Power Electronics and Distributed Generation
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Lecture - 20
Ring and Network Distribution

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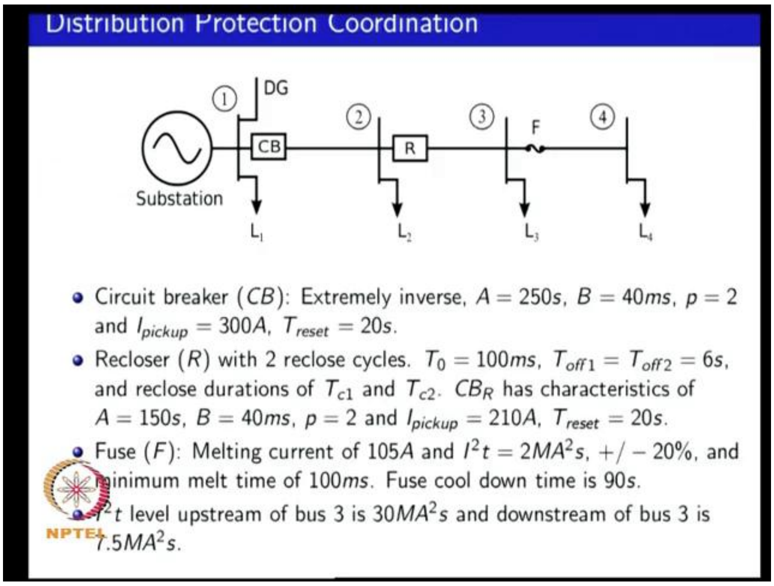

Welcome to class 20 on topics in power electronics and distributed generation. In the last class we were discussing example problems on fault protection with circuit breakers and fuse. And we looked at distribution system with 3 components circuit breakers, recloser with a embedded circuit breaker and the fuse.

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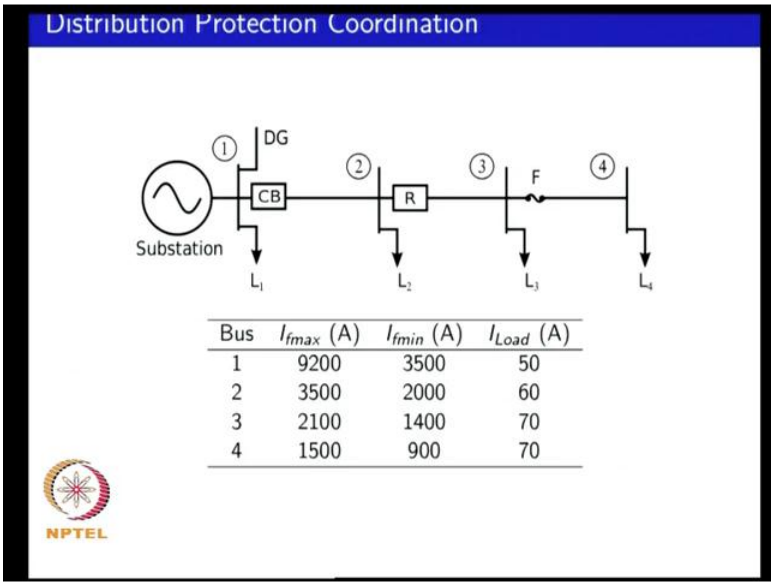

And we plotted trip time versus current characteristics of such a device we had the nominal fault current ranges the load current ranges. So, we looked at the properties of the individual devices. And then we looked at the time over current coordination between a upstream device, and the downstream device. We also checked whether we have backup protection in case one protective device fails. We also looked at the time margins and the settings of the protection, whether there is a adequate margins available in the settings.

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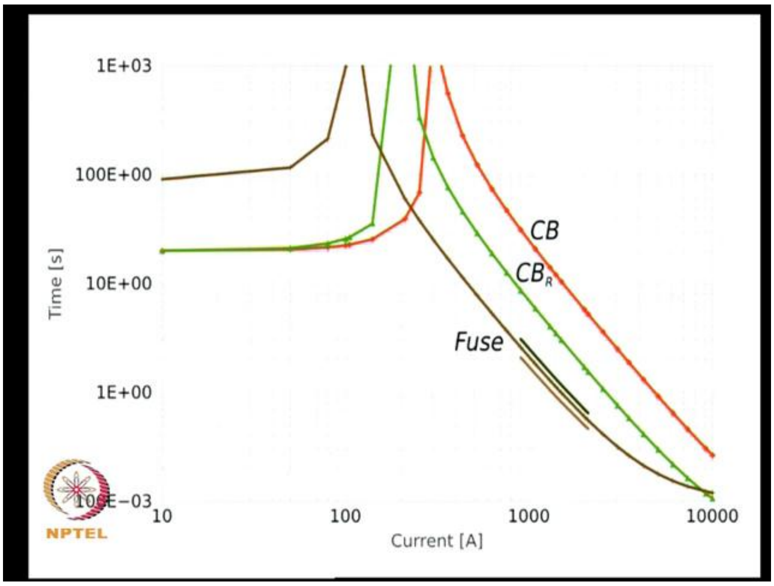

So, today we will specifically look at so we looked at plotted the curves were the trip time versus the current curves.

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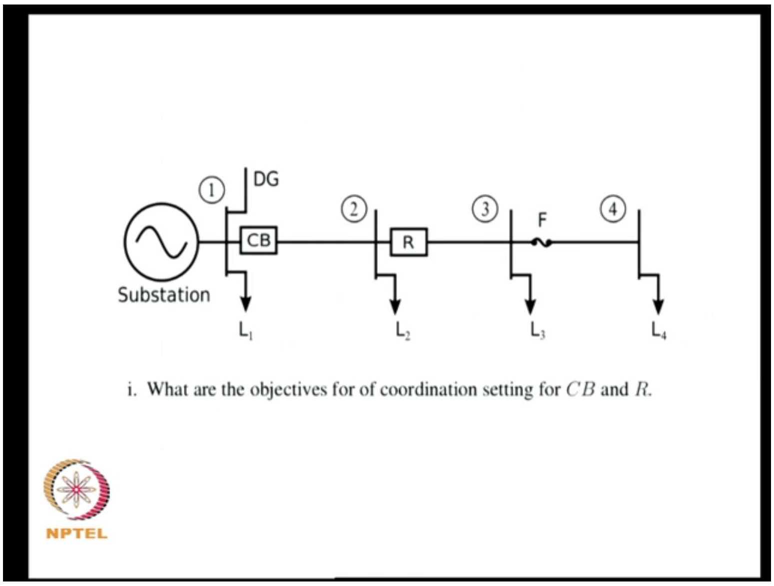

Today we will specifically look at the coordination of the circuit breaker with the recloser and the recloser with the fuse. So, the first thing we are looking at what are the objectives of coordination of the circuit breaker with a downstream recloser.

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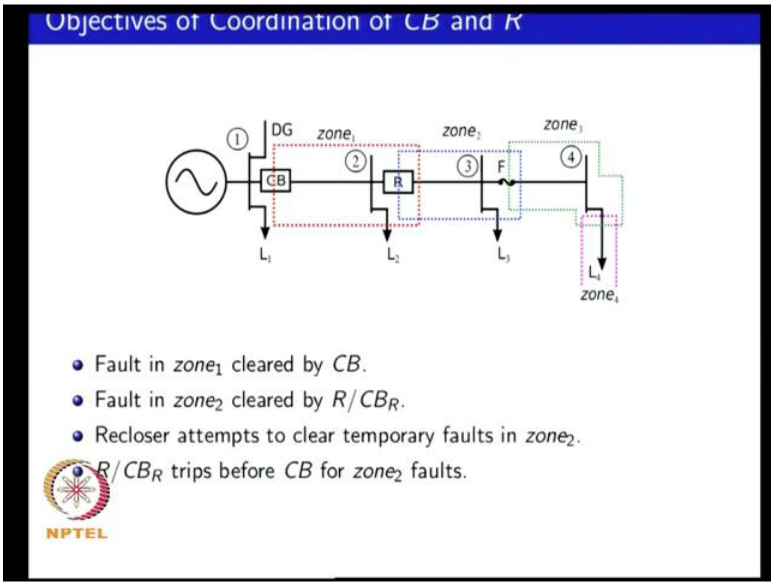

So, the objectives of, the coordination of a upstream circuit breaker and a downstream recloser is will cause zone 1 to be the zone of protection for a circuit breaker. And zone 2 for corresponding to the recloser. So, if you have a fault in zone 1, it is a circuit breaker that has to protect. If you have a fault in zone 2; the recloser with it is underlining circuit breaker characteristics should provide the protection. If you are having temporary faults in zone 2 then, the reclose attempts should clear temporary faults. If there is a permanent fault in zone 2 then, 1 has to ensure that the recloser locks out before your circuit breaker upstream breaker trips. So, that is the overall objective you would have for this particular coordination problem.

