Power System Protection and Switchgear
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Lecture 8
Current Based Relaying Scheme 3

So, in the last class we have discussed regarding the application of instantaneous overcurrent relays on the radial multisection radial network. Let us continue with the same, we were discussing at that time that what are the disadvantages of instantaneous overcurrent relays. So, we have discussed the two disadvantages, the first that is it is not possible to provide backup protection if we use instantaneous overcurrent relays.

And the second is the setting of instantaneous overcurrent relays are affected by ZS by ZL ratio, where ZS is the source impedance, that is impedance from source to relaying point and the ZL is the impedance from the relaying point to the fault point. So, as it has only current setting, no time setting exists in the instantaneous overcurrent relays, so they are affected by changes by ZS by ZL ratio. So, now, let us discuss the third disadvantage that is the all instantaneous overcurrent relays are affected or suffered by the transient overreach phenomena.

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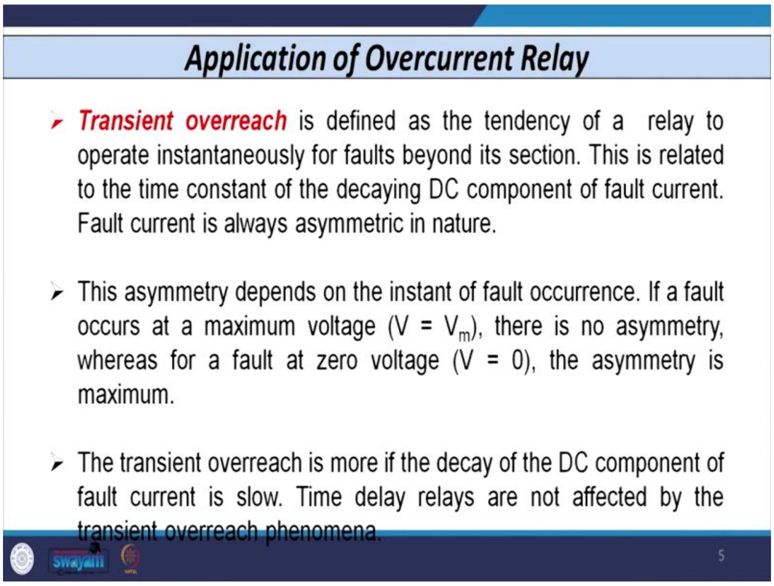

So, let us discuss first what is the transient overreach phenomena. So, to understand this, let us consider first the simple transmission line that is connected to the bus.

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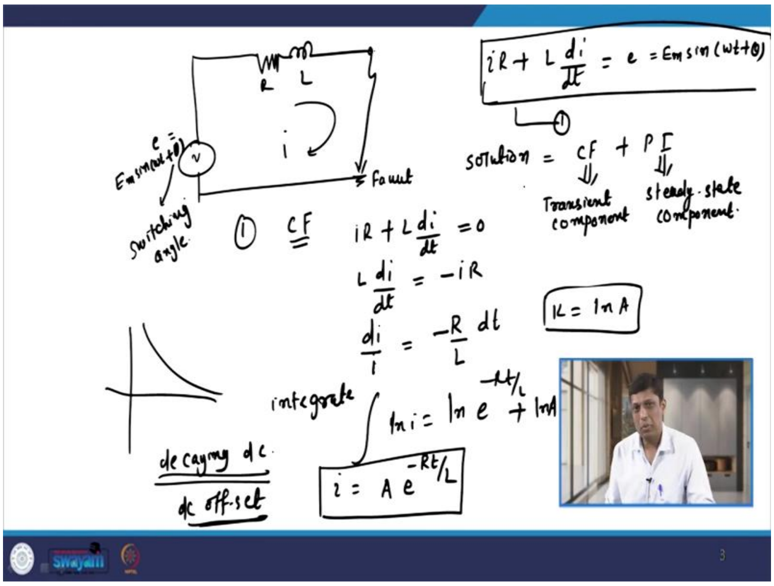

So, let us consider that there is a source connected here and the transmission line is connected. So, its parameter is let us say R and L and at this point let us say fault occurs. So, that is the fault point and because of that the current i flows in this circuit. So, if this is the case this source is, let us say E which is given by the Em sine omega t plus theta, where theta that is known as switching angle, switching angle. So, if fault occurs here in this case, we want to analyze, what is the impact of transient overreach on the instantaneous over current relay.

So, for that, let us consider this network and if fault occurs at this instant, then the current flows, magnitude of current that is very high. So, if we solve this then we have the equation that is say iR plus L di by dt that is equal to e that is source, which is nothing but Em sin omega t plus theta. So, we need to solve this equation. Now solution of this equation, that is given by, so if we want to solve this equation one, then its solution is given by complimentary function plus particular integral.

So, in this case complimentary function gives you the solution of transient component of the, that exists in the fault current and the particular integral that gives the solution of steady state component that exists in the fault current. So, let us start solving this using complimentary function, which gives transient component part of the fault current. So, if I want to solve this in equation 1, we have to keep the left hand side of this equation 1, we have to equate it with 0.

So, if we do it, then we have L di by dt that is equal to minus i into R. So, di by i that is equal to minus R L comes in the denominator into dt. So, if I integrate both the sides and then solve. So, if I integrate this then it is the ln i that is equal to ln e raised to minus Rt by L plus ln A, where ln A that is equal to some constant k. So, if I solve this then I have the solution that is i is equal to some constant A into e raised to minus Rt by L. So, this is the solution of the first part, that is complimentary function.

