Power Electronics and Distributed Generation
Prof. Vinod John
Department of Electrical Engineering
Indian Institute of Science, Bangalore

Module - 01
Lecture - 16
Solid State Circuit Switching

Welcome to class 16 on topics in power electronics and distributed generation.

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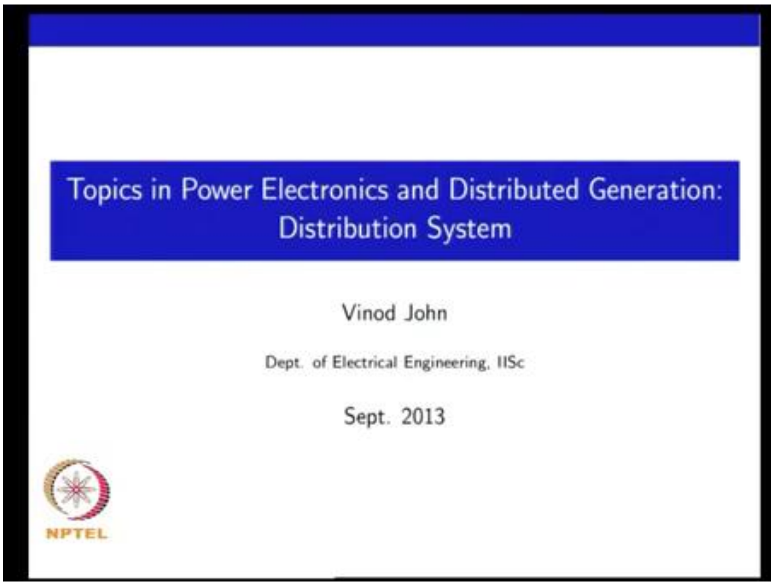

We have been talking about active anti islanding in the class and last time we looked at the relationship between power and voltage. We model the feeder as a parallel RLC resonant circuit and looked at the relationship between power and voltage. Then, how you could add power voltage characteristics to cause the voltage to have not a stable operating point, but actually go out of the nominal range. Then we started looking at the reactive power versus frequency relationship.

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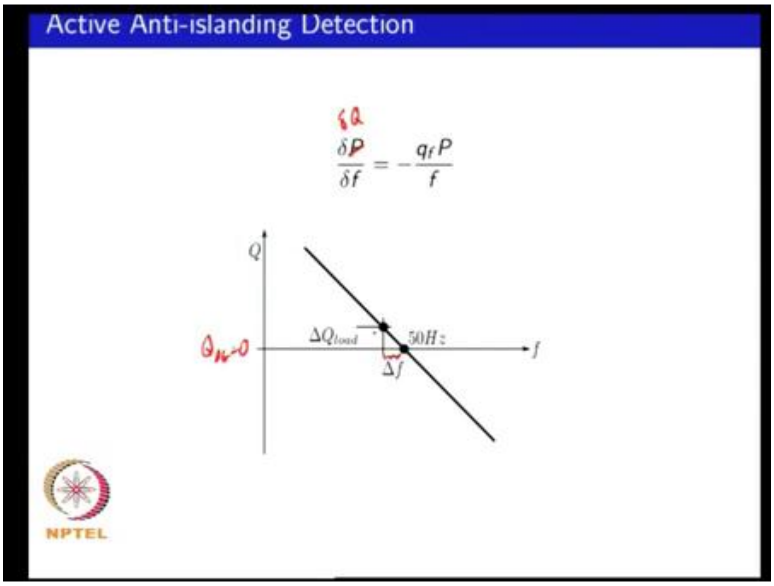

We are able to get a relationship this should be the relationship between reactive power, so this is q the relationship between reactive power and frequency related to your quality factor power and frequency. At the nominal 50 Hertz, your power of the injected by the DG is 0 and we saw that if your frequency deviates by delta f, say reduces by delta f, then your reactive power drawn by the load would increase by delta q. If your frequency increases by delta f, the power drawn by the load would reduce by amount of again some delta q load, but with a negative polarity.

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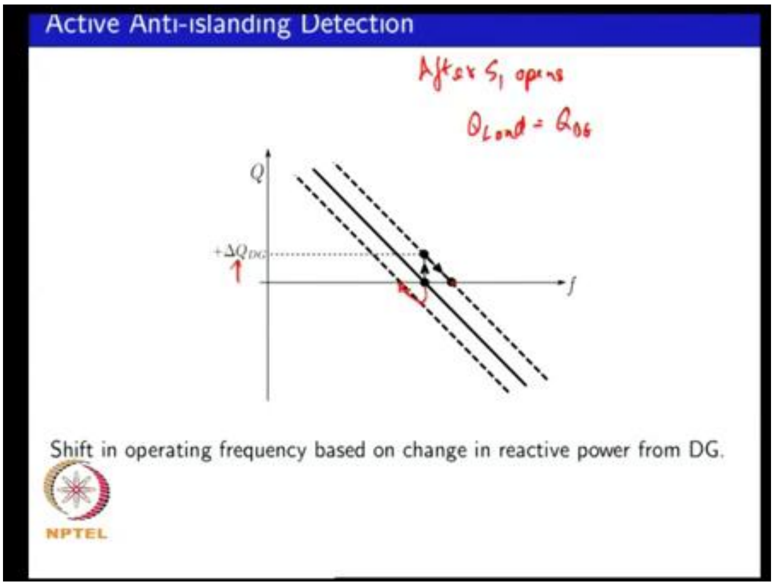

Then, we looked at what would happen if you had variations in L and C around the nominal values and if essentially your q of your load increases that would correspond to the situation where your L reduces, so drawing more reactive power or C also reduces. So, this would correspond to then a situation where your resonant frequency will now settle down to a higher value. On the other side, if your q load changes in a polarity, where your q reduces that would correspond to L prime going to L plus delta L and see some C prime being C plus delta C.

