Power Electronics and Distributed Generation
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Lecture - 10
Consumption and Distribution Grounding

Welcome to class 10 in topics in Power Electronics and Distributed Generation. In the last class we were looking at the issues of fault co-ordination and we looked at the case where you had a existing feeder, and then distributed generation source was added to the feeder and then we looked at what is the resulting system. So, we saw that in general in a distribution system, the fault current level scan actually increase, decrease or stay the same.

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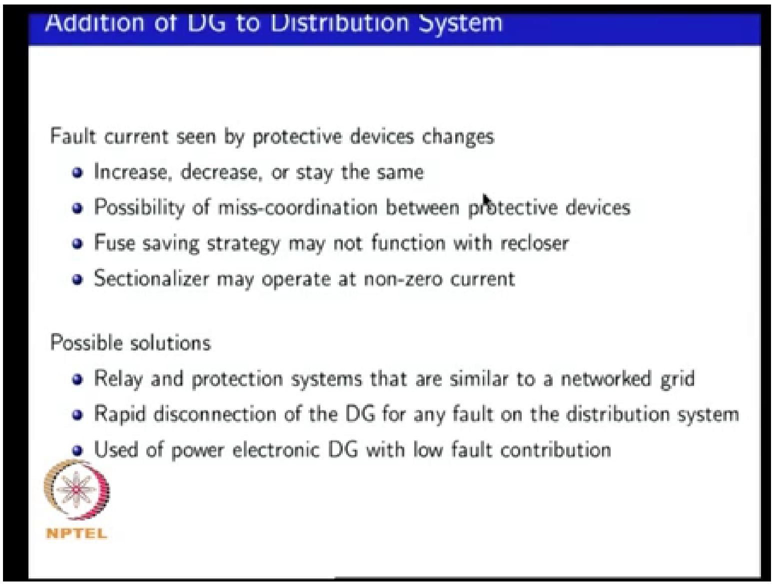

So, if you have fault current level changes, during to the addition of a distributed generated source, then there is a possibility of miss-coordination between your upstream and downstream device, because of this change into the current level. And you cannot uniformly say that the current level is always going to increase, at the protection point it can actually go in all three ways.

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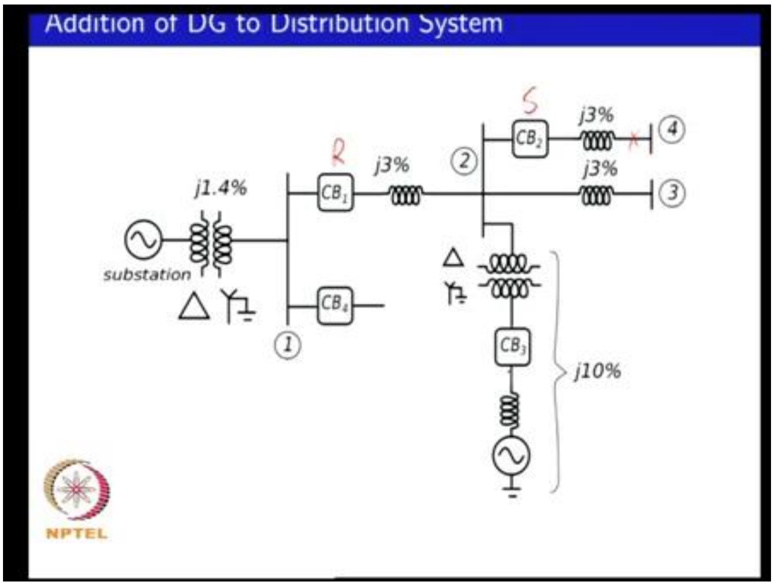

So, if you look at them in the case of for your parallel connected circuit breakers, supposing you add a DG source and then you have a parallel branch which is going into an enabled facility and that could be a situation similar to this particular circuit breaker too. We saw that the current that needs to be handled by this parallel breaker can put initially go up, so in parallel with the DG system, there can be numerous bit breakers, because you have many modes, many possible branches, that are there in parallel; and there is a possibility that the current level may go above the interoperating of that particular parallel breaker.

In which case that particular device need to be replaced with a higher volted device and then the issue was becomes more complicated, because a parallel breaker may not be owned by the person who is introducing the DG. And then you have the question of who will buy the upgrade cost is it going to be the ((Refer Time: 02:41)) provider, utility provider or the person who is installing or who was the owner of this parallel branch protective device, so there are question with that which arise.

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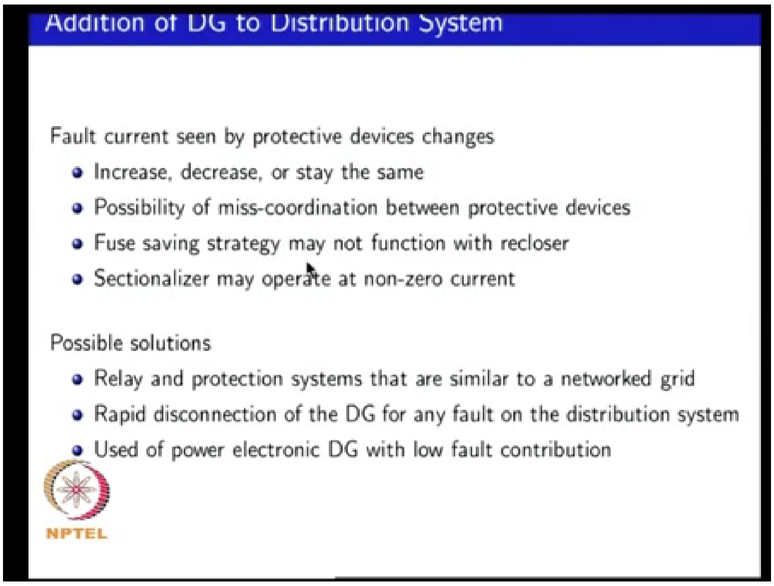

So, you also have the situation were say in because of the change in current level, a recloser which might have been say the co-ordination settings might have been done to obtain fuse saving strategy; and because of the change and the current levels with the addition of DG. Now, the fuse saving strategy may not work, so now there is a direct cost impart on the utility, because of the addition of the a DG source also for example, if you have a sectionalizer, a sectionalizer is suppose to operate with a upstream recloser.

