relays has more overrun time and so. So, these are different factors which the fault here can be clear, even after we consider the relay, there is some time. So therefore, when you are coordinating to this relay, these relays must wait till the corresponding protection arrangement here clears the fault at F_1.

Now if it is find that the corresponding fault is not being cleared and it called continuous for longer period then the corresponding back up relay should act. So how much time it should wait is nothing but decided by the coordination time interval which depends upon this factor and typically that happens to be within 0.2 to 0.4 s. Today in numerical relay you can prefer the lower limit also that is around 0.2 s or so.

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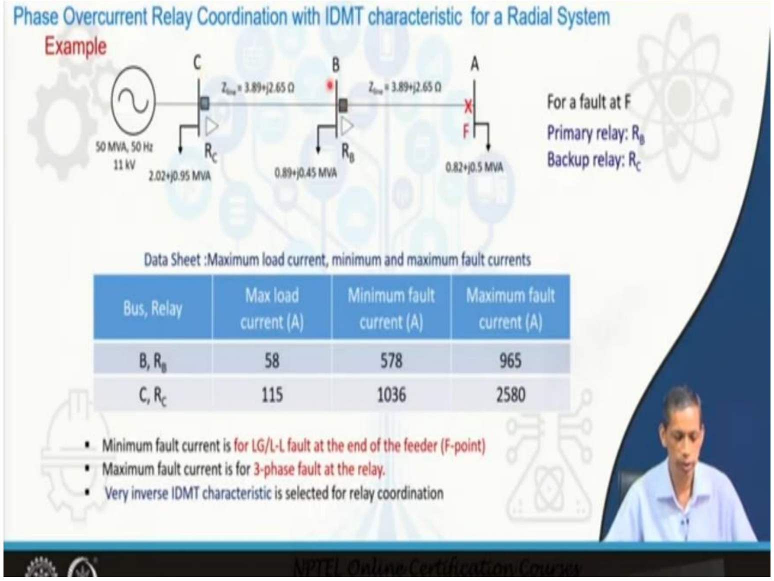

Phase Overcurrent Relay Coordination with IDMT characteristic for a Radial System

Example

For a fault at F

Primary relay: R_B

Backup relay: R_C

Data Sheet :Maximum load current, minimum and maximum fault currents

Bus, Relay	Max load current (A)	Minimum fault current (A)	Maximum fault current (A)
B, R_B	58	578	965
C, R_C	115	1036	2580

- Minimum fault current is for LG/L-L fault at the end of the feeder (F-point)
- Maximum fault current is for 3-phase fault at the relay.
- Very inverse IDMT characteristic is selected for relay coordination

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Now we go for an example to elaborate this coordination principle, how we can realize in relay system design for a system. We have taken a very simple system for understanding. This is, you can see that is a 11 kV 50 Hz system and then we have two sections. Load here, load here and load here. They are defined and then we have two sections CB and BA. So, the protection section here and protections section here and to designs relay R_B and relay R_C the corresponding settings have to be obtained and then how they can be coordinated as we have elaborated on different guiding factors. So, for fault at F, the primary relay will be R_B and the backup relay will be our R_C.

That you have understood. In case of failure at this point, the R_C must take care. So that is why you can see. Now as already mentioned, we require fault analysis to decide on different relay setting perspective. So we have table like this with the data sheet which contains maximum load current, minimum and maximum fault current. So, minimum fault current is required for pickup setting. Maximum fault current is required for the coordination business. So, we see here at bus B and R_B, the corresponding maximum load current seen by this relay is 58 A. The minimum fault current 578 A. For the extreme end fault F you can see it here and that can be obtained by line to ground or line to line, whichever gives you the minimum because that must be handled by the corresponding relay because it is fault in that section. That is its responsibility. So, we see, then the maximum fault current 965 A. Maximum fault current happens to be here that is 3 phase short circuit that leads to 965 A. Similarly, for relay R_C at C, we have maximum load current 115 A because the load here is also added to this load and then the minimum fault current is 1036 A for the corresponding fault at here for this section and then the maximum fault current for this will be close to here will be 2580 A. This is obtained by the fault analysis through which you can obtain these figures. Now one point here you note, this relay R_C takes care of this section as its primary and this section is as backup. So this will also take care this section. It means that the relay R_C should see this fault at F. It means that nearer to the bus A. So, therefore the 578 A is nothing but the minimum fault current. This minimum fault current at this point also should be seen as a fault by R_C. That is what we like to see and the corresponding guiding factor that have elaborated that the maximum fault current here, that happens to be 965 A, this will be the guiding factor for the coordination between C and B. We will see that in further details.