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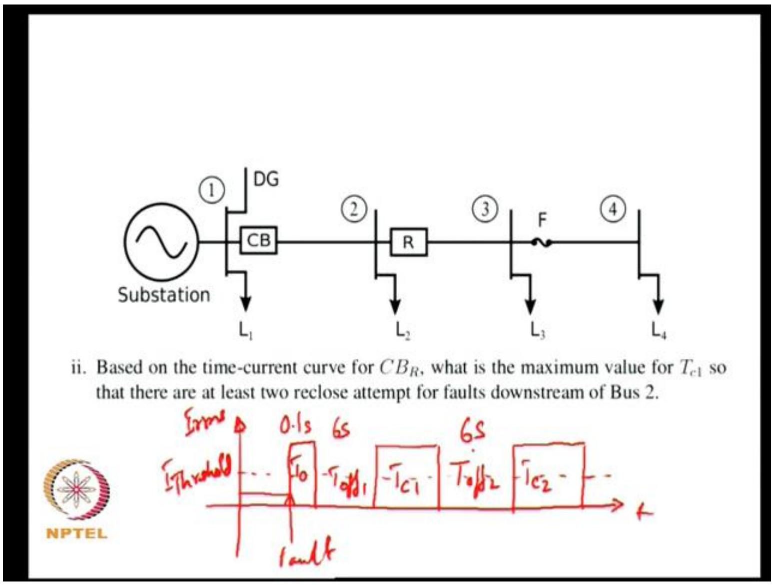

So, we are looking at then based on the time current curve for your circuit breaker under underlying circuit breaker the recloser. And for the upstream breaker, find out the timings required for the recloser. And again when we look at timings what we are looking at is essentially; if you have the recloser caring some nominal current, and at some point of time a fault occurs. And the current goes up and what is plotted is your I r m s versus time. And you have some duration we will call it as T 0, and for which the high current would flow.

Then, you have the first open duration T off 1 that is what we have called in this problem, when we have a duration T; were the recloser recloses which is T c 1. And then, you have a duration were it opens again T off 2 and then, it recloses that is a reclose attempt for a second time T c 2. And if the fault is still persisting then, it locks open. And this occurs when the current level is higher than some I threshold and it is provided to you that the duration of T 0 is about 100 mille seconds 0.1 seconds. T off 1 is 6 seconds, and T off 2 is 6 seconds, and you are required to find out what settings you could use for T c 1 and T c 2.

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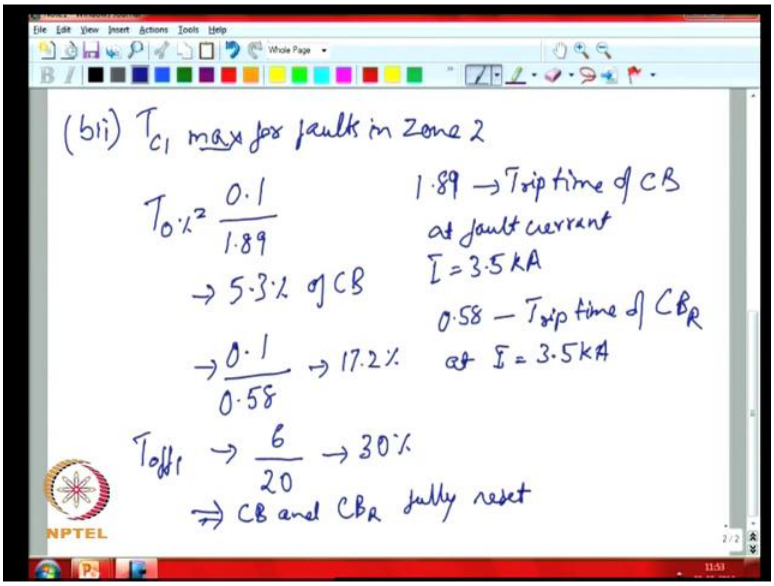

So, for T c 1 and T c 2 we have we are asked to find what is T c 1 max? So, we have T 0 is 0.1, and if you look at it as a percentage of time required for your upstream breaker. So, 1.89 if you was the trip time of C B at a fault current level maximum fault current level which was I is equal to 3.5 kilo amperes for a fault in zone 2. So, this is essentially this is the 1.89, and T 0 is corresponds to 0.01. So, if you are looking at essentially as a percentage this corresponds to 5.3 percent of the tripping of the circuit breaker, C B is tripping. And if you look at this duration how much it would correspond for the tripping of C B R.

So, this would be 0.1 divided by 0.58, and if you remember the 0.58 in the last class discussion was the time of C B R at I is equal to 3.5 kilo amperes. And so this corresponds to about 17.2 percent of the way into tripping. If you look at T off 1 duration that corresponds to 6 seconds, and we know the reset times for breaker C B and C B R is 20 seconds. So, it would reset by 30 percent in the 6 second duration so if you look at both C B and C B R it is fully reset by the end of your off duration.

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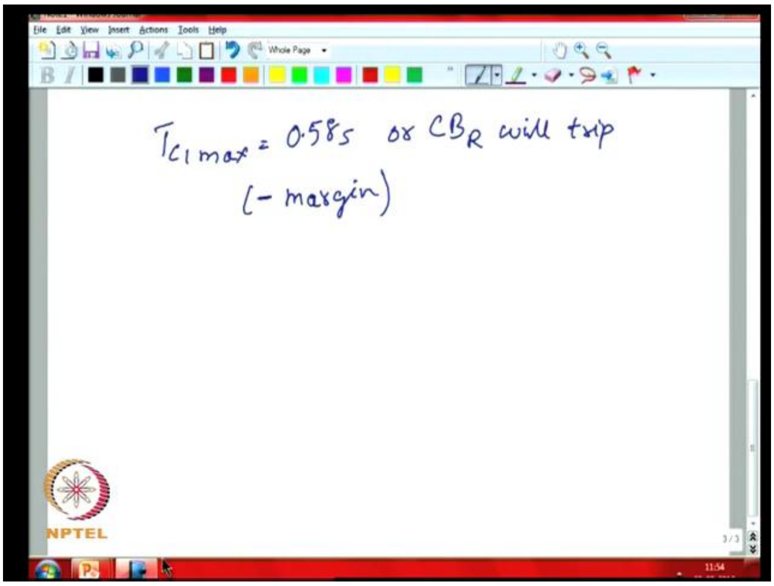

So, if you look at then, the next duration available T C 1 max, if you allow for another duration of 0.58 duration. Then, this C B R itself would actually trip so there is no point pushing your reclose duration to be larger than 0.58 seconds. So, or C B R so you need something less than this, add something less than this over margin. If you take something longer it would the underlying C B R characteristics would cause the device to trip. So, need it to really something that is smaller than 0.58.