So, if you look at the previous example, suppose CB 1 was a recloser and CB 2 was a sectionlizer, then essentially the sectionlizer would open for a case of say fault or at this 4. Suppose you have a fault at this 4, when we saw that essentially what the recloser along with a sectionlizer would do is that the sectionlizer would try to clear it temporary fault over here make use of the characteristics of the recloser.

But, now if you have a parallel DG which is sending current through the recloser, the recloser will now have to interrupt non-zero current, where it was design to interrupt a zero current level, also if the current that the DG is providing is now higher than the setting for it is counting. Then, the counting of the sectionalizer might get affected, so there is a possibility that thus the sectionalizer might mal-operate or might operate at a non-zero current.

So, for a variety of these reasons you would just need to address this particular issue and one possibility is to address the issue of miss-coordination between protective devices, you could think about upgrading or a protective devices from the simple time over current type of characteristics to something more complex like what is being used in transmission systems or in meshed network. Where you can have multiple sources and then you try to protect sections of the network by things like directional relays, distance relays etcetera.

So, that would be one possibility, but then that drastically increases the cost which may not be acceptable for a distribution system, then the second, other possibility is say to increase say to upgrade you distribute distributed generation source. So, that you rapidly disconnect the DG for any fault under distribution system. So, in this particular example that you have for any fault ((Refer Time: 06:19)) in any part of this particular system, essentially you need to rapidly operate CB 3, so that you disconnect CB 3 and rapidly in response to a fault.

Then the feeder goes back to the traditional distribution system operation and then the previous old setting for co-ordination would work. But there is always a problem in situation such as this that you have to operate this CB 3 extremely rapid which means that it is more prompt towards opening; under nuisance conditions is a circuit breakers have a finite number of opening and closing before it need servicing, so you would need much higher maintenance for the circuit breaker.

So, just being able to rapidly open the breaker, may not be again sufficient and all or in all situations. So, another way of addressing this particular situation potentially was instead of having traditional say voltage behind a impendence type of DG, if you can operate your DG such that you have it control more like a current source were. Now, your current injection level during fault is almost the load level current, than your contribution of fault current from DG is now much lesser this is what is more typical in a power electronic type of DG, where often if you look at existing power electronic systems you have some disturbance coming from the grid, you power converter might actually just trip off. So, many times the contribution coming from you power converter might be extremely small, so if you could have a power electronic DG, rather than a machine type of DG. Then that might address this issue to some extent, but again this has a cost impact I mean the cost of power electronics is higher than cost of machines.

So, ideally are then the challenges can you make the cost of a power converter as low of that a machine. So, you can see that the variety of challenges in when you connect DG distributed generation source to the distribution system and there are possible solution, but it has to be addressed in a clean manner and meaning of this problems are actually non technical like who is the owner of what particular device which is not a clear technical problem. So, you will have to actually look at it in multiple factors rather than just a technical way of looking at the electrical system.

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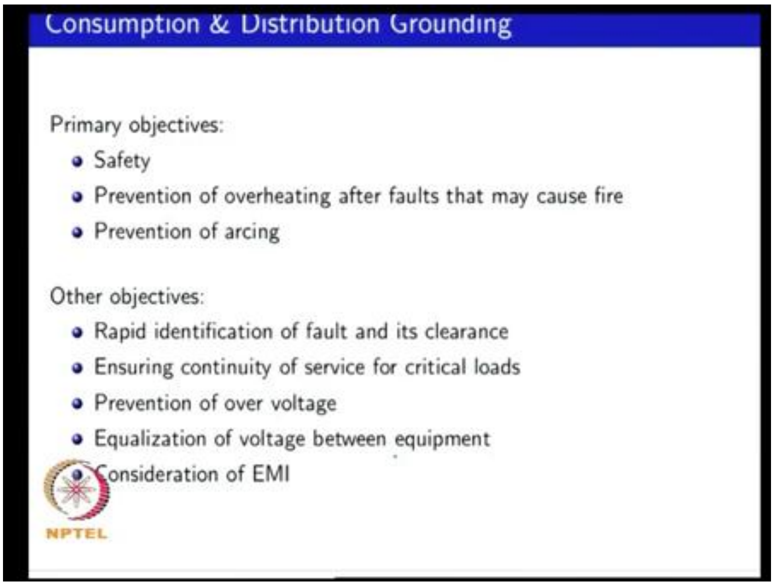

Now, we will look at any another aspect of the distribution system important factor again, it has implications when a DG gets connected and that is grounding. So, if you have a any electrical system you would ground it and the primary objective of grounding of a system is actually a human safety, someone should not touch electrical system and get a shock you should not get electrocuted.

So, human safety is a very primary objective, if you touch a cabinet you should not get a shock, so you should have low touch potential and if you also want to prevent over heating of conductors, after you have a fault you can have over current and if the current level stays high for a longer duration and the conductors would heat and have electrical fires. So, to prevent electrical fires is a important criteria and to prevent both high touch potential lasting for long duration and for insuring that you do not create over heating you need to actually rapidly disconnect the fault.

So, even for there is a short o potential for a fault duration that duration is very small, then the resulting damage can be quite small, also another important objective is say prevention of arcing, when you have a fault always there is a chance you might have vaporization of metal very at very high current levels, you have lot of energy in the arc. And people who might be standing near the arc might get severe burns, electrical burns is a very severe category of burn and to prevent that you want to actually ensure that the energy in the arc is kept minimal, so you want to prevent electrical the energy in arc falls.

The other factors that are important for example, rapid identification of the fault and its clearance is a important aspect for many equipment ensuring the continuity of the electrical service is a important prime factor. So, if you have a fault in one equipment and if the equipment is critical and if the equipment goes down, there might be a consequences of shutting down the particular electrical section.

So, you might have critical equipment where even after a fault you might need to ensure continuity as service, so sometimes the need for continuity of service might conflict worth the need for rapidly clearing the fault after identifying it. So, you need to have a definite strategy of what exactly is more important for the portion of network that is being considered.

