Power Electronics and Distributed Generation
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Lecture - 12
Modeling of islanded distribution systems

So, welcome to class twelve of topics in power electronics and distributed generation. In the last class, we were talking about grounding of distribution systems.

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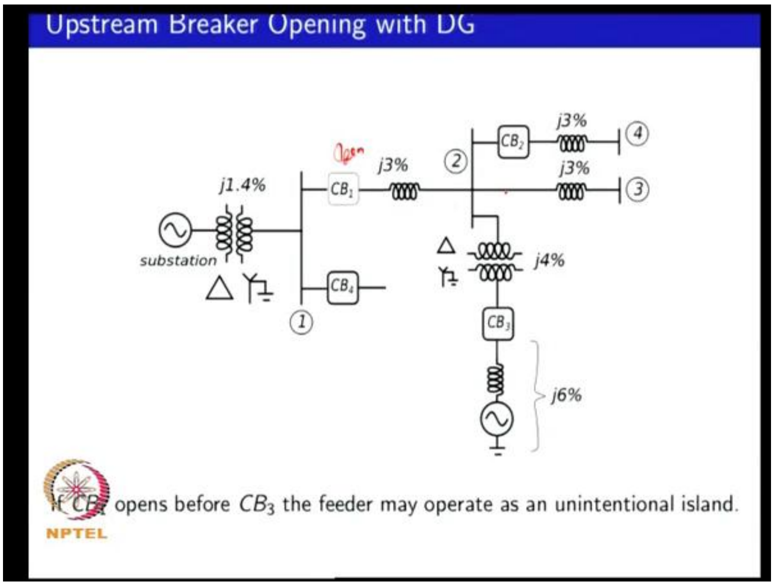

We saw that in the example that we were discussing in class that there is a possibility where you might have an upstream breaker in your circuit opening. When a d g is downstream, d g is still connected to the system and there is a possibility that this connected d g may operate and continue to excite the feeder even when upstream breaker has opened. This particular situation of upstream device opening and the rest of your distribution system operating being excited is called an unintentional island. Here, for some unintentional reason an upstream breaker opened, but the d g if it can actually stay connected and provide power to the loads on the system, it will continue to actually excite the feeder.

We will see that islanding is important issue when we look at distributed generation, so when we talk about islands in a distribution network in geography an island is a land body, which is a disconnected from the mainland separated by water.

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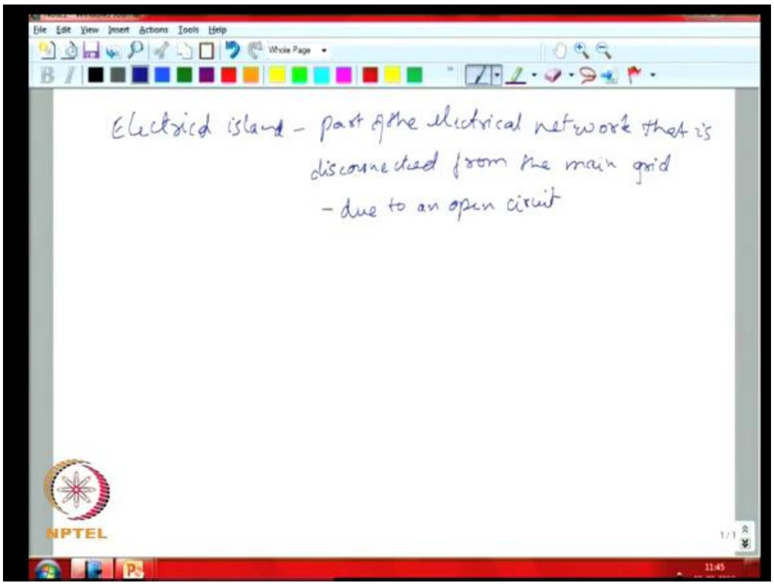

So, if you look at a electrical system, electrical island is essentially a small part of the distribution electrical network in the distribution system and this the smaller network is disconnected from the main grid due to a open circuit. A typical cause of the opened might be a upstream breaker opening or a fuses bank can be just a wire physically breaking. So, that can be a variety of reasons why you might result in a island commonly in situation would be a breaker opening and electrical island in situation, it can be of two varieties one is you have a intentional island or you can have a unintentional island.

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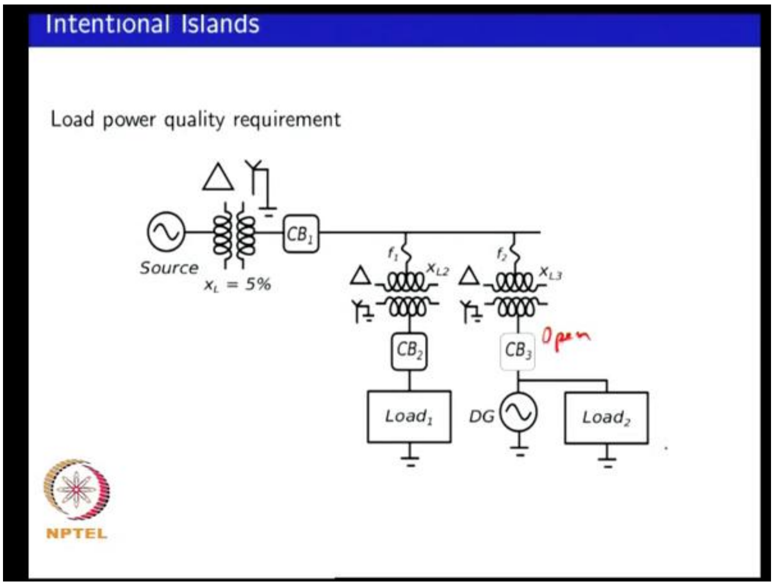

So, if you look at intentional island, the reason why one would typically have a intentional island is for a reason of power quality and the idea is you open say a breaker, which connects to the main grids. Then, your source can actually feed a local load when there is a poor power quality in the main grid. So, you want to isolate yourself on the main grid and continue to feed higher quality power to your load in a dedicated manner, so the reasons why you intentionally operate as a island.