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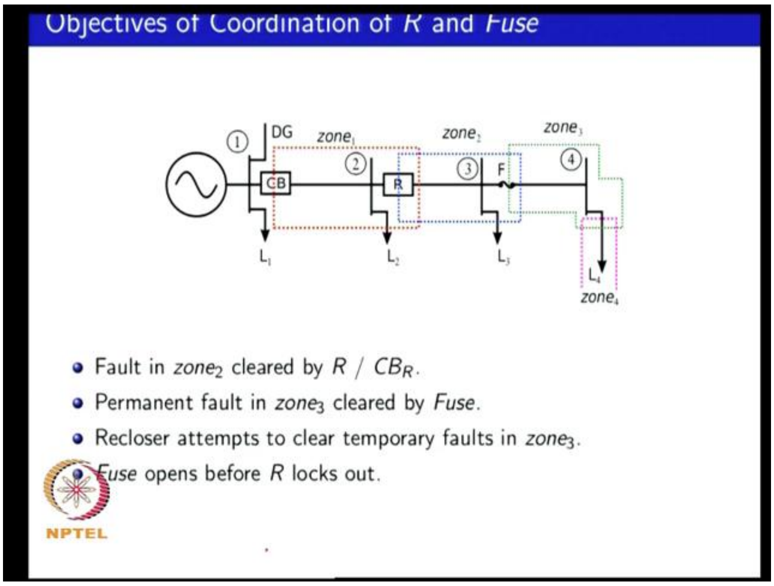

So, the next problem is to look at the objectives of coordination of the operation of the recloser, and the fuse. So, if you look at the objectives of coordination between the recloser and a downstream fuse. So, if you have a fault in zone 2 then, that has to be cleared by the recloser, or it is underlying circuit breaker if you have a fault in zone 3, if it is a permanent fault in zone 3 that has to be cleared by the fuse. Whereas if you have a temporary fault in zone 3 then, the recloser tends to clear the temporary faults, but before the recloser locks out open or locks out. Essentially the fuse has to blow so this is this would be the requirement for coordination between the recloser, and their downstream fuse. So, if you look at then, what the duration of T c? The T c durations are for this particular condition.

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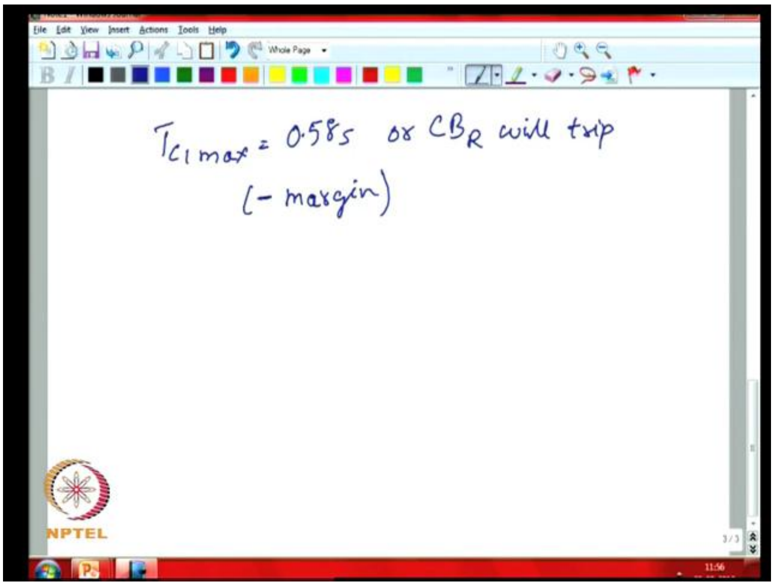

So, if you make the time duration to be too small then, there is chance that the fuse will not blow, and the recloser would lock open. So, you want durations to be larger in this particular case. So, as to ensure that the fuse blows for a permanent fault before the recloser locks out so you look at the case for couple of conditions.

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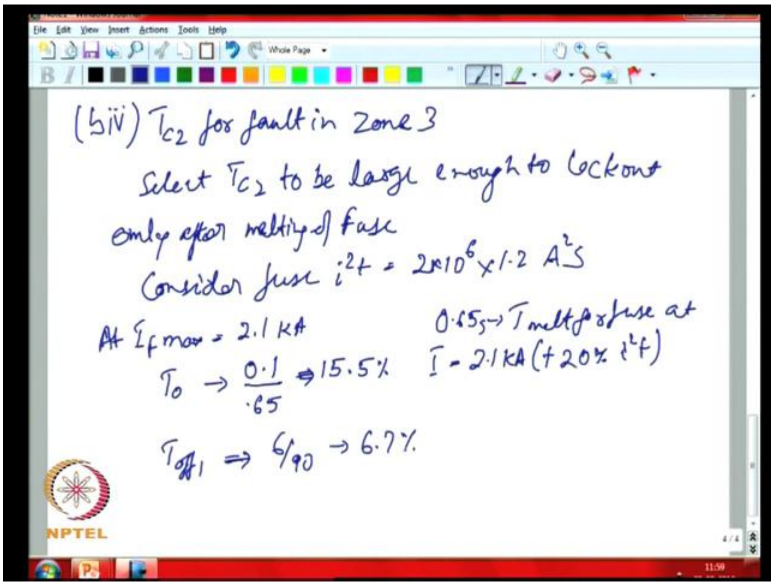

So, you are looking at what should be the settings for T C 2 for fault in zone 3, and you need to select T c 2, only after melting of the fuse to be earlier so that the lock out does not happen. So, if you look at this particular condition you need to look at, also know that your fuses have a tolerance of plus or minus 20 percent. So, you consider say the larger plus 20 percent, because you are looking at the worst case duration. So, you can look at the situation at the maximum current, and the minimum current for the fault in the zone. Your T 0 would correspond to 0.1 divided by 0.65 is this would be 15 correspond to 15 percent, were 0.65 is the T melt seconds is the T melt for fuse at current i is equal to 2.1 kilo amps which is the maximum current level for fault in zone 3. And for the fuse with a plus 20 percent i square T. Then, if you look at T of 1 that corresponds to 6 by 90 so this is 6.7 percent.

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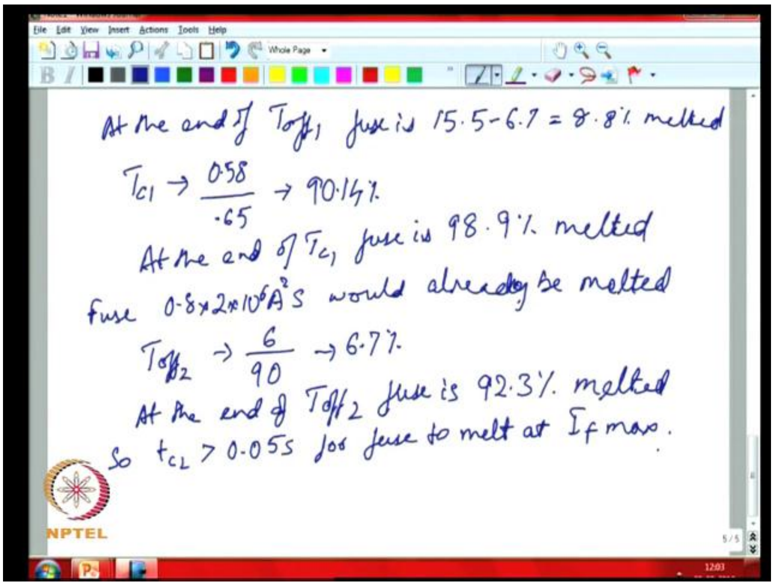

So, at the end of T of 1 fuse is so we could consider to be the fuse to be 8 percent melted. And then, we have your T c 1 that corresponds to 0.58 which we determine from the previous problem. And if you then look at 0.58 as a percentage of a fuse blowing time this would be 90 percent. So, at the end of T c 1 now, if you look at what would be the situation here, we have considered a fuse with i square T of plus 20 percent above the nominal, if you took the fuse which is plus minus 20 percent below the nominal i square T. So, if you look at a fuse, which was 80 percent of the i square, T rating would already be melted. So, if you look at a desirable setting of that 0.58 it might be desirable to actually reduce it to actually prevent the melting of the fuse in the first recloser cycle itself, because of the settings of the recloser.

But we will continue with this particular problem; if you look at T of at this particular maximum current of zone 3, if you look at T off 2 which is 6 seconds, and 90 seconds is the cool down time of the fuse. So, that corresponds to 6.7 percent so at the end of T off 2 fuses about 92 percent melted. So, if you look at the remaining 7 to 8 percent melting you need a T C 2 which is greater than 0.05 seconds at I max, I off max of zone 2.