Also, if you look at equipment during fault there is a chance that the phases which are not faulted with potentially experienced voltage and voltage can cause damage to insulation and you want to ensure that you do not have a voltage, because of the way in which you have grounded, your grounding also has a impact on equalization of voltage between multiple equipment. Suppose you have especially when you are looking at communication, computer networks etcetera, you have equipment in one implication trying to communicate to another particular location.

And you want to ensure the integrity of signals. So, how you ensure what is reference at the two locations would become a important factor for ensuring equalization of voltage and the integrity of communication. Also things like how you ground your cabinet can have a impact on EMI, both EMI susceptibility and the imitations scan being impacted by the way in which you have grounded. So, overall grounding is a important aspect of a any system that you’re building or how you operate the system this is a important factor.

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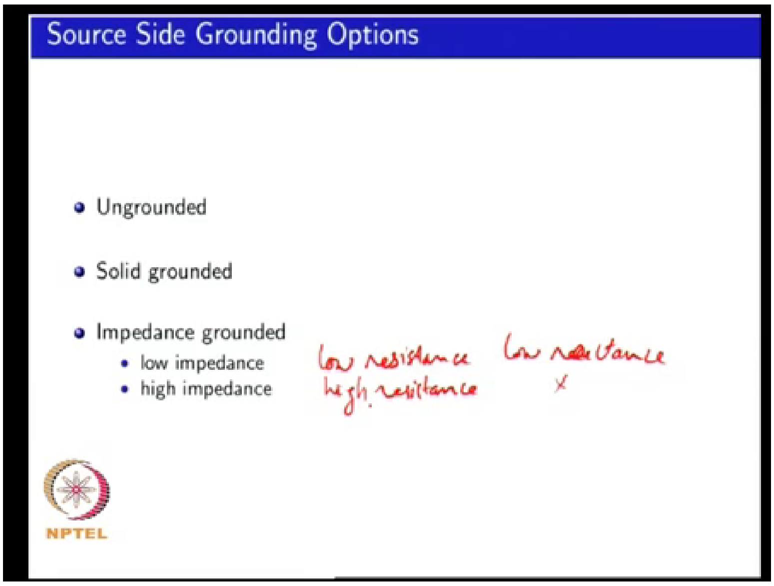

So, if you look at the grounding of a distribution system you can think about what are the possibilities of the source and the source end, you can have an ungrounded system and when you have an ungrounded system, you might have Y or section of transformer which is with a insulated neutral or you might have delta connection at your source. So, ungrounded is one possibility, you can also say have solid grounding essentially, it means that you can have a wide transformer with a neutral solidly connected to ground can have a zigzag transformer.

So, with different possibilities you can have a very no intentional impendence added between your neutral and the ground is what is solid grounding, then you had the third option which is impendence grounding and when you connect the impendence between your neutral and ground, then the question is what is the impendence your connecting there are two possibilities, one is you have a high impendence or you have a low impendence.

And then there are further two possibilities whether you are connecting a resistance or a reactance. So, you can have a high resistance grounding, low resistance grounding, so or you can have a high reactance or a low reactance grounding, high reactance is not that common there are some special cases, where people talk about resonant grounding etcetera, but that is only for special cases where you have a lot of control over the parasitic capacitance to ground. The common impendence grounding methods are high resistance or low resistance or low reactance.

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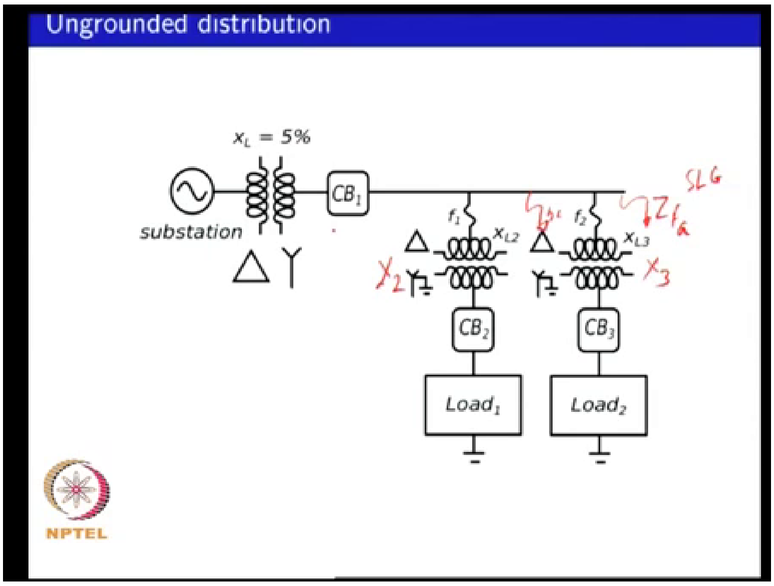

So, we will look at a case of when you have inflated or ungrounded system and we will assume that you have a delta Y transformer and the y point is not grounded and say you are feeding two modes L 1 and L 2 which in turn are connected through delta Y transformers and say you have a transformers X 1 and X 2, X 2 and X 3 and so you have a fault to ground occurring on the feeder say with fault to dense ZF. And you want to look at what would be the result of such a scenario in this particular system and we are looking at a single line to ground fault which is common type of fault that can occur in this system. So, to analyze this we will draw the sequence network to analyze this particular fault.