The corresponding resonant frequency that would settle down to is at a lower value. If you look at what would be the operating point with the nominal reactive power being 0 or put from the DG that would be essentially be flat line. You could look at then what would be the final operating frequency depending on what the final resonant frequency of the particular system is that you could look at what is the next situation.

Here, we looked at where there is variation L and C around the nominal value. You could then look at what would happen if your there is a change in reactive power from the DG here. What we are assuming is the DG power variation is modeled as a equivalent L C load variation and essentially if once your upstream switch opens in the in on your feeder.

Then, essentially under that condition after switch is one opens, you have your q load is equal to q DG because there is no delta q coming in at that particular point from the model of the system that you are trying to analyze. So, q load is being consumed and q DG is what is being probably sourced at the DG point and if your DG operating q shifts by a value of delta q DG.

So, this would be your original value and if it shifts up, then essentially you could be think of it as now operating at a equivalent as equivalent load with what we saw those. It would be L minus delta L or C minus delta C, so you would settle down at a higher operating frequency. So, similarly if you have a drop in reactive power, then essentially your operating frequency would actually come down to a lower value. So, it is possible to shift the operating frequency of your island based on adjusting the amount of reactive power that you are injecting from your DG, so if you look at it from a way on what would you do to destabilized the feeder .

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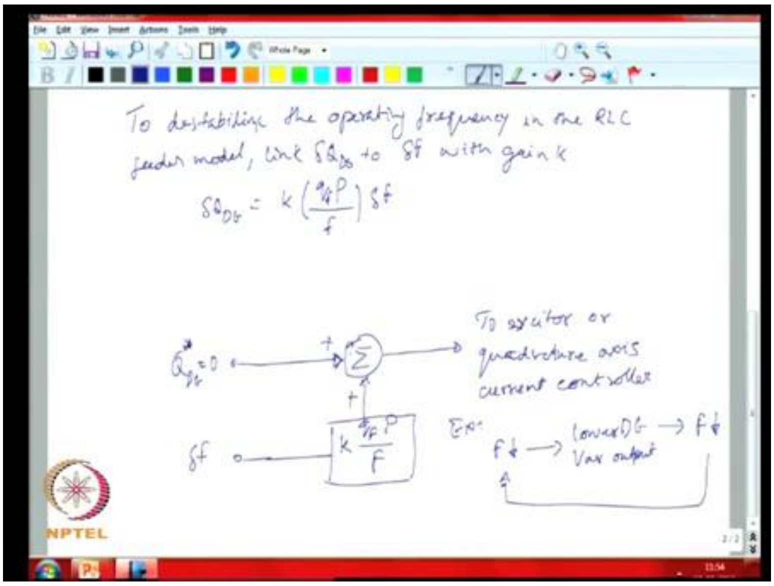

You could link your reactive power to change in frequency that is measured in the DG, so essentially what you would do is change your output of your DG with some gain times q quality factor power operating frequency with delta f. So, you could think of essentially your block diagram as on the nominal conditions q DG command would be 0.

You could measure the frequency and pass it through high pass filter or a wash out network to get the change in frequency. You can link that with k q f and provide this and depending on the type of DG that you have whether it is asynchronous machine or a or a inverter, you could link it to the exciter. So, in a synchronous machine you can control your output wall by adjusting the excitation level in a power converter. You would can control the amount of a reactive power output by controlling your quadrature axis current, which you are in phase current would correspond to real power.

Your quadrature axis current would correspond to the reactive power, so by linking in a manner in this particular manner. You could think of shifting the operating frequency, so the idea if you have a disturbance which would cause say your frequency to lower. So, as an example if you have a case where your frequency dips, then essentially what you would do is you lower the war output from your DG.

The lowered the war output from the DG would cause a further depending a frequency and this is further measured at your same point leading to further reduction in frequency. Essentially, your operating frequency goes out of bound, so one thing that you can see in this particular analysis that we did for your feeder along with the distributed DG source in a case, where you have unintentional islanding is that. Compare it with what you expect from additional power systems analysis book in a traditional power system analysis. The link is between power and frequency and between voltage and reactive power, so whereas, that is not the case what we have not analyzed.

So far, the main reason is that the model that we take for the feeder is different from the model that is considered typically in power systems analysis. If you look at the large transmission systems, the large generators, the major portion of the loads in a power system is actually a machine loads more than 60 percent of the power consumed actually goes into large motors. So, if you look at that the model in that particular case is a machine with large inertia, so there the link is between the energy and speed of the machine where the model is of the power going to accelerate or decelerate the inertia.

Then, the other thing is that you look at the lines the equipment they are predominantly inductive, so you have say transition lines with high x by r rations. So, you can consider that to be primarily inductive, so in the situation such as that the link would be different from what you get in the model of a feeder. Here, we have taken the model of the feeder to be a parallel RLC resonant load, but overall the objective and a the case where we are trying to detect an unintentional island is a to make your operating point unstable.