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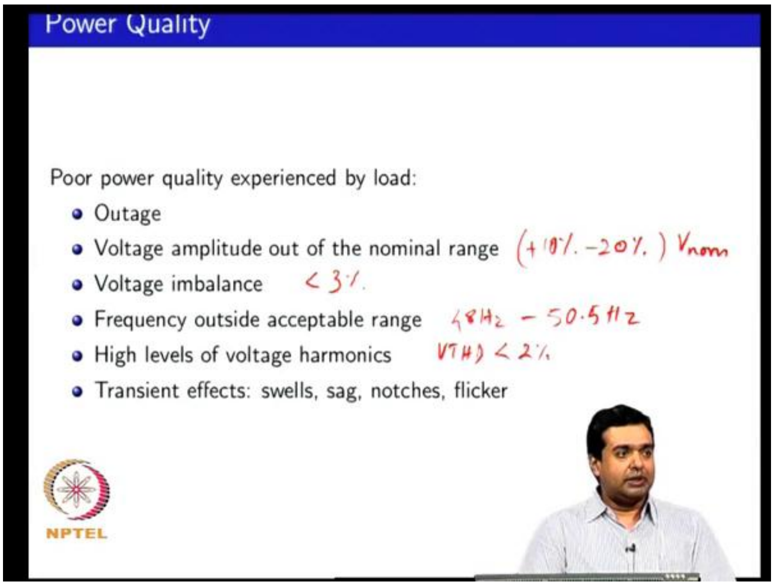

So, the question comes what do you mean by power quality or is more often measured by what you mean by power quality being poor as seen by the load. So, a load seeing poor power quality from the supply can be for a variety of reasons the primary reason being that there is no supply at all. There is an outage and you want to actually feel your load, so that is a primary reason if you have if you are having a electric supply you expect your voltage line to neutral voltage to be 230 volts some nominal voltage. Typically, a band around a nominal might be acceptable you might have your voltage say plus 10 minus 20 percent band.

There are nominal, might be considered acceptable power quality to go beyond that, you may want to disconnect rapidly you might have say voltage in balance in your voltages might be closed to nominal. Your fuses may not have equal amplitude voltage or there are may be some phasors, it depends on the type of load.

I mean say for example, if you are feeding similar phase loads, then the imbalance may not be a measure thing, but if you are feeding say induction machine load. Then, even a imbalance of 2 percent would be considered unacceptable and we can see why say 3 percent might be considered unacceptable a typical induction machine has leakage in the turns in the range of say 15 to 20 percent. So, a 15 to 20 percent imbalance would mean that even at no load, your current drawn, imbalance current drawn would correspond to almost full load when there is a 15 percent imbalance.

So, if you are having something like 3 percent imbalance, it means that you are having 20 percent of your current coming in because of your imbalance. So, you might have a service factor of 20 percent on a machine, so that may be the maximum that you can tolerate on a continued basis. So, your imbalance percentage is typically much tighter then what is your acceptable voltage amplitude also your frequency might be outside what is your acceptable range. I mean depending on what is the process that you are trying to do you might be trying to do some speed control there might be some machines which are susceptible for mechanical resonances.

So, if you are having something like a computer power supply it might be able to accept a wider range of frequencies, but if you have fans mechanical loads you might need a tighter range of frequencies. Locally, we might say 48 hertz to 50.25 hertz might be considered something which might be acceptable if you go outside the range you might want to disconnect again be coming on your load what is expected at the load and your nominal frequency is 50 hertz. Another thing that you might say would be a situation of poor power quality is when you have a harmonics in your load, you have distorted wave forms people measure harmonics in wave forms in terms of total harmonic distortion.

So, an acceptable TSD level for your voltage might be less than 2 percent, so you want to make sure that your voltage that is being supplied to you is not very highly distorted. It depends on how sensitive your load is you might have some tighter requirements or very sensitive type of load, you can have transcend effects, which will effect power quality. An example is short term duration of voltage amplitude increasing or a short duration where the voltage dips there is a sag or a swell. You might have notches in the wave forms if you have equipment such as power converters connected to your point of common current.

You can have flicker in your load if say someone is operating electric arch welder in your a same street as where your living then chances are you will see a lot of flicker in your voltage. So, you can see that as lights that are growing brightly and then it becomes dim and then growing brightly some people are extremely sensitive to variation of light intensity. So, for meaning of this power quality reasons you might want to intentionally disconnect from the grid.

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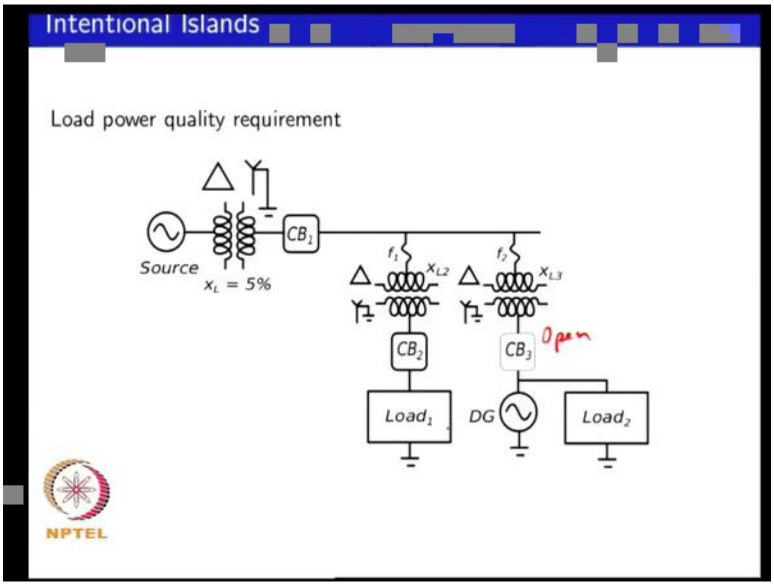

To open a breaker and then feed your local load from a d g so that when the power quality is poor, you have your critical load being fed from a d g. When the grid power quality comes back to an acceptable range you would then close the circuit breaker and operate in a normal condition and the common systems that use such a property are UPS systems, gensets. They all operating in this particular manner where you are addressing power quality by adding such components.