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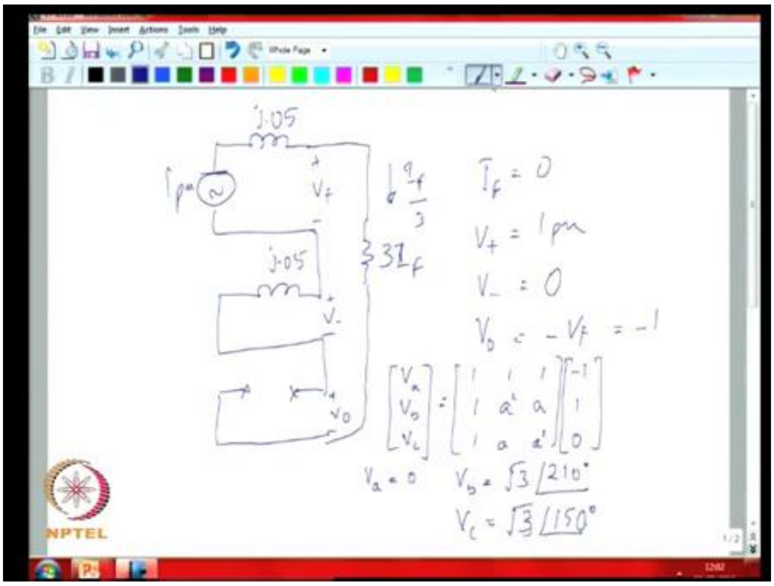

So, you have your positive sequence network, so in this particular case we had assumed that you have a transformer with 5 percent reactance and the zero sequence network is actually now open circuit, because it does not grounded. So, if you look at the there can be no fault current in this IF should be 0 in this particular case. So, you have V plus is equal to 1 per unit and V minus is 0 and V 0 is 1 minus V plus minus 1, so then if you look at your phase voltages using the sequence transform.

So, your VA is 0 which is what you would expect, because that is the phase that has a fault, VB is root 3 and so you can see that phase b and c are conductors seeing line to line voltage with respect to ground and but if you look at the loads L 1 and L 1, the loads L 1 and L 2 would not see any disturbance, because it is connected through transformers and the transformers block the zero sequence voltage.

So, the loads do not see any disturbance, but the feeder would see a some phase b and c would see a increase voltage voltages and the amount of our current is actually zero which means that you can actually continue to operate under that condition for actually a long duration of time. The main concern of this particular situation is that the phase which is which has a fault would typically have some level degree of arcing which means that whatever conductor what grounded would have arcs and that arcs could periodically act like a switch which is on or off between depending on whether there is a nature of the arcing.

And your parasitic capacitances in your feeder along with your physical inductances of your circuit components would potentially have a resonant oscillations, where with a fairly q factor because there are no loads that are now directly seen for this particular zero sequence voltage and then essentially would have higher phase voltage which can potentially now be much higher than the root 3 times of the voltage, that we saw and you can damage insulations.

The people almost never use ungrounded systems, what would be more common is to use a high resistance grounded grounding system where the resistance would help dampen out oscillations and provide the required damping and also one need to keep in mind the type of old voltage protective devices, that are used in the systems, suppose you have a surcharge resistors which are rated for light to neutral line to ground voltage of some with some particular margin.

Now, if it is saying 1.7 times the nom nominal voltage, then you need to actually on a longer term basis you need to ensure that your over voltage protective devices are rated for the appropriate level of voltage. The second thing is to consider is if you have one fault saying occurring on phase a and now you have a second fault now occurring on phase b or c or maybe even on at a neutral, then the resulting fault would be now having much higher volt of current levels.

Because, it acts like a phase to phase fault and then the over current would immediately trip the breaker and you do not want to ensure that you want to ensure that the fault which has occurred first is attended to at some particular point before the second fault occurs in such a system. So, you would like to have some sort of a monitoring system which monitors the voltage and ensure that there is a good availability of and one of the attractive features of this particular case system was that even after the force fault, you had a continuity of service to load 1 and load 2.

So, with a high impendence or grounding people try to make use of the ability for the system to be both available after the first fault, but at the same time you need to have insulation monitoring and residual currents measurement etcetera to ensure that some maintenance in being done, and so that before the second fault occurs, the first fault is ideally found and cleared.

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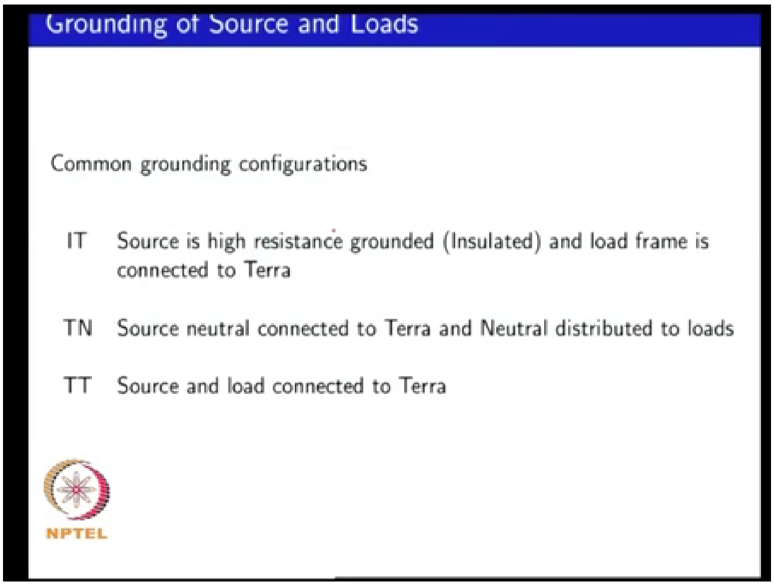

If you look at the grounding of a typical system, one should also not just look at the grounding of the source alone, you have to look at both grounding at the source and at the load. This is important, because if you look at physical distribution system, there is a geographically the source might be a dist distribution transformer at the end of the street and the loads might be individuals houses all along the street.

So, there is a big separation between where the load is and where the source and unlike say if you have a printed circuit board your power supply and your load on particular circuit board is on the same board and geographically much closer together in distribution system distance between a source and the load is actually much larger, so you have to think in terms of both grounding at the source and grounding at the load.

So, based on the grounding at the source of the load some of the common ways of nomenclature are configurations for the grounding system, one is a IT system, where the first word I reference refers to the first word Insulated and the word T refers to Terra. So, your source is a higher system is grounded or the neutral is insulated from ground and the load frame is connected to earth or Terra.

That is one possibility another possibility is the source is connected to Terra, through no intentional impendence and the earthing from the source is now your neutral point is distributed to the load and this is this configuration is called a TN configuration. Also you could have power volts, earthing points both are the force and at the load this is called a TT configuration where both the source and the load is connected to Terra.