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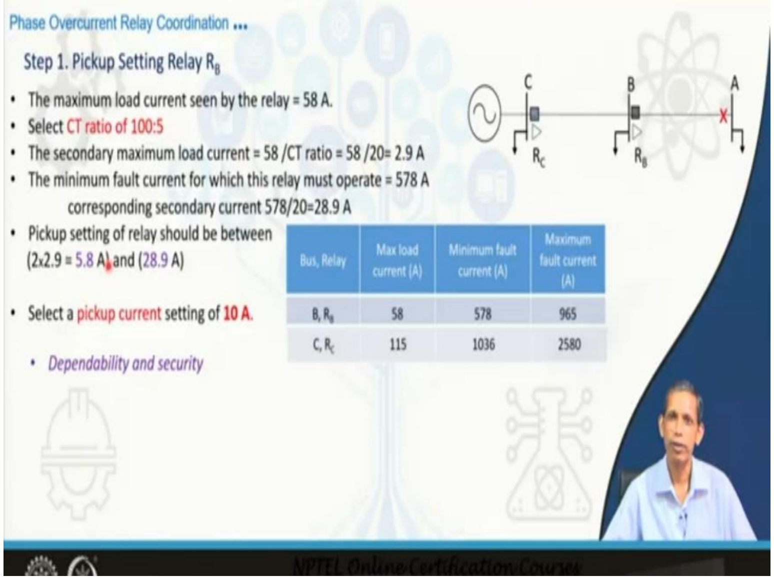

Phase Overcurrent Relay Coordination ...

Step 1. Pickup Setting Relay R_B

- The maximum load current seen by the relay = 58 A.
- Select CT ratio of 100:5
- The secondary maximum load current = 58 /CT ratio = 58 /20= 2.9 A
- The minimum fault current for which this relay must operate = 578 A
  corresponding secondary current 578/20=28.9 A
- Pickup setting of relay should be between (2x2.9 = 5.8 A) and (28.9 A)
- Select a pickup current setting of **10 A.**
  - *Dependability and security*

Bus, Relay	Max load current (A)	Minimum fault current (A)	Maximum fault current (A)
B, R_B	58	578	965
C, R_C	115	1036	2580

Now, phase overcurrent relay coordination. We will go one by one. Let us first fix the pickup setting relay. Pickup setting for R_B and R_C. So, we are talking about R_B here. So how much will be the pickup setting for this? Before that we will first fix what will be the CT rating for this. The maximum load current seen by the relay is 58 A. That is from our table. Select CT ratio of 100:5 as per the availability. We have considered here 100:5. So 100:5 CT connected here and that is connected with the relay. The secondary maximum load current is 58 / CT ratio. How much current will be seen by the relay in actuality that is how much current is injected to the relay? However, the relay takes the corresponding voltage signal converting the corresponding current signal. So the relay sends a current of 2.9 A. However numerical relay, when you divide this into CT ratio, however numerical relay you can multiply this corresponding ratio to this 2.9 and again get back the corresponding system level of current. So, the relay can calculate based on system level current with the primary current side or in the secondary side. Here we are calculating everything in terms of the secondary current side.

So, this secondary current for these 58 A becomes 2.9 A. Now we will see the minimum fault current for which the relay must operate. This relay must operate for this extreme end fault towards the bus A and for that we have a 578 A. So, these 578 A, how the relay we will see, divided by the 20, CT ratio that gives 28.9 A. The pickup setting of the relays would be as per the guideline factors. We have seen in the earlier lecture that twice of the load factor, 2 times of this corresponding maximum current 2.9 A as seen by the relay.

So, 5.8 ampere and in between what the minimum fault current. How much is the minimum fault current as seen in the secondary side or relay side? 28.9 ampere. So, between 5.8 ampere and 28.9 ampere here, we have to select the pickup current. We have selected pickup current to be 10 ampere in this example for easy understanding. Now see how this falls between this and this. Now someone will say that I will take 20 ampere, someone will say that I will take 7 ampere and so there can judgment on this.