So, this equation clearly indicates that the component of fault current, that is transient in nature and it decays exponentially. So, if I draw the curve, then we have the curve like this, it decays exponentially and this decay depends on time constant of the circuit. This decaying component is known as the decaying DC component or sometimes it is also known as the DC offset component. So, we can call it either decaying DC component of fault current or we can call it as DC offset. So, that is the solution of first part, that is complimentary function.

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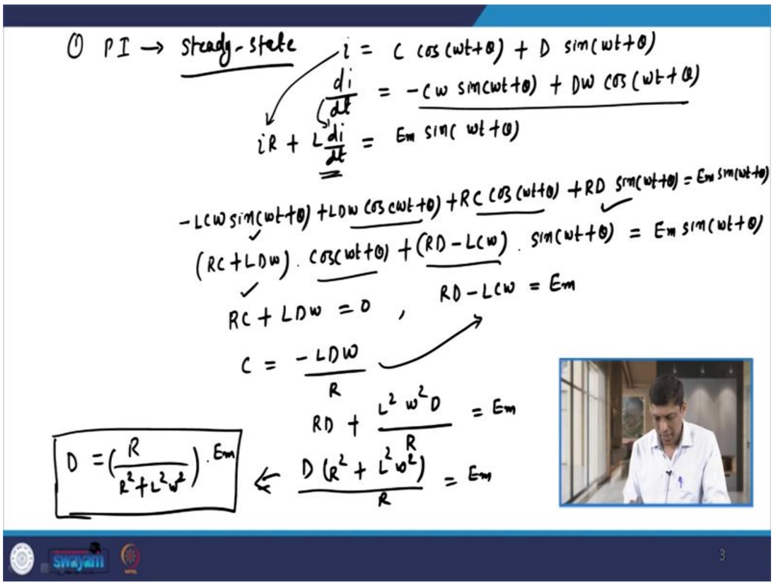

So, now, let us consider the second part, that is the particular integral which gives you steady state component of the fault current. So, to solve this, let us consider the value of i, let us say it is given by some constant C and in that cosine term. So, cos omega t plus theta and plus some another constant let us say D, which is given by sin omega t plus theta and we also have let us differentiate this, so with respect to time.

So, di by dt that is given by the minus c omega, that is sine omega t plus theta, that is first part and plus the second part is d omega sin that is cos omega t plus theta. So, our original equation that is the iR plus L di by dt that is equal to Em sin omega t plus theta. So, if I put the value of i here and if I put the value of di by dt here, then we have the value. I am writing the second term first, L is multiplied with whole term, this term. So, we have the minus LC omega sin omega t plus theta plus LD omega and cos of omega t plus theta, that is the first part Ldi by dt plus iR, so i is here.

So, plus R into C cos omega t plus theta plus R into d, R is multiplied with this, that is sine omega t plus theta the whole equal to Em sin omega t plus theta. So, let us combine this cos term. So, that is RC plus LD omega into we have cos omega t plus theta and then plus let us combine the sin term. So, we have the RD minus LC omega into sin omega t plus theta, the whole equal to, on right hand side we have the Em sin omega t plus theta.

So, if I equate on both the sides coefficient of cosine and sin term. So, we can say that on the left hand side we have coefficient of cosine term that is this one. There is no cosine term on this side. So, this term RC plus LD omega, that comes out to be zero as there is no cosine term right-hand side. If I equate the coefficient of sin term, then we have this term that is on left hand side RD minus LC omega, that is equal to the coefficient on right hand side is Em, so that is equal to Em.

So, if I find out the value of C from this equation. So, that is nothing but the minus LD omega by R and if I put this value here in this equation, so then we have the value that is RD minus, this minus and this minus becomes plus. Then we have L square omega square D whole divided by R that is equal to Em. So, we have R square plus L square omega square whole, that is by D divided by R that is equal to Em.

So, what is the value of D from this point. So, the value of D, that is given by the R divided by R square plus L square omega square and the whole that is multiplied with the value Em. So, value of D that is given by this. If I put this value here in the, this value of C, so then we have the value of C that is equal to minus LD omega by R.

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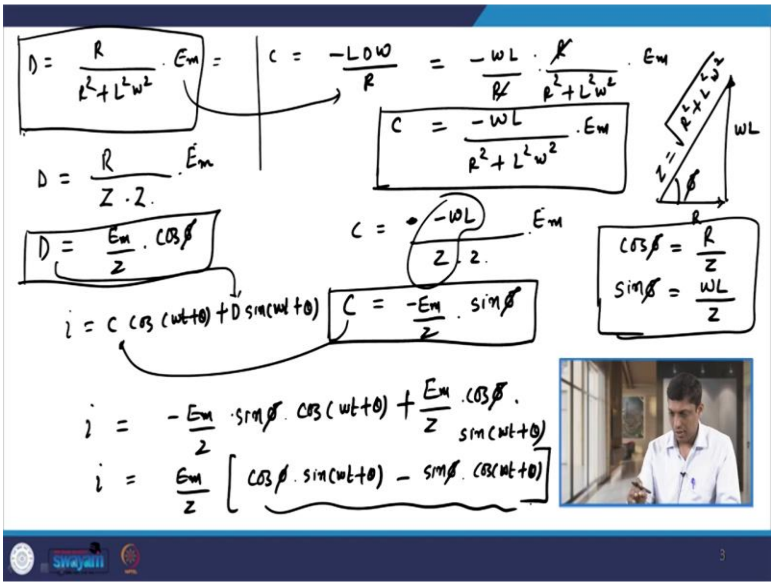