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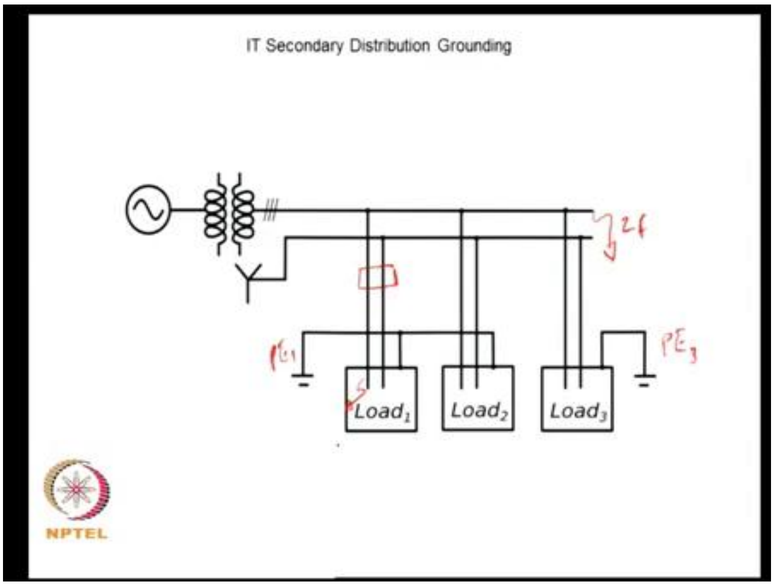

So, and these are important especially considering the secondary distribution network, so this is the low voltage network which comes from your distribution transformer which might be 11 KV to 450 volts and then coming to the individual homes or establishments and an example of a ungrounded secondary distribution network is a IT network, where you can see that the neutral is insulated from the ground and the loads have their own local grounds.

So, you can have a say a power earth for say load 1 and 2 may share up on it load 3 might have its own power earth at a different location. So, these are essentially grounding loads, that are connected to the ground, so essentially load 1 is cabinet is connected to power earth, load 2 cabinet is connected again to power earth, load 3 cabinet is connected to its power earth, there are three wires plus the neutral from the transformer goes into the load, so your loads maybe three phase or single phase.

So, in this particular situation this corresponds to the situation were, if you have a fault say on line to ground basis, then you can potentially continue to operate with the loads as we saw in the in the ungrounded system, but say suppose instead of the fault occurring at this particular point could also have a situation. Where say the fault occurs say in load 1 and in which case you need to ensure that the load 1 is disconnected is before, because there might potentially be a second ground fault maybe at some other point in the system.

Now, if you want to disconnect load 1, because there is no high current after the force ground fault, you need to ensure that you need ground fault detection capability at which particular load and not just that your circuit breaker, should now have the capability to disconnect all four conductors. So, it is not a just 3 port circuit breaker, is a 4 pole type of circuit breaker, because even if you disconnect say the three phases r by n b by load 1 and say you have a fault in the load.

Where, phase r is connected to the cabinet in load 1 suppose you now have a subsequent fault in load 2, that particular fault can actually propagate through the neutral in through load 1. So, that to ensure that load one is fully disconnected you have to actually also disconnect the neutral. So, the type of circuit breaker that you would use in IT network would be different from what you would use in some other type of grounding method network.

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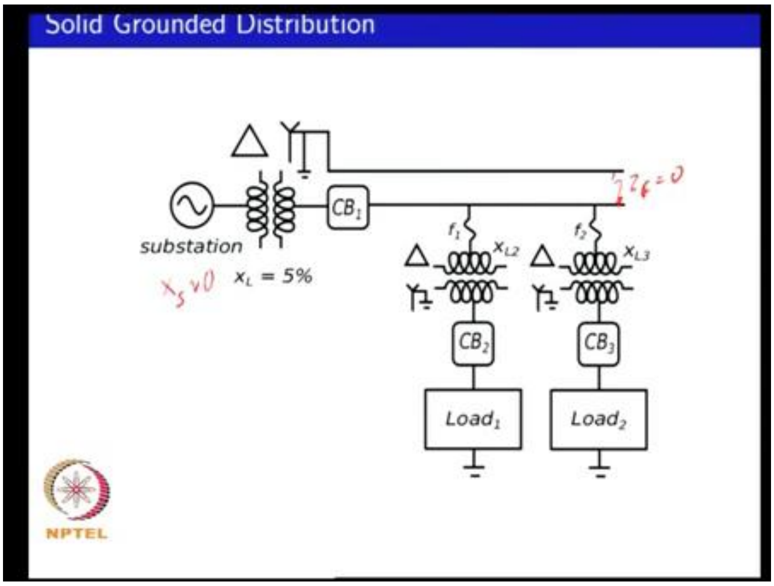

So, the next possibility is say instead of having a insulated or an ungrounded source you could actually have a solidly grounded source. So, this is an example where you have a delta Y transformer which is acting which Y is now your source and the neutral is now connected to ground through no intentional impedance and for the analysis, we assume that the source side impedance is 0, and whatever is limiting the current is essentially the transformers leakage and suppose you have a fault between any phase to ground.

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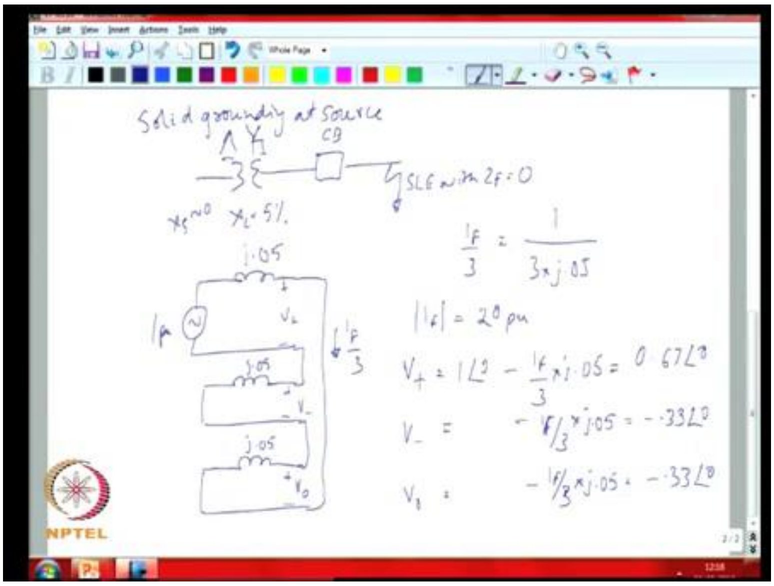