We have already considered that this dependability and security. So, dependability demands that the corresponding current should be as smaller as possible towards the maximum load current side and security says that it should be higher and higher. It should go towards 28.9 ampere. Security says that unnecessary tripping can be avoided and dependability says that any fault must be tripped by the relay. So therefore if you increase the corresponding 10 A to 20 A many faults may not be detected. Of course, it will be hardly having false trip due to overload or so but if we bring it towards 6 A or 7 A, most of the fault will be taken care but sometimes overload will create problem, unnecessary tripping may result and that sequence where you have to make a judgment on this factor here. Here we have selected 10 A for this example.

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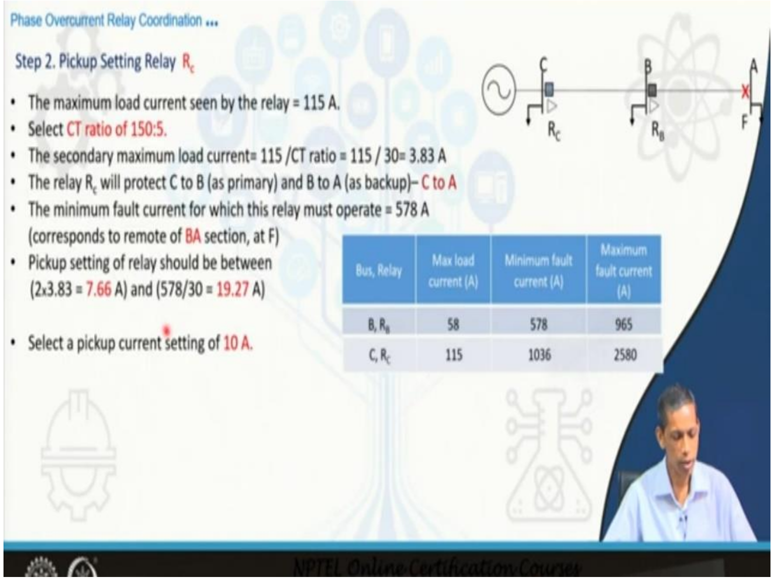

Phase Overcurrent Relay Coordination ...

Step 2. Pickup Setting Relay R_c

- The maximum load current seen by the relay = 115 A.
- Select CT ratio of 150:5.
- The secondary maximum load current= 115 /CT ratio = 115 / 30= 3.83 A
- The relay R_c will protect C to B (as primary) and B to A (as backup)– C to A
- The minimum fault current for which this relay must operate = 578 A (corresponds to remote of BA section, at F)
- Pickup setting of relay should be between (2x3.83 = 7.66 A) and (578/30 = 19.27 A)
- Select a pickup current setting of 10 A.

Bus, Relay	Max load current (A)	Minimum fault current (A)	Maximum fault current (A)
B, R_B	58	578	965
C, R_c	115	1036	2580

Moving forward. Pickup setting for relay R_C. Let us first learn the pickup setting for relay R_C. So, now we are going for the R_C. So as I have already mentioned, the R_C relay will have a coverage from C to B as primary and B to A as secondary. So the whole coverage will from C to A but at A, the corresponding fault is already mentioned. Minimum fault current is 578 A. The relay at this point sees a maximum current of 115 A. So 115 A we have selected 115 A Based on 150 A maximum current we have selected a CT ratio of a 150: 5.

This is already a guiding factor for this. We have taken 5 A CT in both the cases for this example. So, this CT selected for R_C is 150: 5. So, 115/30 gives you 3.83 A in the secondary that is relay current for maximum load current. Now, the minimum fault current which will be seen by R_C is 578 A. So, 578 /30 will be 19.27 A. So, this is what will be seen by the corresponding relay for the fault at this. Therefore, the corresponding pickup current should be 7.66 A, that is 2 × 3.83 and this 19.27 A. In between, these corresponding setting has to be obtained. So, 7.66 A and 19.27 A. Here also, we are taking the pickup current to be 10 A. Not necessarily, you can take 15 A, you can take 20 A and so and so the way it has been elaborated in the case of R_B also, dependability and CT prospective. So, this pickup current setting of 10 A, CT ratio 150: 5 for R_C relay.