You can also have a situation where the to address power quality it may not be just your own facility breaker that you open you might for some reason be capable of opening a breaker at the network and providing poor power. Improved power quality on the feeder itself it depends on what are your distributed generator set has the capability to provide that level of power both real end reactor also, whether it can operate stably with such a big network wider network. Well, you could also have other technical conditions which might be need to be satisfied is this d g capable of clearing faults in your neighboring load.

There may be non technical issues such as what is an economic benefit of a providing power to your neighbor or there might be legal questions like who owns different aspects of the system where the entity might own the lines. The one entity might own the d g another entity would own the next load so a number of issues to be addressed. Well, if you are trying to operate in as a intentional island on a broader sense and people refer to such a situations as micro grid at the distribution level not micro grid at within a small facility, but micro grid at the distribution level. So, if you look at then the other situation where you can have an island.

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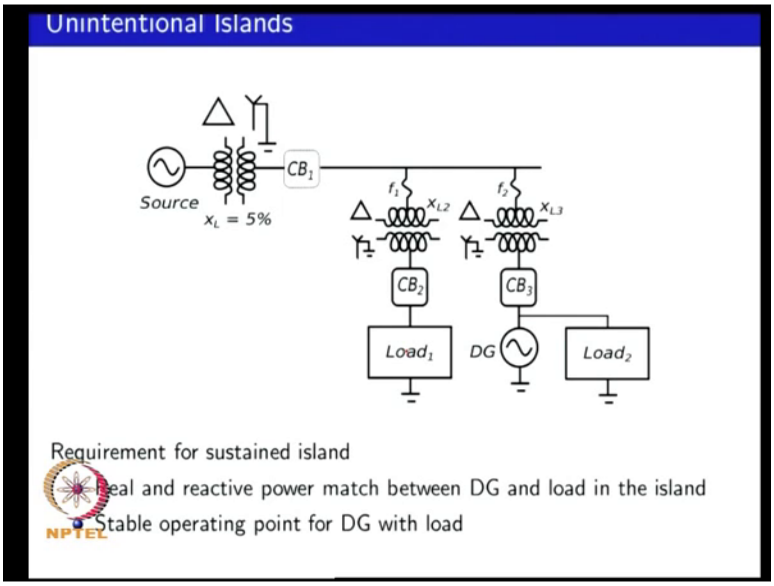

So, what we discussed so far was when you have an intentional island you can also have the situation where you have unintentional island and unintentional island as we just saw in the example that we discussed. It is not because you intended to actually open a upstream breaker, but it opened for a variety of reasons and for some unintentional reason now your d g is exciting the feeder, the common network the feeder network and it can lead to aa variety of problems. We will and even for forming a unintentional island you have requirement that the d g that you have should be capable of for a providing the power for your neighboring loads.

So, if you are load total load on the feeder is of the order mega watt and your d g is 1 kilo watt, obviously it cannot form island. So, you are talking about capability of your d g and your load to be similar both in terms of real and reactive power requirement being able to match that and for the unintentional island. We operated in a sustained manner you need to have a stable operating point of the d g and the load, so there are variety of reasons why a unintentional island is not desirable.

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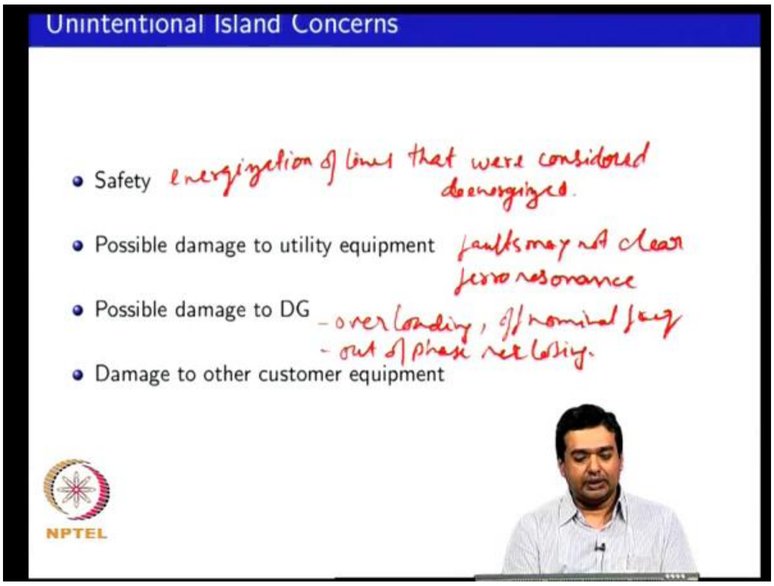

The primary reason is safety concern typically when you open a upstream breaker in a distribution system the assumption is whatever downstream of it is de energized which means it is potentially safe to go and touch. Now, you have a d g system you open a upstream breaker now potentially the downstream system is still energized. So, if a person line man goes to repair the downstream system he can potentially get a shock he can get electrocuted so safety is a measure concern. So, you can address this issue in a variety of ways you can try to have live line type of a repair then go to larger transmission system you can do repair of the transmission system components without de energizing the line using people in fire etcetera.

That makes it more complicated operation more expensive, so safety is a big concern when you are having a possibility of a d g source forming a unintentional island also you can damage the utility equipment in a unintentional island. We saw that the faults may not clear the capability of the d g to provide fault current to trigger a protective device might be lesser than the main grid. So, we might have the change in protective coordination settings as we saw in our example you can have a sectionalize at a open under load. You also have the possibility of what people refer to as ferro resonance, so on a distribution feeder you would have capacitors could be for power factor correction and then when you are connected with the grid you have those capacitors.

