Power System Protection
Professor A. K Pradhan
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur
Lecture 11
Overcurrent Relay Characteristics

Welcome to the NPTEL Power System Protection course. So today, we have a module on overcurrent relaying and we will discuss on this lecture on overcurrent relaying characteristics.

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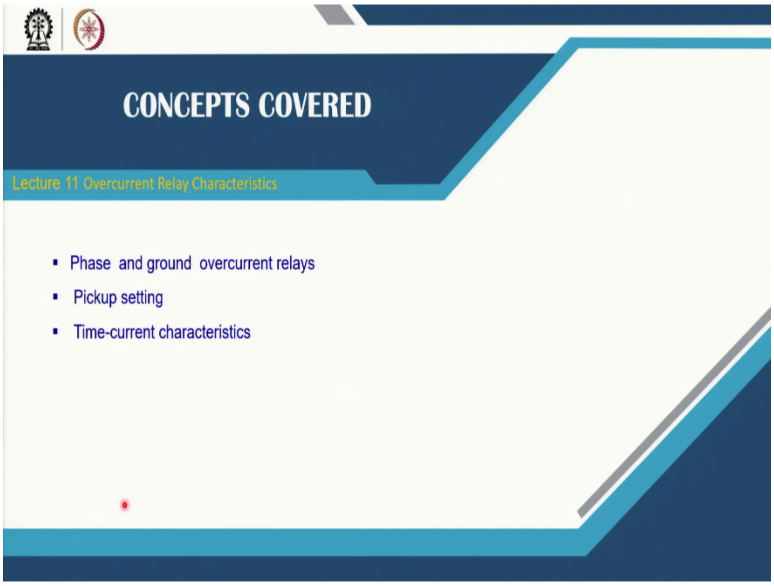

So, the coverage in this lecture will be on phase and ground overcurrent relays, then we will go to this how to select pickup setting, and the required time-current characteristics for a particular protection scheme.

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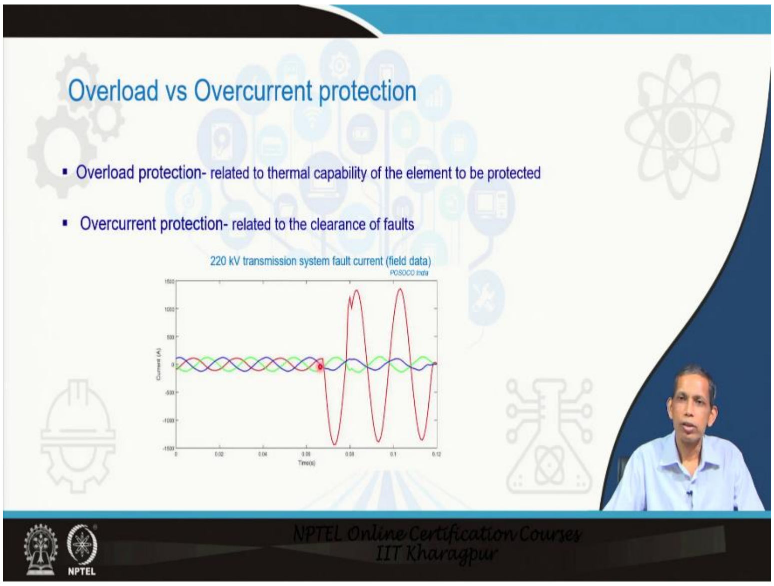

We say in power system overload related to load and we call overcurrent protection. So, let us clear these two issues, different issues before proceeding to this overcurrent relaying principle. Overload protection is related to load and which is related to the thermal capability of the element to be protected, so an element motor also or generator or transformer also running continuously, and the load to that element may increase and that way heating in the element may create problem to overcome that issue we say overload protection or so. On the other end, overcurrent protection is related to tackling faults like short circuit faults or so, where the current may be substantially high. So, the distinction is one is load issue and the other is fault issue. Like in this plot, we see, during a fault in a 220 kV transmission system, the continuous current was flowing to the line, and suddenly at this point there is a fault inception, in one of the phases there is a fault, line to ground fault, and then the current becomes substantially higher in that phase as compared to normal current. The fault current generally tends to be very high. So, this is a fault situation, this is not an overload situation.

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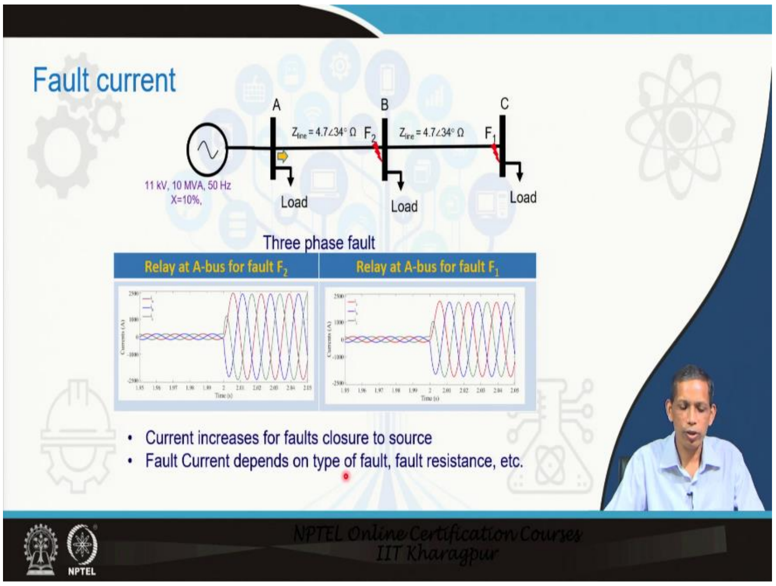

In furthering our discussion, we see the magnitude of fault current depends upon so many factors. Fault analysis is carried out, and you have already done by the sequence component analysis. So, that tells about that how much fault current will flow through a line at a specific point and that depends upon so many factors like you see here, this 11 kV system we have 3 buses with loads, and let us we are observing, take at node A at this point, and 2 cases we have simulated, 3 phase faults at F_1 and F_2. F_1 is a remote fault and F_2 is a close by fault with respect to F_1 for the relay or the sensors at node A. Now, if we see this 3-phase fault situation, for F_1 the corresponding fault here. For F_1 fault, the corresponding current becomes this amount around 2000 A in all the 3 phases for thid 3 phase fault. Whereas on F_2, it is closed by fault, the corresponding current is near into 2500 A peak in all the 3 phases.

