Power Electronics and Distributed Generation
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Lecture - 19
Grounding, Distribution Protection Coordination Problems and Examples

Welcome to class 19 topics in Power Electronics and Distributed Generation, in this class we look at couple of examples, these are homework problems for the students in class. We will look at one problem on Grounding and a second problem on Distribution system equipment called Protection and Coordination.

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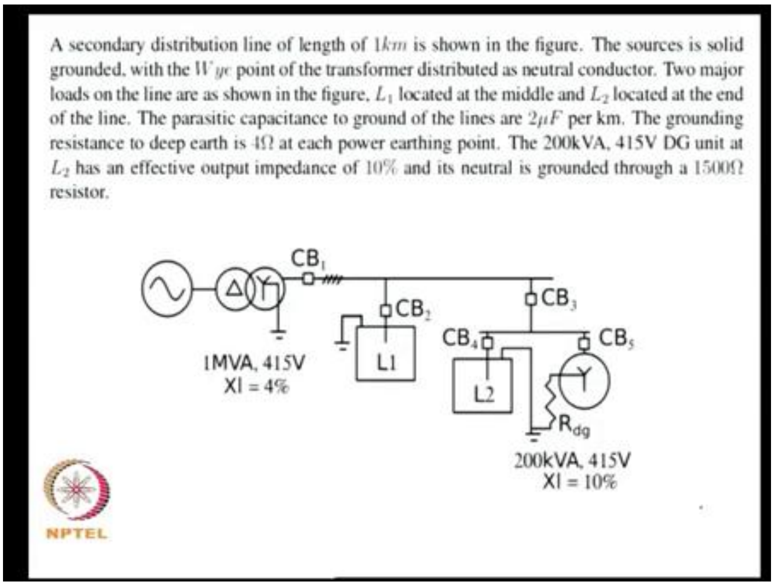

So, in the first problem we have secondary distribution system, so essentially at the consumption point essentially 415 volts distribution of length 1 kilo meter, and we have couple of major loads on this distribution, which is load 1 and load 2. And the sources delta y transformer may be the y point solidly grounded, and each grounding is with solidly grounded, but the ground resistance to deep earth this about 4 ohms, which is essentially the resistance between the earth electrode and the soil to deep earth. And we have parasitic capacitance to ground for the lines and that is 2 micro farads per kilometer. And you have a DG, now connected at load two potentially it could be for providing power or power quality reasons you have added a DG, and that is grounded through a resistor R DG.

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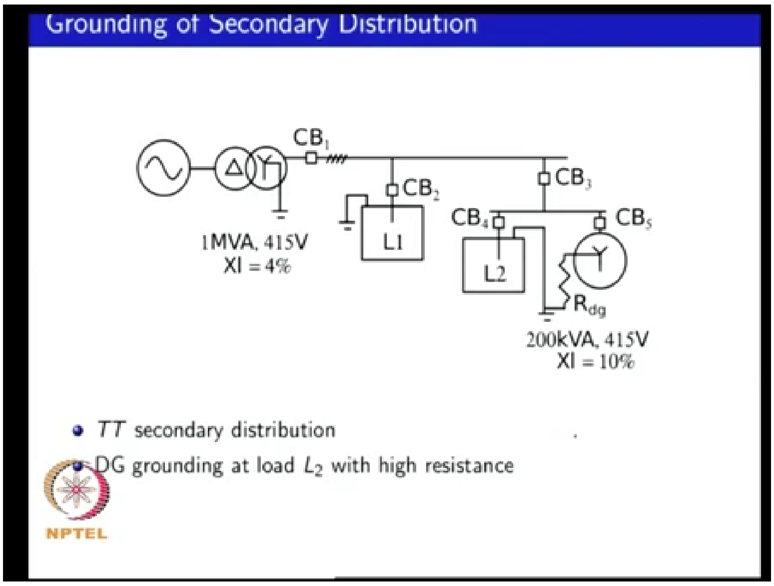

So, if you look at this particular example, this is essentially you ignore the DG for now this is essentially a T T distribution secondary distribution were sources grounded directly to terra earth and each load has it is own grounding electrode. And load 1 and load 2 is connected the earth the ground wires are connected to earth, but if you look at the D G the D G is connected at load two with a resistance. So, overall you can see that this is system which has both T T aspects to it and also high resistance grounding aspect to it. So, in a actual system, it is actually possible to have multiple grounding options present in the same system depending on what exactly your objectives are.

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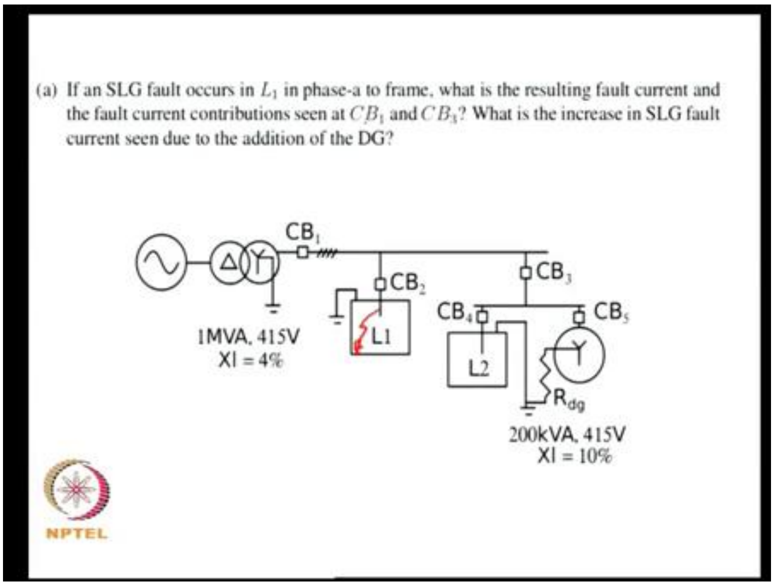

So, the first problem is to look at what happens if you have a single line to ground fault in load 1 and what is resulting fault current seen at circuit breaker 1 and circuit breaker 3 through which the D G is interconnected; and you want to see whether there is increase in fault current due to the addition of the D G.

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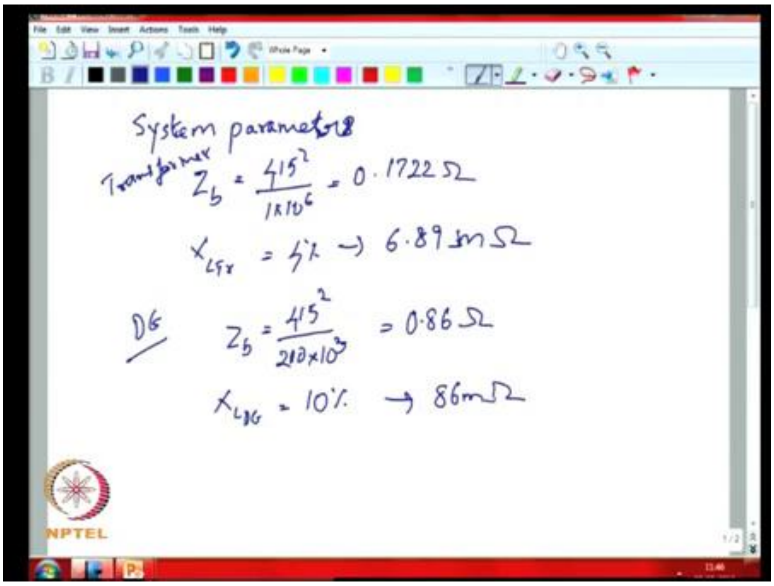

So, if you look at this problem you have the system parameters, so you have the source, which is one m a 415 Volt, so it is base impudence would be 172 Milliohms and we are told that the leakage in the terms of the transformer is 4 percent. So, this corresponds to 0.04 into 1.722 or 6.89 Milliohms. So, about 7 milliohms is the impudence from the reactance of the transformer, if you look at the D G, there is a base for a D G s it is a 200 K v D G. So, it is a base resistance is base impudence is 0.86 Ohms and you have the effective leakage of the D G being about 10 percent. So, that corresponds to 86 Milliohms.