You are magnetizing branches of your transformers etcetera which are connected in parallel to a stiff grid which prevents your voltage from going to be different from your nominal value. When you connect a d g source which might have a much higher impudence and you disconnect the voltage source the chances of the resonances could be high. So, their resonance between a magnetizing branch and capacitances might be power factor correction capacitors or it can be capacitances of cables can actually lead to ferro resonance and you can see highly distorted wave forms with sharp peaks.

That can damage utility equipment, you can also damage the distributed generation source itself because you can have a overloading because you are trying to carry a wider set of loads of the entire feeder. Your frequencies might drift outside nominal values also, you have something that is possibility is that is out of phase reclosing. We will see that out of phase reclosing was actually a important issue when we consider a situation of damage, it can actually damage the d g can damage other customer equipment it can also damage utility equipment.

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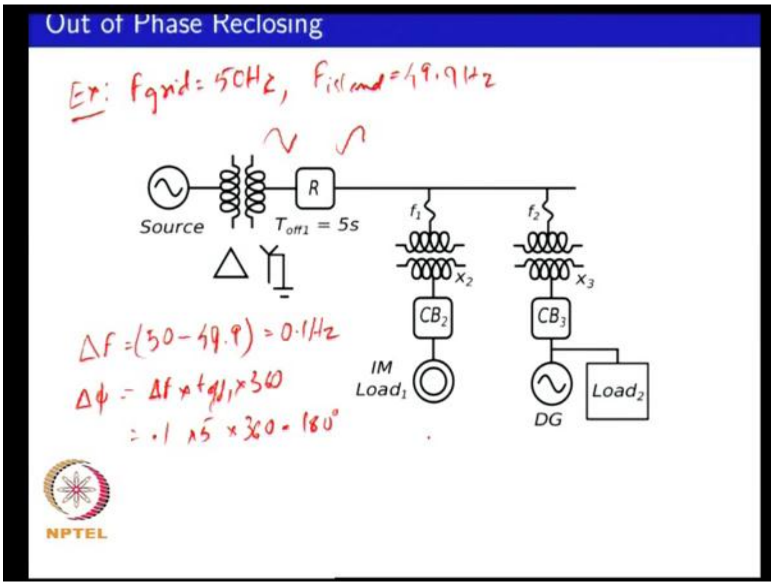

Such a situation can arise where say you have a upstream re closer and we will look at an example where say the upstream re closer high of duration of say 5 seconds. So, we will look at an example where your grid frequency is 50 Hertz and you assume that after the re closer opened then the loads with your d g in the island. The frequency shifted to some other value say the d g the system frequency shifted to f of the island shifted to say 49.9 hertz. After disconnection of the main breaker and the re closer say stayed opened for five seconds and then it tries to reclose. So, we will look at what would be the phase of the voltage on the grid side and phase of the voltage on the island when the re closer is reclosing and to determine the phase of the voltage you have.

You know your delta f is 0.1 hertz and then you look at what is the phase shift that occurred in this duration your delta shift in phase is delta f into t off into 360 degrees. So, this is 0 into fi6ve into 360, so this is 180 degrees, so you can see that there's a this wave form would be a sine wave like this.

Over here, it could be to have the opposite polarity so when the re closer closes, it is trying to introducing a up, but 180 degree phase shift in the voltage that is now getting applied to the system. So, you can see that in any electrical system even a nominal direct online start will cause a large in rush, now you are having a star almost like a 180 degree phase shift. Your currents that can flow in such a situation as much higher than the normal the direct online start and you can have severe repercussions you can if this is synchronized machine type of a.

Then, you could potentially damage the d g source of the fuses on the distribution system the current that it might draw might be large enough to damage open the fuses. What we will see is that if you have neighboring load when the voltage over here drifted for 5 seconds and we came out of a phase then essentially the phase of your flux reactor in your machine is also following that particular voltage in the island. Now, you have an induction machine where it is induced magnetic field as in one polarity and when voltage that is now being applied from the grid is 180 is trying to create a magnetic field 180 degrees out of phase.

So, the current that flows into this in rush in rush to the machine can be as high as twice your current that you would see in direct online start or even higher because of saturation effects. So, you can possibly have things like 10 per unit peaked arc that you would see on the shaft of the machine potentially, it can actually damage the shaft. The shaft can actually be crack open, so there can be extensive damage not just for the d g, but for all loads that are connected under feeder.

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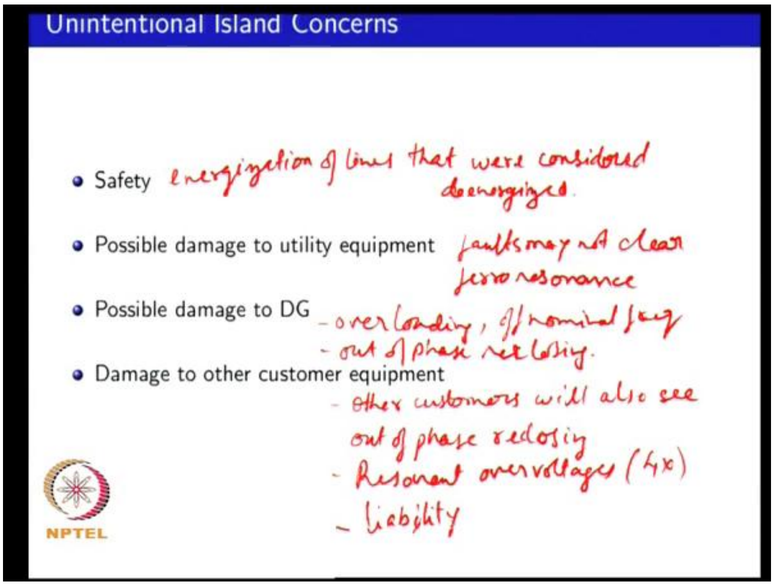

So, you can see that this is very Important consideration when you have a d g system, so the other customers and if you are applying a step voltage of twice the peak value, you can have resonances with parasitic capacitances on the line. You can get resonator voltages that grow up to four pi unit. So, that is really high voltage and if you end up damaging the neighbors electrical equipment, then there's a big question of whose reliable?

