Power Electronics and Distributed Generation
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Lecture - 9
Impact of distributed generation of distribution protection

Welcome to class nine on topics in power electronics and distributed generation. In the last class we had talked about coordination between protective devices. We had looked at coordination between a circuit breaker, upstream and downstream circuit breaker, upstream and downstream fuse, we briefly discussed about that. Then we looked at an example of recloser with a downstream circuit breaker and we started the discussion on upstream fuse and a downstream recloser.

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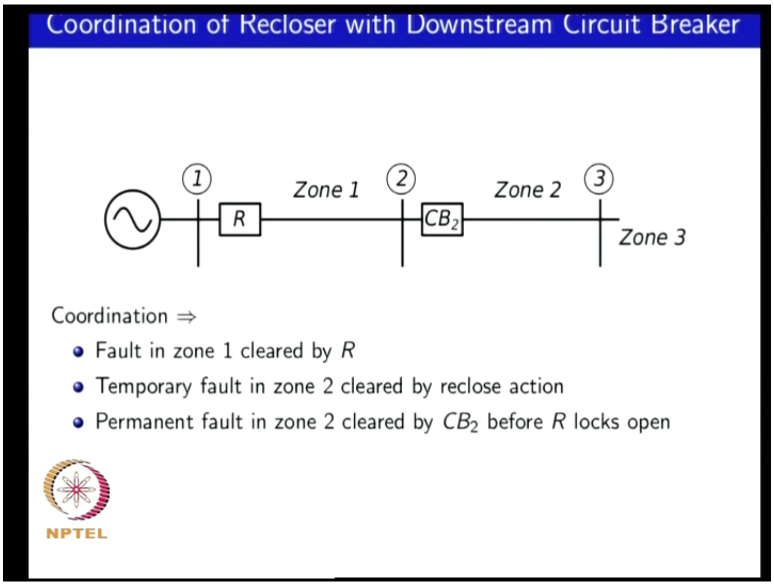

Coordination of Recloser with Downstream Circuit Breaker

Coordination ⇒

- Fault in zone 1 cleared by R
- Temporary fault in zone 2 cleared by reclose action
- Permanent fault in zone 2 cleared by CB_2 before R locks open

So, if you look at the case of the upstream recloser with a downstream circuit breaker, we defined what coordination implies and what we saw was that the lower ranges of current levels we need to ensure that see your circuit breaker operates before the recloser locks out. So, for a fault in zone 2 or may be further downstream, the fault current level may be small which is that C B 2 will need longer and longer time for it to operate, and you want to ensure that even under that condition you have coordination which means that R does not lock out before the operation of the downstream, appropriate downstream device. So, that is one thing that we saw in the last class.

So, today we will look at the coordination of a upstream fuse. It could also be a circuit breaker with a recloser, and last time we were saying what it needs, what it means by coordination in this particular case. And say for example, for a fault in zone 2 you want to ensure that the recloser operates to clear temporary faults and it should not lock out, say in a situation where the lock out duration is longer than the time for the fuse to melt. So, you do not want fuse f 1 melting for faults in zone 2.

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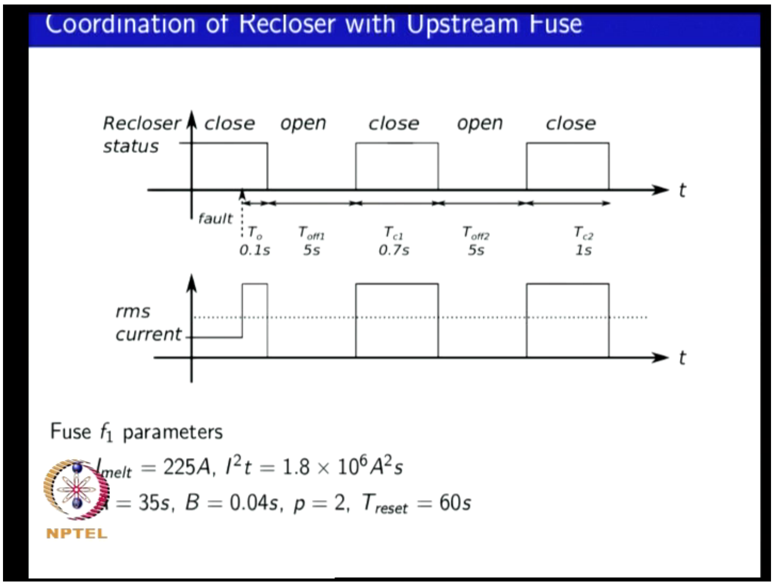

Coordination of Recloser with Upstream Fuse

Fuse f_1 parameters

$I_{melt} = 225A,\ I^2t = 1.8 \times 10^6 A^2s$

$A = 35s,\ B = 0.04s,\ p = 2,\ T_{reset} = 60s$

So, we will look at an example of the coordination of the few upstream fuse and a recloser. And for the analysis what we will do is we will use the data that we had for our circuit breaker example. And we will look at then what the device parameters are, in this particular case. So, for the recloser we again look at a 2 cycle recloser where if a fault occurs at say some duration of time, for a short duration T naught you allow the fault full current to flow and then the recloser opens. So, your off duration in this particular example is 5 seconds, and when you reclose, you reclose for a duration of 0.7 seconds.

If the fault is at 3 percent then after 0.7 seconds it opens again, it waits for another half duration; in this example it is again 5 seconds, then it recloses second time and it stays closed for 1 second. And if the fault continues in this particular duration, after 1 second it locks open after it completes, in this case 2 recloser atoms. It can be the, reclosing atoms can be programmable to be more, lesser, etcetera. So, if you look at the rms current levels this would be the pattern of rms current levels where you have a permanent fault downstream of the recloser.

For the upstream fuse we will assume that the fuse has a melt current of 225 amps. So, if you had a circuit breaker you will be talking about pickup current level here looking at what current, at what is the minimum current level at which the fuse would melt and we will take it as 225 amps. We will take the r l square t as 1.8 into 10 to the power of 6 ampere square second, and the corresponding parameters we will assume that the fuse needs at least 2 cycles of 40 milliseconds to operate. It is extremely inverse characteristic.

So, p is 2 and corresponding to the i square T you get and the i melt you get A of 35. And you have a reset time is essentially the cool down time of the fuse of 60 seconds; its means that after its gets fully hot after a minute the fuse cools back to nominal temperature. So, if you look at this particular example then you can ask what would be the response of the fuse and the recloser for faults under different conditions.