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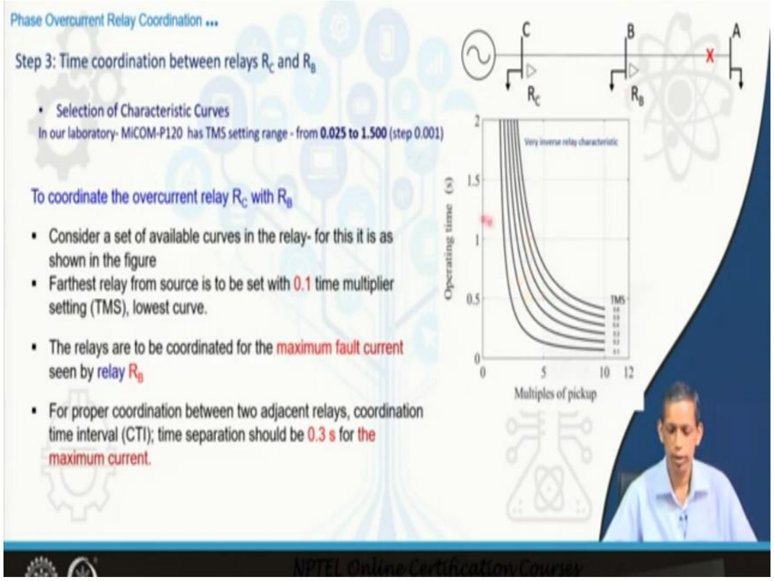

Phase Overcurrent Relay Coordination ...

Step 3: Time coordination between relays R_C and R_B

- Selection of Characteristic Curves

In our laboratory- MiCOM-P120 has TMS setting range - from **0.025 to 1.500** (step 0.001)

To coordinate the overcurrent relay R_C with R_B

- Consider a set of available curves in the relay- for this it is as shown in the figure
- Farthest relay from source is to be set with 0.1 time multiplier setting (TMS), lowest curve.
- The relays are to be coordinated for the maximum fault current seen by relay R_B
- For proper coordination between two adjacent relays, coordination time interval (CTI); time separation should be 0.3 s for the maximum current.

Now I will go for the coordination business. For these two relays to be coordinated, we selected characteristic curves first, like we have already mentioned that will take IDMT curve and we have taken very inverse characteristics for this case. Note that, the corresponding TMS values for these different relays provide different things, numerical relay will have enormous different characteristic curves and also lot of variations like TMS settings also like in MiCOM-P120 relays in our lab we have variation of TMS from 0.025 to 1.500 with a step 0.001. It is very small, so many curves you can get for this setting range.

For clarity and understanding we have taken TMS variation from 0.1 to 0.6, a set of curves. Out of these set of curves available we have to set these two relays in this case. Agree? So we have fixed the corresponding characteristic curves available to these relays and we have to set accordingly so that the coordination will be achieved. To coordinate the overcurrent relay R_C with R_B that is our target. A set of available curves that we have already picked up. Farthest relay from this source is to be set with the lowest curve. The farthest relay that is R_B is to be provided with the lowest curve. The relays are to be coordinated for the maximum fault current.

So, relay R_B and R_C that we coordinated for maximum fault current for the R_B that is maximum fault current happens to be here- 3 phased fault that we have already seen. For proper coordination between the two adjacent relays, we have coordination on time interval of 0.3 s. 0.3 s corresponds to 15 cycles and where we have to coordinate to have these coordination. The coordination has to be for the maximum fault current that is for R_B relay. That is what the guiding factor.

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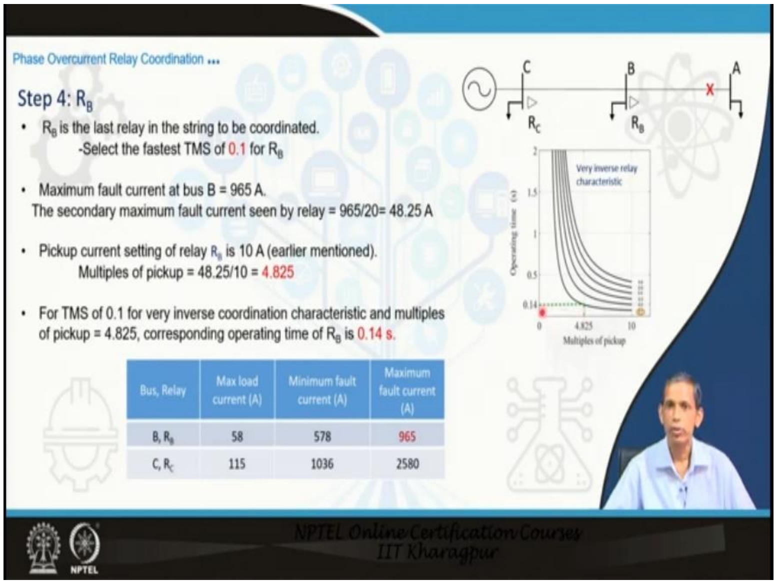

Phase Overcurrent Relay Coordination ...