So, you observe that the magnitude of current is more for close by fault to the source as compared to the farther fault. Therefore, the relay at node A will observe different amount of currents depending upon the fault location, farther fault, and lesser magnitude of the fault current.

Furthermore, these fault current depends upon other factors like type of fault, like phase to ground, phase-to-phase, 3-phase, phase-to-phase to ground involve including earth- fault resistance, tower footing resistance, pre-fault loading condition and so on. So, these factors also govern the amount of fault current through the relay or so during the fault situation.

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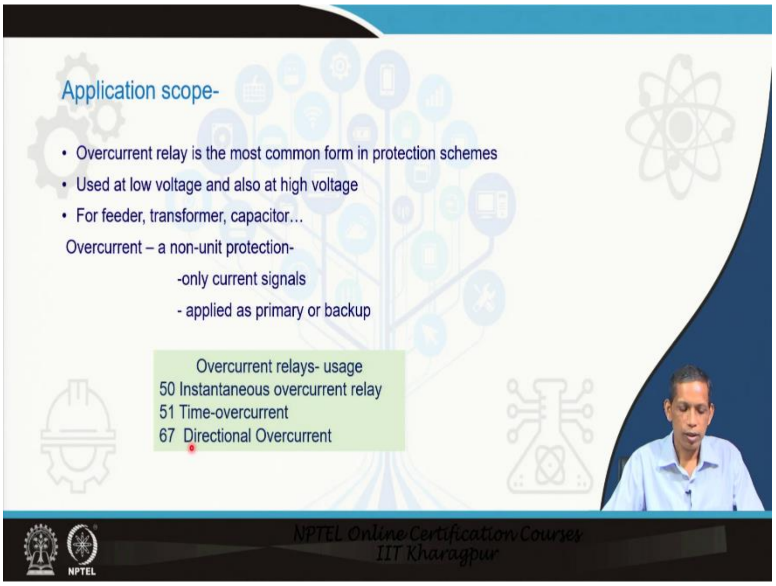

Now, overcurrent relay finds scopes, therefore that current becomes higher during fault. So, with that approach, the overcurrent principle can be applied and that is pretty old principle till now being applied in most of the systems. It is very useful. Now, there are different applications for this overcurrent principle because any such shot circuit faults leads to large amount of current. Overcurrent, the most commonly used in protection schemes, used at both low voltage and high voltage with different perspective, of course, for a feeder, transformer, capacitor protections widely used. Overcurrent again is a non-unit protection. It takes signals from the local end only one and only, it does not require any communication for a decision. It uses only current signals that is also advantageous and it can be applied, it is being applied either or both primary as well as backup protections in many applications today in numerical relay, because of the multifunctional nature of the relay, it can be used for triggering units and many other perspectives to have a better decision process.

Overcurrent relay has a different application and accordingly different IEEE standard element names. Instantaneous overcurrent relay is with number 50, 51 was for a time overcurrent relay, we will come to those what are these terminologies, and 67 is directional plus overcurrent relay combined is with number 67.

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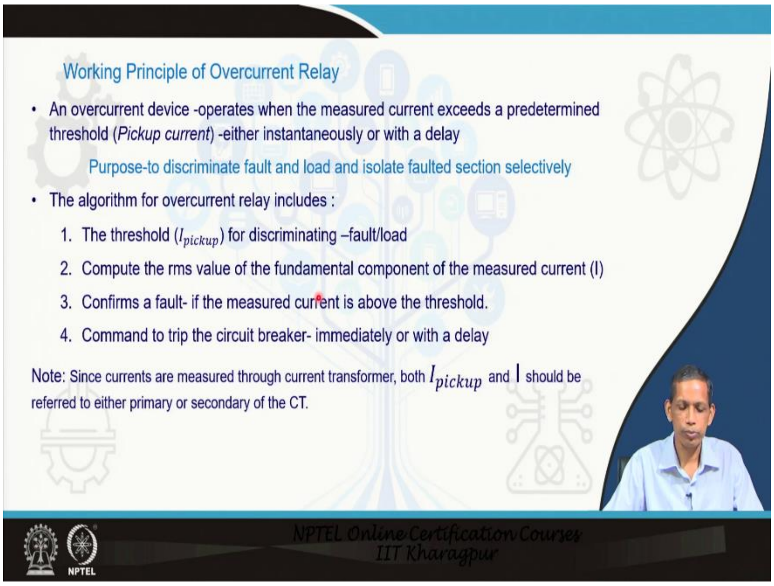

So, the working principle of overcurrent relay is that such a device operates when the measure current exceeds a predetermined value called I_{pickup}. This device operates either instantaneously or with a intentional delay, predefined delay it may be.

The sole purpose of this objective, this above step is to discriminate fault from loads and isolate the required faulted section, required faulted section selectively, so that the rest of the system remains intact. The algorithm embedded in an overcurrent relay platform includes the threshold value, the pickup current above which the relay operates and that discriminates the fault from other things like loads and so, it computes the rms value of the fundamental component of the measured current, confirms a fault if the measured current is above the threshold that is above the pickup, and then it commands to trip the required circuit breaker either immediately or with a delay, intentional delay.

So now, we see here one perspective here that it computes the fundamental component of the measured current. In the current during transient, in earlier classes we have seen that the transient process decaying DC and other components may be there. So, to get the fundamental we require essentially either DFT, Cosine Transform or least square perspective that we know, phasor estimation technique that gives us pure fundamental component as accurately as possible.