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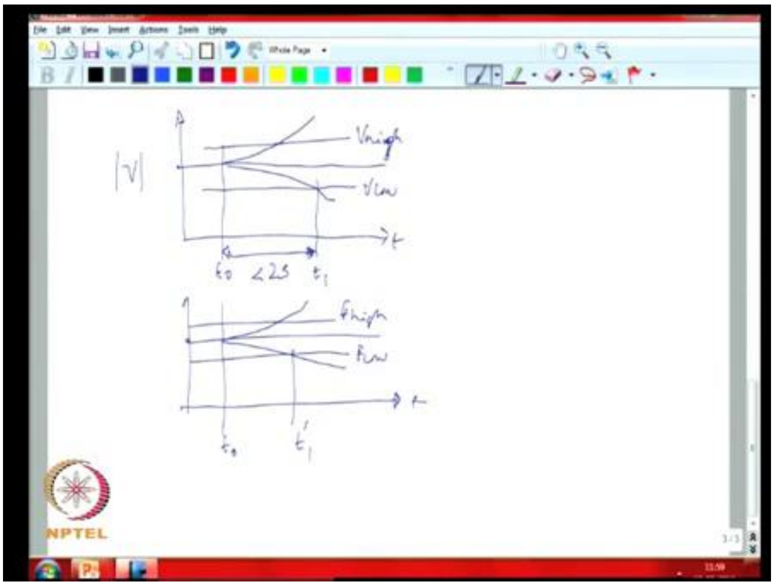

So, if you have say your voltage amplitude versus time and at some particular instant say t not is your upstream, switch open the idea is to have a destabilizing term such that your voltage goes out of bound. So, you have V high or a V low which would be your threshold detects and disconnects and depending on what where it is. You look at the ability you your anti islanding algorithm to be able to detect in a short duration that your voltage has gone out of bond, or you have the frequency you are looking at your frequency versus time.

You have say a nominal frequency and at t, not your upstream switch disconnected and then you have a f high or a f low and depending on when you are able to detects frequency out of the bound. You can trigger the relay at your DG source at something has your nominal condition has gone beyond or range the operating condition has gone beyond the expectable range, DG has to disconnect.

This duration that you typically has is a less than 2 seconds because you want to able to detect that unintentional island has occurred before off stream re closer. So, you want this detection to happen fairly quickly, so the disconnection can happen anywhere upstream of the on the feeder. The DG can be located anywhere along feeder after the disconnection, the nut actually making the detection of whether it the islanded situation or not is detecting its voltage at locally. It is not able to detect at some other point taking its measurement on a local bases and based on the local bases measurement whether to stay connected or to disconnect.

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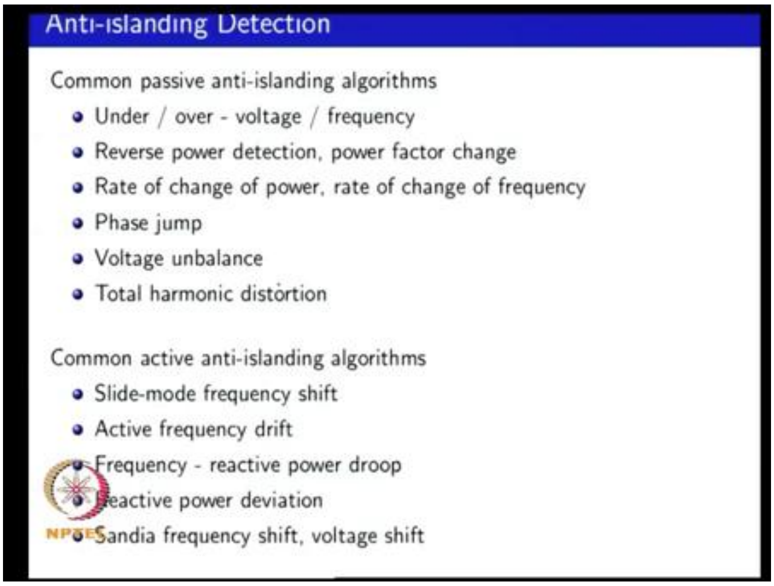

So, in literature there are a variety of algorithms, people have looked at methods at people have looked at or both the passive and a active anti islanding. We looked at under and o voltage under over frequency we also looked at reverse power flow based detection. People have looked at other methods such as power factor change, rate of change of power, rate of change of frequency, whether this is sudden phase jump on in your system. There is a large imbalance happening on in the in terms of the voltage, whether there is increase in THD that is being measured.

So, some of this methods would be considered passive here, just observing the active methods, you are trying to introduce such as actively trying to change your operating frequency or change your power level voltage level etcetera. So, it goes by a variety of names, but you give now have feel for what is a underlying principle that people are trying to adopt. Essentially, you are trying to take stable operating point and make it unstable so that your actual voltage is measured and if see that your power level, your voltage amplitudes frequency goes out of bond. That would correspond to a situation of a unintentional island.

Also, you there are always advantages and disadvantages for many of these schemes and to find improved methods for detecting an unintentional island are an area of a active research. So, one thing you had seen that from the point of view of detecting and responding to a fault on your feeder. If you have variety of reasons, you would need to disconnect from your feeder and you would need to that fairly quickly.

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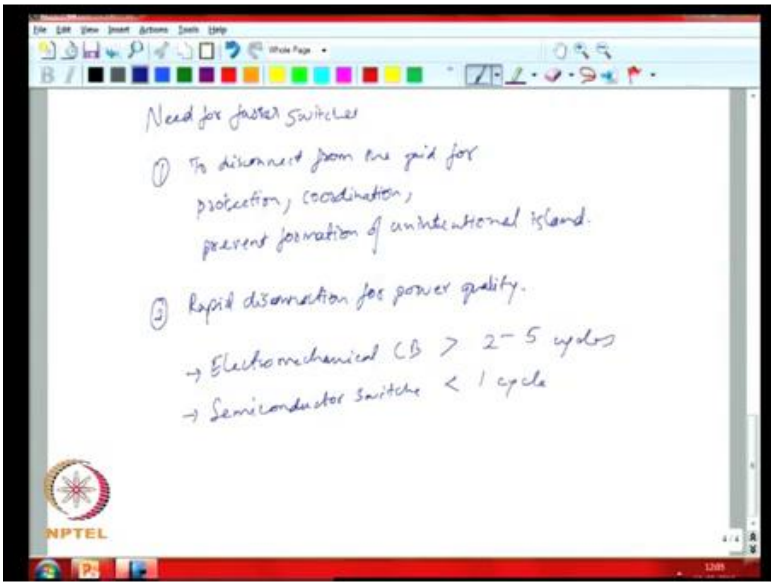

A couple of primary reasons would be to disconnect from the grid for protection coordination, protection coordination, also to prevent also to prevent unintentional island. Another reason why you would like to disconnect rapidly from the grid and this is where you want to operate as an intentional L island.