So, if you look at it typical electrical system, the cost of all the equipment that is connected to the electrical system you might have very expensive process equipment. Your goal to data center you might have lots of expensive computers, so the connected loads would have much higher value then the original electrical system, which is actually providing the energy feed. If you end up damaging all the loads, then there is a severe liability issue and typically your electricity service provider takes insurance.

They would cover in case they provide extremely poor service that your equipment is damaged they are liable to actually paying you for the damage that they have caused. So, now if a d g is doing this then the question is who is responsible is the d g owner, is it the service provider or should the customers themselves be taking the liability. So, the issue of how to deal with a electrical island especially the unintentional island is important concern in d g systems.

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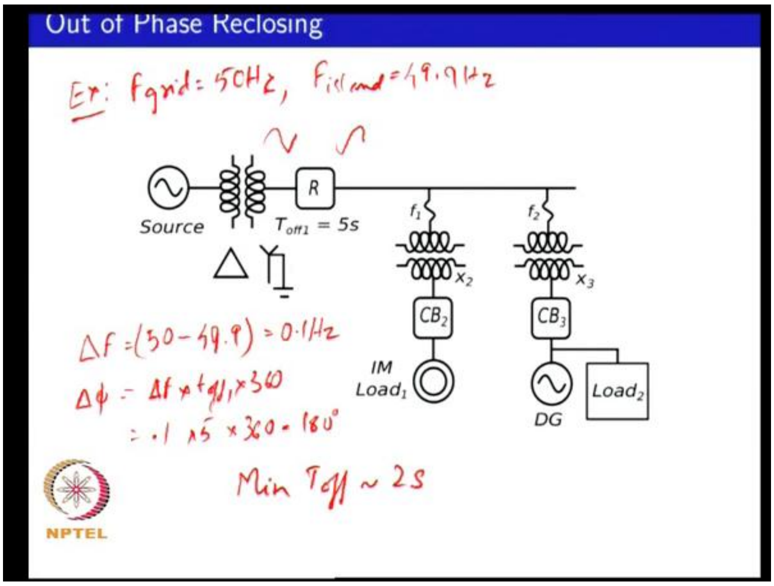

If you look at the example that is over here we looked at a reclose where your t off is 5 seconds and the amount of duration that your t off can have can vary. I mean you can have a fast re closer you might have slow reclosing and the people considered 2 seconds to be reasonably fast reclosing. So, if you look at standard such as IEEE 1547, it says that distributed generation force should the disconnect before 2 seconds after opening of a upstream device. The reason is that before the upstream device recloses you need to be able to detect that something upstream has opened and denergizes the d g.

So, you do not have a possibilities of out of phase reclosing, so minimum t off, so you need to detect a situation of unintentional island in a fairly short time frame. You cannot use algorithms which might take tens of seconds or minutes you need to able to detect that something like this has happened in a second or 2 or faster.

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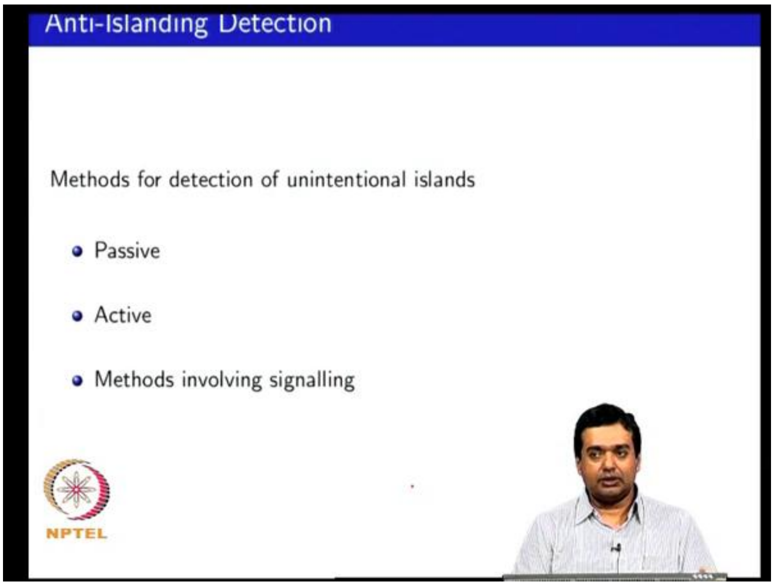

So, if you want to detect a situation of an unintentional island people have employed methods people call it anti islanding algorithm. Essentially, what detects a situation that there has been an unintentional island and their types of anti islanding detection methods can be taught of as a being passive or it can be active or it can involve signaling or communication.