Note, all the designs here also, most of the protection’s designs which are based on sequence impedance and so for fault analysis perspective, when we talk about impedance that relates to fundamental component. Therefore, design process is being carried out in terms of 50 Hz component. Therefore, the relay would take decision for the accuracy using the fundamental component. Earlier older version of the analog relays were not able to do that and therefore accuracy was being compromised. Now in the numerical platform we can estimate the fundamental component accurately for better decision process. Since currents are measured through current transformers, then while selecting the pickup and the corresponding I which will be measured either to the CT secondary side or to the system side current. Then it becomes the comparisons for the decision-making process becomes correct. So, in numerical platform, this is a calculations, so one can do in the secondary side all the calculations or one can do in the system side also using the CT ratio for the purpose.

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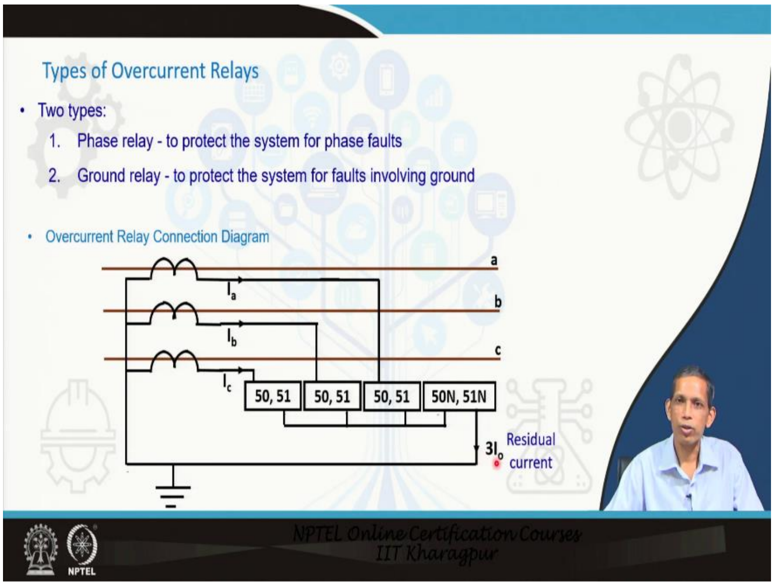

Now, how these corresponding relays are? Overcurrent relays in one perspective can be divided into two, we call them a phase relay and ground relay. Phase relay takes care the phase faults like ab fault, abc fault that is 3-phase fault and ground relay takes care of all faults involving grounds like phase a to ground phase b to ground and so. So, these are the two types of overcurrent relays that are used in system protection perspective for different elements.

Overcurrent relay, the connection for this perspective that we see here, in all the 3 phases, we have the CT connection and then there goes CT connection goes to different relays. These 50 51 are, either 50 or 51, they are instantaneous or inverse time. We will address more on these on the later slides. So, in each one we have a phase relay, and then here in all these 3 summation goes to the $3I_0$ that is a ground current, neutral current in this case that is otherwise called as residual current, summation of these 3 currents and that is 50N, N for neutral 50N. So, 50N or 51N can be used for this purpose.

So, you see here, this is a ground relay for that these are 3 phase relays. However, for phase-to-phase faults, out of these 3, we can use only 2 also for this perspective. That is what another way of doing the business for phase faults.

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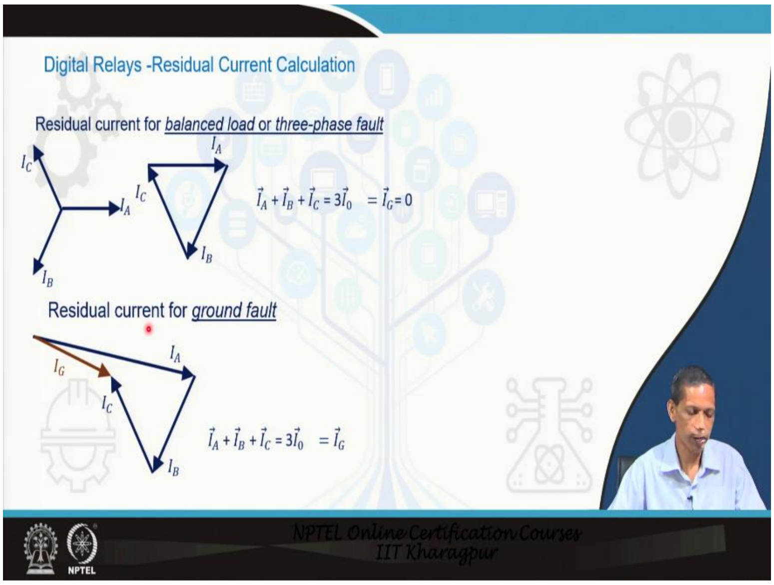

The ground relay, you adjust the ground currents 3 I_0 as you have seen in this earlier diagram. For that what you can do also there, because all the numerical relay calculates the phasors for the fundamental quantity. So, I_A I_B I_C are being computed for the 3 phases. $3I_0$ that is the residual current is nothing but

$$3I_0 = I_A + I_B + I_C$$

as you know. Therefore during the balance load condition or 3-phase balance fault if you see here this I_A, I_B, I_C are balanced. So, summation of these 3 leads to 0, so no ground current for the balance load condition, no ground current, for 3-phase also ground current is 0. Now, when there is a ground fault, you see here, I_A for phase A to ground fault, so the I_A current is significant now and then I_B , I_C currently remains intact. So,

$$I_A + I_B + I_C = 3I_0 = I_G$$

this I_G is nothing but a $3I_0$ is now substantially high due to the ground fault the magnitude of these will be indicative of fault leading, fault involving with ground that is what the principle of, ground fault relay.