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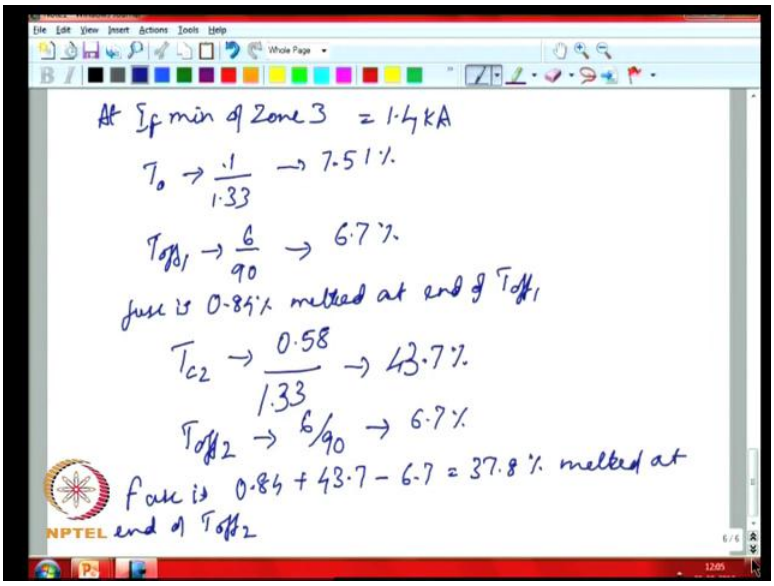

Now, we will look at what happens at the I f main current level of zone 3. So, you have now T 0 corresponding to 0.1 by 1.33 so 1.33 is the melt time corresponding to the fuse with plus 20 percent I square T. So, that would now correspond to 7.51 percent T off 1 corresponds to 6 by 90 this is 6.7 percent. So, fuse is 0.84 percent melted. So, then you could calculate T C 2 if it is 0.58, and 1.33 is the melt time at this particular 1.4 kilo amps current level that would be 43.7 percent. And T off 2 is then; one can calculate the condition of the fuse so fuse is. So, if you look at the time that is required to melt it for the remaining percentage for this number to reach 100. So, you can calculate what your T c 2 has to be? It has to be larger than that.

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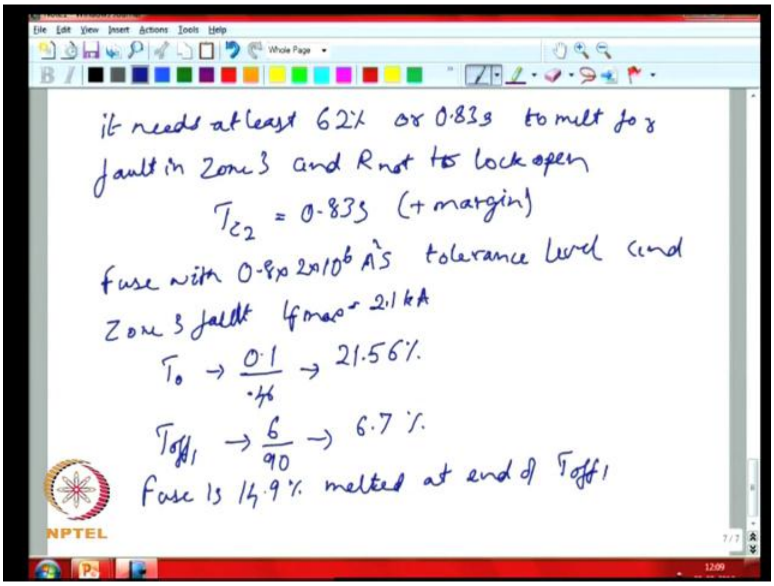

So, what you would see is T c 2 has to be larger than 0.83 seconds with some margin. So, that the fault current in zone 3 does not cause the fuse to still conduct when a permanent fault is still in that particular zone. So, we saw in the previous case that at the point the 0.58 seconds settings particular fuse is already melted. So, we can also look at the situation were; T C 1 is modified to ensure that the fuse even at the lower end of the tolerance range does not melt by reducing the T C 1 duration. So, even can calculate what could be T C 1 duration. So, if you look at the fuse with the 0.8 level and zone 3 faults with I f max equal to 2.1 kilo amp. You have T 0 corresponding to 0.1 by 0.46 that corresponds to 21.56 percent. T off 1 corresponding to 6 out of the 90 seconds of the fuse cools down time; that is 6.7 percent.

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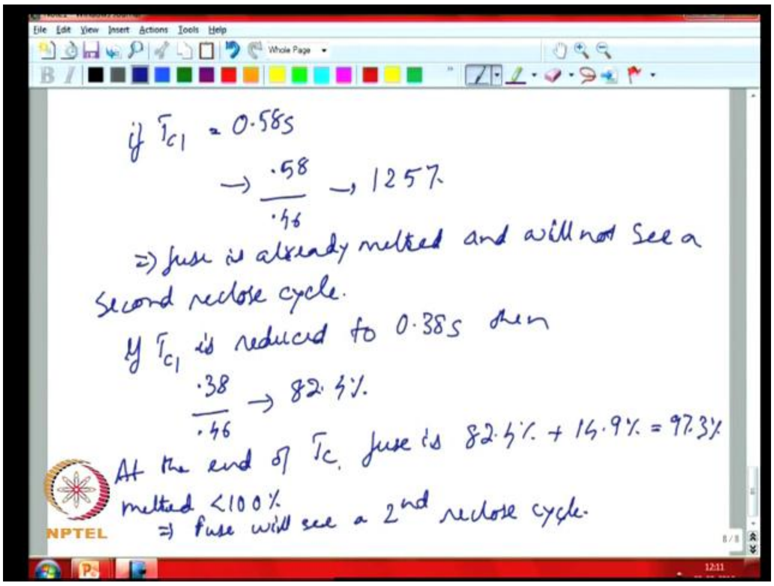

So, fuse is so if you look at so if T c 1 is 0.58 seconds. This would correspond to 0.58 divided by 0.46 or this is 100 and 25 percent. It means that; fuse is already melted it will not see a second reclose cycle. So, if T c 1 is reduced to a smaller value, say we will take it as 0.38 seconds then, so at the end of the T c 1 is 82.4 percent melted which means; it is not fuse is not at damaged at that particular point. So, the fuse will see a second reclose cycle, and then; we will have to then recalculate what T c 2 has to be for this new setting of T c 1.

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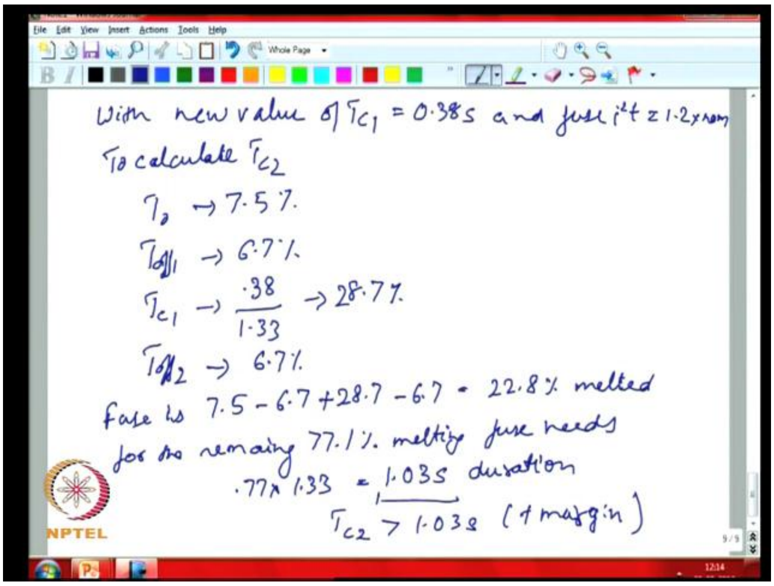

So, 1.2 times and nominal value, which is 2 into 10 to the power of 6 amperes per second so you can calculate T c 2. So, you can calculate T 0 which would correspond to 7.5 percent, T off 1 would correspond to 6.7 percent, T c 1 which is 0.38. Now, divided by 1.33 this corresponds to 28.7 percent. So, for the remaining 77.1 percent, melting 1.03 seconds duration. So, the new value of your T c 2 should be greater than 1.03 seconds with a margin. So, you can see that if you want to make sure that you do not you prevent fuse range by trying to make the maximum use of the recloser. You will have to make sure that you are doing the operations. So, that you do not have a necessary wastage of fuses and you do these calculations to ensure that you save the fuse as far as possible.