So, this primarily for power quality reasons, so if your grid power quality is poor for some reason and your switching speed is slow, it means that means your load expose to poor power quality for longer duration. So, rapidly disconnect from the grid, it means the duration of the poor power quality is seen by the load can be reduced by fastest switch. If you look at the traditional electromechanical circuit breaker, your operating duration is 2 to 5 cycles and that would be considered instantaneous.

So, the fastest disconnection might be of the order of a multiple cycles, whereas you look at semi conductor base switch you could switch in much faster manner less than a cycle. So, if you look at situation where you have the grid potential distributed generation source and then switch which can connect or disconnect, then you have two possibilities.

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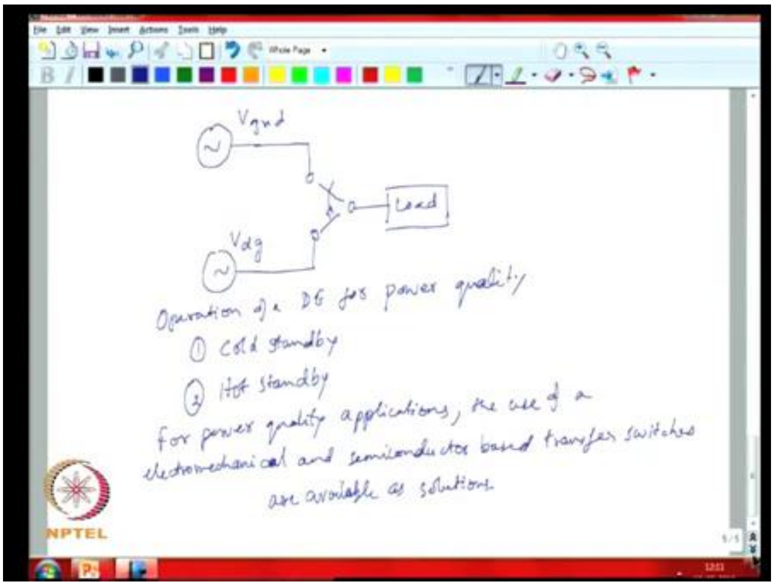

So, you could have the grid, so you might power quality perspective you might be nominally normally under normal condition, you might be connected to the grid. If you have a situation where your grid power quality is poor or the grid goes away, you have black out. Essentially, you want to switch over and connect to a DG, then in terms of operation of DG for power quality perspective, there are two possible ways in which you could operate your DG.

You could have see cold stand by which means that your DG is reenergized and it needs to start up before. So, nominally the grid voltage is there you need to change over first you need to start up your source before actually transfer over to the source and this would be typically you would be run a diesel generator set. If you look at start up time of a genset, it can take 20 second for really fast start up genset, 2 minutes for something which might need a little bit warm up time to actually startup and stabilize to a normal operating condition. So, one possibility is aim response to grid power quality poor, you then startup a genset.

Then, the duration of outage seen by the load would be longer of the order of the 20 seconds to a minute of 20 seconds on what your start up time, another way of running it be hot standby. You look at essentially a situation such as that it means that your voltage over here is available over all the time. So, that would correspond to situation where for example, you could have the machines spinning under no load or it could be UPS, which because the power loss in the UPS can be much smaller compared to the power loss in a genset.

Your UPS is always having a output voltage or mini UPS can be start up in a much shorter duration depending on how quickly can startup your inverter. So, that would correspond to a hot standby basis which means that essentially you have voltage available. In this particular case, with which you are able to transfer over, is then entirely limited by the speed of the switch. So, here you are not waiting for DG to start up if your switch is faster, you can transfer over in a much faster manner if you look at a power quality applications.

So, use of electromechanical and semiconductors based transfer switches or are commercially available solutions. So, they are commercial transfer switches that are both solid state and electro mechanical, so then if you look semiconductor based switches, what you and compare it with say electro mechanical switch. Then, you can look at what would be your advantage and what would be the penalty that you would have.

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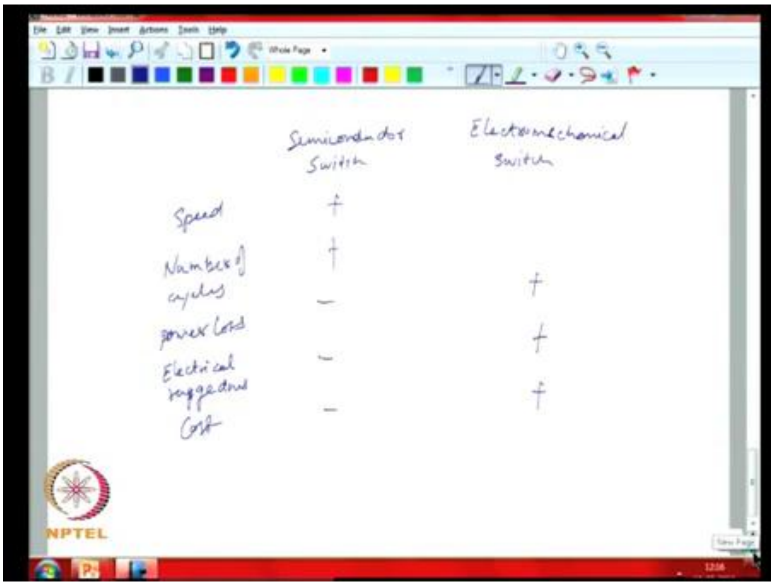

If you look at the speed, definitely the electro mechanical switch must faster, if you look at the number of cycles, your semi conductor based switch and operate much larger number of times compared to mechanical circuit breakers. After given number of operation 10,000, 20,000 cycles, you might have to look at your spring and do the servicing of your breaker where as your semiconductor base switch can operate for millions of cycles and without much degradation. Then, if you look at the other aspects you look at power loss, the power loss in the semi conductor based switch is much higher because of conduction loss on state drop etcetera.