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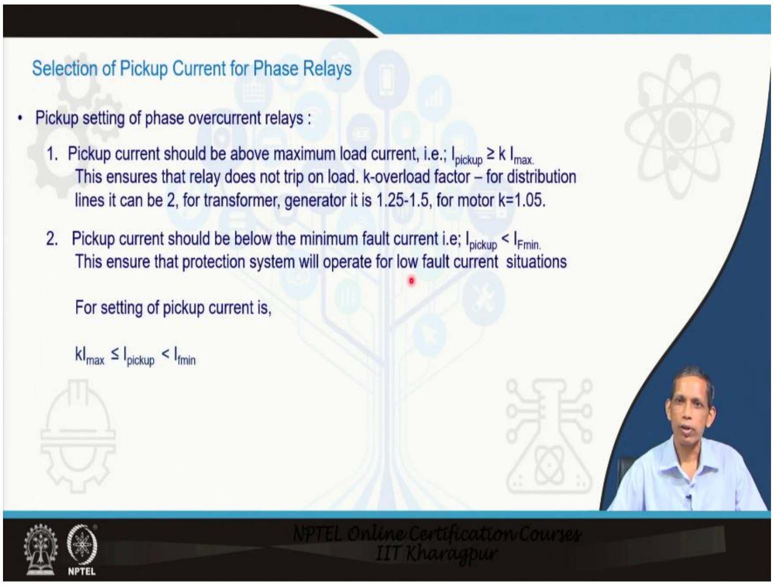

And continuing, now we will see this pickup current above which the relay takes a decision is very critical in the relay design perspective. Now, how the pickup currents for the 2 types of relays: phase and ground relays are being selected that we will have to see. So, first you can see that for phase relays selection of pickup current.

The guidelines are, the pickup current should be above maximum load current because the relay should not trip for all non-fault issues like over load and so. Therefore, the corresponding pickup current should be greater than the maximum load current in the system or rather greater than that. So, let's say

$$I_{pickup} \geq kI_{max}$$

Where k is called as overload factor also. For a distribution line protection typically it can be 2 for a transformer generator it falls in the range of 1.25 to 1.5, and for motor typical value of k equals to 1.05. Pickup current should be below the minimum fault current. So, in, whatever section or zone the relay is taking care, for all faults it must trip, therefore, what are the minimum fault current, that form, that minimum fault current will also, the relays would able to see as a fault and trip. So, judging from that, we see that $I_{pickup} < I_{Fmin}$. So, these are the two aspect that by which the corresponding pickup current is to be guided, selected. Therefore, you can see that there were the corresponding overcurrent relay should trip for the phase fault, it should trip for any fault in that element and it should not trip for any load issue and so on. So, for setting pickup, we see from the above

$$kI_{max} \leq I_{pickup} < I_{min}$$

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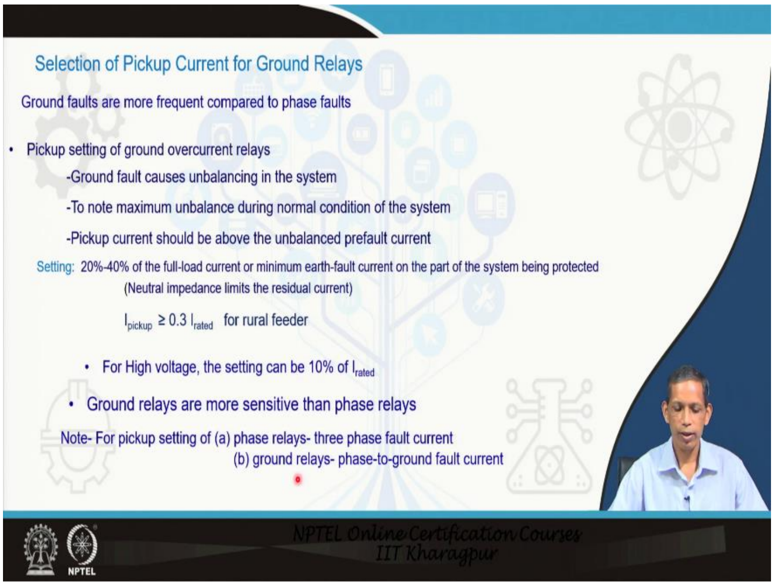

Selection of pickup current for ground relays that is fault involve with grounds, the ground faults are more frequent compared to phase faults. Most of the fault, 60-70 % of faults are involved with ground. Ground faults maybe a starting point and finally, it may culminate into higher phase-to-phase fault or double phase ground fault and other kinds of fault. The pickup setting for the ground overcurrent relays, ground fault causes unbalancing in the system, that is what we see because no more I_A, I_B, I_C will no more be balanced. To note maximum unbalanced during the normal condition of the system that is the possibility of unbalance which will lead to ground current. So, during normal condition means there is no fault in this system, because like in distribution system, we know I_A, I_B, I_C may not be always balanced and the system is grounded. So, there will be some amount of ground or leakage current also in the system. So, that will be also a counter for this one, those are not fault situation. Therefore, to discriminate fault and non-fault situation we have to take care of non-fault situations what are the possible ground current. So, pick up currents should have above the unbalanced prefault current, this pickup current should be above the unbalanced prefault current.

Thus during maximum unbalance condition in the system, what is the ground current the pickup current should be above that; typically, you can say that this pickup setting is (20 – 40) % of the full load current, note here, (20 - 40) % of the full load current, and the other way if in the system the minimum earth-fault current, the pickup settings will be governed by the minimum earth-fall current on the part of the system being protected. These are the 2 guiding factor.

Now, note that the neutral impedance limits the residual current that is the ground current perspective. So, during fault also the current may be limited substantially in some of the cases depending upon the neutral impedance in the, in that system. So, they are the guiding factors for the pickup current setting are these 2 factors. So, I_{pickup} factor for a rural feeder or so, it can be

$$I_{pickup} \geq 0.3 I_{rated}$$

And for high voltage systems, the corresponding unbalance is less, so therefore, the pickup setting for that can be 10 % of the I_{rated}, that is $0.1 I_{rated}$ and so. Note that ground relays are more sensitive than phase relays. In phase relays, we talk about k to be 2 times of the full load current or maximum current, whereas here we are talking about as low as 0.1 that becomes, 10% you can say that I_{rated}. So, the ground relays are more sensitive. We will see one example also. For pickup setting of phase relays, we always consider only 3-phase fault analysis and the corresponding 3-phase fault currents. For ground it is only phase to ground fault and the associated currents.