Step 4: R_B

- R_B is the last relay in the string to be coordinated.
  -Select the fastest TMS of 0.1 for R_B
- Maximum fault current at bus B = 965 A.
  The secondary maximum fault current seen by relay = 965/20= 48.25 A
- Pickup current setting of relay R_B is 10 A (earlier mentioned).
  Multiples of pickup = 48.25/10 = 4.825
- For TMS of 0.1 for very inverse coordination characteristic and multiples of pickup = 4.825, corresponding operating time of R_B is 0.14 s.

Bus, Relay	Max load current (A)	Minimum fault current (A)	Maximum fault current (A)
B, R_B	58	578	965
C, R_C	115	1036	2580

Now, we will see what is the corresponding R_B relay characteristics and the corresponding for the R_C relay. First the R_B relay. R_B relay is the guiding factor. Select is the fastest TMS that is in the set of curves. The lowest curve is the 0.1 so select this curve for the relay at R_B. Now, the maximum fault current for bus B at this point is 965 A. This relay that is your maximum fault current for R_B is 965 A.

So, this 965 A because R_B relay is the CT ratio of 100: 5 that is a factor of 20. So, this current will be seen as 48.25 A by the CT secondary or the relay current. Pickup current setting for relay R_B is already 10 A, we have already selected. Multiples of pick up that we have to see here that this 48.2 5 A / 10 is 4.825 A. So, these multiples of pickup for maximum fault current at this point. So, for this pickup current, for this multiples of pickup, the corresponding curve, which we have taken for this R_B relay with the time becomes 0.14 s. It means if the fault happens to be at this point and that fault current leads to 965 A through this path, the R_B relay with this curve will decide with the time of 0.14 s. This is what we can say.

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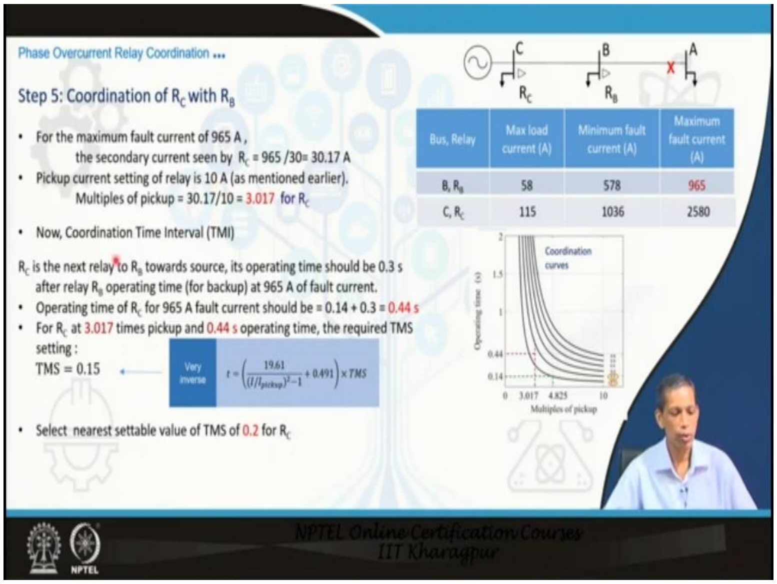

Phase Overcurrent Relay Coordination ...

Step 5: Coordination of R_C with R_B

- For the maximum fault current of 965 A,
  the secondary current seen by R_C = 965 /30= 30.17 A
- Pickup current setting of relay is 10 A (as mentioned earlier).
  Multiples of pickup = 30.17/10 = 3.017 for R_C
- Now, Coordination Time Interval (TMI)

R_C is the next relay to R_B towards source, its operating time should be 0.3 s after relay R_B operating time (for backup) at 965 A of fault current.