We will assume say a phase to ground side fault, then essentially in this particular case you can then look at what is the resulting voltages and currents, we will assume a source should be circuit breaker. So, your sequence network is essentially IF by 3, so you are for count level for a single line fault is 20 per unit. In this particular case, we have assumed that you are your source impendence is 0 in which case you are 3 phase fault current and your single lined current fault is actually going to be the same.

If your source impendence is not 0, then your single lined ground fault current with a delta Y transformer with Y which is solidly grounded, the single lined ground fault current can actually be higher than the three phase fault current, because the zeros sequence impendence back at the source is not captured in the zero sequence or network. So, sometimes people might consider adding a neutral grounding impedance for the transformer.

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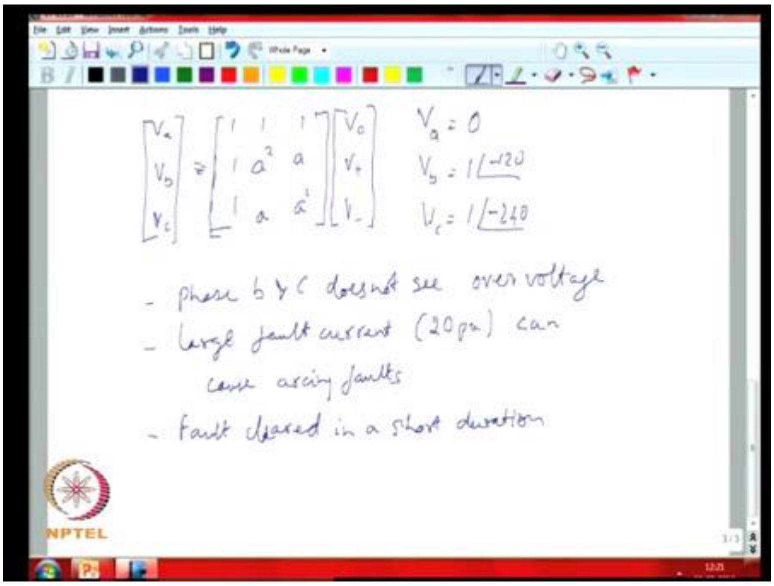

Even in this particular case, but to look at the analysis of this particular situation you can then look at what is the is resulting voltage V plus, so V plus turns out to be 0.67 and angle 0, your V minus, so we can calculate our phase voltages, so VA is 0. So, we can see that the in this particular case, when you have a solid grounding your phase b and c does not see a voltage, but you can say that your fault current level is quite large and in our example, it is 20 per unit can cause arcing faults.

However, you can see that even though the fault current is quite large and the current level is large implies, that your circuit breakers would act on a instantaneous basis, so the duration of our current would be a shorter, so your fault is cleared in a short time. So the thermal damage may not be that bad, but you can have arcing for your short duration and is a high current flowing when there is a singled line ground fault.

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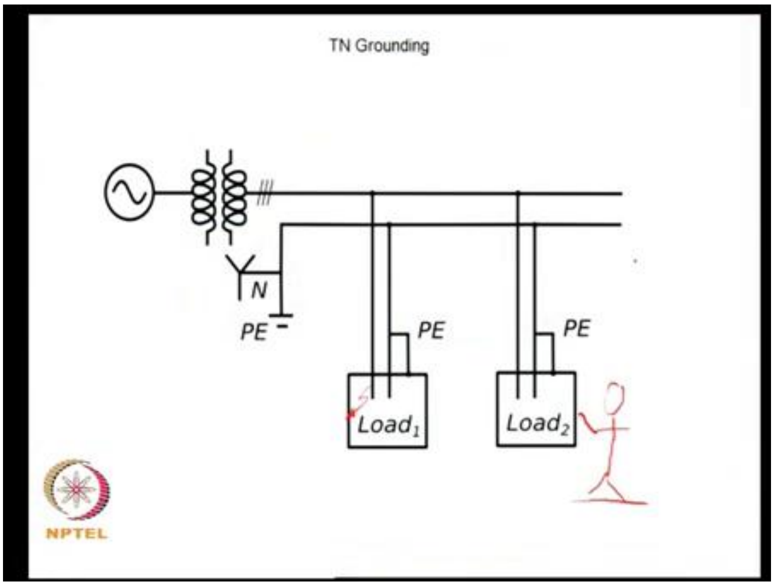

So, if you look at them an example, system were you have a solid line solid line to ground and in solid grounding of the source, an example is that TN network, where the Y point of your transformer is solidly connected to power earth and the neutral is then distributed to all the loads and so that the neutral is now expected to be up low voltage at the ground voltage, because it is connected in a tight manner to power earth.

So, your loads are load 1 and load 2 cabinet is also now connected to the distributed neutral, so you have a situation where you can say for example, you might have a fault in load 1 and you will now have large current flowing between phase conductor and returning back to the source through. This neutral wire and the current level is quite high and one thing, it is it can be quite difficult to distinguish between now unbalanced load current and flowing through the neutral and ground fault current which is now coming through the neutral because the ground conductor is being shared.