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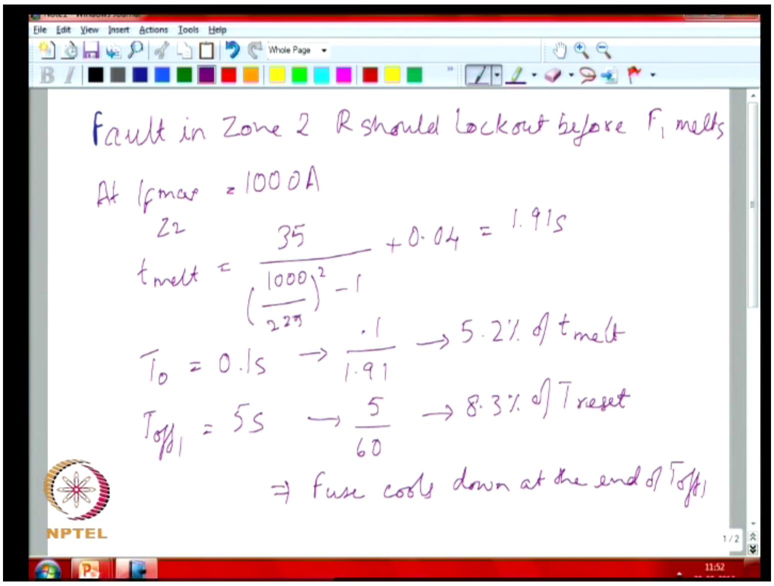

Fault in Zone 2 R should lockout before F_1 melts

At $I_{f\,max_{Z2}} = 1000A$

$$t_{melt} = \frac{35}{\left(\frac{1000}{225}\right)^2 - 1} + 0.04 = 1.91s$$

$$T_0 = 0.1s \rightarrow \frac{.1}{1.91} \rightarrow 5.2\% \text{ of } t_{melt}$$

$$T_{off_1} = 5s \rightarrow \frac{5}{60} \rightarrow 8.3\% \text{ of } T_{reset}$$

$\Rightarrow$ Fuse cools down at the end of T_{off_1}

So, for a fault in zone 2; and if you look at the range of currents in zone 2 your I f max is 1000 amps. So, at I f max of zone 2 of 1000 amps you have your t melt for f 1 is given by 35. So, it would melt in about 1.9 seconds. And so, if your course duration T naught corresponds to 0.1 seconds, 100 milliseconds. So, that corresponds to 0.1 divided by 1.91 or 5.2 percent of t melt.

Then if you look at T off 1 which is 5 seconds; so, that corresponds to 5 by 60 because 60 is now the reset time; this corresponds to 8.3 percent of T reset. So, at this particular point at the end of T off 1, so at the end off T of 1 over here you can assume that the fuse is cooled back down to the ambient temperature.

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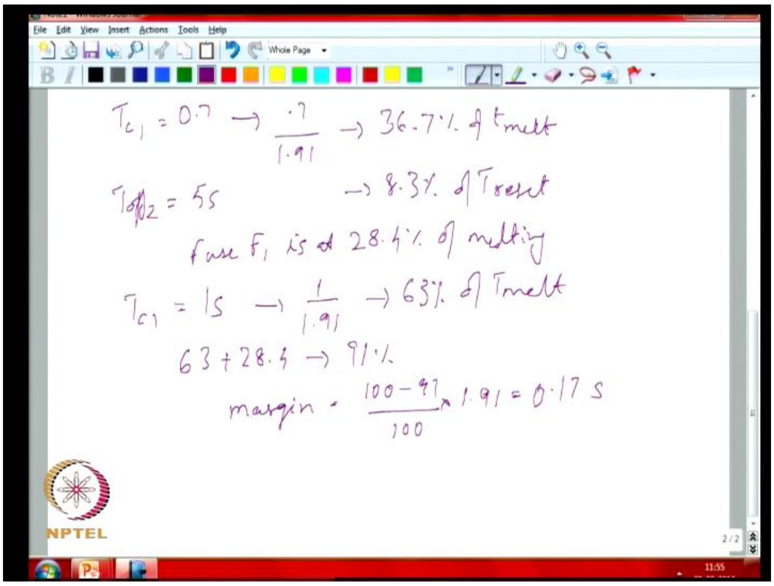

$T_{c_1} = 0.7 \rightarrow \frac{.7}{1.91} \rightarrow 36.7\%$ of t_{melt}

$T_{off_2} = 5s \rightarrow 8.3\%$ of T_{reset}

fuse F_1 is at 28.4% of melting

$T_{c_1} = 1s \rightarrow \frac{1}{1.91} \rightarrow 63\%$ of T_{melt}

$63 + 28.4 \rightarrow 91\%$

margin $= \frac{100-91}{100} \times 1.91 = 0.17\ s$

So, then if you look at what happens in the next duration your first reclose cycle you have T c 1 and we have 0.7 seconds. So, 0.7 divided by 1.91 that corresponds to about 36.7 percent of t melt. And then if you look at the subsequent of duration your T of 2 which is again 5 seconds. So, this corresponds to again 8.3 percent of T reset. So, at this particular point 36 minus 8.3. So, the fuse F 1 is at 28.4 percent of melting. So, into the melting point it has reached about 28.4 percent of the way.

So, if you look at your T c 1 which is your second reclose cycle, your T c 1 which is 1 second. So, which is 1 by 1.91 or 63 percent of T melt. And if you take this 63 plus 28.4 that is 91 percent of your melting point, so your recloser would actually lock out before the fuse melts because it would melt at the 100 percent point. So, it reach 91 percent of the melt time. So, the margin that you have between the 91 and the 100 percent is 100 minus 91; it is 0.17 seconds. So, 170 milliseconds before the fuse would have melt your recloser locks open.

So, if you look at the system, at this particular point the fuse did not melt if you have a fault in zone 2 which was permanent; 170 milliseconds before the fuse would have melted your recloser locked open for a permanent fault in zone 2. So, that achieves the objective of not damaging the fuse for a fault in zone 2. So, then we look at what would happen when you have this is at the high current end of the range, what would happen at the low current end of the range. So, in this what you did was zone 2. There were 2 reclosers at end and time to clear a temporary fault twice and if that did not happen then it should be which is lock out.