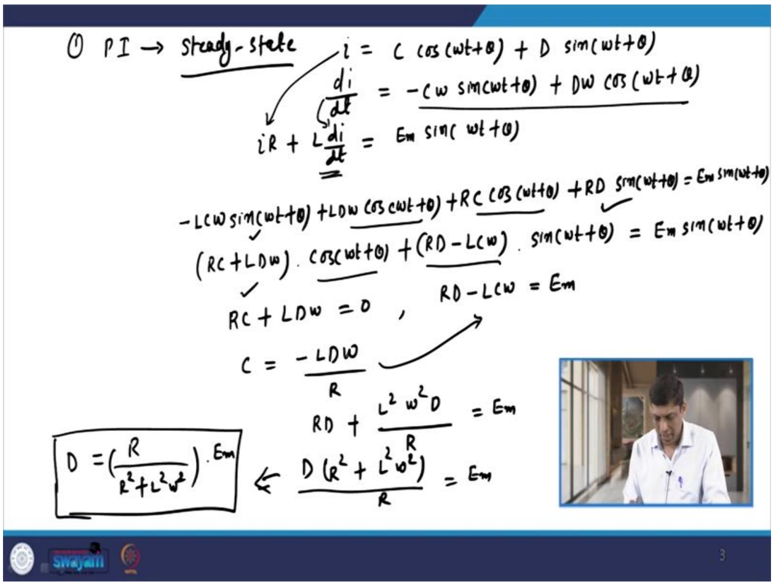

So, the C value is given by minus LD omega by R and if I put the value of D here from the previous slide, then we can say that D is equal to R upon R square plus L square omega square into Em. So, the value of D that is given by R divide by R square plus L square omega, R square plus L square omega square into Em. So, if I put this value here in value of C, then the value of C, that is given by what we have the minus omega L, divided by R, and now, I am putting the value of D that is this value.

So, that is R divided by R square plus L square omega square into Em. So, this gets canceled and we have the value of C, that is minus omega L divided by R square plus L square omega square into Em. So, this is the value of C and we have also the value of D that is given by this term. Now, if I consider the impedance triangle, then we have in impedance triangle say R and we have in impedance triangle say omega L. So, this value at an angle phi, where phi is equal to tan inverse x by R.

So, this is given by Z, that is equal to square root of R square plus L square omega square. In this impedance triangle, if I take cos of phi, then that is given by R divided by Z and if I take sin of phi, then that is given by omega L divided by Z. So, this two equations are important. So, if I use this two equations in the value of D and then the value of D that is given by R. I can write this R square plus L square omega square that is Z into Z into Em. If I put the value of R by Z, that is cos phi. So, we have Em by Z into cos of phi, that is your value of D.

Similarly, if I put the value of this sin phi is equal to omega L. So, then we have the minus omega L divided by Z into Z into Em. So, if I replace this minus omega L by Z, omega L by Z, so we have minus Em by Z into omega L by Z, that is your sin phi. So, this is nothing but your value that is C. So, if I use this value in our original equation of I, which is given by C cos omega t plus theta plus d, sin omega t plus theta. So, if I put the value of D from here and if I put the value of C from here.

So, then we have the I that is given by C that is minus Em by Z into sine phi and then we have cos of omega t plus theta plus we have D, that is again Em by Z into cos phi and into sine omega t plus theta. So, if I take Em by Z common, then I have the value of I, that is given by Em by Z common. So, we have cos phi into sin of omega t plus theta minus we have the sine phi into cos of omega t plus theta.

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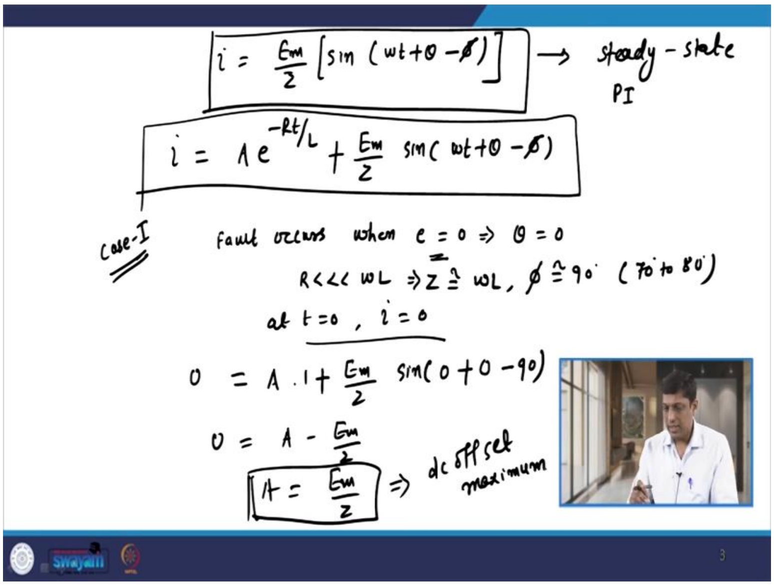