So, your electro mechanical switch is actually more attractive from power loss perspective. If you look it in terms of electric racket ruggedness, your electro mechanical switch can take much more in terms of surge current surge voltages etcetera compared to a semiconductor based device. So, there is definitely advantage of electro mechanical compared to the semiconductor based switch in terms of electrical ruggedness, cost. Definitely, the semiconductor base is actually much going to much more expensive, there are traders. So, you can see cost is important factor form any the commercial application.

So, if you are willing to pay the cost, it means that your load has some definite advantage by the improvement and quality that the semi conductor base which can provide. If there was no net overall cost advantage, then there would not be a incentive to go for semi conductor base switch. So, then in terms of semiconductors look at a what are the possible semiconductors, if you look at the earliest available solid state, those would be the power diodes the SCR's the tidersturs. The SCR's or the silicon control rectifier would be a early device that was that how that has been available since the 1960s. So, comparatively compared to other devices its mature technology compared to IGBT's transistors etcetera, it has much higher surge current rating.

So, if you look at the peak to nominal current rating of SCR it would be much higher rating of IGBT. Also, if you look at in terms of the on state drop which has a implication for power loss the on state of SCR is actually lower than that of a typical transistor. So, of similar rating SCR based semiconductor switch has been some other thing particular technology that people have looked up looked at for now quite a while.

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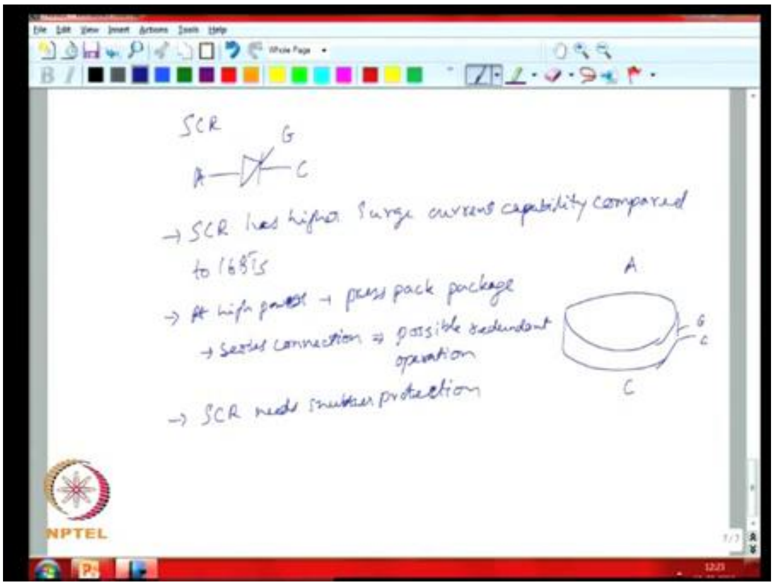

So, if you look at SCR, so it can be thought of as switch where to turn on, you apply pulse between the gate and the cathode when you have positive voltage across the anode and cathode then the device will turn on, a SCR cannot turn off by itself.

So, you need an external circuit to turn it off in an AC system, you have voltages going through 0. Your current going through 0 crossings, so you have points where your currents go through 0 and you can make use of that to stop conduction within say a cycle or so. A power turning off you would need to keep your current in the SCR to be below the holding current of the device for duration greater. Then, it is a turn off duration and with no great policies applied, so that would be is required to turn off the device after its off to turn it back on you have apply a gate cathode voltage pulse. When you have positive anode to cathode voltage, so what we mentioned was an SCR has higher surge current capability.

So, if you look at the higher powers SCR commonly available in what SCR’ s they are commonly available in what is called as press pack packages. So, essentially the press pack packages have a couple of advantages that a are beneficial, one is a it is possible to have very high current, current devices. So, press pack package is essentially what is a like a plate cylindrical plate if and essentially, now one side would be anode, the other side would be cathode. You will have lids for gate and cathode that is coming in the side, so to hold a press pack devices device in place you apply pressure on the top and the bottom.

Now, that would mean that you have conduction of power loss from two directions compared to one direction for a traditional, say IGBT module that is mounted on a hit sink your thermal resistances can be advantages in terms of thermal resistances. Also, you are pressure from the top and bottom of such a device, you feel a device typically feel short because any failure would cause the device the local junction to get damaged. The damaged junction would essentially then will shot anode and cathode where as in module type of device modules are connected wire bonds, some reasons the module ruptures.

Then, there is the possibility that the rupture can cause the fail module to fail open in which case. You can have failure that can either be short circuit or open circuit in case of mounted module, whereas in a press pack package when you have a failure. It is typically a shot circuit, which means that if you have a device that fails have the series connection of couple multiple devices. You can have redundancy because you have the feel device is short the next device can always be used to actually control.

So, many high power applications where redundancy is important concern, you could then consider a press pack package which will give you a benefits. One disadvantage of the SCR compared to something like the modern day IGBT is that SCR need the slumbers for protection. So, you have d V d t snubbers to prevent spurious trigging spurious turn on also you have you need over voltage protection. If there is a surge voltage to prevent the surge from voltage trigging, the evidently your SCR, you need a voltage protection.