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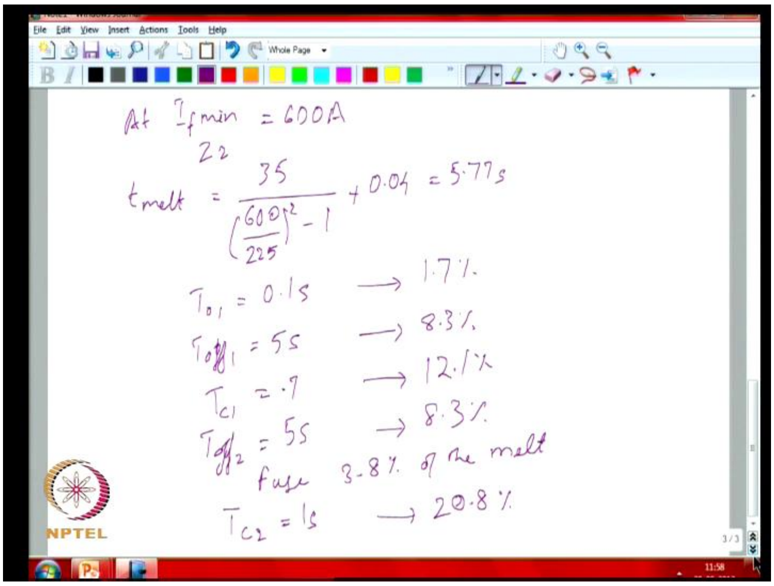

At $I_{f\,min} = 600A$
Z2

$$t_{melt} = \frac{35}{\left(\frac{600}{225}\right)^2 - 1} + 0.04 = 5.77s$$

$T_{o1} = 0.1s \longrightarrow 1.7\%$

$T_{off1} = 5s \longrightarrow 8.3\%$

$T_{c1} = .7 \longrightarrow 12.1\%$

$T_{off2} = 5s \longrightarrow 8.3\%$

fuse 3.8% of the melt

$T_{c2} = 1s \longrightarrow 20.8\%$

So, if you look at, then at I f min of zone 2 which is 600 amps, your t melt is 5.77 seconds. So, at 600 amps it would need a longer time for it to melt. So, if you look at them your calculations your T 01 your first duration of current pulse which is 0.1 seconds would take the huge to 0.1 percent of melting.

If you look at T off 1 which is 5 seconds, this corresponds to 8.3 percent of duration of its reset time. So, here again it is fully reset or fully cooled down. Then if you look at T c 1 which is 0.7 seconds, this corresponds to 12.1 percent. And T off 2 which is 5 seconds again, which is 8.3 percent. So, at this particular point the fuses 3.8 percent of the melt point, the time at which it would melt. So, if you then look at T c 2 which is 1 second, this corresponds to 20.8 percent of your time to melt.

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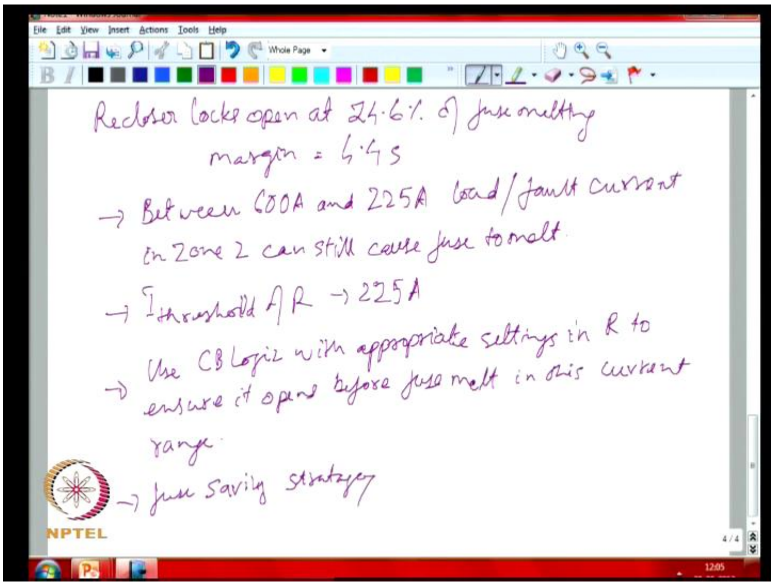

Recloser locks open at 24.6% of fuse melting

margin = 4.4 s

→ Between 600A and 225A load/fault current in Zone 2 can still cause fuse to melt

→ $I_{threshold}$ of R → 225A

→ Use CB Logic with appropriate settings in R to ensure it opens before fuse melt in this current range

→ fuse saving strategy

So, if you look at the point at which the recloser locks open at 24, 25 percent of the fuse melting. So, your margin is 4.4 seconds. So, you can see that at the lower current level your margin actually improved. So, that is not the, what you need to pay closer attention is actually at the high current levels rather than at the low current levels; what you saw was for the co ordination with the downstream breaker of fuse you have to pay attention at the lower current, with the upstream and you have to pay particular attention at the higher current level.

So, the margin is actually improving as your current level is reducing. So, if you look at between, there is actually a fairer arranged between 600 and 225 amps. So, if you take your, just a plane recloser and say you are having a threshold where it actually somewhere close to 600 amps; then between 600 amps and 225 amps there is still a possibility of the upstream fuse operating because of fuse melt current is 225 amps; so, a load current, so much of fault current.

So, if you want to then co ordinate this downstream recloser with a upstream fuse you can do couple of things- one is you could use a I threshold of recloser to be 225 amps. So, this would be with trying to ensure that the recloser would operate for any current level which can potentially damage this switch, the fuse, but if you set your threshold levels for protection to be extremely low then there is always a possibility that the recloser will be prone to nuisance faults, any time a motor in the downstream starts up, etcetera, you might have nuisance trips in your recloser. So, you do not want to push your threshold level to be too low.

So, what you could actually do is make sure that at the lower current levels you have not just the reclosed logic, but also have embedded circuit breaker characteristic which would actually enable your faults to be cleared at in your downstream device at a faster, earlier instant of time compared to a upstream fuse.

So, you can see that you have to pay attention to the entire range of a possible currents that flow in this particular devices to actually ensure that it operates in a proper manner. In fact, what you saw was that the recloser can be used say along with a fuse, it can be either a upstream fuse or a downstream fuse, in such a manner that the fuse does not get damaged for temporary faults. So, without a recloser if it was just a circuit breaker with long delays, etcetera, it would just operate without the ability to say clear temporary faults; and most, large number of faults a majority of faults are actually temporary faults.

So, this strategy of using a recloser to actually, prevent fuses from blowing is called a fuse saving strategy because anytime a fuse blows you have to go in and replace it. So, it actually saves cost by making use of the appropriate protection settings to prevent a upstream or a downstream fuse from getting damaged by appropriately timing and doing a proper coordination of your protective elements.