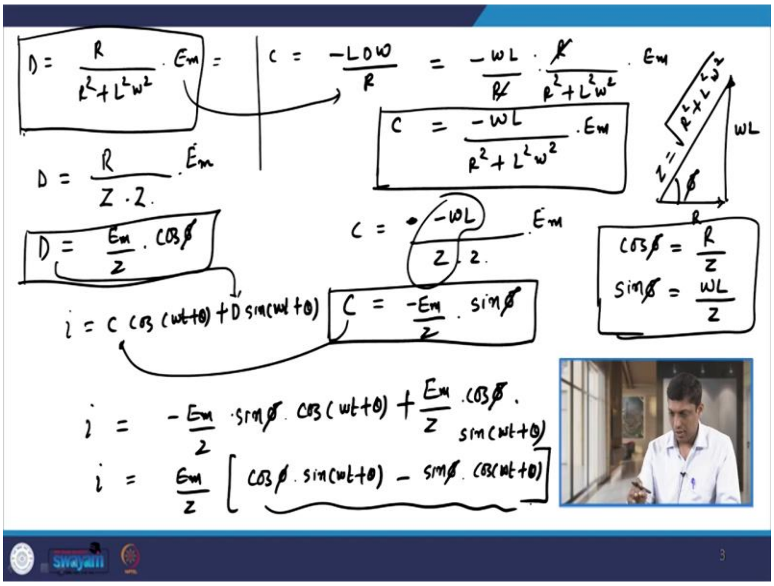

So, this equation that is given by I is equal to Em by Z and we have sin of omega t plus theta minus phi. So, this term is given like this. The previous term you can see sin alpha cos beta cos alpha sine beta, that is given by sin omega t plus theta minus phi. So, this is the equation of current for steady state component. This is for steady state component which we obtained using particular integral. So, if I combine both the component of current from transient and component of current by steady state, then the whole i that is given by A e raise to minus RT by L.

This is from transient component, complimentary function and the other one that is Em by Z into sin of omega t plus theta minus phi. So, this is the equation of the fault current that contains both transient component and the steady state component. So, now using this let us consider the two case. The first case we consider, say in this case fault occurs when the voltage wave is passing through the 0. So, your E, that is passing through 0. So, when voltage wave is passing through 0 means in this case your theta switching angle that is also 0.

Further we know that the transmission circuit or line is highly inductive in nature. So, the value of R, that is very very less than the omega L, that is your reactance part. So, we can say that Z is almost equal to omega L and hence in this case the value of phi almost equal to 90 degree, ideally. Practically it should be between 70 to 80 degree.

So, if I consider now this value, and if we assume that fault occurs at t equal to 0, when current is also 0, this is true because whenever fault occurs the natural 0 comes for AC circuit that is every half cycle, the arc is always extinguished when current passes through natural 0.

So, at t equal to 0, i is 0, if I use this value in our equation, then i is 0, A e raised to minus minus R t is 0, so that is 1 plus we have the Em by Z and sin of omega t, t is 0.

So, this part this term is 0 plus theta, theta is also 0 and your phi, that is 90 degree. So, sine of minus 90 that is you have A minus Em by Z that is 0. So, A that comes out to be Em by Z. So, this indicates that if fault occurs when the voltage wave is passing through 0, then the value of decaying DC component or DC offset, that is maximum. This is maximum, that is the other case.

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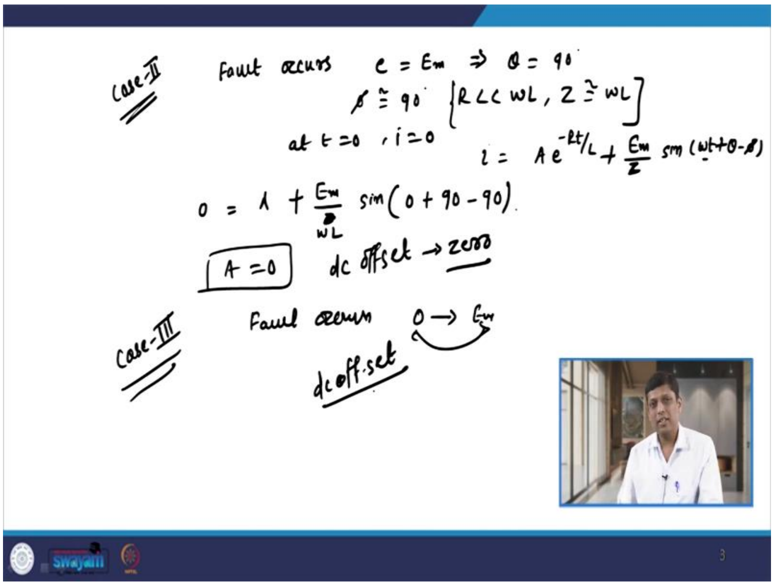

Now, if I consider the next case, that is the second case. So, in this case let us assume that fault occurs when the voltage wave is at its peak value. So, E is equal to Em. So, in this case your theta, that should be 90 degree. As our phi is again almost 90 degree, as we told you that R is very very less than omega L. So, your Z is also almost equal to omega L. So, with this if fault occurs at t equal to 0, the current is also 0.

So, in previous equation that is I is equal to A e raise to minus RT by L plus Em by Z sin of omega t plus theta minus phi. In this equation if I put the value, then i is equal to 0, we have A, t is 0, so that is 1 plus Em by Z sin of, here omega L comes. Sin of the omega t first term, that is 0 theta that is you have that is 90 degree and phi that is also 90 degree. So, sine 0 that is 0. So, A that is equal to 0. So decaying DC component, DC offset that is 0 in this case and if I consider the third case where the fault occurs and at that time the voltage wave is passing between 0 to its maximum value, that is Em.

So, in any case whenever switching takes place it is between 0 to Em, then the DC offset is present, DC offset that is present in the circuit, in the fault component. So, we know that fault current is asymmetrical in nature.