Also, you have need a DIDT protection and because once you turn on if suddenly a current large current flows through device in a rapid manner. You can have current crowding over heating of and formation of hot spots and that can lead to damage of the device, so you with SCR, you would need to use snubbers for its operations.

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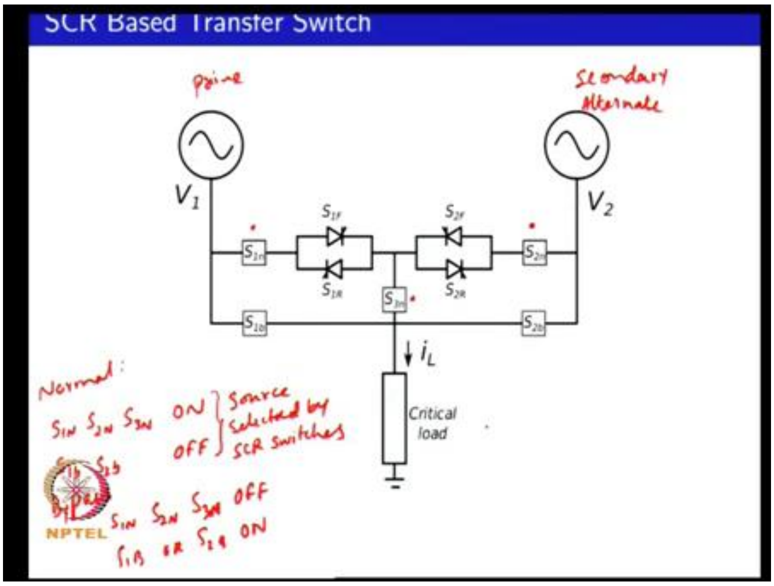

An example of SCR is transfer switch is shown over here, so what is shown is essentially a single line diagram of a single line diagram of a transfer switch. You have two sources might be considered as a prime source. So, under normal conditions your power flow would be from your prime source when a prime source for some reason is the power quality becomes poor you switch over a secondary or an alternate source. You have a typical transfer switches you may also have additional switches for normal operation.

For bypass operation for example, under normal operation your switch S 1 n, S 2 n, S 3 n would be and your bypass switches S 1 b S 2 b would be off whether your power is flowing from source one or source two depends on which set of thyristors you are triggering. You might have a bypass operation, where S 1 n, S 2 n, S 3 n is off and S 1 b or S 2 RH is on depending on which source you want to bypass. So, you might make you of this bypass switches to say, for an example if you want to repair your mean SCR s and still provide power to your critical load or you want to do some modifications on your alternate source.

You might typically operated in a bypass mode and then ensure then what was servicing modes occurs during the bypass modes and under normal modes your are able to switch between your prime source or your alternate source. If you look at what this arrangement would try to do under normal condition your power flow would V from V 1.

So, your S 1 f and S 1 i are would be triggered under normal condition and if for some reason power quality, we want becomes poor the voltage drops. If it is gets distorted, some parameters goes out of the acceptable range or the critical load, then you want to shift over to V 2 and there are few methods for shifting over to V 2.

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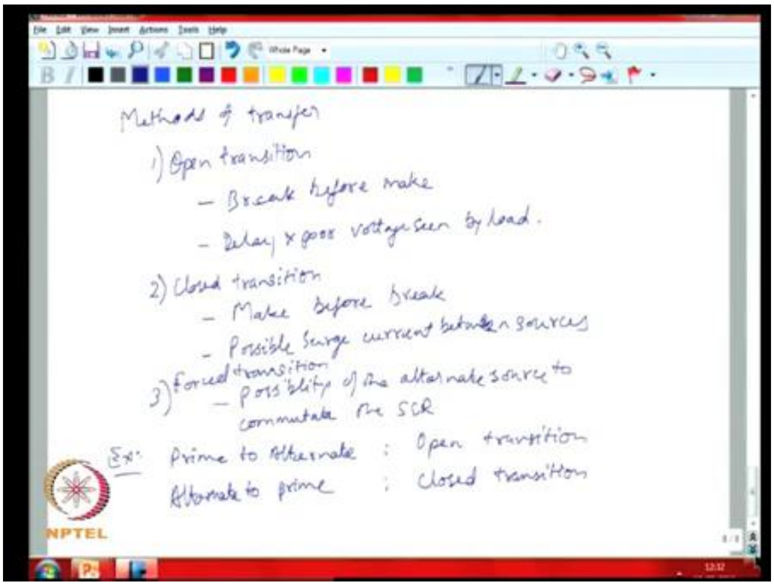

So, methods of transfer, one is called a open transition, in open transition essentially it means that to transfer from one source to other, first you open both the switches and await for small for the small delay to ensure that the switches are perfectly open. Then, you turn on the switch for which you want to transfer to, so here you are having a break before make operation and here the delays can be longer. The power poorer voltage would be seen by the load for a longer duration.

The other possibilities a closed transition in a closed transition, essentially you turn on both the switches first and then you turn off the switch you want the source, which you want to disconnect from. So, here this is make before break and here if the voltage of the sources are not well matched, then there is possibilities for surge current between your two sources. So, it would be the closed transition will not work under all situations or you might end up with trip tripping a breaking some other switch. Also, you could have say something forced transition and where if a primary source and your alternate source can be controlled.

It can be controlled in such a manner that you could make use of the voltage and current capability of your alternate source to actively force commuted. Your outgoing SCR, then you could have a transition in a shorter time frame. So, if you look at a typical situation, you might use a combination of these methods, for example when you are going from prime to alternate. You might use a open transition, because a the prime to alternate transition is because you might have outage in the mean power. If you do a close transition you have a surge, surge between the surge powers, but as you go from alternate to prime, you might have a close transition.