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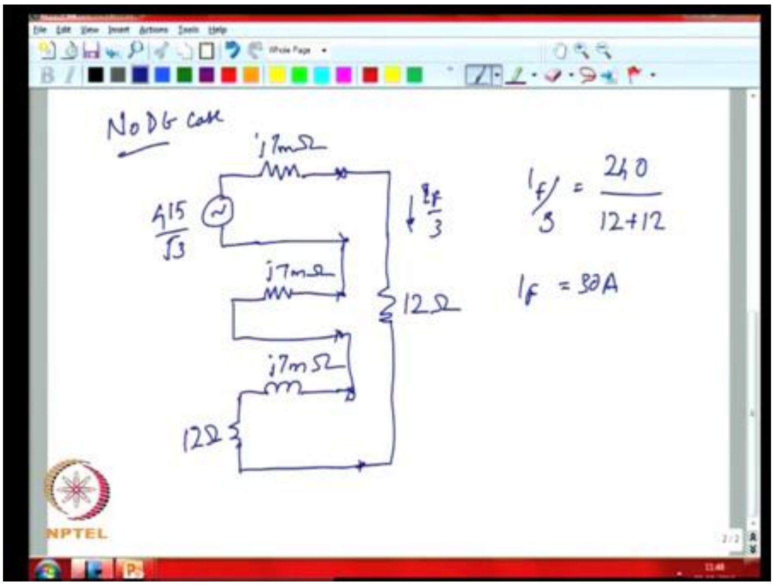

So, next we could look at the case, for the first case we will look at the situation when there is no D G connected. So, if you have a single line to ground fault, your equivalent sequence network would be and your source is grounded through and you have the earth impudence coming in between, which is 4 Ohms. So, 3 times 4 would be 12 Ohms, seeing from the source side and when you have a fault occurring within load 1((Refer Time: 07:13)); essentially the path for a current is through this electrode, through this system out into load 1, into the frame of load 1 connected through the ground grounding wires into the ground electrode that would also have a 4 Ohm resistance equaling grounding resistance. So, you could calculate the fault current, we are neglecting the 7 Milliohms, which is much lesser than the 12 Ohms, so you have fault current of about 30 Amps. So, then next case is when you have the D G also connected, so when you have a D G connected.

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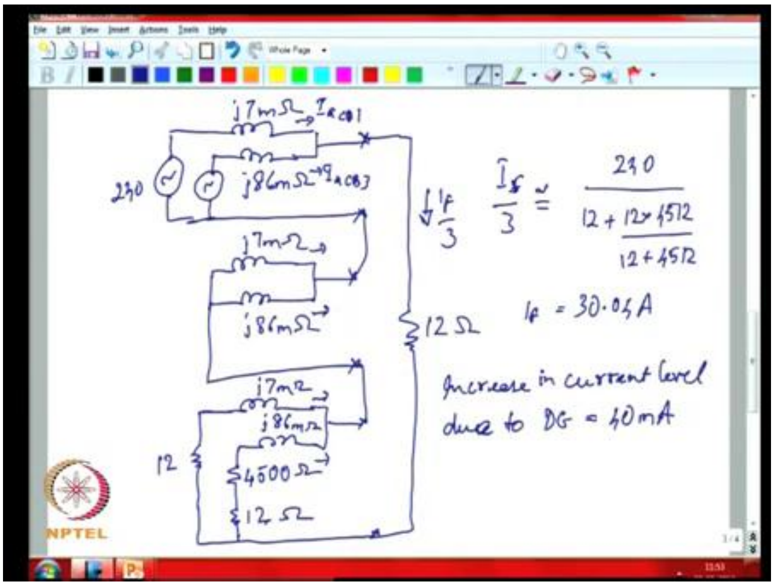

You now have your sequence network, which would have two sources, one is your original source and you have the D G. And if you look at the zero sequence network and you have the grounding resistance of the D G, which is 1500 Ohms. So, in your sequence network you would have 3 times watt which is 45000 Ohms, thus the grounding resistance of 12 Ohms, 12 Ohms at load 1 and you have 12, 3, 4 Ohms at the source which shows up as 12 Ohms equivalent.

And I have by three flowing through the circuit and again you can see that the milliohms can be neglected compared to the 12 Ohms and 45000 Ohms, so I f by 3. So, it is the parallel combination of these two resistance circuits, so you get I f equal to 30.04 Amps, which means that the because of the D G increase in fault current seen, because of the D G is about 40 Milliamps. So, you can see that there is almost no change in the current level because now you have added the D G for a single line to ground fault.

So, the question is to figure out, what is the current seen by breaker 1 and 3 and so to calculate that we will have to look at your sequence quantities. So, if you look at you are your current flowing through the circuit you have this would be I a s 1, in circuit breaker 1. And this would be your I a in circuit breaker 3. So, similarly you can find the sequence currents in the branches of this particular circuit, so you have the overall currents, so you have to find out how the current splits between this two branches.

So, you could find out the share of current for the positive sequence, negative sequence and zero sequence, so you could do that calculation.

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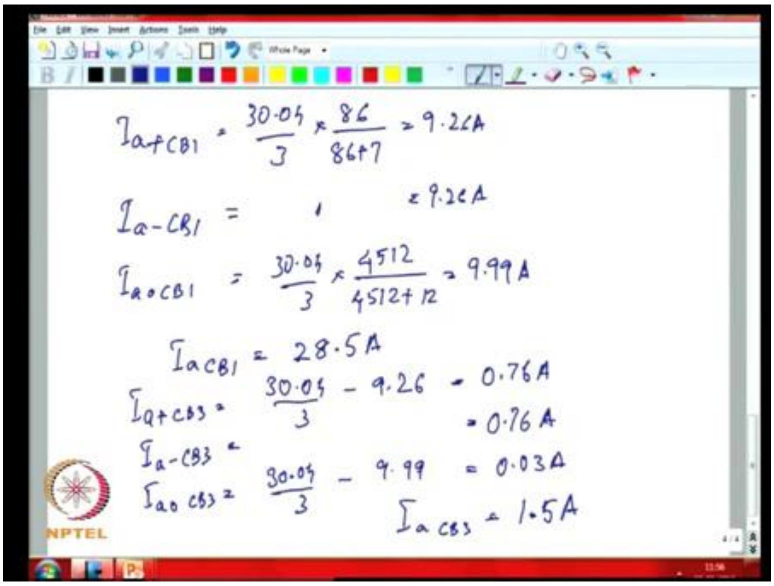

So, you get I a s 1 positive sequence through breaker 1 is; so here you have two parallel reactance of 86 Milliohms and 7 Milliohms. So, the breaker would be 9.26 Amps I a negative through C B 1 would be the same similar calculation you will get 9.26 Amps I a 0 sequence through C B 1 would be…

So, in case of the split over here again 12 ohms and 4,512 Ohms is much larger than the 7, 86, so you could take your currents split as. So, you can then calculate your I a s 1 by going from the sequence to phrase transformation. So, it is I a plus, I a minus, I a 0, so this is 28.5 amps flowing through phase a of circuit breaker 1. So, to calculate the current flowing through phase a of circuit breaker 3 you have, so if you then calculate, what your I a through C B 3 is, this is the sum of these three currents you have about 1.5 Amps flowing through the circuit. So, at this point you have calculated what would be the current flowing through C B 1 and C B 3, because of a fault in load by 1.

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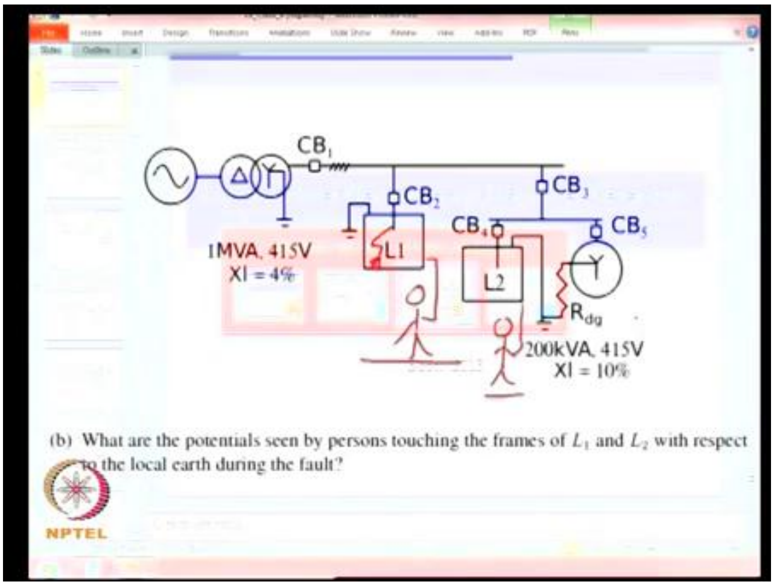

So, the next problem is to see what would be the touch potential for a person say standing at load 1 or load 2. So, if some person is touching some electrical equipment, whether that person would feel a shock then such a fault has happened.