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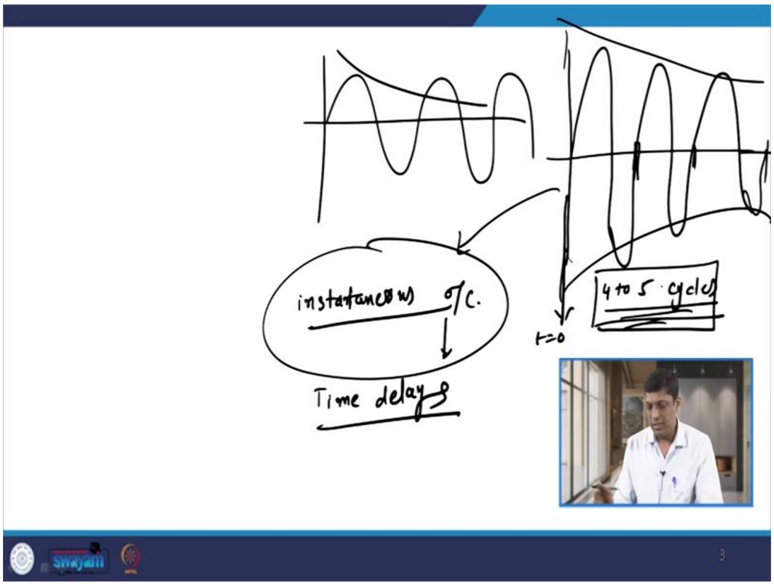

So, if I just draw the wave shape of fault current, then this is our decaying DC component and this is our steady state component. So, if I combine this 2, then we have the fault current magnitude like this. So, this type of wave shape. So, you can observe that during first cycle is here, second cycle is here, the third cycle is also here. So, during few first few cycles say four to five cycles, after the inception of fault at this instant, fault occurs at equal to 0.

So, during first four to five cycles, the wave shape of fault current is asymmetrical in nature and this asymmetry contains both transient component as well as steady state component. So, wherever the fault current contains both transient and steady state component and the transient component, it can be 0 and it can be maximum, that depends on at what time whenever fault occurs, then at what instant fault occurs, when voltage wave is passing through 0 or when voltage wave is passing through its peak value. So, depending upon that the value of transient component changes.

However, we cannot predict the fault that the at it fault occurs at this instant only, even nobody can predict. So, we can say that whenever we design the any relay, relaying circuit, then we consider the worst case, that means, the maximum value of decaying DC component is present and based on that we carry out the design. So, as the fault current wave shape is asymmetrical in nature and that asymmetry depends on the instant at which fault occurs. So, that is decaying DC component.

So, due to this reason we can say that and keep in mind that this component, transient component that will die out after four to five cycles and our instantaneous over current relay operates instantaneously and as this decaying DC component present up to four to five cycles after the inception of fault.

So, this relays are affected by this term, that is transient overreach which is because of decaying DC component. Time delayed relays, this relays are not at all affected by this decaying DC component because their operation time, that is not in cycles may be in seconds. So, that is why this type of relays are not at all affected by the decaying DC component.

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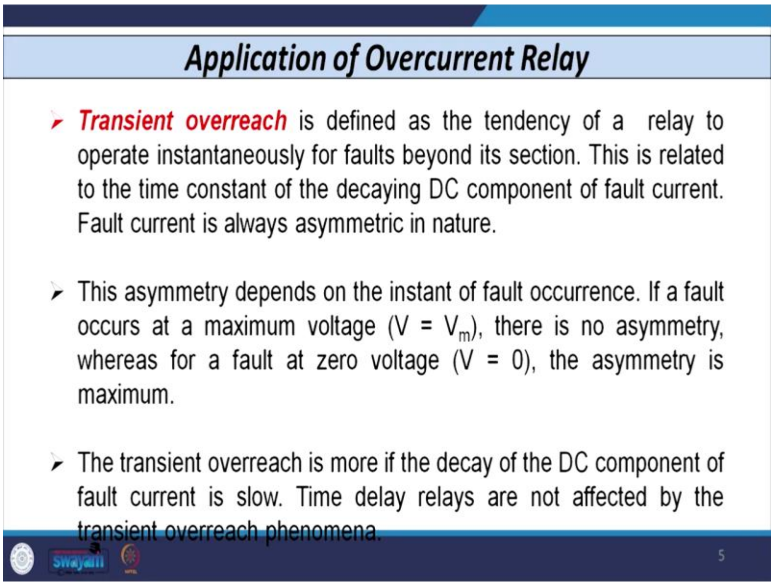

So, if I consider the transient overreach, as I told you it is the tendency of relay to operate beyond its own section and this is because of fault current and that particularly because of decaying DC component of fault current exists in the fault and as I told you the asymmetricity of fault, that depends on the switching angle, that is not in our hand. So, the transient over each part, that is more if the decaying DC component decays at a very slow rate. So, more decaying DC component is present when instantaneous over current relay operates.

If the rate of decaying DC component is high, then the transient over reach, that is also lower compared to the previous case. So, this is very important, time delay relays are not at all affected by the transient overreach phenomena, but all instantaneous overcurrent relays are affected by this phenomena. So, this is very important point we have to consider.

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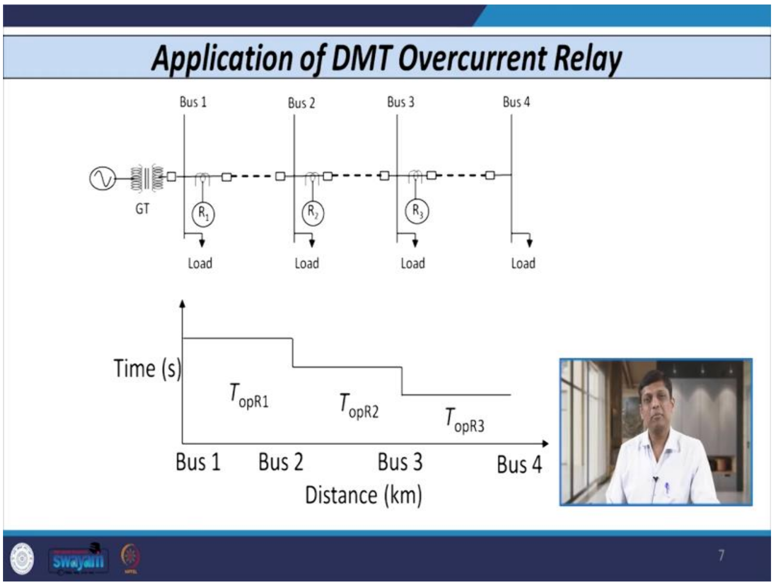

Now, with this background, let us consider the next relay, that is known as definite minimum time overcurrent relays. So, let us consider the multisection radial network. So, if I consider the multisection radial network as shown in this first figure, so, we have three relays R1, R2, R3 connected between the four buses, bus 1 to bus 4 and in each section we have 1 relay stop and let us assume that this relay R1, R2, R3 all are definite minimum time overcurrent relays.