Now, your grid has return back to normal and you want to turn off from your alternate source and return back to the grid, because both are now in the nominal range. You can actually connect the two sources together without having a big surge current, and then with minimal disturbance to the load, you can actually achieve the transfer. Also, you could think about a situation where you have possibility of making use of one source to commute to second source.

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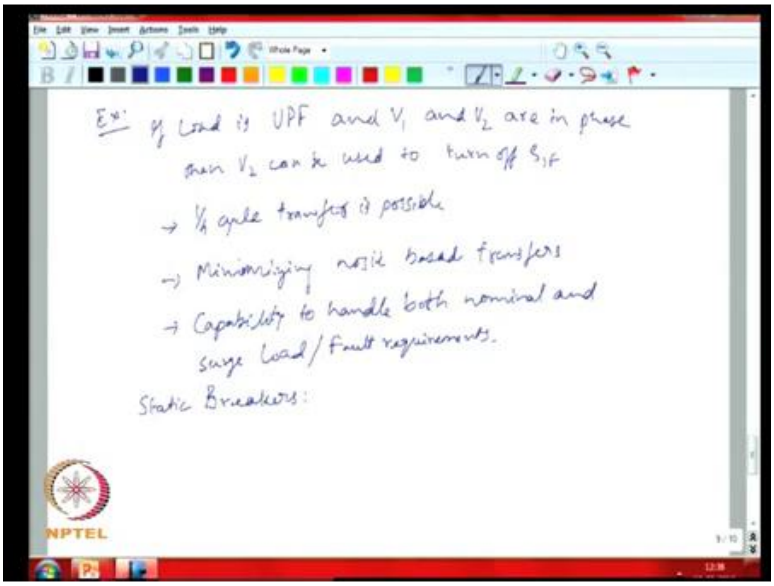

So, say if the load is load is unity power factor, so if you assume it a resistive load V 1 and V 2 in phase and then you could think about operating in the positive half cycle of the voltage. If it is under that particular condition, if the prime source voltage went away because of an outage.

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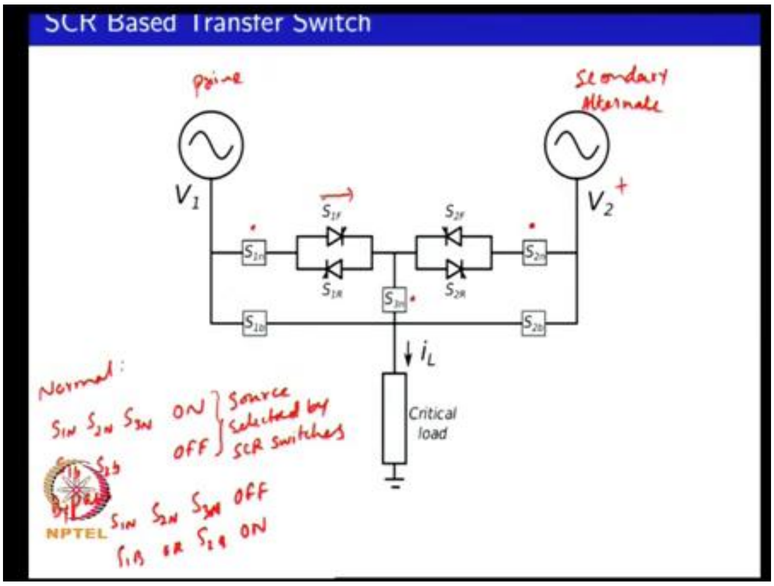

Then, essentially if you look at the switch that would be conducting under that condition, it would be S 1 f is the positive half cycle S 1 f S f is conducting current because the resistance load is unity power factor. So, this voltage has gone down to 0 and now this voltage also in phase, which means that this is also seeing a positive voltage. So, if you can turn on S 2 f, then you could reverse the apply a negative biers to thyristors S 1 f and be able to turn off thyristors by making you of a alternate source. So, in this particular manner you actually get the faster transition and you could look at what would be the worst case scenario, what would be maximum delay possible.

Typically, what people have seen is that with a transfer switch you can have quarter cycle delay so people talk about a transfer switch of quarter cycle TRNA quarter cycle speed. A challenge in many of this transfer switch is to differentiate when to transfer and when not to transfer because you can have many fault trips. For example, you might have small phase jump or smaller amplitude changes and some common x, when to transfer and when not to transfer that is actually a challenge in a transfer in such a configuration.

So, when do you need to definitely make the decision to go across and when not to, because if you are thinking about the large load, you are think about a larger amount of power from one source to another source? So, there are consequences of shifting the large amount of power, you do not want to minimize the number faults change over the third requirement of transfer switch.

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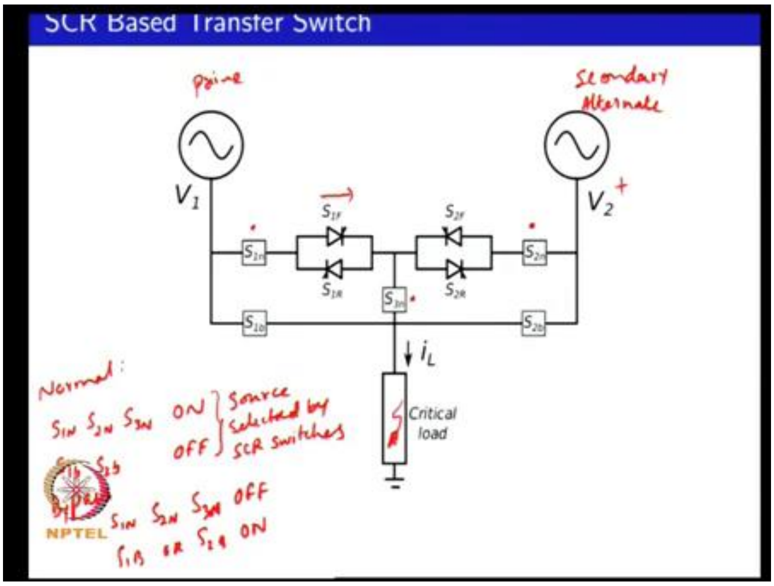