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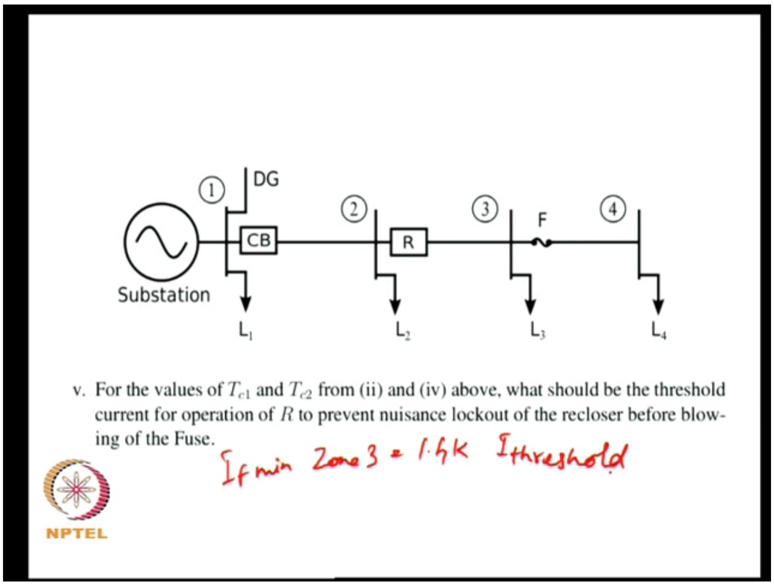

So, the next problem is from the value of the T c 1 and T c 2 that has been calculated. What should be the current threshold level for operation of the recloser to prevent nuisance lock out of the recloser before melting of the fuse. And we solve this problem the as the current level reduces you need more time for the fuse to melt. So, if you allow at the threshold level to be too low, when the amount of duration you need for the recloser to for T c 2 becomes longer and longer. So, as to ensure that the fuse melts first before the recloser locks out, so as to attain the objective of the coordination that you had were a permanent fault over here, causes this to fail before the upstream device locks out.

So, suitable threshold level can be corresponding to the time that you have used for the I f main calculation. And I f main calculation that we had in the example that we looked at was I f main for zone 3 was 1.4 kilo amps. We could use that as the threshold so that as for current level below that you do not have nuisance lock out of an upstream device for a fault in the down downstream zone.

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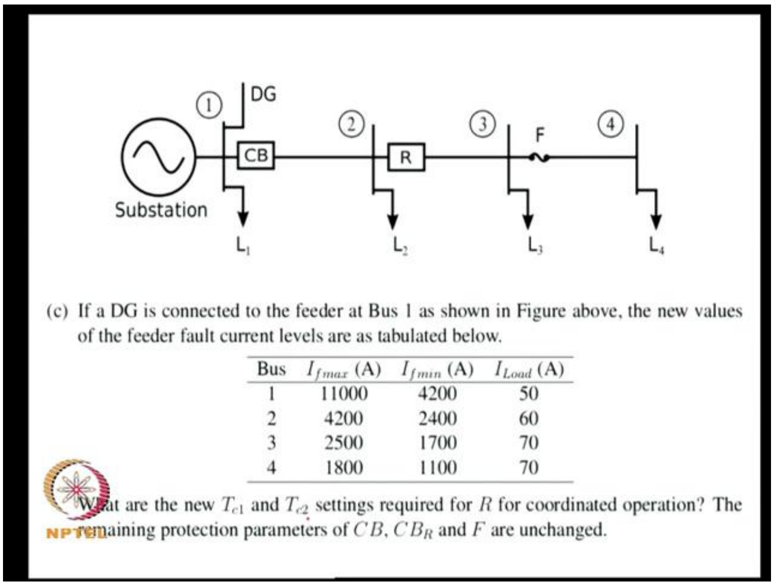

So, then you given the next problem were you have D G that is connected, and because of the connection of the D G so we are looking at the case were the D G is connected close to the substation itself. At the very upstream which causes the fault current levels across the feeder to actually go up with the fault this is simpler possible configuration, we could have D G is connected anywhere along. The feeder so because of fault current levels have gone up, you are asked to actually recalculate your T c 1 T c 2 settings etcetera, for achieving coordination. So, we will look specifically at what the concerns are rather than redoing all the calculations.

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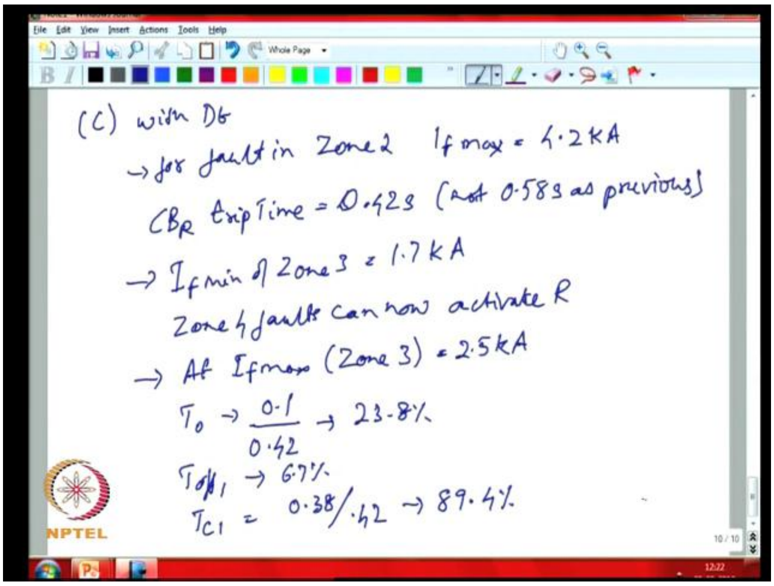

So, if you look at this particular situation; with the D G in it in zone 2; 4.2 kilo amps. So, the C B R tripping is 0.42 seconds and not the 0.58 seconds that we had as calculated previously. So, if you had set the C B R settings so that is a possibility that now, because of your C B R setting, because your C B R trips earlier you can have the C B R trip earlier, for a fault in zone 2 rather than, allowing a reclose action which will do multiple attempts to clear a fault, for a fault in zone 2. So, essentially you look at the situation over here; if you are having a fault over here now, because of the reduction in the circuit breaker timing. Because of the higher fault current you will now have the possibility that the underlying breaker would cause it to lock out before the reclose attempts complete. So, there is a possibility that a temporary fault would see an outage of the downstream zone rather than a reclose attempt.

So, another concern is a if you look at I f min of zone 3; is now 1.7 kilo amps. So, one could be the possibility that now an over current from zone 4 can actually activate the recloser, because your current levels you expect the recloser to protect temporary faults in zone 2, and zone 3. Now, even zone 4 can have faults which might trigger the recloser also; if you look at a situation at of I f max this may not be too bad I think, because if it is a temporary fault in zone 4. The recloser is helping out, but if you have a large load that is starting in zone 4, like a large induction machine reclose attempt will cause your delay in start up of the machine, which can potentially be caused over heating etcetera. If you look at I f max of zone 3, and look at the T 0 1 duration corresponding to 0.1 by now

0.42 so that is 23.8 percent. And T off 1 which is 6.7 corresponding to 6.7 percent. So, the fuses about 17 percent melted at the end of T off 1 the, if you look at T c 1.

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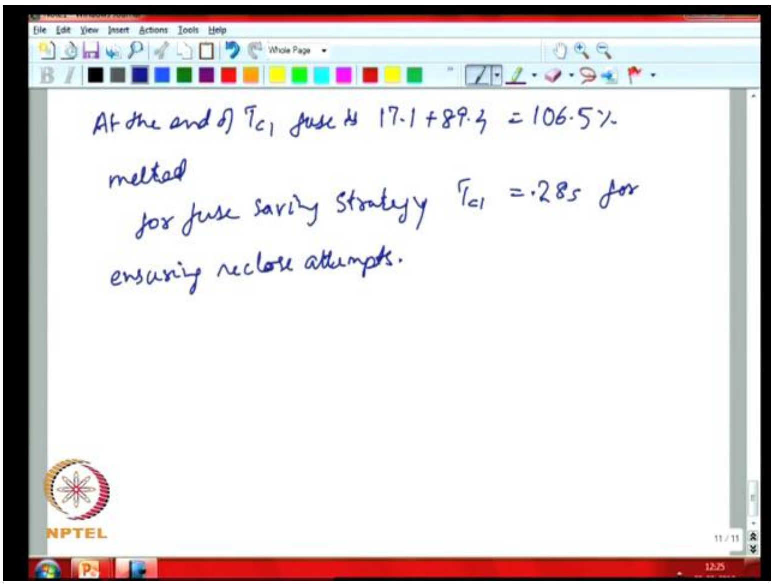

So, the fuse has already melted at the end of the first reclose cycle. So, you can see that the previous setting of 0.318 seconds for T c 1 with the additional the D G is now already causing the fuse to melt. So, your fuse saving strategy is not working so you need to further adjust T c 1. Can be further adjusted so to 0.28 seconds further reducing T c 1 for ensuring recloser attempts. So, you can see that what you would have originally considered as the settings might have to change once you add the D G into that particular system. Which is why one of the concerns were because the D G might be added by one party were as the recloser etcetera, might be set by some design engineer of the commissioning of that particular feeders.