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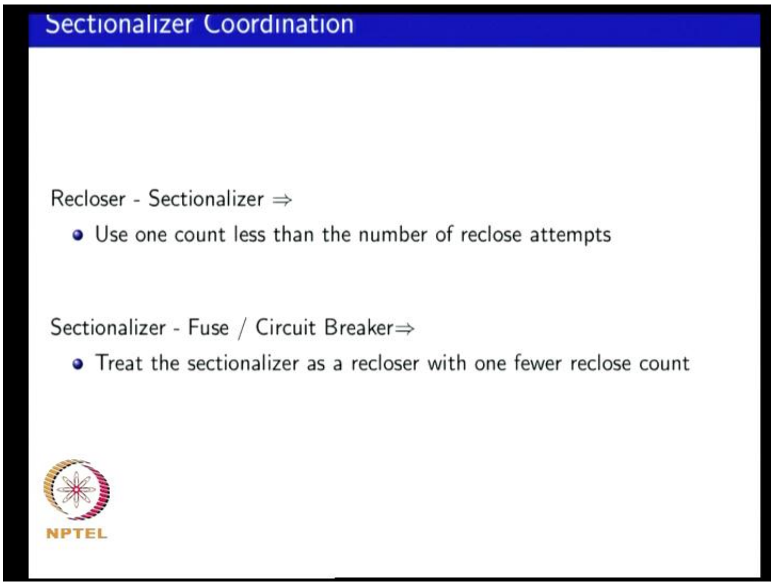

Sectionalizer Coordination

Recloser - Sectionalizer ⇒

- Use one count less than the number of reclose attempts

Sectionalizer - Fuse / Circuit Breaker⇒

- Treat the sectionalizer as a recloser with one fewer reclose count

So, if you then look at what could be the other elements where you could say, think of coordination, you could have a coordination where you are looking at a may be a sectionlizer with a recloser. And we saw for a sectionlizer with a recloser what you do is you would ensure the number of counts in your sectionlizer is 1 count lesser than your up upstream recloser. So, this sectionlizer is intended for use downstream of a recloser.

In case you have a sectionlizer with a fuse or a circuit breaker, what you do is you do the same calculations, but with now 1 fewer number of current pulses or 1 fewer reclose counts. And whatever calculations that you, that we looked at with the recloser would work with the sectionlizer; except that the number of cycles that would be 1 fewer. So, what we have done so far can be applied in a broader setting where irrespective of the possible combinations of protective device that is being used in the system.

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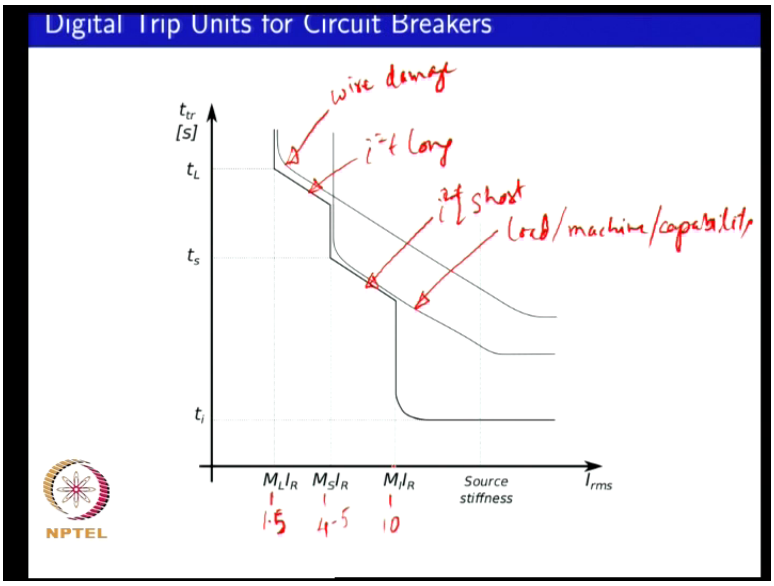

Digital Trip Units for Circuit Breakers

Now, if you look at a circuit breaker characteristics that we have just seen, it is having a single, i square t, value or equivalent a b parameters, a b t parameters, etcetera. But, many modern circuit breakers, it is actually having digital trip units which means that you could actually have more complex protective settings. So, you could have settings that incooperate a multiple protection curves in a single circuit breaker.

For example, what is shown over here; this is a circuit breaker with settings for long term, short term, and instantaneous protection. So, if you look at the protection curves you might have 1 i square t. So, if you look at what is plotted over here, it is current magnitude on your x axis and your tripping time in your y axis, plotted on a log basis.

So, some multiplier times your rated current would be your long current settings. So, you could have multipliers which might be rated of the order of say 1.5 for your M I; so, 1.5, 2, etcetera. Similarly, you would have short term current levels where you are looking at multipliers like say 4, 5, etcetera. And you might have instantaneous trip levels where 10 times your rated current would cause instantaneous trip. So, you are talking about much higher current level for instantaneous trips.

And, corresponding to your current level at which you have long term protection versus your time at which you would at you have i square t long, you would have i square t short, and your instantaneous trip settings; and you might have much higher current level that can potentially flow through the circuit that depends on what is the upstream impudence of your circuit.

So, if your upstream impudence is high which means that it is a weak grid then the source stiffness will ensure that the current maximum is lower; if the upstream is impudence is low which means the grid is very stiff then the fault current level is higher. So, you have limit of how much currents the grid can also provide, in terms of be able to activate your protective devices.

So, if you look at, then curves like this, these can be used beneficially in applications; say for example, when you have say, possibly multiple downstream elements you might have circuit breaker, you might have a long section of wiring and then you might terminate it at a motor. So, you might have a, i square t, level for the motor; you might have a, i square t, level for your wiring.

So, if you take a typical motor, for starting you might have a short duration where your current level goes fairly high. So, you want to ensure that even at current levels of say multiplies of 4 to 5 is rated current, your trip does not happen. So, in a region such as this, you might want to operate for a short duration so that the motor can start without tripping a circuit breaker. But, quickly once the motor starts your current level will come back down to the load level before you actually switching your mechanical load.

So, you would have may be a few seconds of in rush current, and then you can operate it, operate your protective device without tripping it. But, then you have a protection curve which is sufficiently small, so that if you have now over loads on your equipment which will cause minutes of over current; then if the over current level is higher than some multiplier level which might be as low as 1.5 then your breaker would open.