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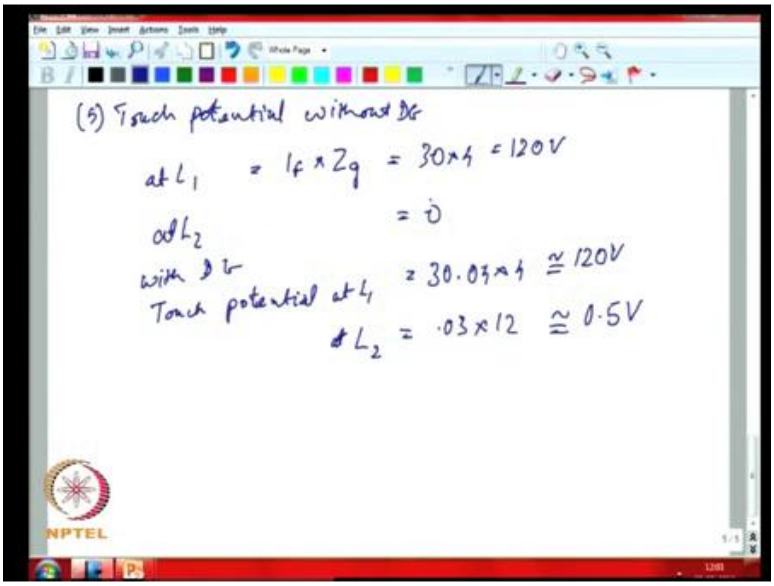

So, the first thing we will look at is touch potential without the D G, so at l 1 this would be the fault current going into the fault times your Z of your grounding, which is 30 Amps into 4, so 120 Volts is what would be seen by the person at load 1. So, so you have a fault over here and you have a person say touching the frame, then because of the resistance between your ground wire and earth electrode this frame gets elevated with respect to ground. So, the person touching it would see a shock of about 120 Volts.

If you have another person, now at second location touching this particular frame with respect to the local earth over there is no current flowing in each, so the person would not see a shock at load 2. So, next we could look at what happens when the D G is there we saw that when the D G is there raise actually small increase in current that flows through the fault; so with D G, so it is the same about 120 Volts. Now, if you look at L 2 you have about if you look at the zero sequence current it was about 30 Milliamps into 12 ohms is what is flowing through the into the ground at load 2, when you had the d g. So, you get about 0.5 Volts at the second location, so you would hardly feel it there is a slight increase in potential, but not much.

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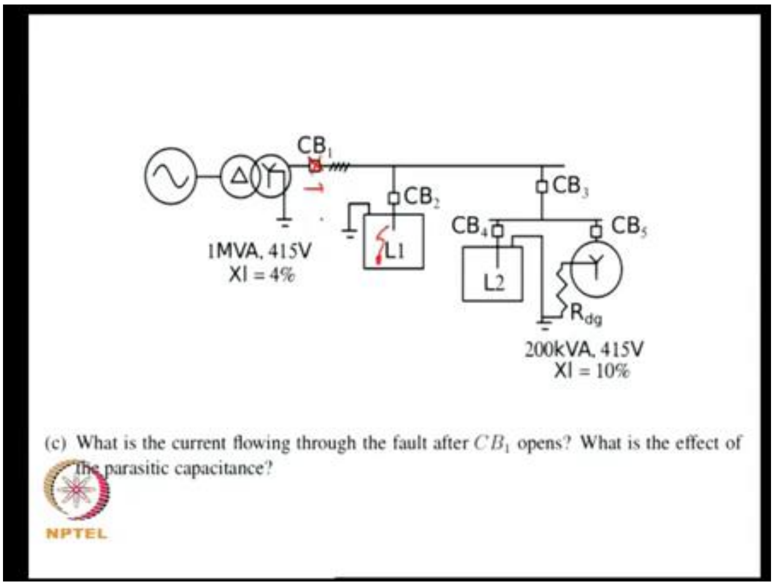

So, the next question is to consider say this situation were because of the fault in load 1, if breaker C B 1 opened then what would be the current flowing through. If you want to see whether C B 1 would open you want to look at the current flowing through switch s 1 considering the fact that you have… So, the question is what is the current flowing through the fault after C B 1 opens, so what is the change in fault current and what is a effect of considering the parasitic capacitance of the of the line when you are doing such a calculation.

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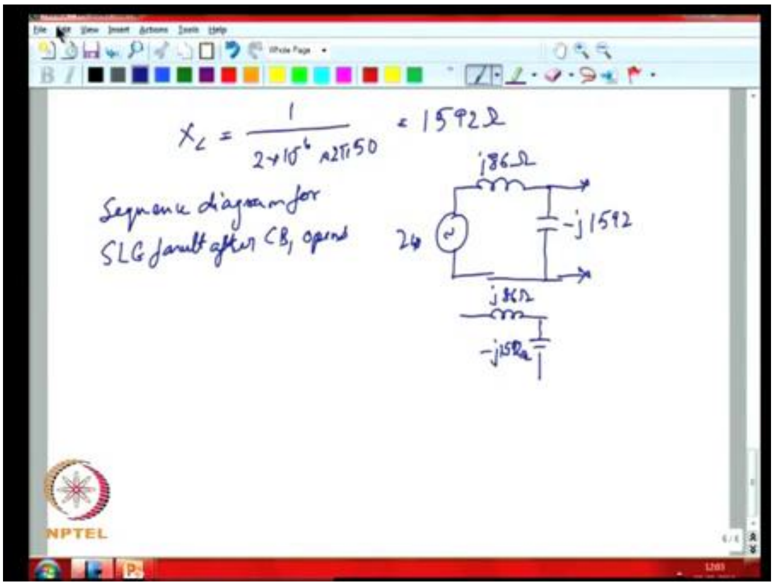

So, if you look at the parasitic capacitance it is 2 micro Farad your X c is 1 by 2 micro Farads into 2 pi 50, this is 1592 Ohms. So, if you are modeling it you could model it as a as a y connected capacitors of reactance 1592 capacitive reactance, 1592 Ohms between each line to ground. So, in a sequence diagram for the single line to ground fault after the circuit breaker opens, so you have now your positive sequence, which is your negative sequence.

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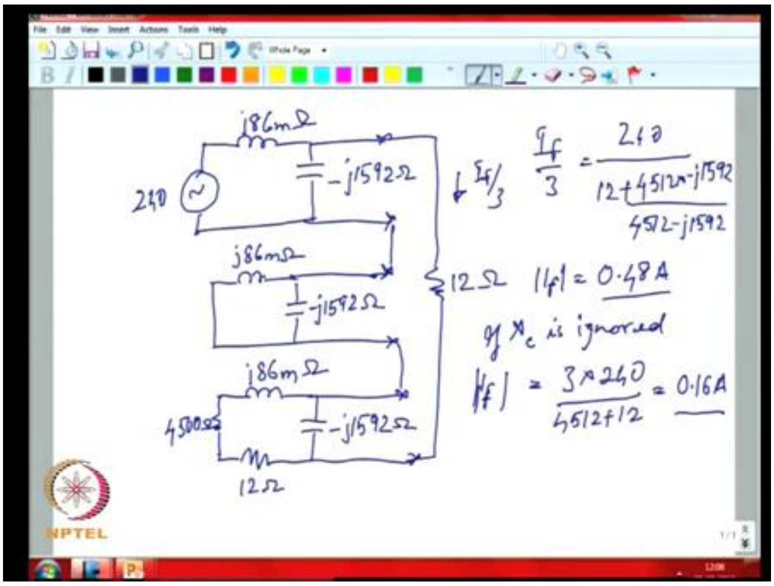

So, you can calculate your fault current level with the capacitor, capacitic capacitance and that would be 240 Volts divided by 12 plus, if you look at the effective circuit that is going to be limiting the current, here you have 86 Milliohms in parallel with 1592 Ohms. So, you just practically just 86 Milliohms, here again you have 86 parallel 1592, practically it is 86 and then if you look at 86 in series with numbers like 4500 and 1592 you have to consider just 1592 and the parallel combination of those two network. So, you would have…

So, you get a magnitude of your fault current to be about 0.48 Amps about half and amp would flow through you are the fault point. Whereas if you look at if X c is ignored your magnitude of your fault current is about 186 milliamps. So, you can see that there is substantial difference in the fault current, especially if you have ground fault measurement device on your equipment. If you looked at the parasitic capacitance, you would expect a smaller current, but because the parasitic capacitance the actual current would be typically be higher.