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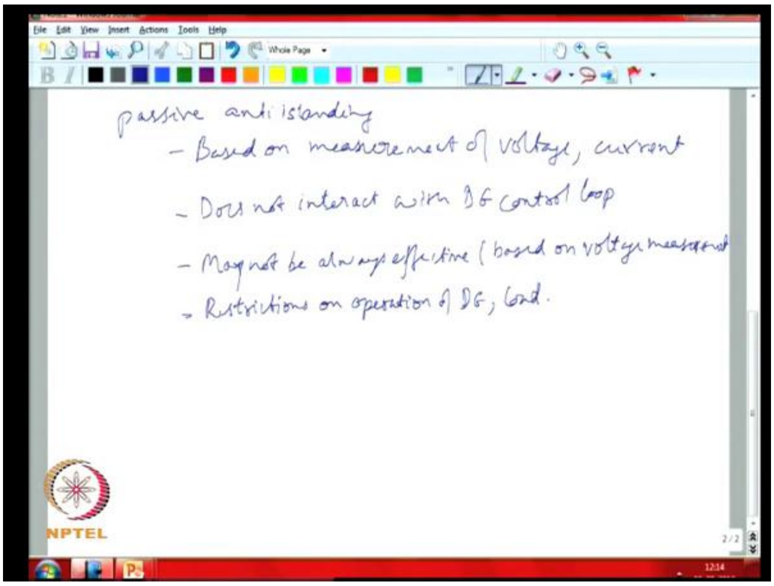

When you look at passive methods for anti islanding, what your essentially doing is you are measuring your voltage and current at the terminals of your d g device or at the interconnection point of interconnection with your main grid. You are measuring it through potential transformers c t's into some protective relay and you decide on whether to open or keep the interconnection breaker. You decide on whether to keep it open or closed based on the decision of the algorithm. Typically, it does not directly interact with your d g currents and at that is one of the reason why it is called passive, because it does not actively try to shift the control action.

the passive methods are not always 100 percent effective especially if it is based on pure voltage measurements and all you might have restrictions on how the d g is operated which will prevent and how the loading is being done in the facility. So, there might be restrictions on operation and if you are looking at the voltage, essentially pure voltage based methods might be you might be looking at the voltage goes to high or to0 low.

Then, potentially there might be a islanding situation or you might be looking at under or over frequency or you might be looking at the direction of power flow. So, we will look at some of these methods of a passive and anti islanding, before that we will also discuss some of what would constitute active and anti islanding method.

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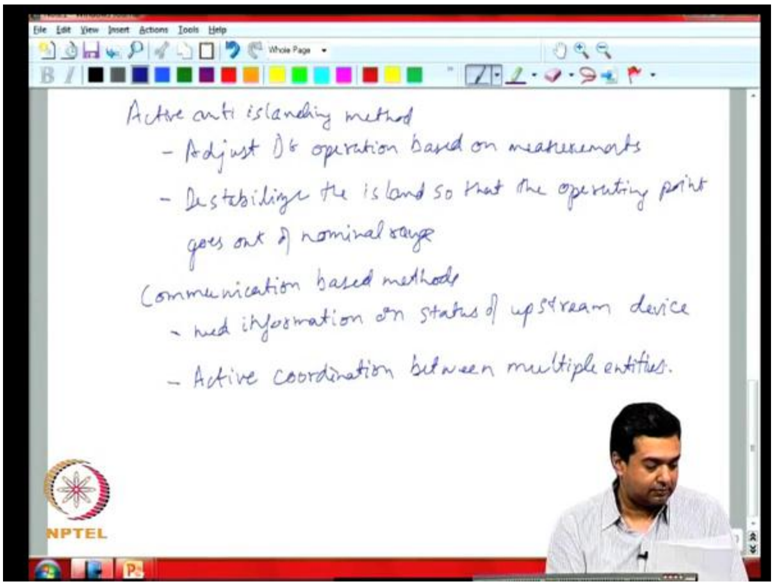

So, this is based on adjusting the distributed generation source operation based on your actual measurements and the idea in this particular case is that you destabilize the island. So, the operating point that you get when you disconnect the upstream device would not be stable and because your operating point is not stable, it means that you are your voltage amplitude or your frequency would go outside, would go outside. What would be an nominal range and far that your voltage frequency went outside the nominal range would use to actually open your interconnection device. If you look at the method of active and anti islanding, it makes use of measurements that you makes use of active controls so it is reliability would be a little bit less compared to the passive method.

Ideally, if a passive method can operate reliably that would be the a better method because active method is now using not just your detection, but now active controls. So, you could think of it as being slightly less reliable, but the chances of detecting an island might be more in the active method. The third method is communication based methods or signaling based methods in the traditional transmission systems people have used pilot release to transfer information from one point to the another point to make better decisions. So, you could use information may be from the substation to d g to inform whether a substation breaker is opened or whether some feeder need to de-energized.

So, you could make use of explicit signaling or communication and in this case now you need an additional channel rather than just the power lines, you need now a communication channel to be also available. So, the cost can potentially be higher when you want such systems to work also reliability of the communication channel might not be as high as the underlining electrical network. So, you have reliability concerns to address some of the cost issues people have looked at methods like power line carrier communication methods to see whether the power line itself could also carry this information on the status.

So, people have looked at variety of such methods to see whether you could have explicit signaling based methods that can be effective, but again in this particular case reliability is a concern. In this case, you have a coordination between multiple agencies for some algorithm to work you have to have coordination from your utility which is sending information in coordination at the d g side which is taking at information and using it to open a breaker. So, that becomes more complex problem rather than one intensity making the decision by itself in a reliable manner.

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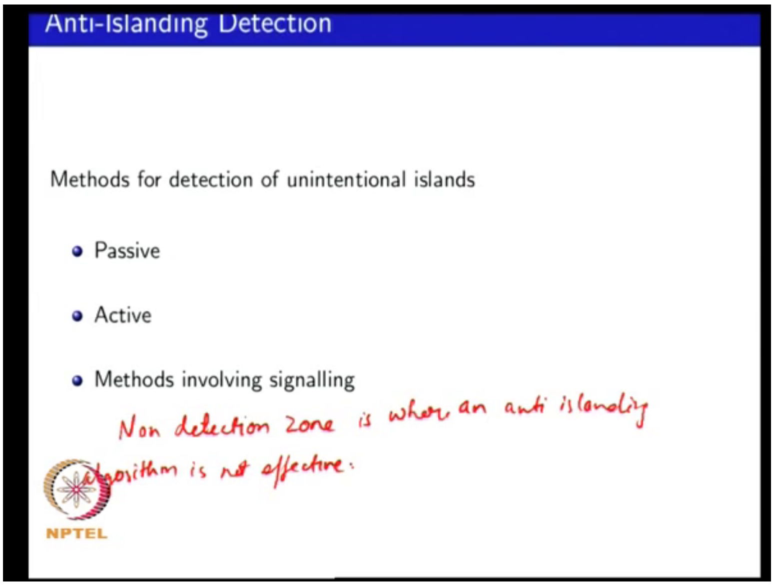

So, we just mentioned it the effectiveness of a anti islanding algorithm, it may not be effective at all times especially in the context of a passive method. You might have your range of values where the method may not work well of range of parameters or a range of system values where the islanding method may not function in a effective manner. The range region where the region of the parameters space where the islanding detection may not be effective is called a non detection zone. So, a non detection zone and the objective of a good anti islanding algorithm is to make the size of this non detection zone to be 0.