So, you have different levels corresponding to your short term allowable current and different level for your longer term allowable current. So, you could do, you could have 1, i square t, curve for wire damage, you could have another, i square t, level for load or may be a machine, i square t, capacity. So, you can see that the protection coordination with even a simple device such as a circuit breaker can become fairly complex. And you have to think to what exactly the logic required for actually setting your protective device.

So, if you look at again the instantaneous trip levels in circuit breaker when you talk about instantaneous, it is not instantaneous in the power electronics sense where when you talk about instantaneous current levels in power converters you are talking about the micro seconds range. Whereas, here when you are talking about instantaneous you are talking about say 1 to 5 cycles, say 20 to 100 milliseconds.

And, with 20 milliseconds you cannot use a circuit breaker or a electromechanical protective device to protect a semiconductor device because a semiconductor device, I g b T, might get damaged in 10 micro second diode or a c r might get damaged in half a cycle depending on what its peak non-repetitive current capability is. So, you are talking about something which is less than a cycle for many semiconductor devices.

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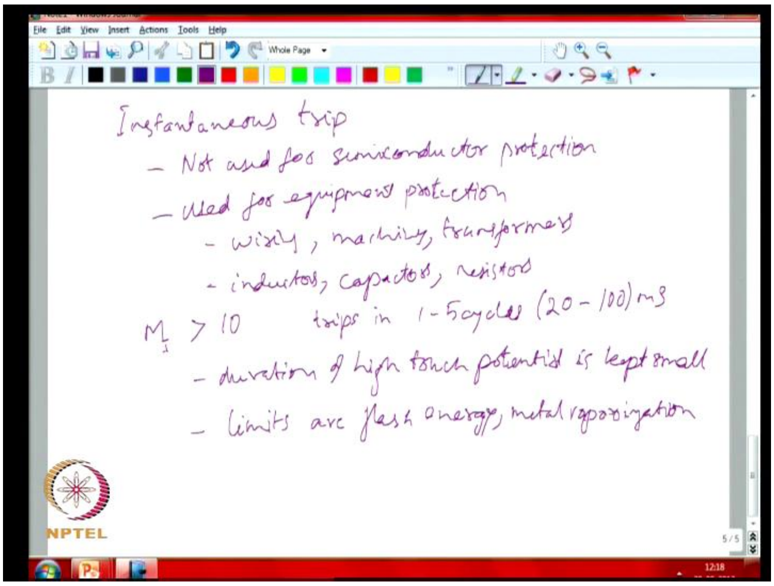

Instantaneous trip
- Not used for semiconductor protection
- Used for equipment protection
  - wiring, machines, transformers
  - inductors, capacitors, resistors

$M_i > 10$ trips in 1-5 cycles (20 - 100) ms
- duration of high touch potential is kept small
- limits arc flash energy, metal vaporization

So, you, these are not intended to protect power semiconductor device; it is actually intended to protect say, electrical equipment. So, you can use it for wiring, machines, transformers, inductors. So, most of the buoyants of equipment which go into even a power electronic converter, you could think of protecting it; this in electromechanical or electro thermal device, but not the semiconductor device.

So, even if this semiconductor device gets damaged that damaged semiconductor device might be forward up with some wiring getting burnt or some inductor getting burnt. So, your protective breaker in that particular case is actually trying to prevent further damaged from happening within your cabinet rather than actually trying to save your circuit breaker or trying to save your semiconductor device.

So, if you look at the instantaneous trips your M I is, you are talking about things that are fairly large- 10, 20, etcetera, and your trip times you are talking about 1 to 5 cycles. So, 1 is extremely fast, you are talking about 20 to 100 millisecond. And what can be achieved with say 20 millisecond trip, it helps achieve a couple of things- one is say when you have a fault your fault current can often be to ground which means that there is current flow into ground.

So, when there is large amount of current flow into ground the ground potential or the cabinet potential itself can get elevated because of the impedances further downstream in the ground. So, if someone is touching a cabinet and simultaneously a fault is happening, your instantaneous trip will ensure that the high voltage is being seen by the individual for a very short duration, for 100 milliseconds or less and not for much longer duration.

The second thing that happens when you have a fault is if you are having fault currents with very high current level, fault current level then you can potentially have arching within your equipment. So, you limit the amount of energy that goes into the arc by keeping your duration of your instantaneous operation to be very small. So, if you have a fault and someone is standing nearby, the amount of thermal energy transferred to the individual depends on the amount of energy in the arc which corresponds to the temperature of the arc.

So, you want to ensure that large arcs do not happen, and it does not spread out into a wider area so as to protect the people who might be happen, happening to be near equipment. So, the amount of energy in vaporized metal, etcetera, is proportional to how much energy has gone in. So, is this would help in aspects such as that.

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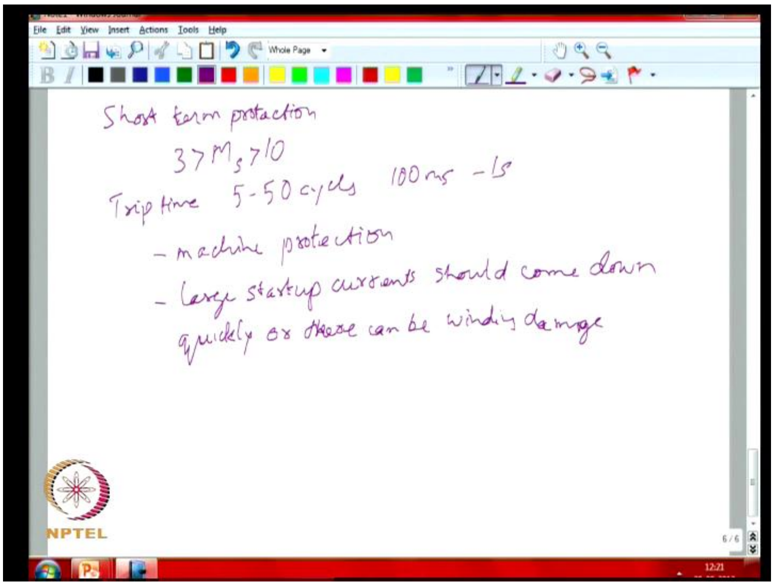

Short term protaction

$3 > M_s > 10$

Trip time 5-50 cycles 100 ms - 1s

- machine protection
- large startup currents should come down quickly or there can be winding damage

So, after the instantaneous, the next possibility is what you could do with short term protection. So, when you are talking about short term protection you are not talking about multipliers say, in 3 to 10 range; and you are talking about now trip times of 5 to 50 cycles; you are talking about say 100 milliseconds to 1 second or may be a few seconds; so, in the range of a few seconds what can happen.