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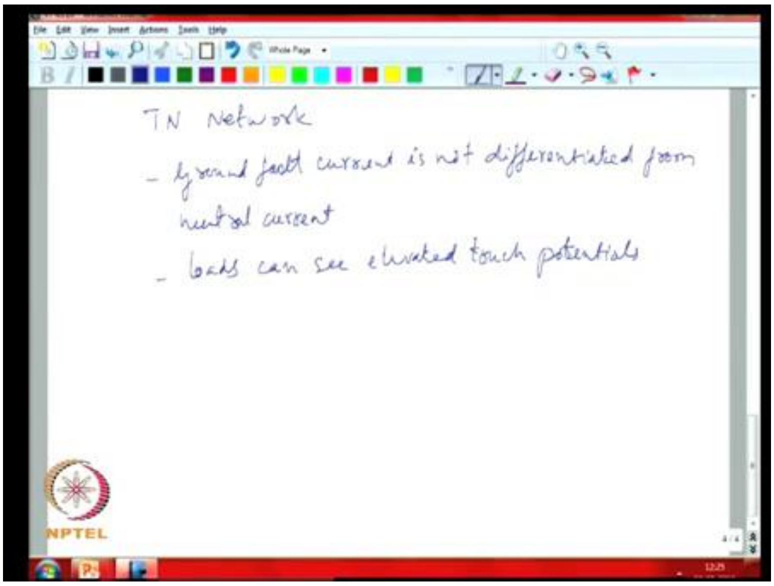

Also, if you look at the network suppose you have a considerable say distance between your source and your load, then your impendence of the neutral conductor might be your not negligible; that means, if you have a high current it is now flowing through this particular neutral conductor. Then the phase who has actually having this hand on say a cabinet, we will see a high touch potential.

Because and the touch potential is now being across the across the network, but it is a typically for a short duration, because we saw that the current level is quite large which means that your instantaneous trips would operate. So, for short duration you would have elevated touch potentials, so one issue was this neutral current is not being differentiated from load current. So, one way of getting around that particular problem is to have something called the TNS grounding.

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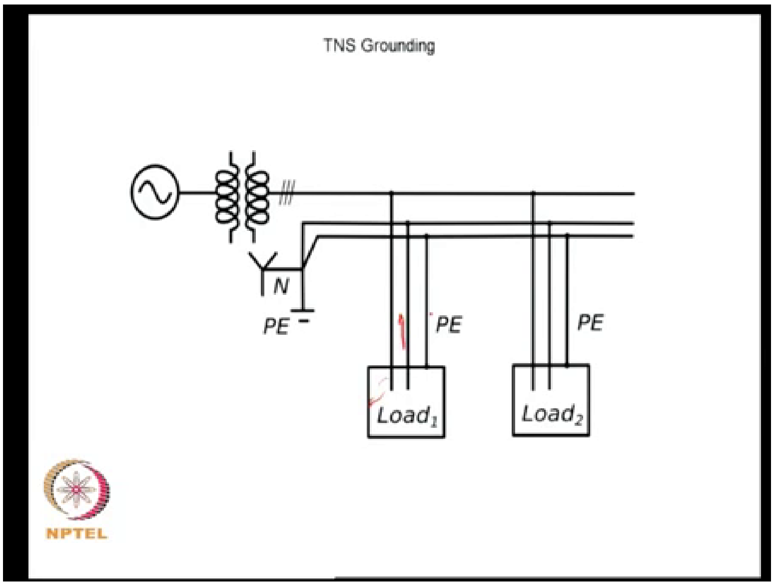

Where, the neutral and the power earth are now separated as conductors, so your unbalanced load currents will flow through neutral conductor and only your fault current will flow through your ground conductor. So this is a TN with separate ground and neutral conductors, here it is now possible to differentiate between a case of unbalanced and ground current, but here again you can see that immediately the cost is high for distributing a power in three phase, when you have five conductors.

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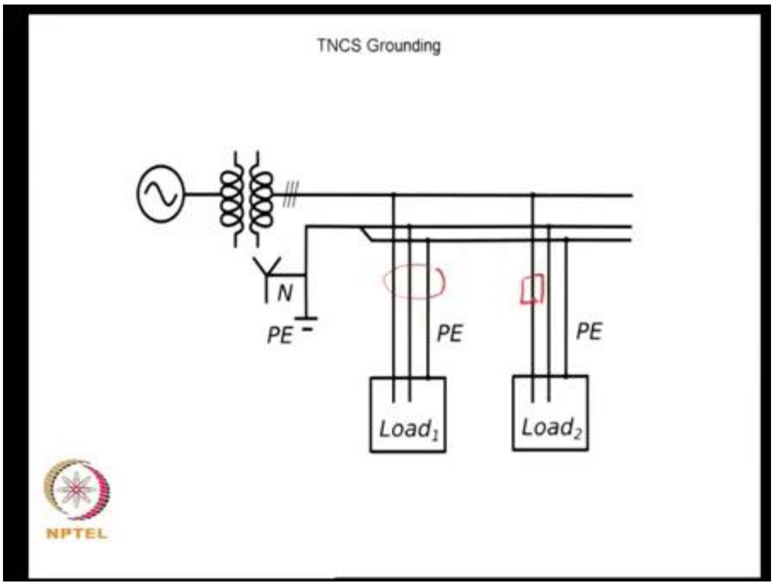

So, then you can say maybe you can have some combination of this, where you meet for some distance, you will have a common say a conductor and further behind, it you can have separate conductors for your network. So, you might have some of this is called a TNCS network, where there is TN combined some section and then separate for the rest of the section. So, as long as the fault current is being monitored say at different locations, where you have the separation then it is possible to look at the sum of the currents and your and phases and along with your neutrality to identify whether there is ground fault, but then you do not have to distribute your loop your ground conductor.

If, I conductors all the way is combined to some extent and then just separate it. In this particular case unlike, the case where you saw in the IT type of distribution networks, it is not sufficient to have a circuit breakers on a three power basis. Because of your solid grounding each phase any of the phase would have a ground fault would see the elevated current and then it would get disconnected from the source and your neutral in ways will be solidly connected to ground, so a three pole circuit breaker would be sufficient in a TN type of network, unlike the IT type of network.