So, the ideally each be 0 each means that it could be a very good anti islanding algorithm. So, what we will do next is to look at a model of your feeder with your distributed generation source so as to look at the situation of a passive anti islanding detection on that feeder.

So, we will look at what it means for this simplified description of the feeder, so what you have over here is the upstream grid modeled as a voltage source this is essentially what comes from your substation. You might have a breaker upstream breaker modeled as the switch s one which can open all the loads on the feeder are modeled as it is modeled as a r l c a parallel r l c load. Typically, you might have your real power consumed by your r load reactive power being drawn by a l your transformers whatever components machines etcetera. You might have power factor correction capacitors etcetera on your feeder, so you could think of your overall load to consist of a RLC equivalent network.

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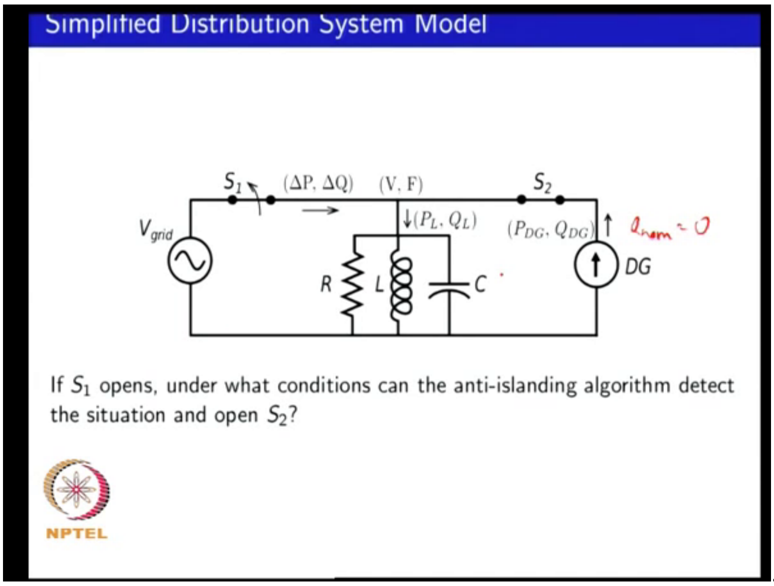

You can model your distributed generation source as a something that injects a power and reactive power. We will assume that the reactive power that is injecting is under 0, it is operating under unity power factor trying to inject power at unity power factor at its point of common coupling. We will look at a situation where the amount of power that is being drawn by the load match as well with the power that is being supplied by the d gif the q reactive power from the d g is 0. It means that the balance reactive power is a difference between the reactive power drawn by land c. If the feeder is well compensated, it means that your q of the load would be almost 0, so if there is any difference between what is being drawn by the load and what is being supplied by the d g.

That is essentially delta p and delta q coming in from your main source, which is your main grid, so the problem can be simplified as when the switch is closed. Your main grid sets your voltage and frequency seen by your r l c load then when the switch s one opens there might be some degradation in voltage and frequency seen at this particular load and can you operate switch s 2, which is downstream. By looking at this voltage and frequency, can you operate the switch s 2 to actually disconnect the d g in response to the changed value of voltage and frequency.

So, that is essentially the anti islanding problem if s one opens under what conditions can the anti islanding algorithm determine this state such as this situation has occurred and it needs to open s 2 as a results. So, the other assumptions over here that the d g is capable of providing power that whatever power is being drawn by the by a your load the other thing is that because your d g is providing power at unity power factor. Then, the assumption is you have very good reactive power compensation, so the feeder is well compensated.

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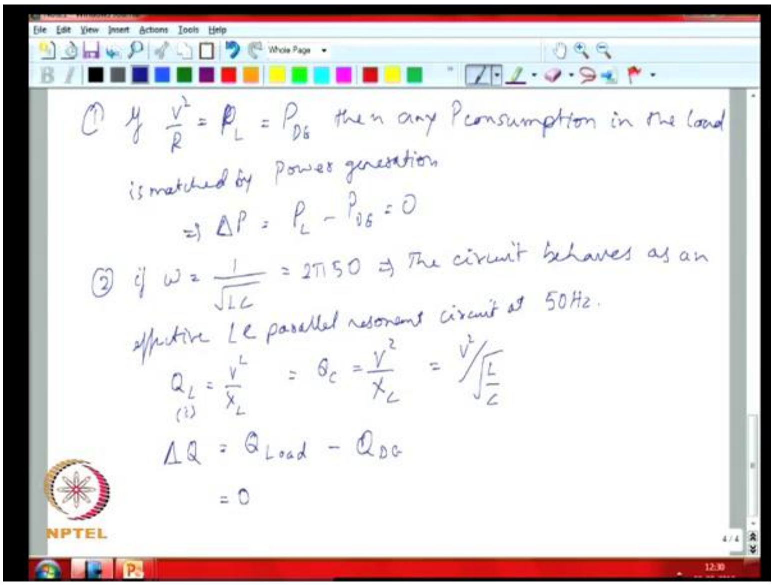

So, if you look at the first situation you have if v square by r is your load power, so this implies that your delta p is p of the load minus p of your d g is 0. So, the second situation is if a you are feeder is well compensated at 50 hertz, then your omega is which is 1 by root l c would turn out to be 2 pi times 50. So, if you have a parallel resonance circuit if your resonance frequency is 50 hertz in a parallel resonance circuit whatever your draw would be in phase. If there is a resistive load or it will not draw any current, if there is no resistance load which means that your reactive wire of a capacitor is exactly balanced by the wires of your inductor.