And essentially what you are trying to ensure in with short term protection is that equipment would have inrush during start up and you do not want the start up current level to actually occur on a longer term duration, but you do not want the starting to be interrupted because every time you are trying to restart equipment you are dumping more energy into that particular component.

So, you like it to successfully start up and you make use of the short term protection levels to ensure that you can take the inrush current for adequate duration before you have a shut down or protective shut down. So, you want to ensure that the windings in machines, etcetera, do not get damaged. So, you want to ensure that the startup current does not happen for a, over a longer time duration.

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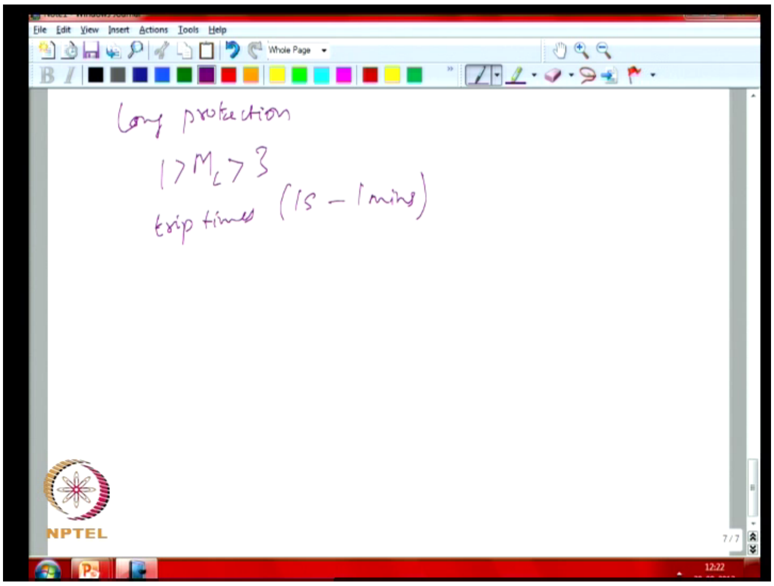

Long protection

$1 > M_i > 3$

trip times (1s – 1 mins)

Then, if you are looking at your long protection, you are having multipliers; of course, you have to continuously carry the rated current; so, M i here. So, you are talking something between, 1 and 3 times, the rated current. So, your trip times are now in the duration which is much longer seconds to minutes because it is essentially how much time would it take for wiring to heat up the thermal time constants of some of the systems might be longer.

So, when you are taking a higher over load it might take minutes for some parts of some of your protective downstream equipment to actually heat up. So, essentially you are trying to ensure that a long duration of over current or over load does not lead to damage. This is essentially what you are trying to do with long protection.

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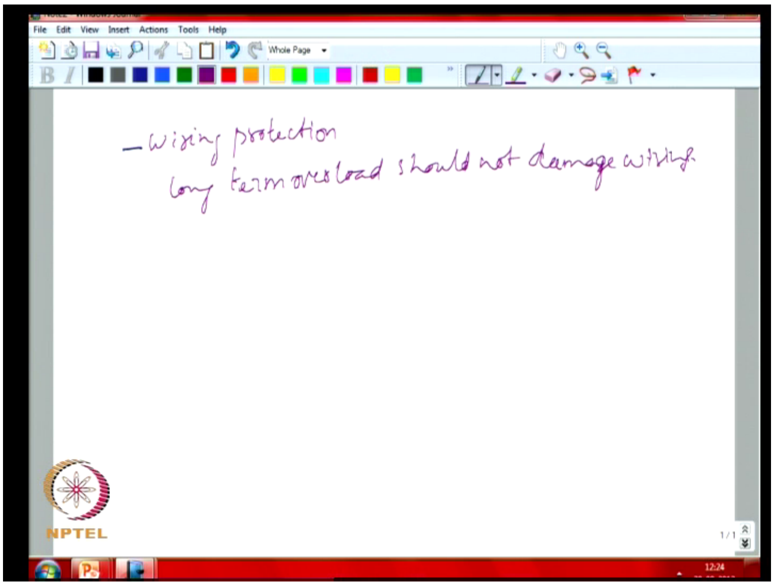

– wiring protection

long term overload should not damage wiring

In fact, a major reason for wires in many buildings people attributed to electrical failure. So, what it means is that some wiring at certain point got over heated beyond its level. So, wiring protection is actually quite important; make sure that you can actually cause fairly seizes damage by not looking at wiring protection in a close manner.

So, now, that we have actually looked at the protection in fairly broad manner; what we will do next is look at, now if you have a distribution system what would happen if you add distributed generation source to the particular feeder and then what would be its impact in terms of protection.

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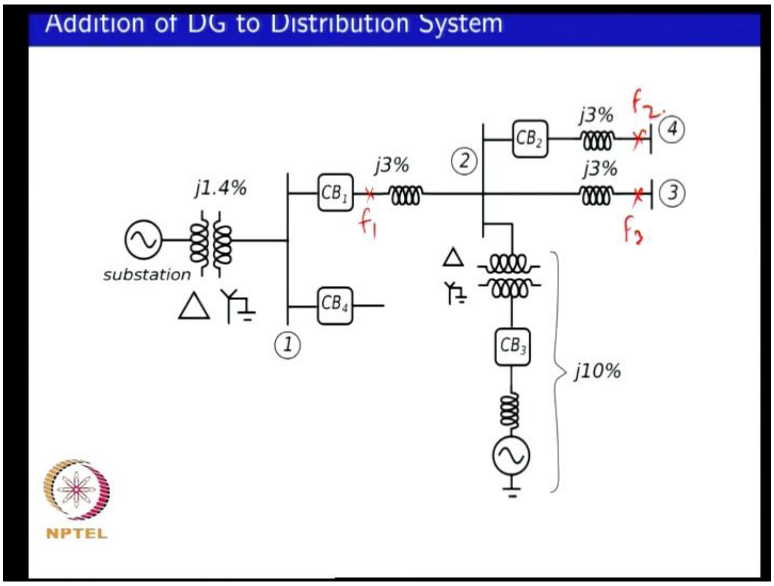

Addition of DG to Distribution System

So, we look an example where say you had, you have a substation and you have a transformer with a given impedance; we look at it in terms of example; and downstream from there you have say bus 1, and you have a number of feeders; circuit breaker 1 is protecting say feeder 1; and you have impudence of 3 percent upstream between bus 1 and 2.