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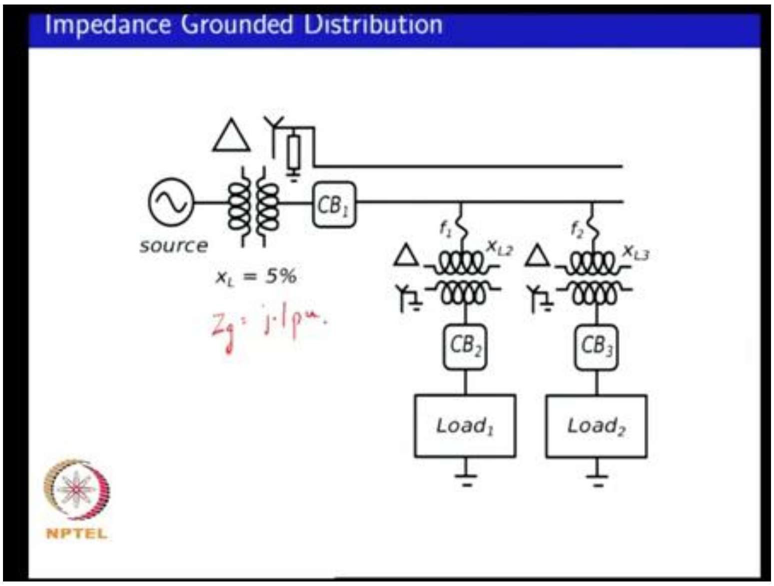

So, next the next possibility of having a grounded grounding in your network is to have a impendence between your neutral and ground. So, you intentionally add resistance reactance to the particular network and then we will look at resulting situation what would happen in this particular case, so in this particular example, we will look at a case where you are actually adding a reactance of j point 1 per unit.

So, the reactance is quite small, so this is a low reactance type of grounding which means that the ground current in this particular case is high, you might select the reactance that is just high just high enough to trigger your instantaneous protections, but to this is not too high that you might have severe arcing damage. So, you get the advantage of the high currents allowing a device or protecting devices to trip rapidly, but at the same time currents not becoming so large that you would have a dangerous arcing at the point of fault. So, your fault damage can be reduced in this particular case, so if you look at the resulting sequence network.

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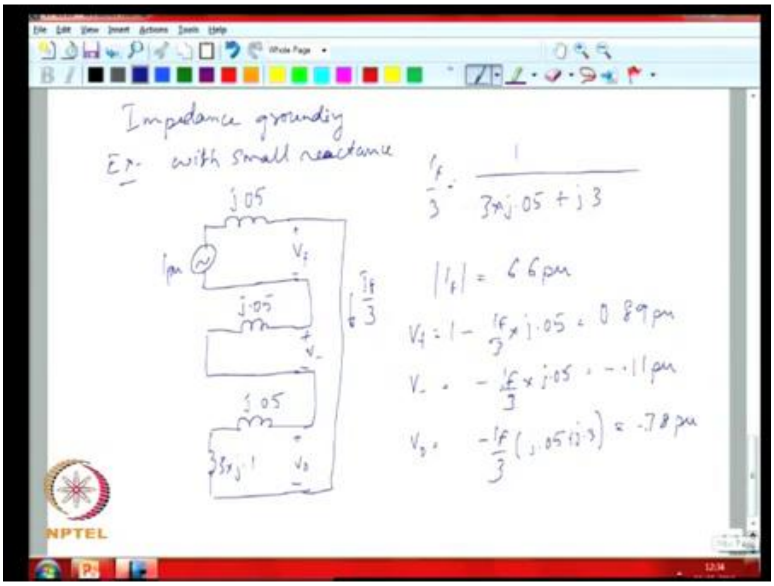

So, we look at impendence grounding and you look an example of j point 1 per unit as we mentioned. So, if we look at what would be the resultant sequence network, when there is a fault, so the positive sequence network is this is a negative sequence network and then assume ZF to be 0 and the current here is IF by 3. So, you can see that your fault current level has come down, when we had side grounding plus 20 per unit, now IF is 6.6 per unit and then we can look at a resulting voltage V plus.

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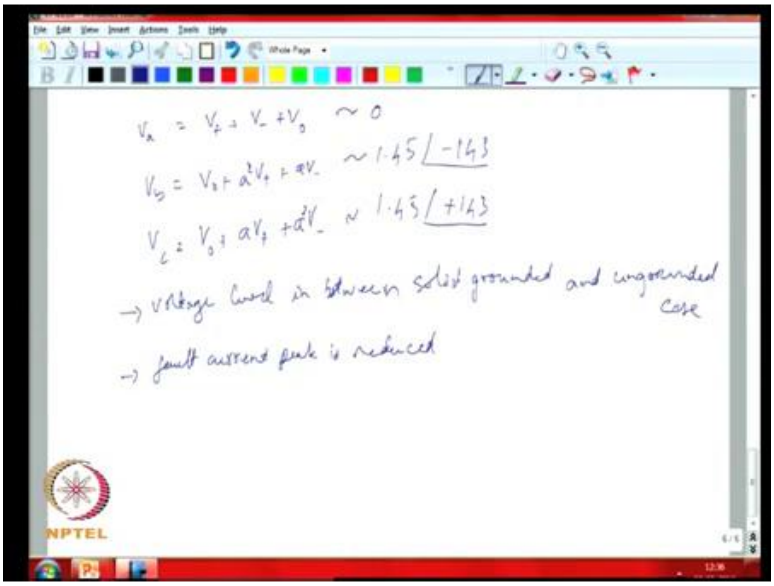

And then you could calculate what your phase voltages are and that works out to be nearly 0, V b is works out to be 1.45 per unit at angle minus 143 degrees, V c is so you can see that the resulting voltage levels its somewhere in between what you would get in solid ground situated ground at situation and ungrounded system. So, in ungrounded system you have 1.7 per minute voltage.

Here in a solid grounded case you have 1 per unit, here you have about 1.5 power unit as your voltage that is seeing on a phase two ground basis and if you look at your fault current level, so your peak fault current level is reduced. So we will we will see that you can have advantages of the two case as well as the now connecting a impendence to your neutral, again depending on what is the particular way your application might have different ways of connecting the grounds.

And we will continue with this discussion of ground in the next class, but you can see that these are important aspect of any system design or even equipment design to ensure that whatever your design is actually a safe and can be used in a manner which would not cost any danger to the potential user of the equipment.

Thank you