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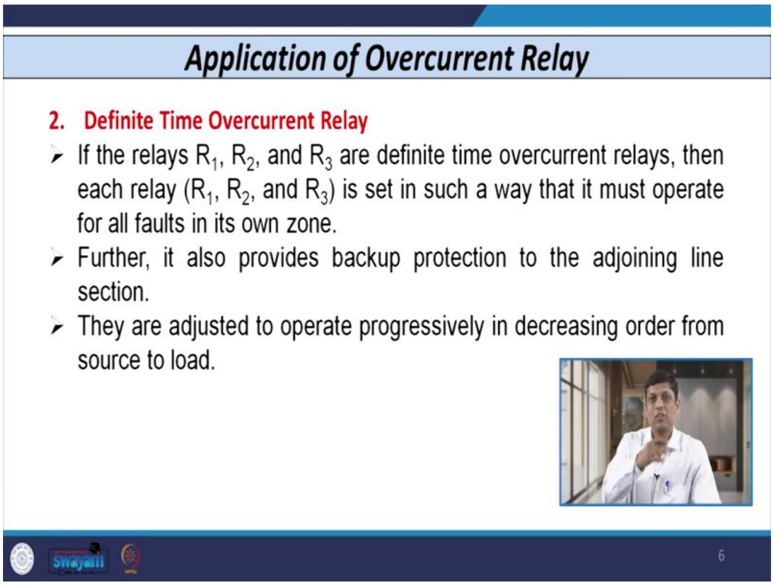

So, this relays are again set to operate progressively and any fault occurs in particular section then the relay associated with that section has to operate as a primary relay, if that relay fails then some other relay that, will provide backup. So, this relays are adjusted progressively in decreasing order from as we move from source to load.

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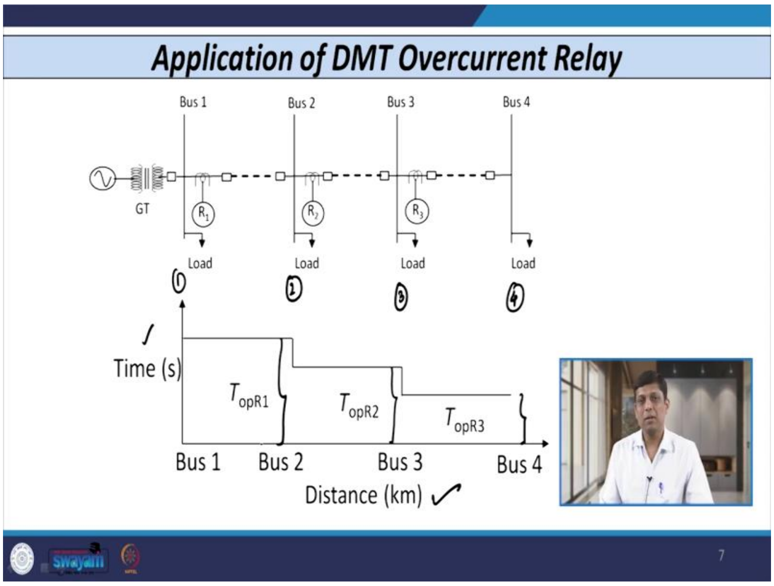

So, let us consider this, if I extend again this, this is my bus 1, if i extend the bus 1 below. This is my bus 2, this is my bus 3 and this is my bus 4, if I extend bus 1, bus 2, bus 3, bus 4 below. So, you can see that I have given the operation of definite time minimum relay with reference to on x axis I have taken the distance in kilometers and on y axis I have taken the time of operation of relay in seconds. So, you can see that the relay R3 is very near to the load.

So, it's time of operation of R3 that is lowest and as we move further from lower to the source, that is another next relay towards the source is R2. So, its time of operation is higher than the previous relay R3. As we move further the time of operation of relay R1, that is also higher than the previous two relays. So, as we move further, its time of operation increases.

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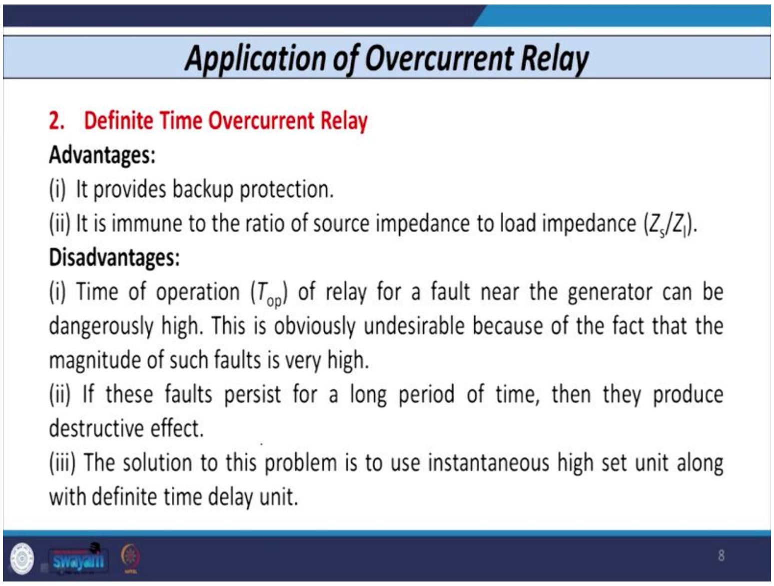