So, the person may not be available at the point when the D G is being added. So, there is complexity of who will do the calculation what should be main settings. So, if there are concerns of protection coordination when you add the D G to the existing system. So, we are seeing that there are concerns; we are discussing about the also the voltage profile on the feeder when you have the d g, and when you have the nominal operation of the feeder. So, we will today look at the other possible configurations of a feeder you could have the majority of the feeders are radial distribution systems which we have been discussing so far in the class.

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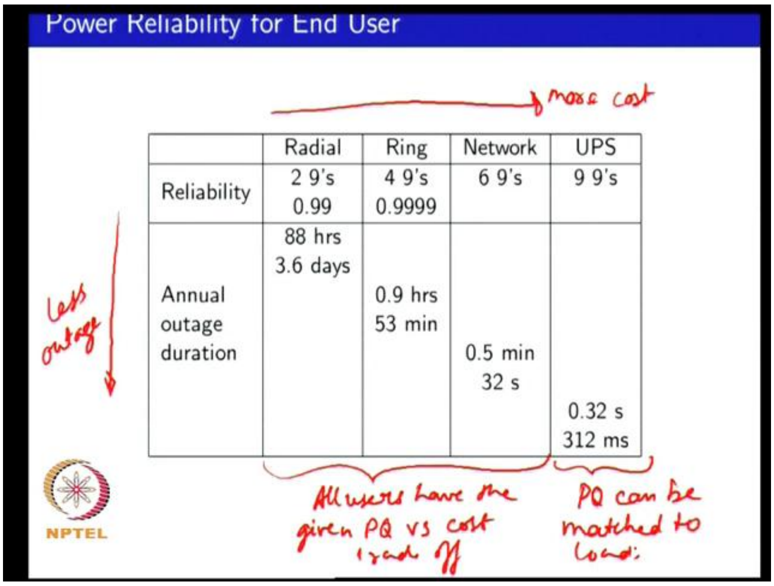

And, if you look at the radial distribution systems; they have say 2 9's of availability or 0.99 percent availability. So, if you look at what is 0.99 percent availability of the year, it means that; out of 365 days you might have 2.6 days of outage. The remaining time your system could work nominally assuming; you have the power available to actually provide the load. You could expect about 3 to 4 days of outage per year on a radial distribution system. And people look at more complex distribution systems so the next more complex network compared to just a radial structure might be a ring structure were; you can actually go around in a loop or in a ring. And if you look at the reliability here you might have 4 9's 0.999 availability which means; we should correspond to about 1 hour of outage a year. So, this is a more complex network but your reliability is improving.

So, if you say what is the next in terms of improvement of reliability is of just having a ring you can have a more complex mashed structure were; your reliability can go to 6 9's. So 6 9's of reliability would mean; that your outage per year would reduce to less than in a minute. And if you have a high end U P S dedicated to specific loads that is a reliability of such a U P S can be even of the order of can actually provide backup power with 9 9's of reliability. So, if you have large computer systems you can have the possibility of outage of less than a second per year with high quality U P S backup systems.

So, if you look at a structure of such system, you can see that as you want that per quality you are going in a direction such as this. And this is actually going in the direction were it is more expensive were you are willing to pay at higher cost for lesser outage. For higher power quality you are going in paying more or getting better power quality. And if you look at these the radial ring or a network type of distribution all the loads connected to the ring, or the all the loads selected to that particular radial feeder. Or, in a networks type of distribution system you will see the same level of power quality. So, irrespective of whether the loads require such a complex network or not you provide that given level of power quality depending on the complexity of the network. Whereas something they can U P S can be for dedicated loads.

So, depending on which particular load needs back up may be a computer system needs very high power quality. Whereas a building terminal system might it might be to actually have a slightly longer duration of outage you did not know if their heaters or air conditioners are switched off. Or, may be a minute or so in terms of lights you might be willing to tolerate a few seconds of outages in the lights. But so depending on what load is being connected; you might have different levels of requirements and ideally it should be possible to tune your particular requirement to the level of power quality, and the cost you are willing to pay for it.

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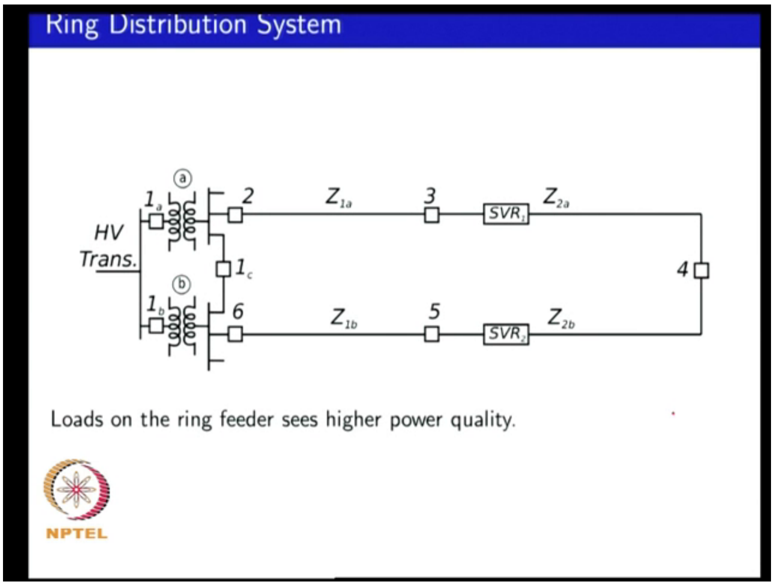

So, we will first start with a net ring or a loop distribution system, and see what we will look at it with an example; were you have a loop. So, what is shown over here is; instead of just a radial structure. Now, you have a feeder which is in the form of a loop and it is being divided in this particular example into 4 zones. Say you have this being fed from substation were you have 2 transformers with level of redundancy. So, even if 1 is out you could provide power using the other transformer, and in the radial system if any point on the feeder has a problem then the whole feeder is down. So, in this particular example you could have a possibility, because there is a possibility of getting power from both from 2 directions you have the possibility of localizing the fault into smaller sections. And ensuring that the entire feeder does not see the outage a smaller sections might see an outage. And you have a overall higher power quality to the average user across the network.

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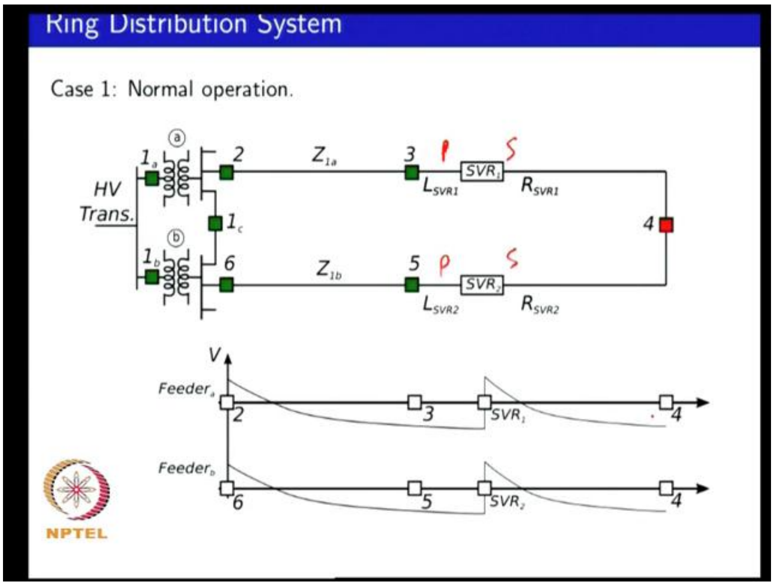

So, we will look at a couple of cases how you would approach a system; say under nominal conditions you might operate it almost like the traditional radial distribution system. Your breakers 1 a b c 2 3 6 and 5 might be closed so what is shown in green indicates a closed circuit breaker; your spore might be open. So, essentially you have feeder a, and feeder b and in this particular example you have; this potentially the ring or the loop can be covering a long distance. So, you might have the voltage regulators that are under ring. So, you have now at the position of the ring; you have a voltage boost being provided as say; if 1 is going from is called as the primary side and the secondary side.