Especially when you have high persistence grounding, so that is when your unbalance really shows up as unbalance currents flowing through your parasitic capacitors. So, some of these levels can actually be used to set how sensitive your ground fault trip device is ground fault, current interrupting devices to what level of sensitivity you need to set them.

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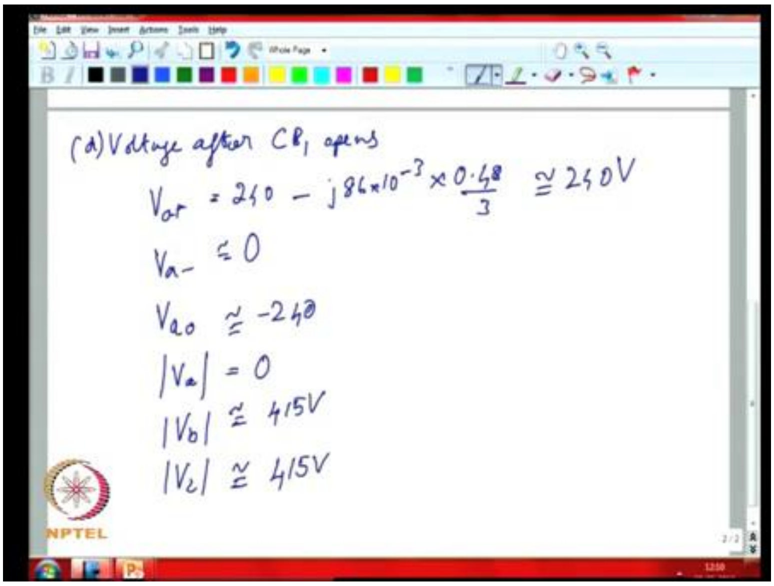

So, the next problem is to look at, so after circuit breaker opens what would be the subsequent voltage seen on a conductor to ground basis. So, if you look at the sequence network that we previously had. So, you could then look at what would be the voltage across the each of your sequence network points. So, you have 240 volts minus the drop is j 86 Milliohms into 0.48 times, which is the fault current level divided by 3. So, this would be your current flowing through that particular network, so this roughly equal to 240 Volts.

So, I a plus is roughly 240 volts if you look at V a minus this is the voltage across these 2 points because of the 0.48 Amps fault current is flowing and you can see that 0.48 Amps will cost a very small drop across the negative sequence network. So, this is roughly equal to 0 and V a 0 is roughly equal to minus 240 Volts, because the voltage drop along that load has to add up to 0.

So, if you look at your voltage, the voltage on which you are fault has occurred that drops to 0 and V b is approximately your line to line voltage and V c is also having a magnitude of your line to line voltage on a conductor to ground basis. So, the next question is what type of relay can be used to actually detect the fault currents and respond in to operate under such a condition. So, if you look at the fault current level, we saw that the fault current level is of the order of 30 amps ((Refer Time: 31:03)).

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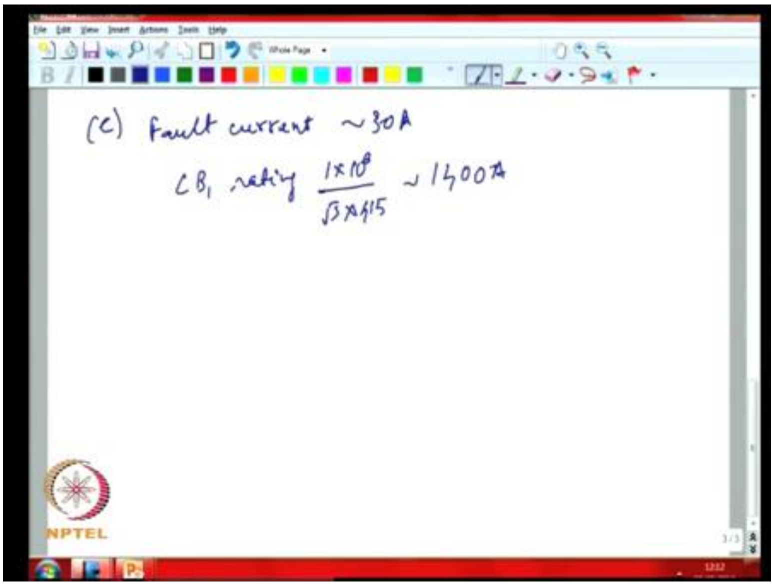

Is of the order of 30 Amps, when the fault occurred in load 1 and if you look at the rating of C B 1 is, it is 1 in a divided by root 3 into 415. So, you are talking something of the order of 1400 Amps, so it would definitely not trip under over current. So, if you want to trip in such a situation you would need device, which actually measures residual currents and trips in response to that.

So, if you look at the ideal situation it may not be that C B 1 has to open ((Refer Time: 32:07)) in response to a fault in load 1, a better situation might be that you want to open see, the particular load at which the fault occurred. So, C B 2 should open in response to a fault in load 2, again it depends on whether C B 2 has the ability to measure residual currents.

If you have C B 2 load corresponding to a power level of the order of 10 K v a, then you might have circuit breakers, which are rated for 15 Amps and 30 Amp short circuit current might cause a 15 Amp breaker to trip maybe in a free cycles is not on a instantaneous basis. But, if you have load l 1, which is now 30 Kilo watts or higher than again the current rating of the load would be higher than the fault current level.

So, you have a you have a possibility that you might have a load and because your breaker may not be equipped to measure residual current you might stay with the fault for a longer duration and cause potential over heating of conductors etcetera. So, you have to look at what your specific rating is, what your fault current is and ensure that you have protection against over heating or sustained long term of operation under faults.

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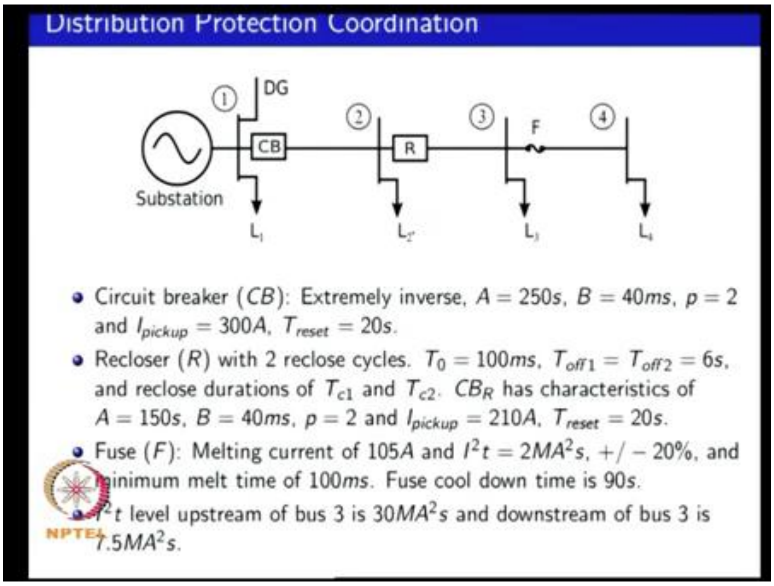

So, in the next problem you are looking at distribution system protection and coordination. So, we have system the source at say the substation end and we look at three devices, one is a circuit breaker a closer to the substation and then you have your recloser further downstream and then you have a fuse, you have four buses. And you have loads at each individual bus and your for the protective devices you are given parameters for the circuit breaker. It is extremely inverse with p equal to 2, you have given it a and b parameters, b is the definite time delay, but you might expect the pickup current level and the reset time of the circuit breaker.