Now, let us discuss what are the advantages and disadvantages of different time delay relays. The first advantage is it provides backup protection, so if any relay which acts as a primary relay, if that relay fails, then the other relay towards the source that will provide backup and the second very important advantage is this relay is immune to the ratio of ZS by ZL. So, any source impedance to load impedance ratio changes, then also on the setting of definite minimum time delay relays are not affected. So, their operation that is also not affected. Now let us discuss what are the demerits of definite time overcurrent relays.

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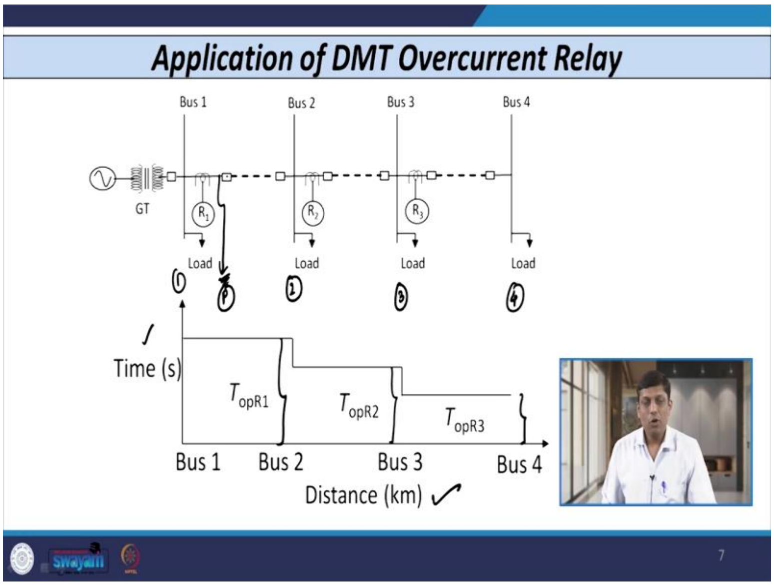

The very important demerit is that if I consider the radial section network here, if any fault occurs in the first section somewhere here, then you can see that the relay R1 operates with the highest it has highest time of operation. So, if fault occurs at point number let us say p in first section where relay R1 is connected, this fault is the severe most fault. Because the if I consider the fault path, then that involves minimum value of impedance. So, this is a severe most fault and we are clearing this severe most fault with highest time delay, because the time of operation of R1 that is highest.

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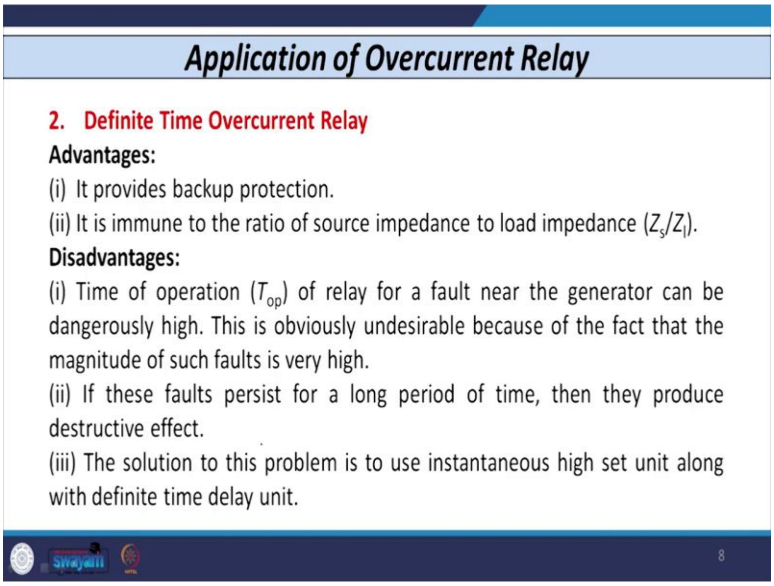

So, that means the severe most fault as we are clearing with a very time, delay time. So, this is going to damage because the magnitude of fault current that flows for a longer period of time then that is going to damage the say other equipments connected in the network. So, this type of main disadvantage, that is not allowed in case of definite minimum time delay relay. Of course, so there is a solution exists that we connect the instantaneous high set unit with definite time overcurrent relay.

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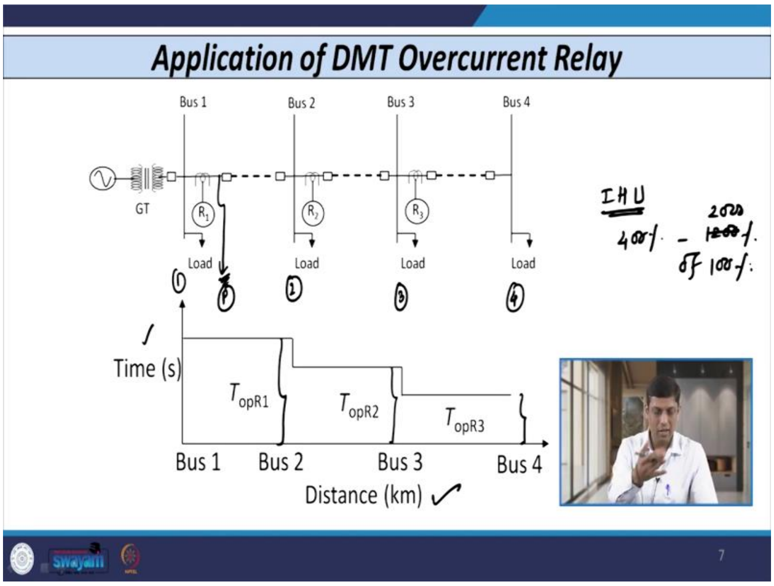