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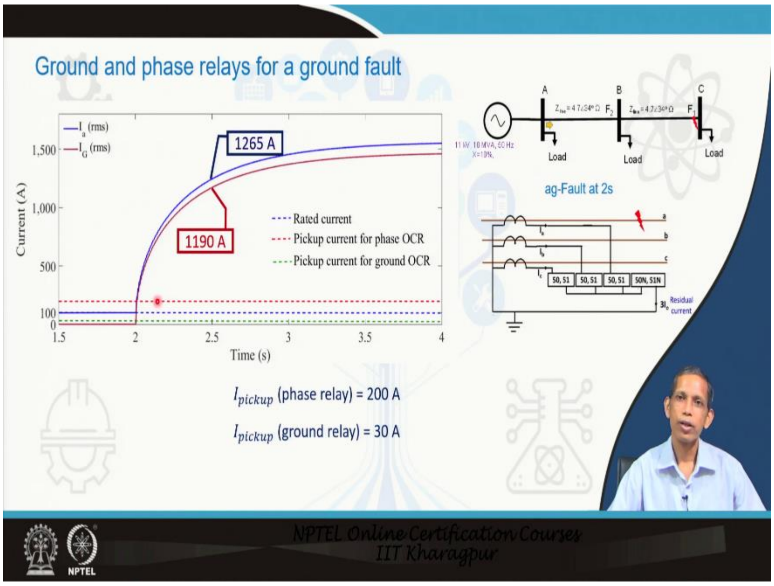

Now, see this example we can say that the difference between performance for ground and phase relays for ground faults. So, we consider, see here, in this case for this relay A, there is a fault at F_1 at this point, so, it is a line to ground fault at 2 s. So, line to ground fault at phase A here. Therefore, in this phase A the current will be higher, other phase the current should be as usual. That means for this phase A the relay at here 50 or 51 will pick up, if the corresponding current is greater than the pickup setting, it identifies the fault.

Also the corresponding neutral current and the ground current, residual current will be high now, because I_A is much higher unbalanced situation. So, therefore, you can say that this, residual or the ground relay will also pick up. So, this two will pick up in this case. Now, out of these two, who takes how that we will have to see. So, the green one is the pickup current for the ground relay. The red one is the pickup current for the phase overcurrent relay and the rated current is this one, suppose the rated current is flowing right now in the system, and then at 2 s, a fault happened should be there. At 2 s, if a fault happens there, fundamental component is being estimated and then you can say that we computed the corresponding I_a, A phase current and also the ground current. So, these two currents are computed and then we can see that we get the corresponding fundamental component like this for this case. In this case, the ground current rms value is 1190 A, and for phase relay, the corresponding value is 1265 A. This, difference between these two is because of the prefault current perspective. Now, once you see here, then we say that these two currents are much higher than their setting because green for the ground and the corresponding red for the phase relays. So, both relays will pick up and because the ground relay settings is lower, so it will identify first before the phase, and the time required for decision making by this ground relay maybe lower. So, that leads to a situation that the ground relay is more sensitive than phase relays.

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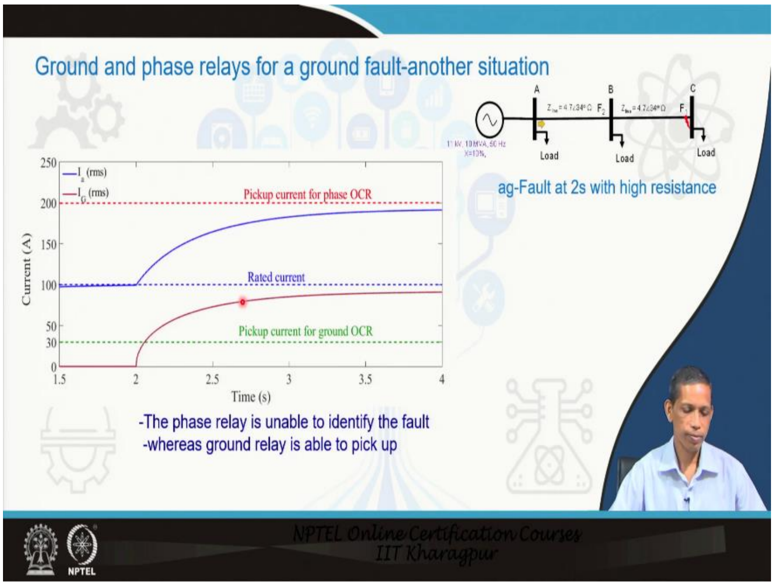

Now, I see another example in the same system for the same fault, when the fault is involved with a high resistance for the line to ground fault at 2 s, then we will observe that the corresponding fault current becomes substantially low. So for this the pickup current setting is 200 A, same example for the phase to ground fault.

and the pickup current setting is that 30 A for the ground fault case and now again in this case, the corresponding current which is the ground current in this case becomes this and the corresponding phase current becomes this. This shows that the ground current is higher than the pickup current, but the phase current is lower than the pickup current setting. Therefore, the phase relay will not able to identify the fault, whereas the corresponding ground really will identify the fault successfully. Therefore, we can clam here that ground relays for the ground faults is more sensitive than the phase relays.

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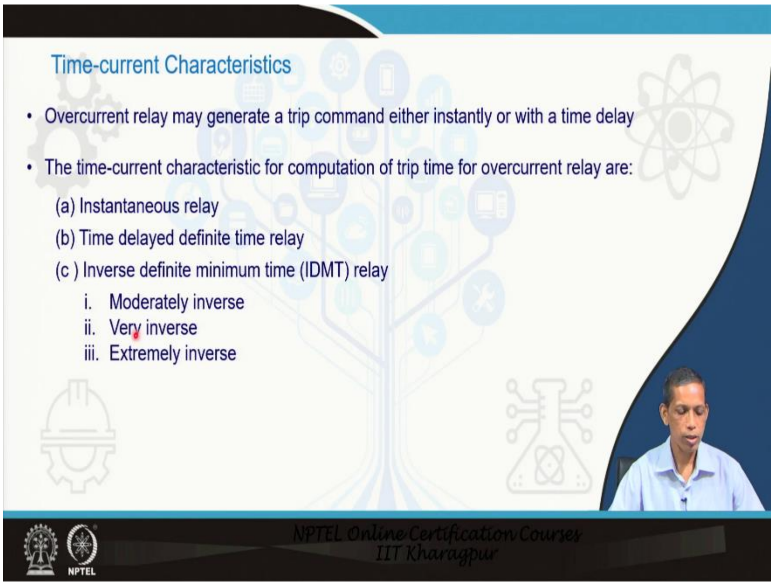