- Operating time of R_C for 965 A fault current should be = 0.14 + 0.3 = 0.44 s
- For R_C at 3.017 times pickup and 0.44 s operating time, the required TMS setting :
  TMS = 0.15 ←

Very inverse $t = \left(\frac{19.61}{(I/I_{pickup})^2 - 1} + 0.491\right) \times TMS$

- Select nearest settable value of TMS of 0.2 for R_C

Bus, Relay	Max load current (A)	Minimum fault current (A)	Maximum fault current (A)
B, R_B	58	578	965
C, R_C	115	1036	2580

Now moving forward, now we will go with the coordination with R_C. So how we will coordinate that current? This 965 A current which are seen by these, at that time the relay R_C also will see 965 A of current but relay C has CT ratio of 150:5, a factor 30. Relay will see 30.17 A in the secondary side.

So, this 30.17 A divided by the corresponding pickup setting by relay R_C obtain so that leads to 3.017 multiples of pickup for R_C. So this 3.017 is the multiple of pickup we got and then we have a CT ratio of 150: 5 and a pickup setting of 10. This is what we have obtained for R_C. Now will go for how to find out the coordination time interval CTI.

So, the next, from the R_B you are going to the R_C so, what we will do that the corresponding time which we have already obtained for same current, maximum fault current 0.14 s will add to this 0.3 s, coordination time extra time. The relay will take decision by R_C. So that equals to 0.44 s. 0.14 plus 0.3 leads to 0.44 s. That is the time at which the corresponding R_C will take a decision for the fault at this point where the R_B relay finds a maximum fault current. So, this is the time which is now important for us for the coordination business.

This is the time and the corresponding multiple pickup is this. So multiple pickup is 3.017 and the time is 0.44 s. So, then we are getting an intersection point here above this whatever curve is there, take that curve. That is nothing but the 0.2. Otherwise from this expression very inverse of the IEEE curve which we have taken for this.

So, this is the expression.

$$t = \{\frac{19.51}{(I/I_{pickup})^2 - 1} + 0.491\}TMS$$

So we see here the I_{pickup} is known to us, I/I_{pickup} multiple is considered 3.017 here. So, this factor you put and time is 0.44 s. Then you can get the TMS and this TMS is 0.15. So, these were the intersection point, it gives 0.15 TMS but a set of curves available to us in a relay, which we have already defined for the purpose is having only 0.2 next. Therefore, the TMS we select is 0.2 for R_C clear? So once again the time required for this is for the same maximum fault current is 0.4 s obtained and the corresponding current having a 3.017 for the R_C relay and these two values are obtained. So substitute these two value here you can get the TMS value and the TMS value is 0.15 s. At 0.15 s you do not have this curve in this set. Therefore, we will go to the next higher point. If we take the higher value then the coordination time which we talk about 0.3 s will be definitely met but if you take a lower value, then that cannot be ensured. Therefore we have to take next higher value. In terms of that, if you do not have a curve on that at 0.15 s in this case.

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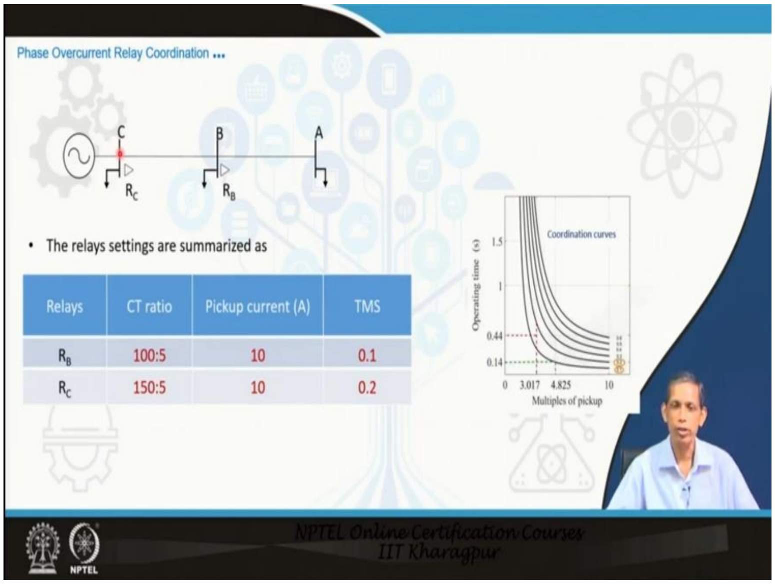

Phase Overcurrent Relay Coordination ...