So, as you are going from the primary to secondary you are providing a boost on the voltage regulator, on the feeder. So, you can have 2 S V R s you could have 1 S V R could be a range of configurations depending on different types of systems. So, overall under nominal conditions you have a feeder were, your voltage is regulated based on what your nominal value is. And it is the system is trying to regulate the voltage to the nominal value.

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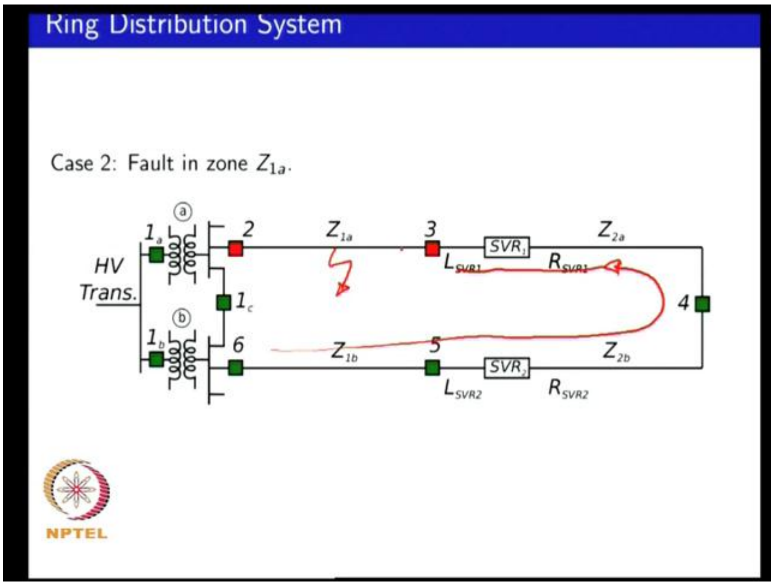

So, you could think about couple of situations say; if you have fault in zone 1 a then, essentially breaker 2, and breaker 3 would open. And then, under if it is just a system when even zone 2 a, would see the outage that now, because you can close breaker 4 closes, and essentially the fault is localized to Z 1 a. And the power now flows to Z to a, and provides power to 3 sections even when you have a fault in 1 particular zone. So, you have power up to this point and essentially 2 and 3 isolates the fault, you could also have may be fault in say transformer a or, you might be servicing transformer a in which case; you might see open 1 a 1 c and 2.

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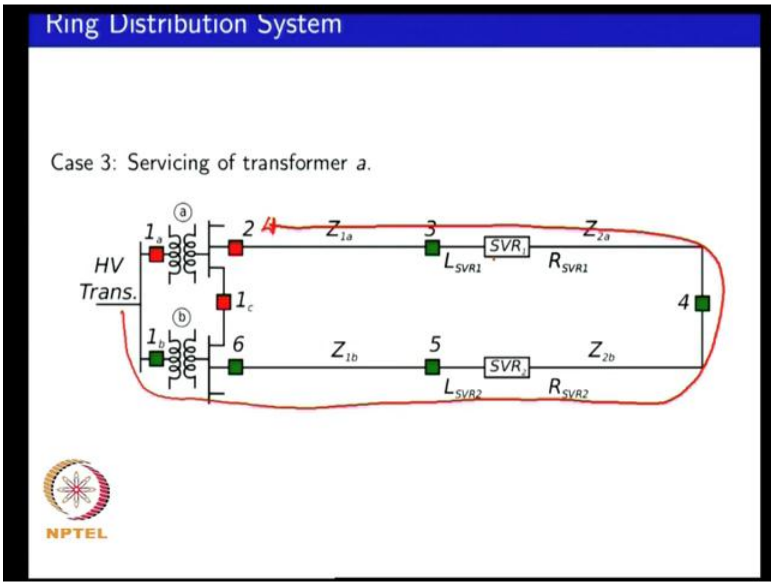

And, each case the power is now flowing through all the way to all the 4 zones, and ensuring that the servicing can be done at the substation without a de-energizing. Or, customers are who the loads under feeder. You can immediately see that the feeder has to be rated each part of the feeder have to cater to the entire load under feeder. So, the cost of the system can be higher than, the traditional. But then, you have the advantage that you do not have outages under a variety of conditions. So, if you then look at this particular scenario were you have the series voltage regulator so if you look at the voltage profile in this particular configuration. So, here you have as you go from your left to the right of your regulator you get a voltage boost. Here in this particular configuration were you go from the right to left; you have the voltage boost.

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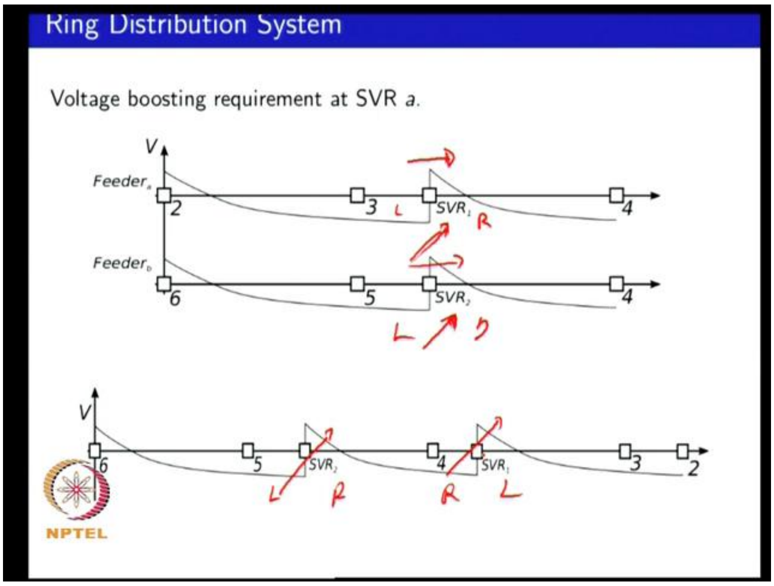

If you compare that particular situation to what was the nominal configuration of under nominal conditions; when everything was under nominal conditions then, we went from left to the right the boost was being provided. Here, if you look at the different zones as you go through this particular. If you as you go through this particular across the series voltage regulator, on the series voltage regulator as you are going from left to right, you are actually getting the boost as would be the nominal configuration. But because now your loop is providing power in the other way, as you are going over here from the closed breaker 4 towards closed breaker 3 it is actually going from right to left.

And, you still need a boost which means that; it is the opposite of their voltage what would be applied at the S V R compared to the nominal configuration, were you had a boost going from left to right. Here you are having a boost going from right to left. So, if you see how this is being accomplished it means that; essentially if the power flow is in this particular direction you get a boost from left to right. But if the power flows in the previous example is in the opposite direction, you need to actually change the polarity of the boost to ensure that your overall feeder voltage profile is appropriate.

If you hence the other way your voltage would further sag below and that would not be a acceptable. So, you cannot just have because these series voltage regulators do not know what the starters of these breakers are. It has to make its decision on whether to provide the boost or a buck; it does not have cables or signals in from starter signals from the other breakers. It is making its decision based on its local measurement and local measurement that it can make is which direction is the power flow.