Now, different characteristics which are being used for the overcurrent relay for different protection perspective including coordination and so. The different time current characteristics for the overcurrent relay may generate a trip command either instantly or with a time delay. That is the distinguishing feature of the overcurrent relay. There are different time current characteristics for computation of trip time for overcurrent relay, which are being usually followed. One type is instantaneous relay, we will elaborate more on this. Other two category includes time delayed definite time relay and inverse definite minimum time relay, which is again categorised into three that are moderately inverse, very inverse and extremely inverse.

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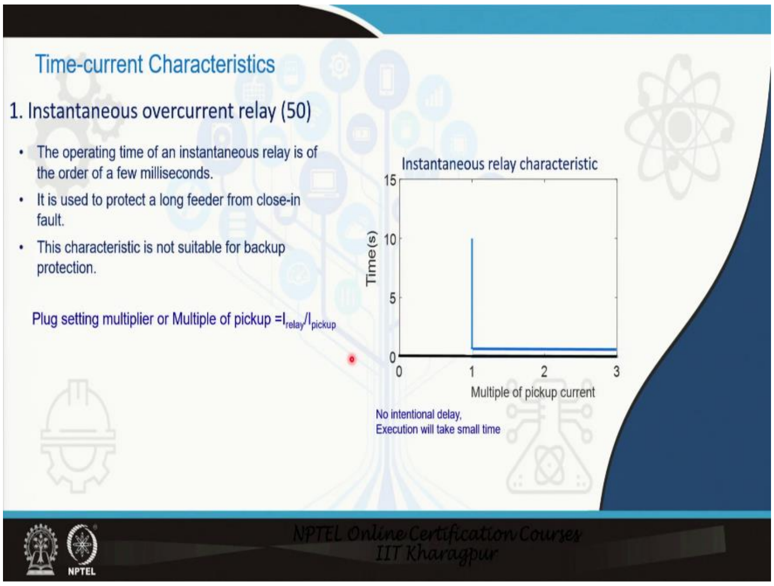

Let us first see first one, the instantaneous overcurrent relay. Instantaneous means no delay. Once the relay finds above the pickup setting, it will trip immediately, designated by this IEEE standard number 50. The operating type of instantaneous relay is of the order of few milliseconds that is the element takes time for computations, calculations and so, that is what the only time. It is used to protect typically long feeder from close-in fault, not for throughout the fault. This characteristic is not suitable for backup protection, because it cannot coordinate.

Plug setting multiplier or multiple of pickup setting, let us define this as I_{relay}/I_{pickup}. Where I_{relay} is the current through the relay and this I_{pickup} is the pickup current settings for the relay. Therefore, you can say that the factor of relay current with multiple of pickup is known as PSM or Plug Setting Multiplier, multiple of pickup. How many times of the pickup this ratio that matters. More fault current, more will be the value, smaller current, smaller will be the value. So, this is proportional to the relay current and the relay current is proportional to the fault current. Or if we take it against their primary systems, the corresponding current which will be used in the relay can be also same as the fault current. Of course, fault, what it means? The fundamental part, because the relaly will take decision based on the fundamental. Now, your instantaneous relay characteristics can be like this that the corresponding relay here takes no time. So, this is the time axis and this is the multiple of pickup current or proportional to the current; therefore, above 1, it will be instantaneously trip here without any international delay. However, execution will take small time in terms of the requirement of calculation and so on.

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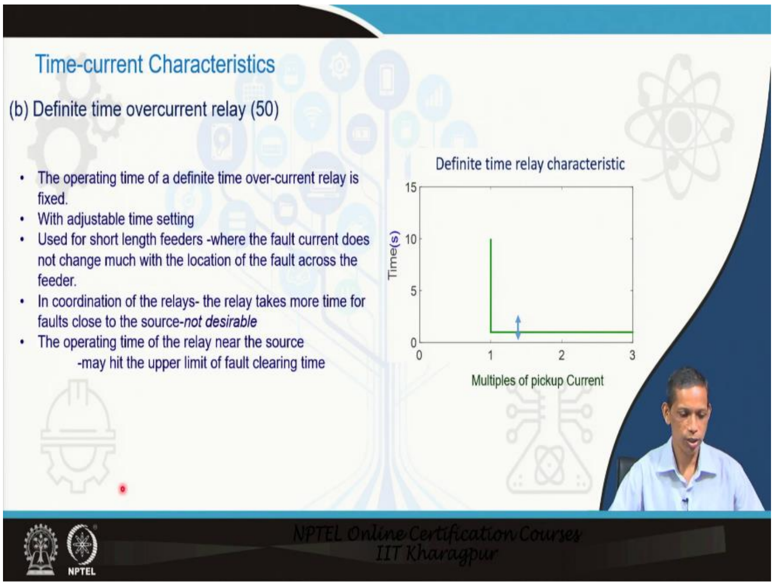

Next, we will see the definite time overcurrent relay. So, here we see again designated by same number. In the definite time overcurrent relay, we see a characteristics we have some definite time delay here, fixed time. However, these definite time delay can be changed as far the wish of the relay setting engineer to have the corresponding requirement.