- The relays settings are summarized as

Relays	CT ratio	Pickup current (A)	TMS
R_B	100:5	10	0.1
R_C	150:5	10	0.2

Therefore, for this in overall, when you are going for the corresponding relay settings for the phase relay. So we have R_B 100: 5 CT ratio, pick up current setting 10 A we have already found out and the TMS 0.1, is the lowest curve. For this relay R_C after the coordination, the CT ratio is 100: 5, pickup current is 10 A and then we got the corresponding time 0.2. So we got these two curves fixed for these. If there are further sections towards this one, we can coordinate in a similar fashion. So, there will be another section here that will be coordinated with the R_C relay and so on. So this is what we call how to have coordination, how to design overcurrent relay for phase relay.

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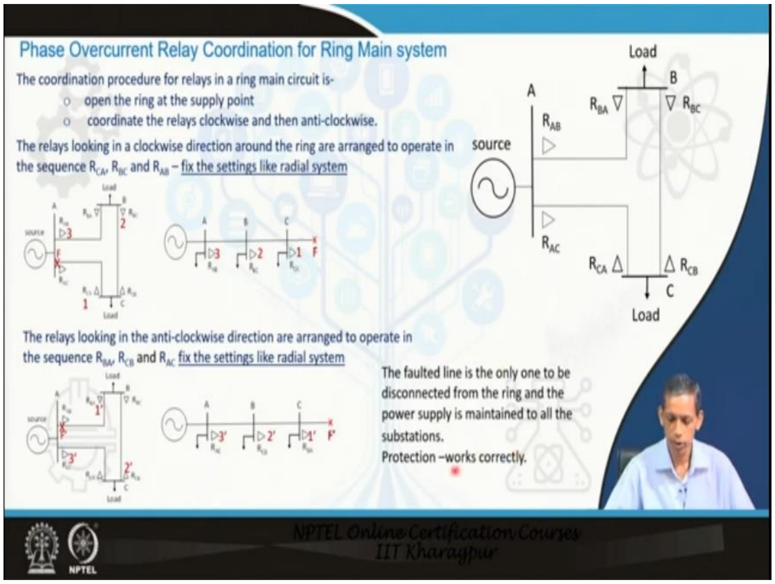

Phase Overcurrent Relay Coordination for Ring Main system

The coordination procedure for relays in a ring main circuit is-

- open the ring at the supply point
- coordinate the relays clockwise and then anti-clockwise.

The relays looking in a clockwise direction around the ring are arranged to operate in the sequence R_{CA}, R_{BC} and R_{AB} – fix the settings like radial system

The relays looking in the anti-clockwise direction are arranged to operate in the sequence R_{BA}, R_{CB} and R_{AC} fix the settings like radial system

The faulted line is the only one to be disconnected from the ring and the power supply is maintained to all the substations.

Protection –works correctly.

Phase overcurrent coordination for the ring man system we will see next. So, for this a ring main system like this, bus A bus B and bus C and we have connections like this and they are having different loads and so ring main system is more reliable compared to the radial system. For this coordination procedure of the relays, open the ring at the supply point, coordinate the relays clockwise and then anti-clockwise. So, upon the ring at the supply point, if you opened here, then that become this and if you open here, this can be fed from this. That is what we are saying. These are the guiding factors and then you will apply the phase overcurrent relay coordination what we have seen for the radial system also. The relays looking in a clockwise direction around the ring are arranged to operate in the sequence R_{CA} , R_{BC}, R_{AB} .

Now, you see what we did here. So at this cross point we open it. This breaker you open it. So, we have a path from here to here to here and this faut will be there. So, this relay, this relay and this relay we will see. They are forward looking relay. Actually, for these different relays we have directional relay also. So directional overcurrent relays are used for this one that is 67 number. So, in that case for this one, if this is open as a guiding factors supply point open, then for a fault at this point, current will flow from this. In that case, this is forward-looking, this is forward-looking and this is the forward looking. So, the end one, farthest relay is R_{CA} is one, and then R_{BC}, the second one and then we have R_{AB} in the third one.