So, your q l is q l of your inductor and you can calculate both of this would turn out to be equal to v square divided by square root of l by c. So, if you look at your delta q that is being drawn from your resource this is equal to q of your load minus q of your d g and q d g 0 and q is equal to q c, so this is equal to 0. So, essentially if you look at conditions one and two what you are going to have in the ideal situation is that you are going to have sustained l c oscillation seven after opening the circuit breaker.

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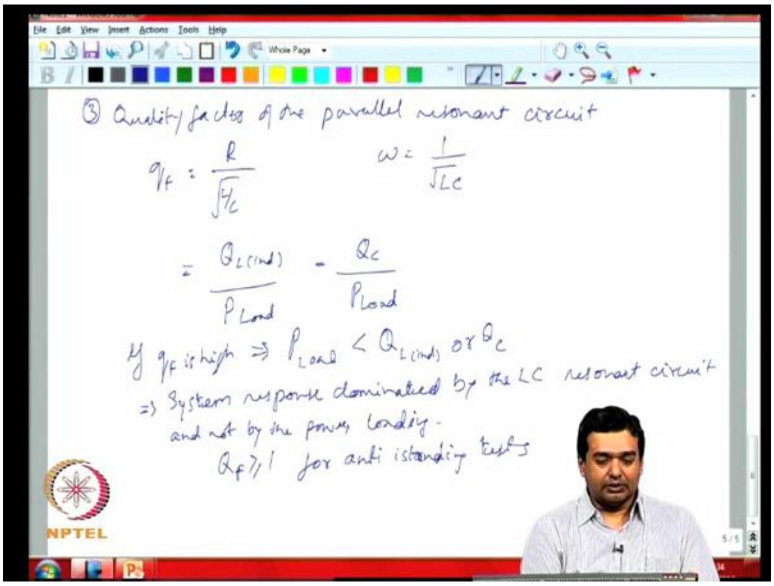

So, the third aspect that we will look at is what is a quality factor of this resonance and your resonance frequency is 1 by square root of l c. So, it turns out that your q f is r divided by root of l by c and you also know that omega is 1 by root l c. So, you can substitute for this you'll see that essentially q f is equal to q of your inductor divided by your p load is equal to q of your capacitor divided. So, in a situation wherein q f is high what this implies is your p load is less than your q of your inductor for q of your capacitor. It means that you are your system resonance point is going to be dominated by your l c oscillations and your loading some.

Even if there are some level of loading mismatch your exponential term which is essentially your damping term, it may not be the dominant term in your overall response in the time frame required in your analysis. So, for you are the anti islanding test, what we will look at is a situation where a q f is greater than or equal to 1. Essentially, what you are looking at is if under in the ideal condition if you are opening this switch and your delta p and delta q is close to 0.

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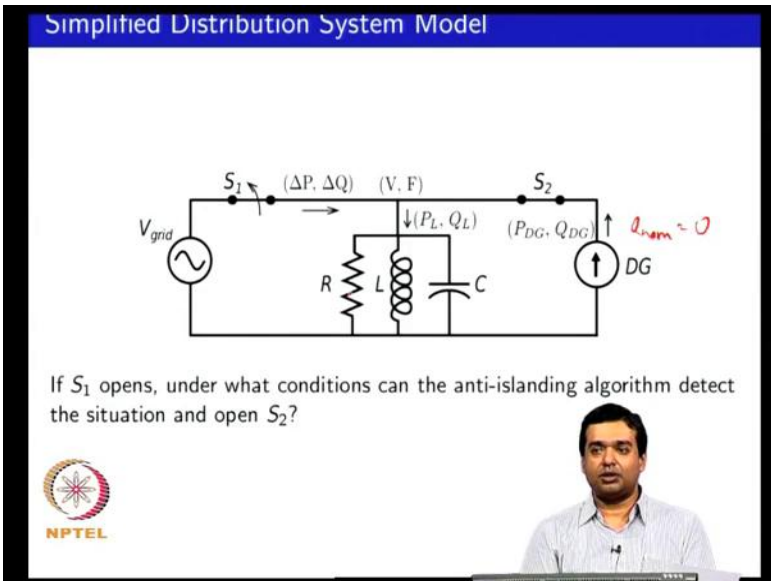

What it means is that after opening the switch, there is almost a delta p and delta q 0, it means that the current flowing through the switch is 0 and opening the switch will not cause any disturbance your v and f will continue to be where it originally was. This means that any method that was that is measuring your voltage and frequency to open the circuit breaker of d g would not be affected.

So, having small use of delta p and delta q it would mean that method with pure voltage or frequency measurement would not work. So, you need to have some mismatch between your delta p and delta q for just pure voltage based methods to work. In our next discussion on islanding, what we will do is try to look at the threshold of your voltage and the threshold of your frequency and look at how that relates to how much delta p is there how much delta q is there to look at what is the relationship between them.

Essentially, you can think of delta p and delta q to be aspects of your non detection zone which is which can again be reflected in terms of what your r l and c parameters are and relating that to their d g and we will try to see how that can be used to set voltage. Frequency thresholds to determine a situation of an unintentional island in a passive manner. Knowing well enough that would not be 100 percent effective in a situation where you have a feeder where your feeder load is 1 mega watt and your d g is also providing 1 mega watt.

There is potential that such a method may not work, but if you would be able to say if you are now feeder is 1 megawatt, can I introduce up to half a mega watt of d g and still be able to detect a unintentional island. So, you could ask questions like that with a such an analysis.

Thank you.