But while in the operation, the relay will be having a particular value. It is not, we are not talking about something changing with timer, so we are changing about that is a fixed value as set by the engineers. The operating time of a definite overcurrent relay is fixed with adjustable time setting, used for short length periods, where the fault current does not change much with the location of the fault across the feeder, the line is short. So, there will be no appreciable impedance changed; therefore, fault at different positions in the feeder will not lead to significant current changes. So, the current amount will be of similar order. Therefore, current may not be able to distinguish that kind of thing this will be very useful for such situation. In coordination of the relays, the relay takes more time of fault close to the source that is not desirable. So, we will find, for the coordination between multiple relays in in the system, in a feeder or so, you can say in feeders or then the corresponding coordination will lead to very large time for relays which are close to the source of substation side. That is not desirable, because faults being close to this source will lead to large amount of current and that may be dangerous from the damage perspective. The operating time of the relay near the source and that may hit the upper limit of the fault clearing time therefore the coordination may not be possible with this kind of thing also. That is what another issue in this case.

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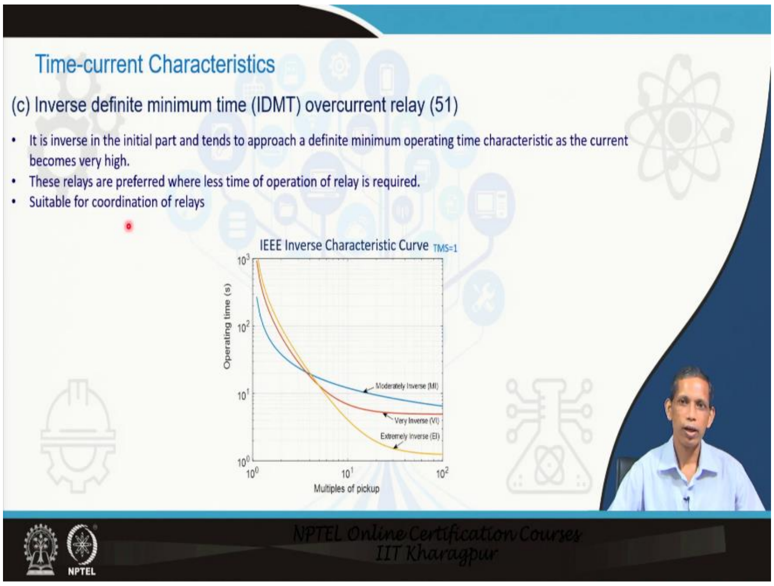

And next more importantly the inverse definite minimum time in an overcurrent relay designated 51, here inverse definite minimum time. So here definite minimum time, definite minimum time. You see here this is almost horizontal line here. So, the time is almost fix that is what the minimum time refers to and inverse it, you can see that more current or more multiple of pickup current setting, the time of decision is smaller. So, time is inversely proportional to current or the multiple of pickup current. Agree? So, the inverse relation in this portion, and then in the higher current region, the corresponding takes minimum time and that is the name inverse definite minimum time.

It is inverse in the initial part and tends to approach a definite minimum operating time characteristic as the current becomes very high. These relays are preferred where less time of operation is required and they are very good in coordination and all these things. We will see wide applications in system and also elaborates on the examples in the following lectures also.

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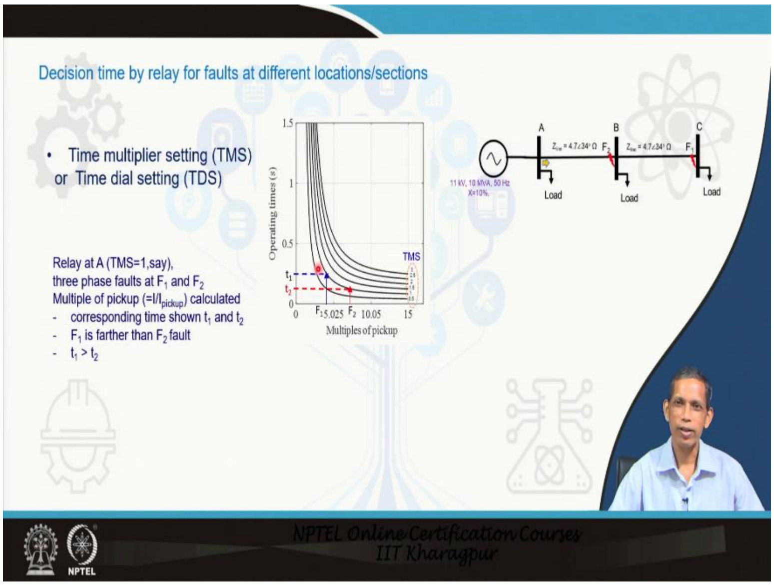

A decision time relay for faults at different locations and sections, see here, time multiplier setting for this one characteristic, let us say this is inverse definite minimum characteristics. So, these are different curves, they are having different time multiplier settings, this one TMS here, if you multiplied 0.5, then we are getting this curve, we multiply with 3 then you are getting the uppermost curve and like that.

So, these were time multiplier setting through multiplying the time, TMS also called time dial setting TDS, we can get different characteristics for the same inverse definite minimum time curves, either very highly inverse or moderately inverse or extremely inverse case also. So, whichever you can considering pick up, if you multiply with different TMS then you can get different curves like this. Now, let us see an application here. So, this system, 11kV system, we can create a fault at F_1 and F_2. F_1 is remote fault and F_2 is close by fault to this relay here at bus A. So, then say here for F_1 the corresponding fault is having less current and for F_2 the corresponding current is high. So, for F_1, the corresponding time, let us say the TMS used by the relay at here is you consider the 1. So, we will pick up these curve, the second curve from the lower side, that means that you can say that for F_1 the corresponding fault current at this level and therefore, corresponding time happens to be t_1 and for F_2 the fault current is larger, So, more multiple pickups therefore, the fault the same 1 TMS the corresponding time is t_2. So, we know that t_2 is less than t_1, so you see here, t_2 is for F_2 is less than, so F_2 is more dangerous, larger on the current. So, the time requires will be smaller and that is why you can say that we are getting, that t_2 is smaller than t_1 and that is why the strength of these IDMT characteristics for this. So, this shows that you can show that if the current is higher than the corresponding time required becomes smaller, that is what is required also and in the system also that is why it is required because many faults may be transient, so we can allow for some time to wait and watch principle for a relay to avoid unnecessary tripping. In that sense, if we can say that the fault having more dangerous should be trip as fast as possible and a fault having not significantly high current, then we can allow some time also. We agree that is what the IDMT characteristics provides that kind of flexibility in these characteristics.