At bus 2 you have a lateral which is now protected say with circuit breaker 2 which has again a impudence of 3 percent to another bus 4. And from bus 2 you have again the continuation of the feeder to bus 3. And at bus 2 you are thinking about adding a distributed generation source. So, suppose you do not have this particular source you would have some level of fault current levels in this particular feeder.

So, the question is now that you are planning on adding say this particular d g unit what would happen to fault current levels; what would it be before, and what would it be after you add this particular source into the system. So, what we will do is we will look at possibility of faults at different locations on this particular simple example, and look at its impact in terms of protection.

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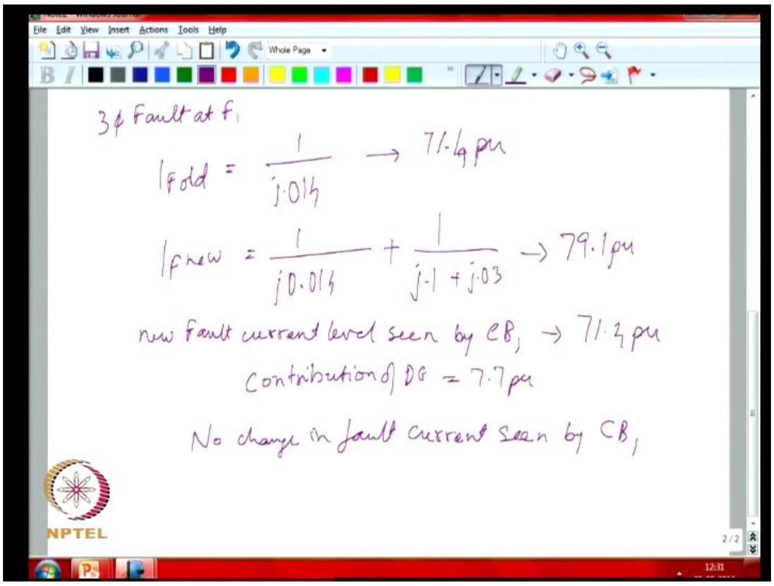

3ϕ Fault at f_1

$$I_{f\,old} = \frac{1}{j.014} \rightarrow 71.4\text{ pu}$$

$$I_{f\,new} = \frac{1}{j0.014} + \frac{1}{j.1 + j.03} \rightarrow 79.1\text{ pu}$$

new fault current level seen by CB_1 → 71.4 pu

Contribution of DG = 7.7 pu

No change in fault current seen by CB_1

So, the first fault that you would consider is say a fault just downstream of circuit breaker 1. And if you look at that particular situation at f 1, if you look at, I f old, this is given by, your voltage is 1 per unit and we will assume that in a example someone has done out a homework and given you all the parameters on a permanent basis normalized for a entire system, and so the upstream impedance in this particular case is the impedance seen for the substation transformer plus the upstream source. So, that is j 0.14. So, this leads to a fault current level of about 71.4 per unit.

Now, if you look at your; now this situation where you have now added the, D G, if you look at your fault current level is; and you have 2 sources- one is the D G, one is your traditional, your substation. So, if you look at the example system now when with the D G you have some amount of current coming in from the substation side and some amount of current coming in from the D G side which says impedance of 10 percent from the D G and 3 percent from your feeder.

So, your total fault current has now increased to 79 per unit, but out of the 79 per unit you will have to look at what thus the circuit breaker C B 1 itself sees. So, you will have to take that 79 per unit and actually see, look at what is the contribution from the source side, what is the contribution from the d g side. So, if you do that calculation you see that your new fault current level C B 1 is actually stays 71.4 per unit. So, eventhough the actual fault, at the point of fault the current level increase the circuit breaker sees the same current as what it is of previously.

And, the contribution of the d g is 7.7 per unit. And if you look at, so there is no change in the fault current levels seen by C B 1 in this particular case which means that the timings when it would trip is not going to change for this particular case.

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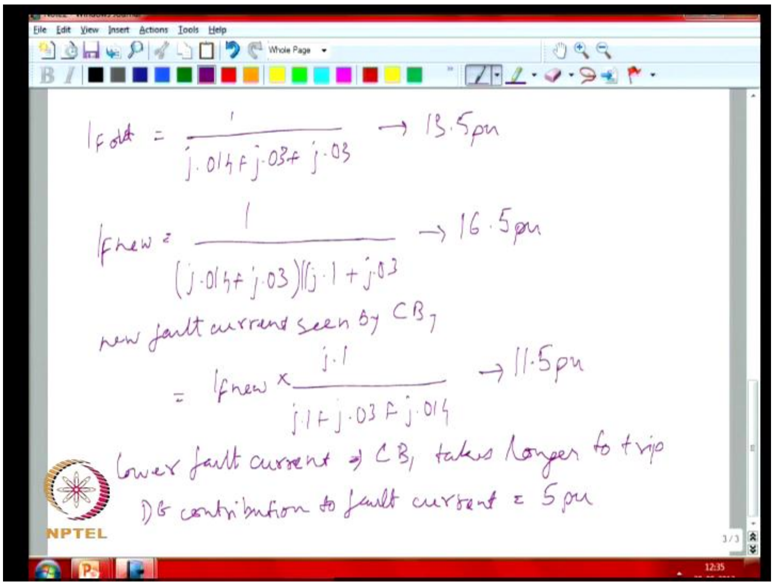

$$I_{F\,old} = \frac{1}{j.014 + j.03 + j.03} \rightarrow 13.5\,pu$$

$$I_{F\,new} = \frac{1}{(j.014 + j.03) \| (j.1 + j.03} \rightarrow 16.5\,pu$$

new fault current seen by CB_1

$$= I_{F\,new} \times \frac{j.1}{j.1 + j.03 + j.014} \rightarrow 11.5\,pu$$

lower fault current ⇒ CB_1 takes longer to trip

DG contribution to fault current = 5 pu

So, if you now then look at a second situation where you have a fault current at say location f 3, and by location f 3 it is; so, you have a fault at location downs at bus 3. Then, if you look at what your, I f old and I f new is, 13.5 per unit. And if you look at, I f new, j.014 plus j.03, and that impedance appears in parallel with your d g impedance which is 10 percent, j.1 plus j.3 which is your downstream impedance. So, your current seen by the fault is now higher which is 16.5 per unit.