You have switch, where you always have the possibilities on a short circuit on the board. Your switches have to able to handle the high current level when your load itself has a failure. This means that the switch should be capable of handling not just the nominal load current, but also the short circuit current that the load might encounter even it is for limited duration of one cycle or a two cycle. The semi conductor should not get damage in that short duration, so designing this transfer switches are quiet challenging people. If you look at the design of transfer switch, you have two source if you then look at that, people also talk about static breakers. Here, you do not now have an alternate source to help with your commutation, which means that it is even more challenging your duration and delays might belong, then the quarter cycle, it can be 1 to 2 cycles.

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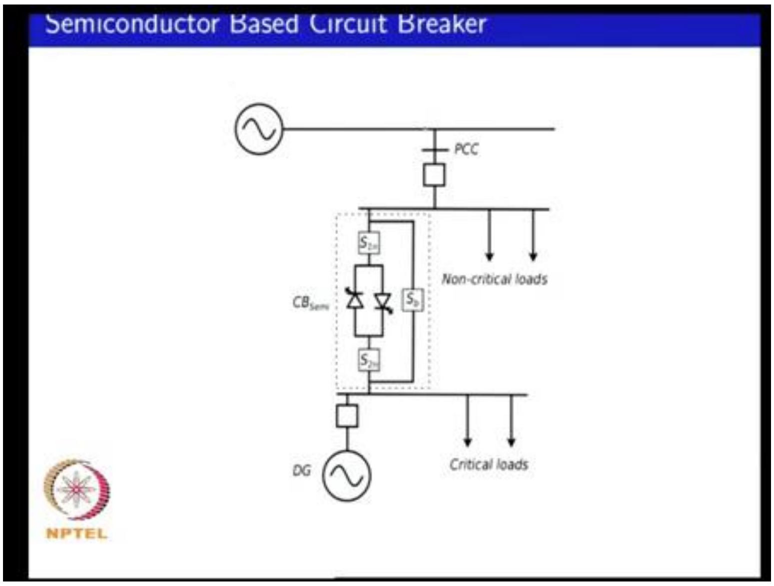

So, configuration of a semiconductor based circuit breakers as shown over here, where you have the semi conductor base breaker with switches for normal operation and switch for bypass operation depending on how you want to operate your system and pure. Again, one main concern in this system is how to handle the peak requirements, the peak to peak in terms of how to handle the fault current requirements. Also, the continuous power loss would happen in the semiconductor device, when it is operating under normal conditions.

People have also looked at hybrid approaches of trying to combine both electro mechanical and semiconductor based switches to minimize your power loss, but have the rapid disconnection capability. So, there are a variety of approaches such as this are available, but again you have the issue of handling the power required the peak power required which would then reflect back in terms of the junction power loss. Also, the increased cost of now having just simple breakers is now being replaced by more complicated system consisting of semiconductors plus the other switches for normal operation different modes of operation. So, in a example such as this you could have a semi conductor based breaker and you have the main breed coming in.

So, in case there is a poor power quality or the need for detection for unintentional island on the feeder then you can rapidly disconnect from the grid using a semi conductor based switch. Your DG would then continue to provide the power to critical loads, you might have some secondary loads which are not that important, which you might be able to say.

It can actually have a black out or a outage, but you might have some important loads which are critical which you want to ensure that it stays up even when the power quality goes down. So, this also shows an example configuration where you are using DG not just for providing power to the mean grid for supporting, but also and simultaneously to provide power quality for your critical loads in your facility.

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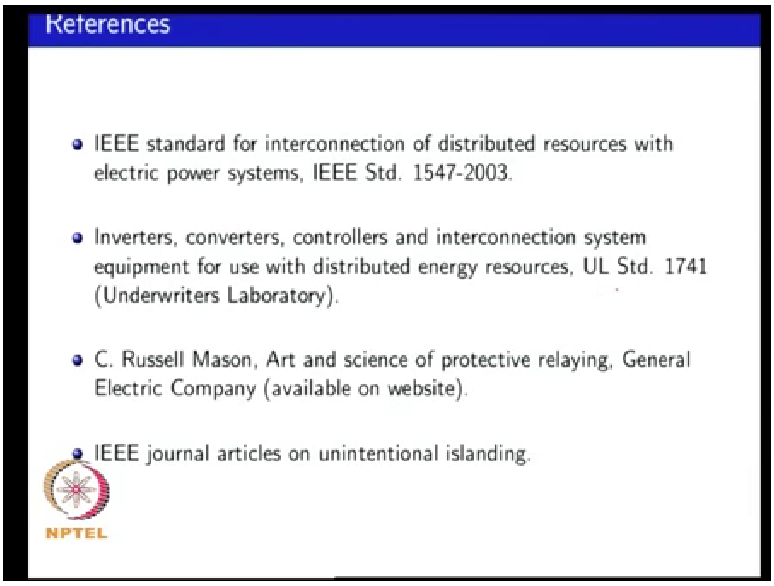

So, for references related to these issues, you have a i IEEE standard 1547, so here this is a recommended standard. It is just a recommendation it is not enforceable, but then you have similar issues that are show in things like a UL 1741, which is a underwriter lab standard. So, if you need a UL seal on your equipment, which is required for may be financing etcetera, you would need to meet that particular standard. So, in mean time recommend standards become indirect financial incentives to actually follow and achieve that particular target. It is one reference, which is available from the general electric website on relaying, so many of this issue reflect back on relaying also you have the general articles on unintentional islanding. Thank you.