So, this is closest to the source. So, we expand this one for this case. This become this, these with these numbers and all these things. So, what we see here, so 1 here, 2 here, 3 here fault is here and this side is open. So, this becomes a radial one. So then what we do with that we coordinate just like we did for the radial systems. We start from 1, the lowest curve then goes the second the R_{BC} upper curve and for R_{AB} we will have the third curve. So we can do a table having the CT ratio, pickup current and the corresponding curves for this 3 relays coordinated in is same way as you did for the radial system.

Now, we have another set of relays. See here now. What do we do we open here, our first case. Now, we go for anti-clockwise. This one is clockwise, anti-clockwise we open here and consider this fault here. So, from this side, the current will flow. So, the end, the farthest will be R_{BA} that is designate 1'. Next relay is R_{CB} that is we designate 2' and then last relay is the corresponding 3'. That is considered close to the source. So, the corresponding R_{AC} will be to this point. So therefore these relays for this situation and therefore if you expand this one this becomes to the source, these 3' will be there, then will be 2', and this 1'.

The farthest one will be 1' so we set the corresponding relay at here first and then consider 2' at this bus and 3' and same way you did for the radial system for what we elaborated earlier. Therefore, we have 6 relays to be set here and these are the 3 in their first group and these are the 3 in second group.

So, we set the relay in accordance with these and then we can fix the corresponding setting for the ring main system. That will work fine, even in case of if ring main system operates at any time for any breaker opens and acts as radial system also absolutely there is no problem on the protection scheme. So, this is what we see from this slide that on how ring main system can be coordinated for different relays can be coordinated like this.

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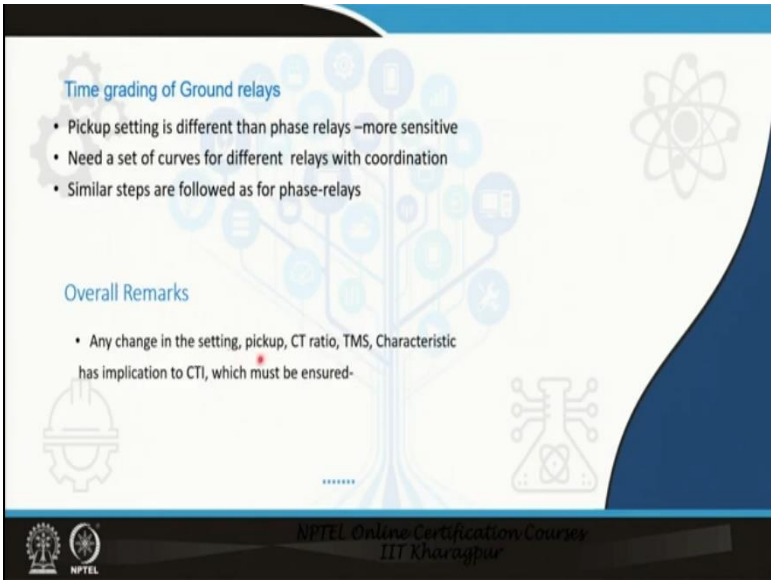

Time grading of Ground relays

- Pickup setting is different than phase relays –more sensitive
- Need a set of curves for different relays with coordination
- Similar steps are followed as for phase-relays

Overall Remarks

- Any change in the setting, pickup, CT ratio, TMS, Characteristic has implication to CTI, which must be ensured-

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So, in overall, we can say that we saw how the corresponding time grading can be obtained in a coordinated way using the IDMT curve, for radial and ring main systems. Time grading or relay coordination for ground relays are different because the pickup settings is different as compared to phase relays and ground relays are more sensitive as you have already seen and they need different set of curves for coordination. Their coordination becomes different. They need different coordination curve but steps are same, similar way what we have discussed for phase relays.

So, for the ground relays you do the exercise similar to what you did for the phase relays, both for radial system and the ring main system. So in our concluding remarks, we say that in this fashion we can design our relay, overcurrent relay coordination in different ways and which will serve the purpose of the protections but one point we see here, any change in this setting during the course of operations or whatever you say in pick up, CT ratio, TMS or characteristic curve if you change, that has an implications to your coordination time interval.

So, that will create problem. Therefore, relays in our concern about that any change anywhere in the relay in the downstream or any middle portion also, that should be ensured that the CTI is being satisfied, then only that change will be accomplished. Thank you.