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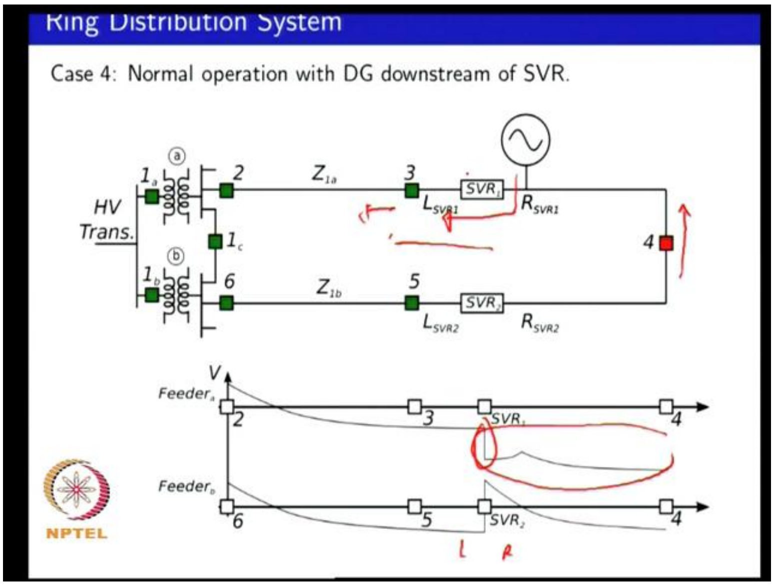

So, you could then think about a situation where, you might have a D G and say if you have a D G downstream of a series voltage regulator, and we are operating under normal condition of this range. And if the D G power is sufficient to send power the other way along the feeder so instead of providing the boost what would be the normal condition. It would assume that now you have a configuration were the switch over has occurred in the power flow is going in the opposite direction. Which means; that instead of providing a boost you could now have the voltage profile flipping over, and now this whole section of the feeder will now potentially see conflict in the voltage. The S V R would try to apply in a voltage of the opposite polarity so which could cause increase in circulating currents within the loop etcetera, which can potentially be damage the system. So, you can see that the issue of introducing the D G can actually cause the potential problems in network more complex networks such as radial distribution systems.

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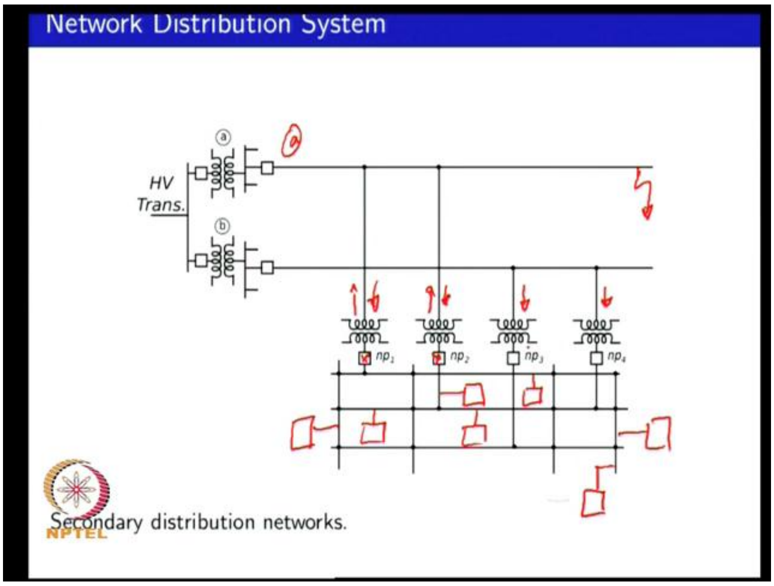

Also, if you look at network distribution type of system, if you look at the traditional network distribution system; the network is not at the regular distribution system. It is actually on the secondary distribution system, is what is being networked. So, if you have transmission system coming to a substation plus feeders, these feeders would be at the medium voltage 11 k v etcetera. The network is actually at the low voltage which might be at 415 volts or whatever is the consumption voltage of the network.

So, here what we have shown is an example of a network you might have loads on the network connected to different points. And essentially if you have a network such as this, you are essentially having redundancy in the power flowing into that particular network. So, if you have a fault on the network essentially the network protectors on such a distribution system, what is shown over here are network protectors in p 1 through a p 4 would act to actually clear a fault within the network system itself. One functionality of a network protector is that it will allow power flow only from your feeder into your network system. So, it will if it detects the power flow is happening in the opposite direction, there network protector will open on a instantaneous basis.

So, within a cycle it would try to open in case it detects a power flow in the opposite direction. So, if you have a fault on say feeder a; because of the fault the flow of power will be towards the fault and detecting the flow of power into the fault. Essentially the network protectors 1 and 2 would open, and essentially the spot network would get immediately isolated from the fault. So, for anything that happens on this particular feeder essentially can be de-energized for servicing repair etcetera, your network protectors would ensure that the power flow does not go out of the network. And the availability on the spot network would stay high.

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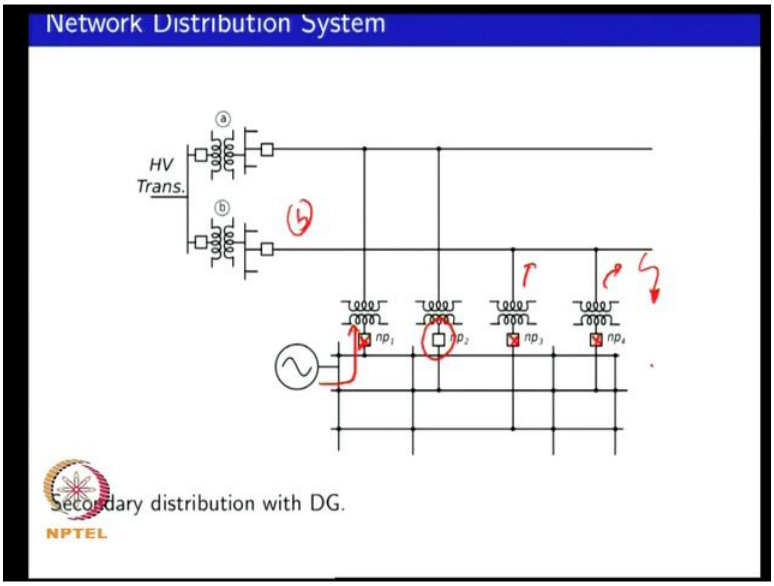

If you now, think about a situation were now you have a D G connected to such a network system; you have the possibility that the D G might try to send power back out into the, into your feeder and your network protector might cycle open in response to seeing the power from D G. And you might still think that even if there is one network protector that cycles; cycling of the network protector is not desirable. But even if you have a network protector that is cycling and say you have a fault now on feeder b. Then, essentially a system would try to send out power and open up these to protectors and might end up over loading.

The only network protector that is available, you might have redundancy that; if 1 set of protectors go away, you might have redundancy but you might not have redundancy even when a reduced set is non functional. So, you might be seeing that the loads in this overall secondary network might see a shutdown. In case you have D G that is connected to a network distribution system, a network secondary distribution system. So, the potential for problems increase once you have more complicated configurations of distribution systems.

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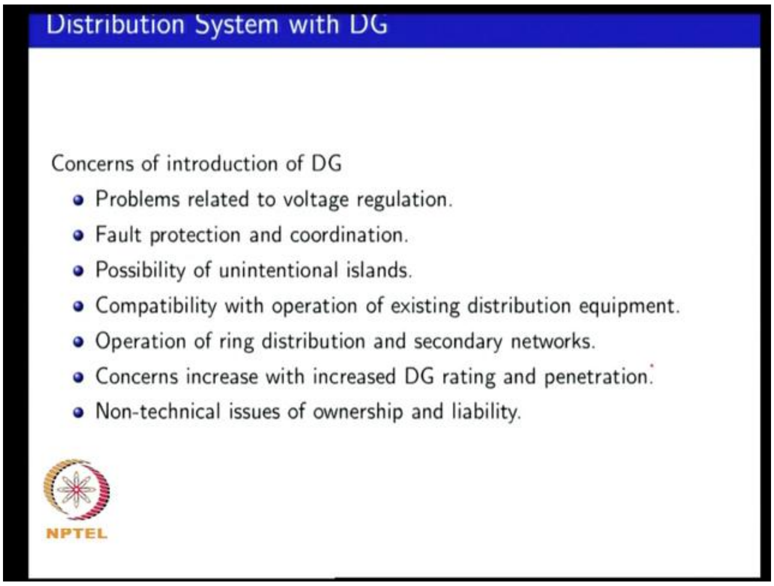

So, with this we can actually look at the concerns of D G's in distribution systems. And we will look at the concerns and the methods address some of the concerns primarily related to how quickly we can disconnect the D G. How quickly we can control the power flow through the D G etcetera, and how many times, how rapidly you can disconnect. So, the trends towards solving some of this are through power electronic means; and so we will look at how effective power electronics means can be in addressing these issues. And power electronics tend to be more expensive than traditional systems. So, we will have to look at first how cost effective it is, which implies that you need to measure cost. And whether you are engineering is cost effective to actually figure out whether you are moving in the right direction to address these problems.

Thank you.