Now, if you look at what is the current seen by C B 1, circuit breaker 1, in this particular case is; so it is a division of current between two parallel conductors. So, you can see that your fault current level seen by C B 1 is now 11.5 per unit. So, your circuit breaker 1 is actually now seen in a lower current in case of a fault at the end of the bus which means that it will trip at a slower rate, which means that it will take a longer duration to trip.

So, there is a possibility in that; earlier you had an idea that it would trip at with a certain time; now because you have a added a D G, now it will trip with a even longer duration of time. And in this case you can again look at the contribution of your D G; it is 5 per unit; and this 5 plus 11.5 that gives you the 16.5. So, even though the actual fault current at the point of fault has increased, the fault current seen by the protective device has actually reduced.

So, if you then look at a third location where you now have a fault at say location f 2; so, f 2 location, I mean over here at bus 4. So, if you do a calculation of fault current at f 2 in the old situation and in a new situation what you would see is the following.

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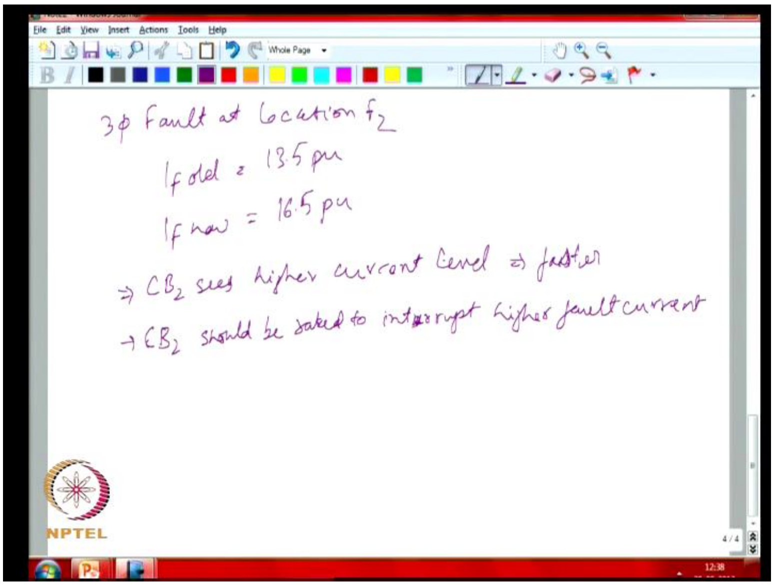

3ϕ Fault at Location f_2

I_f old = 13.5 pu

I_f now = 16.5 pu

$\Rightarrow$ CB_2 sees higher current level $\Rightarrow$ faster

$\rightarrow$ CB_2 should be rated to interrupt higher fault current

So, in the previous situation you had a fault current level, f old, situation of 13.5 per unit, now with the addition of the D G it is gone up to 16.5 per unit. So, if you then look at the current level that C B 2 needs to interrupt for clearing a fault at f 2; now C B 2 needs to interrupt a higher level of fault current. So, you have the possibility that C B 2 is capable of clearing that higher fault current level.

But, you also have the possibility that if the rated interrupt current level of that particular breaker was 15; then by adding this particular D G unit over here, you potentially needed to operate that circuit breaker to handle the higher fault current level; implies it would trip faster. So, if you had an existing circuit breaker in the system and now you added a D G, then you potentially need to increase the rating of that particular breaker.

The same situation is to for say a fault at f 4. If you have a fault over here, f 4, then you will find that the fault current rating of C B 4 can potentially be higher than what it was previously. And what can complicate this particular situation is that the owner of this C B or this D G might be 1 individual; whereas the person who is owning the other C B's that are in parallel with the system might be a third person. So, it becomes a quite complicated question of who is responsible for what. So, will look at a discussion of the implications of these issues on terms of how to add distributed generation unit; we will have a discussion about this.

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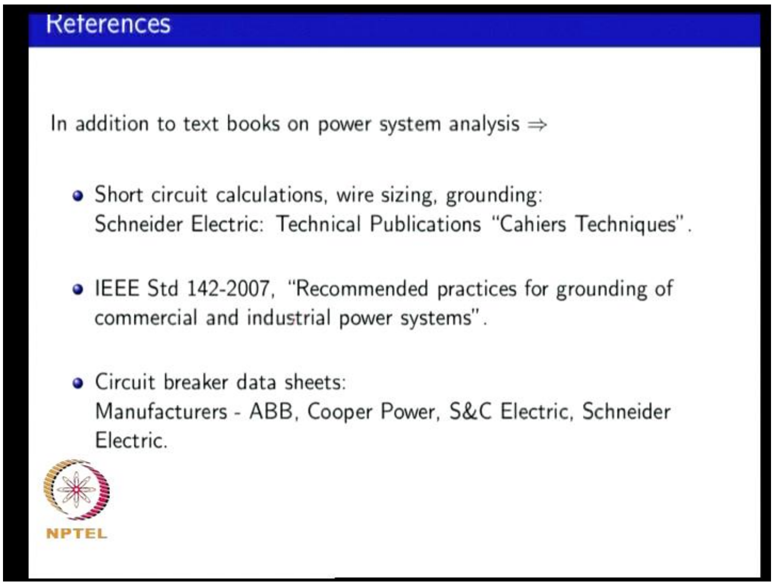

References

In addition to text books on power system analysis ⇒

- Short circuit calculations, wire sizing, grounding:
  Schneider Electric: Technical Publications "Cahiers Techniques".
- IEEE Std 142-2007, "Recommended practices for grounding of commercial and industrial power systems".
- Circuit breaker data sheets:
  Manufacturers - ABB, Cooper Power, S&C Electric, Schneider Electric.

We have done actually a bit of analysis of how to do protection and coordination in the distribution systems. And textbooks would actually provide quite a bit of background on this material. You can have lots of good material out there. You can actually look at data sheets from manufacturers; you can get, for example, manufacturers of circuit breakers like ABB Cooper Power, S & C Electric, Schneider Electric.

There are also technical notes that companies provide like is “Cahiers Techniques”. These are actually Cahiers I think French for report. So, they have I think about 100 reports on technical publications related to protection and distribution systems, etcetera. Also a good reference material is this, IEEE standard 142- 2007, “Recommended practices for grounding of commercial and industrial power systems”. This particular standard is sometimes referred to as the green book; it is a commonly referred book when you want to look at details of a grounding and protection, etcetera.

So, these would be actually good background material to actually look at in addition to what you might have in a textbook on power systems analysis. So, we will continue with this discussion on implications of adding the D G in the next class, and then we will look specifically at some other issues with grounding.

Thank you.