The recloser will here has been considered to include two aspects, one is the recloser might have it is own intrinsic circuit breaker type of operation program into it is whether it is relay action and also it has on and off durations. As soon as if fault occurs it stays on 400 milli seconds, then it sets off then it recloses for a duration of T c 1, then it shuts off again for 6 seconds, then it recloses again for a duration of T c 2 and looks at whether the fault has cleared by that particular duration of time. So, this is a two reclose cycle recloser, it also has a underline circuit breaker C B R with a b and p values as given with the pickup current and reset time.

For the fuse you are given melting current level of 105 Amps your I square t with some tolerance range around the nominal and minimum melt time of 100 milli seconds. So, that could be considered as its definite time delay here also given that it takes 90 seconds for the fuse to cool down after it gets heated up. You are told that upstream of bus 3, so the conductors and the region between bus 1 and 2 and 3 has a I square t level of 30 mega Ampere square second and the bus downstream of between 3 and 4 has a I square t of 7.5 mega Amperes square second. So, that could be used to determine the settings of the components to see whether you are adequately protective.

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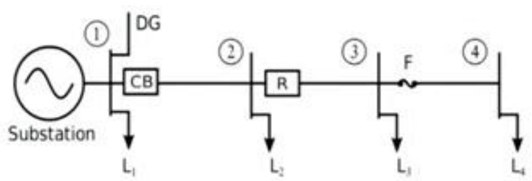

Bus	I_{fmax} (A)	I_{fmin} (A)	I_{Load} (A)
1	9200	3500	50
2	3500	2000	60
3	2100	1400	70
4	1500	900	70

You are also given the load current level, so the load at bus 1 is 50 Amps at bus 2, 60 Amps and 3 and 4 it is 70 Amps each. And based on the parameters of the circuit someone has done say fault study and found out what the typical maximum level of fault current is minimum might correspond to some particular fault configuration could be single line to a ground fault with some ground impudence etcetera. So, you are given a fault current range to that could be expected at each of this buses.

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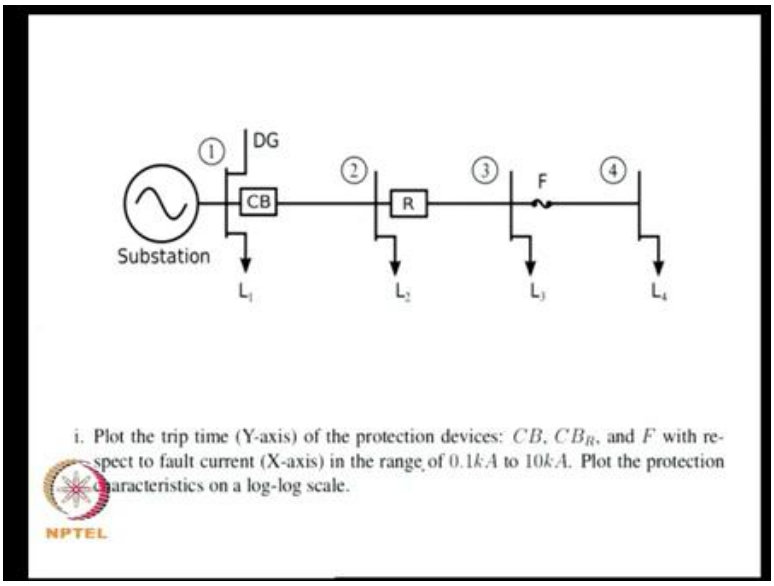

So, the problem is first to plot the trip time of the protection device versus current of the circuit breaker, the circuit breaker and this recloser and for the fuse in a range from 100 Amps to 10 Kilo Amps, so to do that we have to look at the parameters of the of the protective devices.

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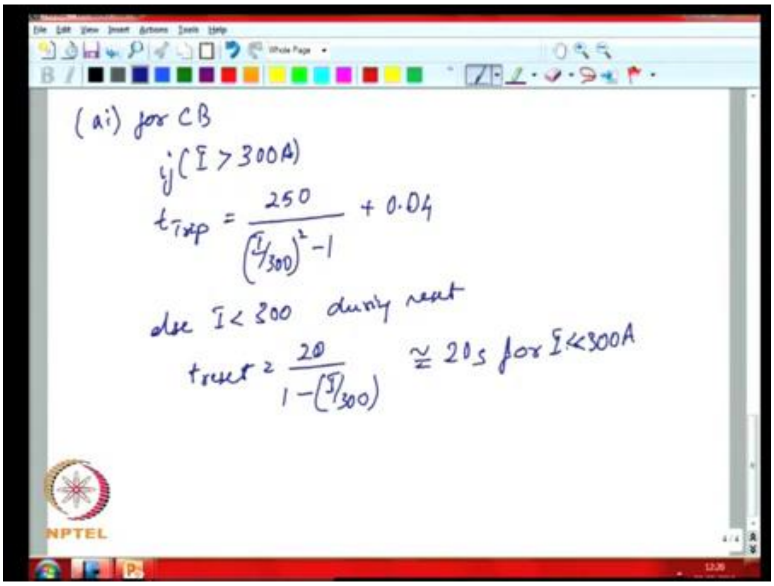

So, for the C B if the current is greater than the pickup current level of the circuit breaker, which is 300 Amps you have your trip time else, when it is just lesser than 300 Amps during reset your t reset is 20 by. And what we will take is if your nominal current is much lesser than 300 Amps this is we can take it as this 20 seconds the pickup current. If you look at the particular breaker if you look at the total load that comes in from load 2, load 3, load 4 ((Refer Time: 39:31)) at this particular breaker that adds up to about 200 Amps. So, if you look at that particular point your reset time is of the order of 36 seconds, but we will assume that the reset time is constant value of about 20 seconds.

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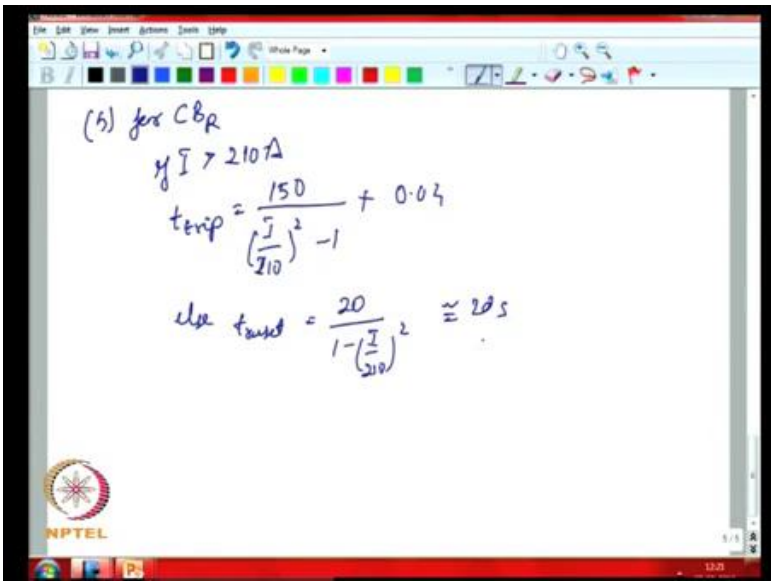

So, next for the C B R, so and finally, for the fuse.

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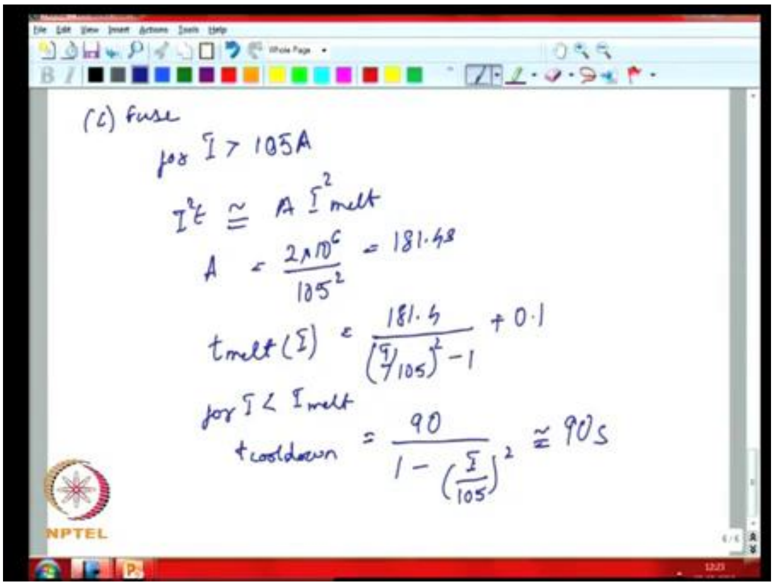

So, for the nominal fuse we have for current greater than the melt current your I square t is A I melt square. So, you could evaluate what your equivalent A is and this is for the nominal fuse 2 into 10 power 6 divided by. So, you could think of it as a equivalent a b p parameters. So, your t melt as a function of current is plus a definite time of 100 Milli seconds your cool down time and you could plot this.