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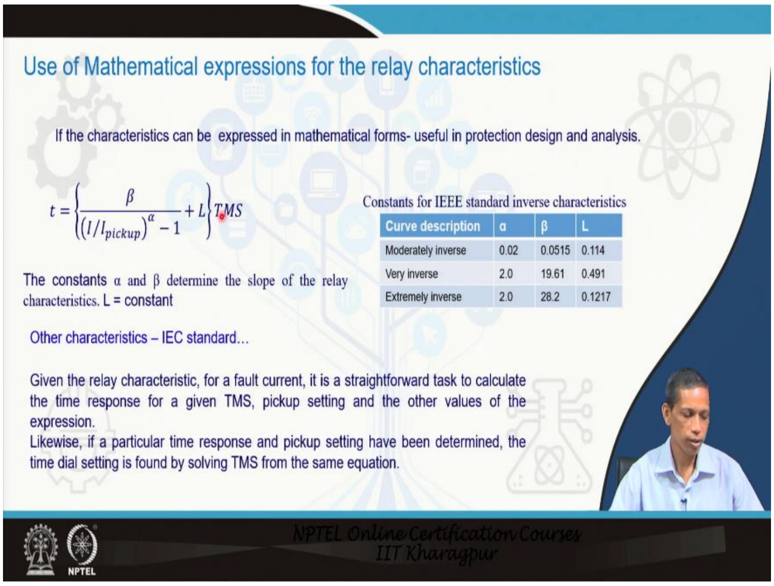

Now for these characteristics, if you can formulate it mathematically that becomes very useful in the design process and analysis process of the protection schemes. So, to have that, a generic equation for the IDMT characteristics is represented as

$$t = \{\frac{\beta}{(\frac{I}{I_{pickup}})^{\alpha} - 1}\}TMS$$

Where α and β depend on the slope, we will talk about that and then L is a constant. So, these α, β, L are the constants for these IEEE standard curves, there are other standard also like IEC standard. You can find these different standard available in the literature for many manufacturers and relay settings. While we are going for the relay settings, either we pick up IEEE standard or any other standard for the particular feeder which are having several series reconnected relays. It should be for one characteristic preferably. In IEEE standards, moderately inverse, very inverse and extremely inverse, as you have seen in the earlier curves, for that the corresponding α, β and L for these expressions are clearly defined here like this. So, that is why the mathematical expression, which will be useful in the computation process for analysis and protection design also. So here, given the relay characteristics, so for a fault, it is straightforward task to calculate the time response for a given TMS. So, anyway, there are two parameters here like when said here pick up current setting, α, β, L which are fixed. So, then you can say that once TMS is known, you can find the corresponding operation time or if the operation time, we are fixing and pickup current setting, you can find the TMS for the particular curve, which you would like to fix for a particular relay and so that is what the corresponding mathematical formulation helps in this one.

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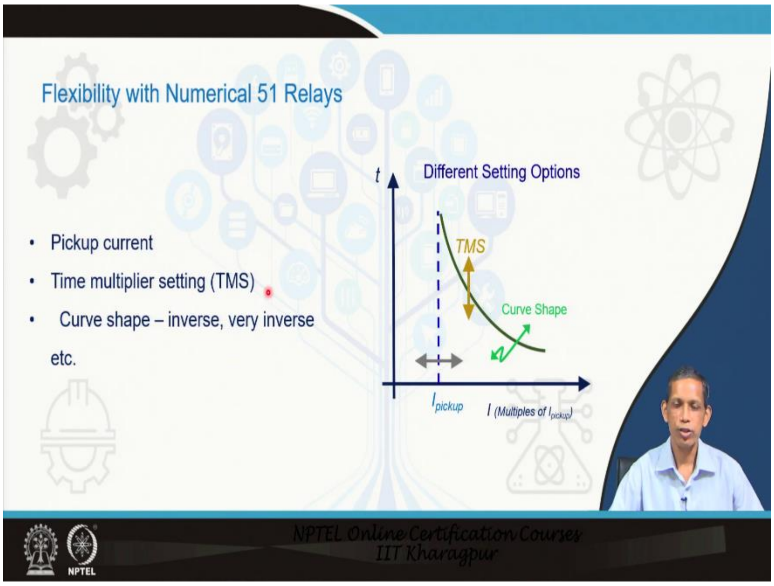

Now, you see here that this IDMT characteristic has flexibility that is IDMT means 51 relay has a flexibility. Flexibility in pickup current, see here, if you change the pickup current then the multiple you can say that obviously pickup this way or that way go. So, accordingly, the decision time will be changed, that is one perspective. Then time multiplier setting TMS, if you are using 1 TMS or 0.5 TMS means down and 3 TMS means up so the characteristic curve can be changed accordingly, curve shape, you can go from inverse to very inverse, and curve shape can change in the same way as relay. Therefore, by changing this you have a lot of flexibility that for same fault, you can have the different time of operation by the relay and all these things as per the requirement of a particular protection design and so on.

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So, in overall, we see in this lecture that there two working relays that are generally available; ground and phase relays and we say that ground relays are more sensitive for the ground faults, but ground relays cannot handle for the phase, only phase that is phase-to-phase faults, because in phase-to-phase faults there will be no ground current. Therefore, you essentially require phase relay that indicates we require both solution of the protection through overcurrent relay. Pickup setting is important aspect of this one because that decides whether relay can successfully intervene or not. Smaller pickup setting means more sensitivity, but smaller pickup setting means many overloads and during load condition also it might trip, that is also not desirable. Characteristics and TMS selection, the characteristics, whether we will go for these IDMT issue, whether going for the instantaneous or you can say time delay, that is one important perspective, and the time multiplier setting is also very important because it will reduce the time and increase the time depending upon the TMS value. So, these, all this perspective and all these things what we saw is very important for overcurrent-based relay protection design perspective. We should be elaborating more details in next lecture. Thank you.