So, in the previous section if any fault occurs somewhere here and if magnitude exceeds some value, then this relay R1 does not wait for specific time period and it operates instantaneously because it is associated with instantaneous high set unit and as I told you earlier, its setting is from 400 percent to 1200 percent, 2,000 percent in steps of hundred percent. So, this you can set and you can set the appropriate value, if that value exceeds the time delay action is bypassed and really operates instantaneously.

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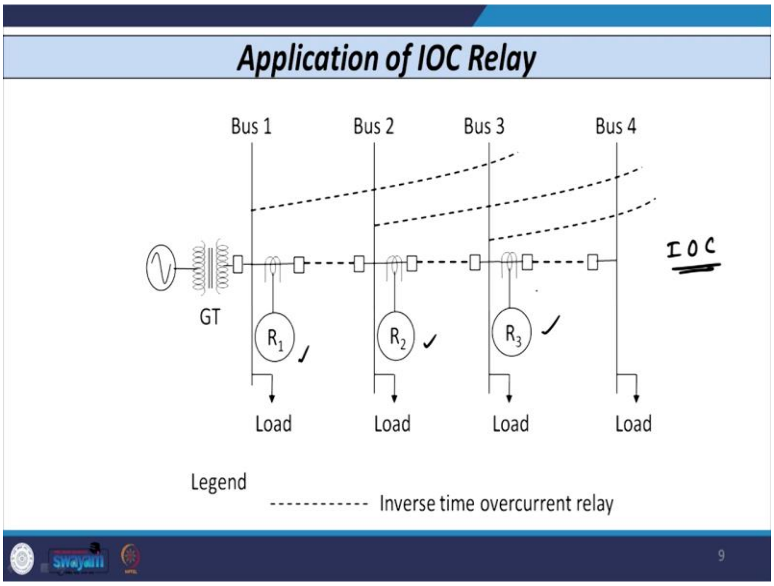

So, that is the main thing of definite minimum time relay. So, now, let us consider the third type of relay, that is known as inverse time overcurrent relay. So, if I consider the same multisection radial network, then 3 relays, let us assume that R1, R2 and R3, this three relays are inversely finite, inverse time overcurrent relays, that is IOC. So, the characteristic of this three relays are also shown with dotted lines. So, the characteristic of first relay R1 is like this, characteristic of relay R2 is below this and characteristic of relay R3, that is also below this. So, if any fault occurs, the first relay R3 operates, then R2 operates and then R1 operates likewise.

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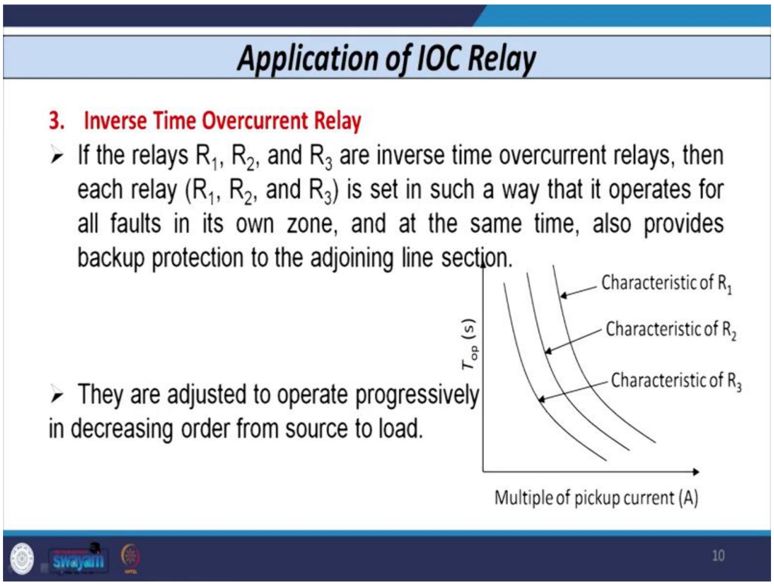

So, now, if I consider the characteristic of really R1, R2, R3, then you can see that in this figure, the characteristic of R3 comes first. So, for any specific magnitude of fault current, let us say here if I consider then the first relay operates that is R3, then the next relay operates that is R2 and then next layer operates that is R1.

So, this three relays are inverse time overcurrent relays and this relay, if any fault occurs in particular section, then each relay acts as a primary relay, if that really fails due to some reason, then the other relays located near the source that will act or provide backup and each relay is adjusted progressively, in decreasing order as we move from source to load.

So, that we have done for other two relays earlier, time delay and instantaneous, same philosophy is applicable for inverse time over current relays. Let us consider the advantages and disadvantages of universal overcurrent relays, we will consider it in the next class. So, in this class we have discussed the very important phenomena that is what is transient overreach phenomena and how the instantaneous overcurrent relays are affected, time delay relays are not affected.

Then we have also discussed the what is the application of time, definite minimum time delay relays when we put in the multisection radial network. We have also discussed the advantages and disadvantages of time delay relays, the main disadvantage is severe most fault that is cleared with delayed time. So, to overcome this we have to consider the another type of relay, that is known as inverse time overcurrent relays. So, the advantages and disadvantages of these relays we will consider in the next class. Thank you.