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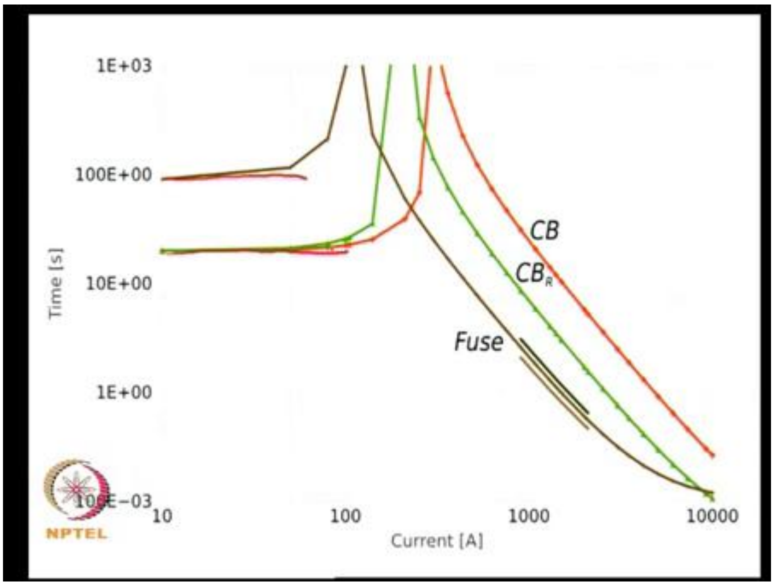

So, what is shown over here is the characteristics of the circuit breaker at closer to the substation, then the recloser and for the fuse and you can see that the nature of the characteristics. So, you have a almost a flat line over here, but then closer to the definite time characteristics with that the with curve starts flattening out, if you look at the fuse you have the nominal curve for the fuse. And then plus 20 percent I square t or minus 20 percent I square t, so it shows up as the band around the nominal curve in the range of interest. If you look at the reset curve you can see that the reset time also increases as you get closer to the melt time, but for I mean practical calculations you can take it to be roughly constant number.

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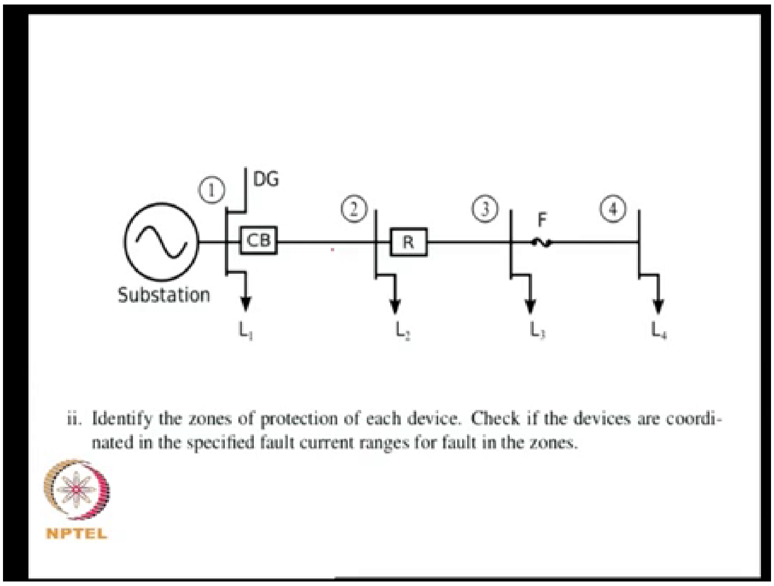

So, the next question is to identify the zones of protection of each device and check the devices are coordinated in the specified current range for the fault in the zones that are being considered. So, you can see that the zones that would be considered would be from one protective device up to the next device.

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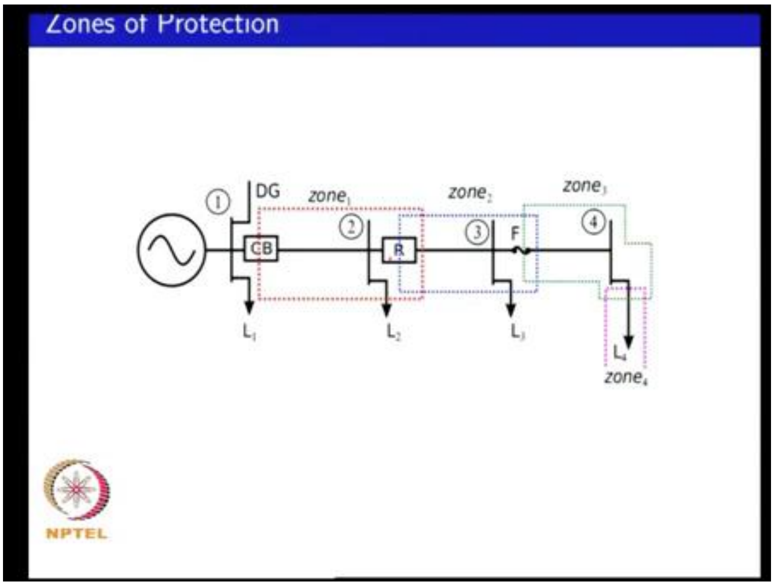

Where the next device would be expected to protect in the zone immediately downstream of that. So, for example, the circuit breaker one would protect up to the recloser plus maybe including a fault at the recloser curve, then there r would be able to protect up to the fuse including a fault at the fuse itself, then we would have the fuse protecting up to spore. And for the downstream of the spore would be the, whatever load is connected the load itself would have its own protective devices it is not mentioned in the problem what it is, but it would have its zone corresponding zone. So, you could identify zone 1, 2, 3, 4 for a system such as this.

So, the next question is to check if the protection systems are coordinated, so what you have to do is you look at your trip curves corresponding to the maximum or the fault current in the ranges. So, for example, for C B 1 it was you looking at 3500 Amps to 90.2 Kilo Amps. So, you might be talking about some current in some range such as this, so you are looking at each range would the curve in the zone upstream zone be lying above the curve corresponding to the downstream zone. So, actually plotting this protective characteristics in a time versus current curve gives you a good feel for, whether it is coordinated what the margins are etcetera. So, if you, gives you a overall picture of what the situation is.

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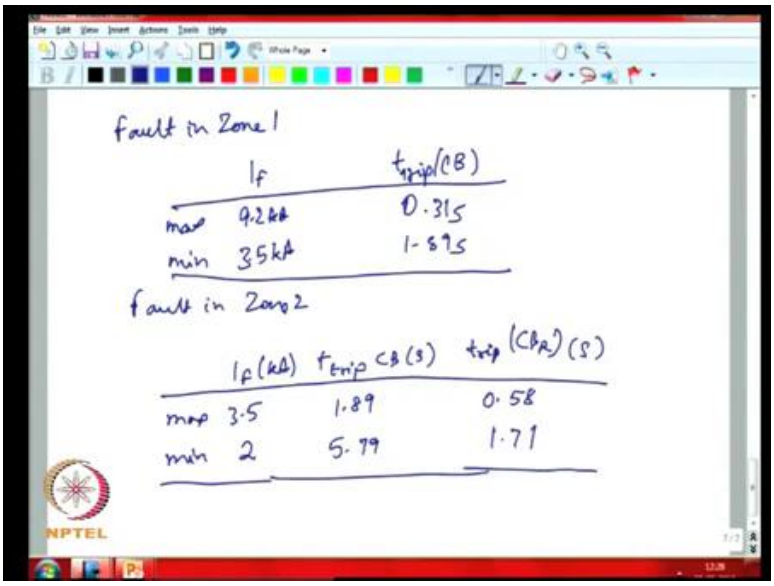

So, in this particular case for a fault in zone 1, if you look at your fault current level and your trip time of C B. So, for a fault in zone 1; obviously, the only device to protect over there is C B for a fault in zone 2, you can see that in the specified range C B R is much faster than C B, so you have the adequate coordination, similarly you could then go for the down.

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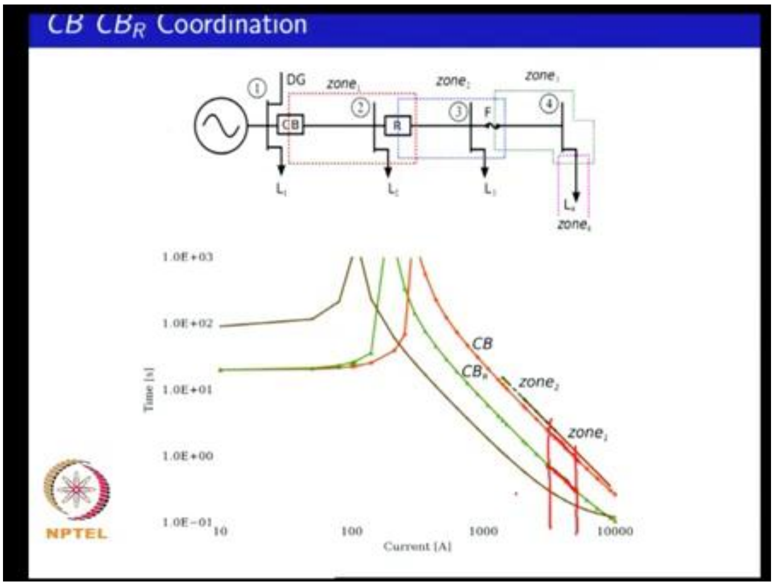

So, if you look at in the range that was being considered like you can see that whatever is the range you have sufficient clearance, between these curves that is essentially what you are looking for, similarly you could look for other fault ranges.

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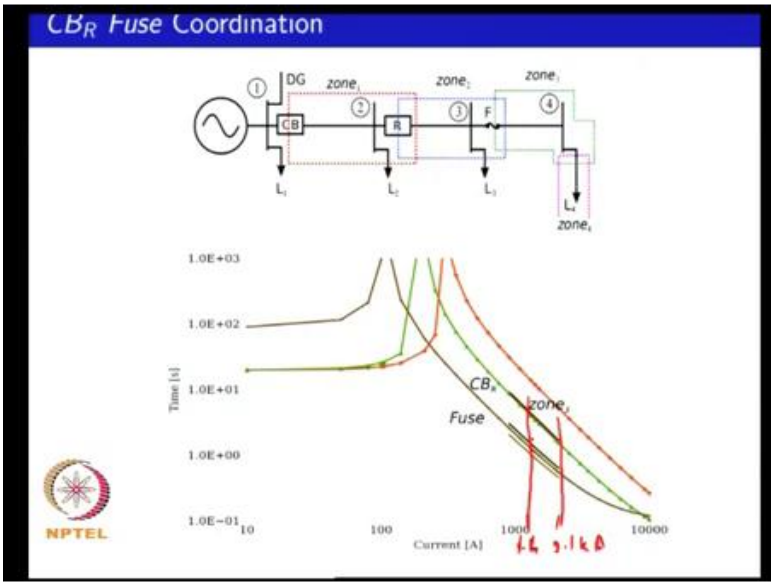

So, if you are looking at fault in zone 3, you are looking at about 1.4 to 2.1, so again in this range you are looking at now the clearance between your fuse and your C B R and again you can see that even with the tolerance you have adequate clearance between the fuse and C B R. So, you have adequate coordination between your C B, C B R and the fuse. So, overall they are presumably well coordinated.

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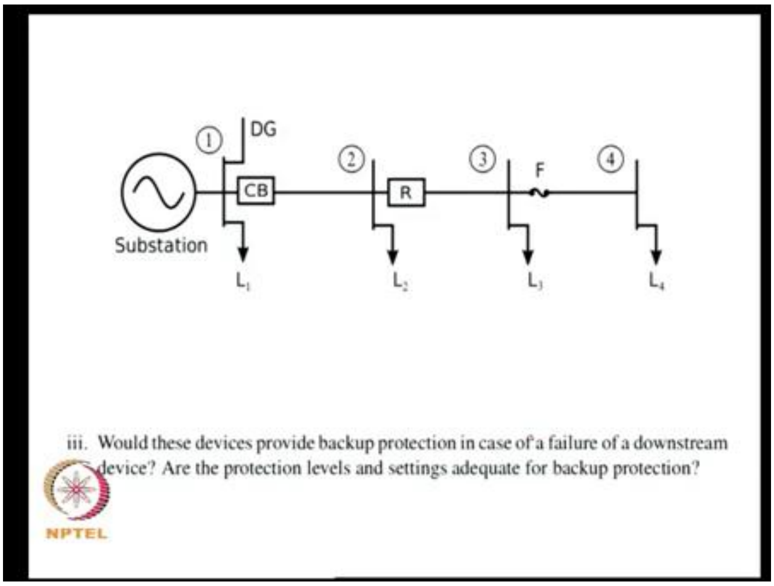

So, the next question is would the would these devices give adequate backup protection. So, what you could consider is if for some reason R fails would C B provide backup protection in the sense that would zone 1, itself be protected when R fails and would zone 2 also get some degree of protection or would is there a possibility that faults over here can propagate over to zone 1. Similarly, if for some reason fuse fails to melt and then would R provide backup protection to zone 3.

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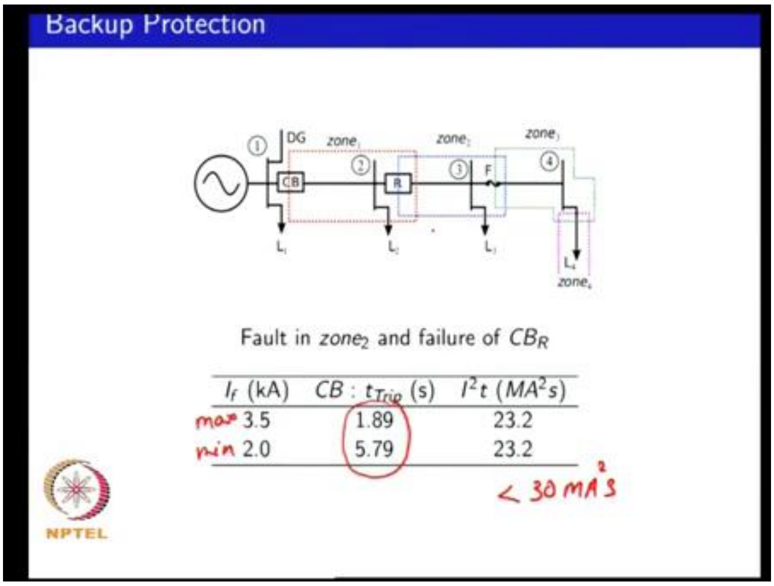

. So, if you look at fault in zone 2 and failure of C B R then the device that is providing backup protection is C B. So, you could look at the maximum fault current level in for fault in zone 2 is 3.5 and the minimum is 2. And you could look at what would be the trip time of circuit breaker for that particular level of fault, then look at what the I square t level would be and you can see that, this is now less than the 30 m mega ampere square second for the conductors of zone 1 and zone 2. So, you can see that the fault in this region and the failure of one particular device to upgrade is being backed up by a upstream device and not just that the fault will not propagate to zone 1, zone 2 itself is entirely protected by the c b also, so in this particular case.

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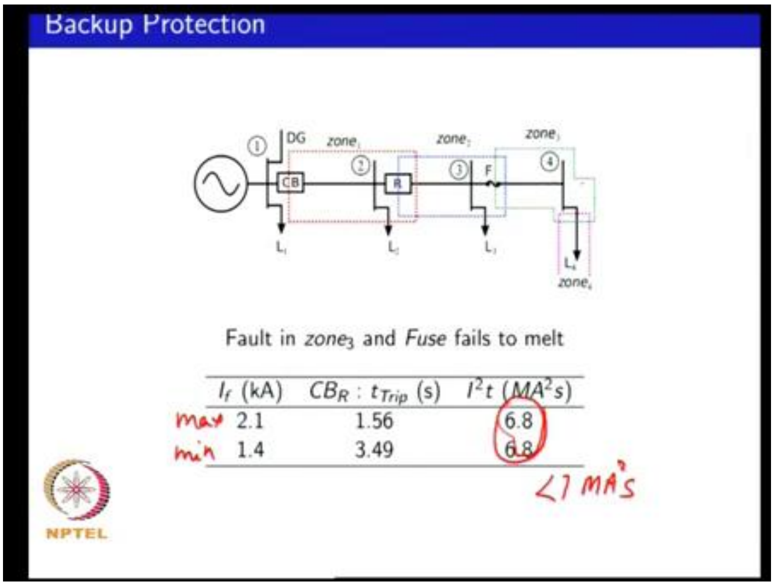

So, similarly if you look at the situation where you have a fault in this particular region and say the fuse f fails to melt, then you can see the what the device that would now give you the backup protection is R. So, you could look at the maximum and the minimum fault current for a fault in this particular zone, look at the trip times of this particular device protective device and look at your I square t level corresponding as I square t level and this is now less than 7 mega Amperes square second. So, it does provide backup protection for a fault in zone 3 Volts or you could also look at a situation where.

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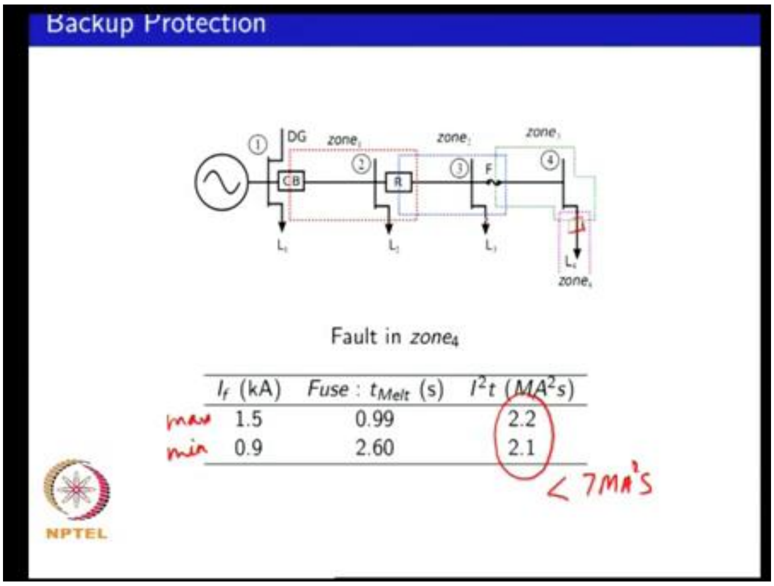

Say suppose you have a fault in zone 4 even though you do not know what is the protective device being used in zone 4, if that device fails to protect would you have backup because of the fuse f 1. So, you can look at the maximum and the minimum fault current range and look at what is the, I square t level and you could again change see that in this particular case the resulting I square t is less than the 7 mega Ampere square second for required for this particular zone. So, again you are having complete backup protection in this particular case.

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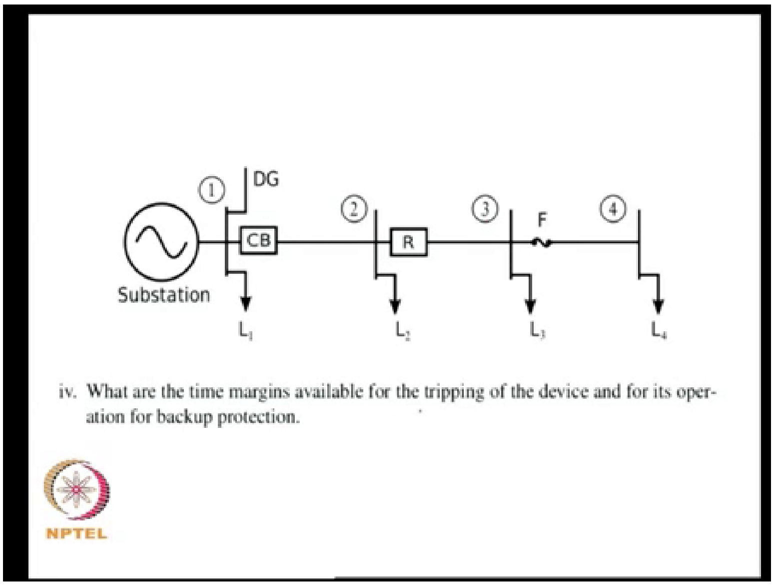

The next question is what is the margin available for between the tripping times for between the actual operation of the device and the upstream device. So, if you look at for a fault in zone 2, so a fault in this particular region.

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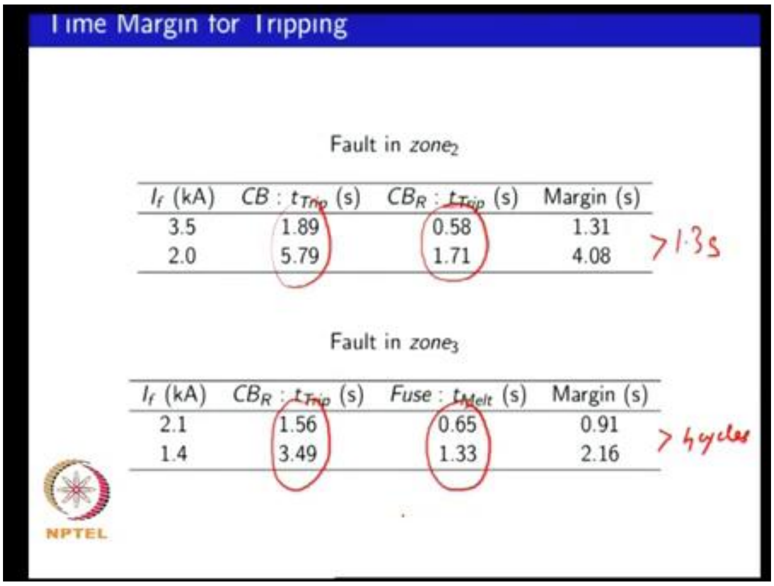

If you look at the tripping times of the circuit breaker it is about 1.89, 5.79 seconds of the C B R is 0.58. So, in terms of time you are having margin of greater than 1.3 seconds. Similarly, for a fault in zone 3 your trip time of C B R is of the order of 1.56 and 3.49 seconds, whereas the melt time of the fuse is about 0.65 to 1.33 seconds. So, you have a margin of greater than say four cycles, so it is more than typical instantaneous trip settings of a circuit breaker. So, you have lesser possibility of some race condition causing a upstream device from operating, when a downstream device should have updated.

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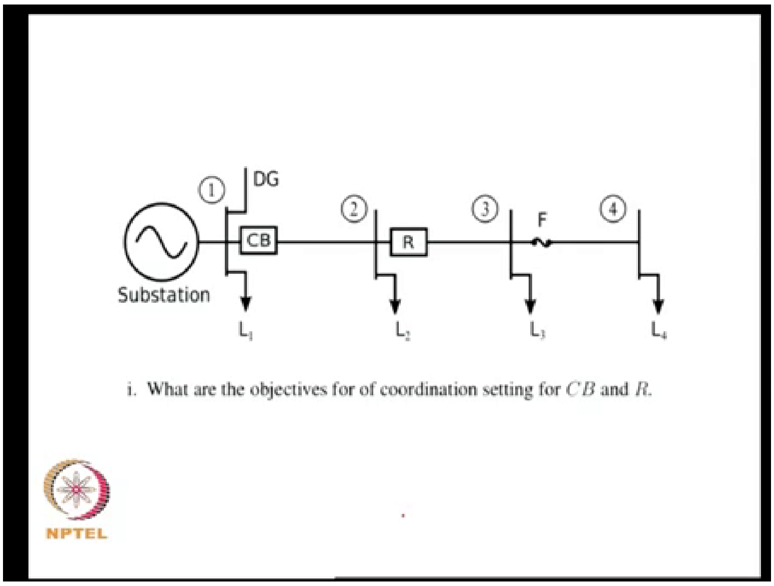

So, in the next class we will look at the question of what are the objectives of the coordination between the recloser and the circuit breaker; similarly between the recloser and the fuse. And look at the settings calculations and what could be done for coordination and what would happen when D G unit is added to such a system.

Thank you.