Power Electronics and Distributed Generation
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Lecture - 1
Course Introduction and Overview

Welcome to this class on Power Electronics and Distributed Generation, there are set of students in the according room of this class also this is been recorded for the saving to the internet, so welcome to all of you.

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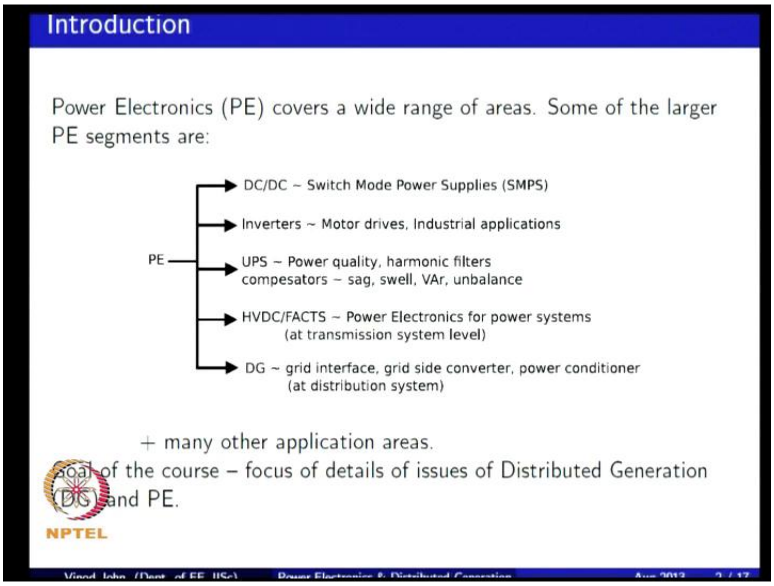

In this course we will be looking at distributed generation and in particular power electronics concepts, which are important for distributed generation. Power electronics is a wide area and it covers a large number of segments a very wide spread segment is a DC to DC converters, such as switch mode power supplies, which are used in computer power supplies household equipment, wide range of a applications, then you have inverters which are extensively used in industrial applications; especially motor drives.

Then you have power quality equipment, a very common power quality equipment that is used is a UPS to ensure that you have power availability, even when there is a disturbance in the grid. Also you have harmonic filters, you have a compensators to compensate wars, compensate harmonics to adjust your voltage in the presence of sags, swells, etcetera. These are all power quality related segments for power electronics and at the very high power level you have HVDC, which is high voltage DC systems, flexible AC transmission systems, which are used at the very high power level.

Then a emerging area which is gaining increasing importance’s distributed generation, where the power converter or any converter in general is use as a interface between your energy source and the grid. So, you can have power converters, you can have machine based interfaces and in general you could call it a power conditioner, which is used to interconnect a distributed generation unit with the electrical grid.

They are many other applications of power electronics in high voltage, pollution control, plasma generation, many applications in medical imaging. But, focus of this course will be on that distributed generation and the issues of connecting the distributed generation unit with the electrical grid.

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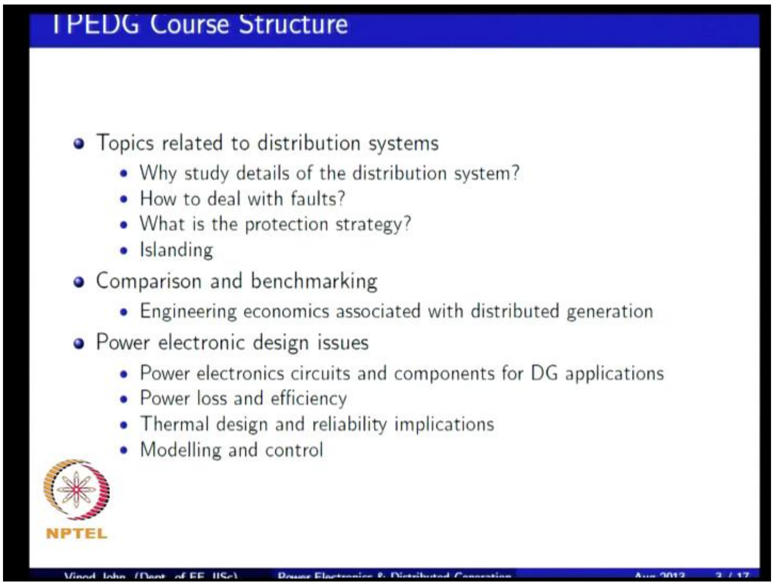

If you look at the structure of the course there will be three parts to the course, the first part is looking at the power system related issues, specifically relating to the distribution system. And will that is the issue of why we need to look at the distribution system closely and the many issues on a steady state bases how large a distributed generation source can be connected with the distribution system. Also transients such as, a bit transients when a fault occurs on the distribution system and how would your distributed generation source in behave in the presence of such a transients.

What is the strategy to deal with protection, especially when you have faults and one thing that can happen, when you have additional source that is in the distribution additional system is that you have the potential to form an island. If you look at the traditional a distribution system, the sources, essentially the grid coming from the substation and you have a feeder coming from the substation to the individual loads, there might be distribution transformers coming to residential areas, commercial areas, industrial areas.

And you are looking at how to interface such systems with the electrical grid and we need to understand the distribution system related issues. The second part of the course we will look at the issue of comparison and bench marking and the reason this is important is, you can have a wide variety of distributed generation sources, you can have wide variety of interconnection systems, power electronic circuits, different circuits, which can do the interconnection.

And the question is are the type of system that you are considering is it actually improving the situation or like are you going backwards. So, it is important to come up with a way of quantifying how good your interconnection system is to make sure that you are going in the right direction. And, so it becomes important into actually come up with a method to evaluate the value of what you are doing and then make a decision is this change that you are making taking you in the right direction.

And this becomes a important issue, where often you have to compare the distributed generation source with the traditional electric grid. And the question is, is it giving you something better are you are you going in a direction where things are getting worse, the third part of the course is related to the power electronic design issues, where we will look at the power electronic circuits for distributed generation applications, we will look at single phase, three phase, different topologies.

The basics of the topologies and the components that going to a typical power electronic circuit. And the component that is go in a typical power electronic circuit, they are essentially inductors, capacitors and switches, you would not intentially put a resistor in a power electronic circuit because it is a dissipative source. So, the question is what sort of inductors, what sort of capacitors, how do you read them, how do you size them, what sort of semiconductors, how do you read them and size them, should go into such an equipment.

They are our implications of the selection in terms of both efficiency and reliability and ideally there is no loss in a inductor, capacitor or switch. But, you always have non-idealities in a practical circuit, so in a practical circuit you will have losses and that implications of loss, one is you lose the generator part that your generating in your generation source in loss. And you have power efficiency that is one impact, the second impact typically is you have more loss, it means that you need more thermal management and your compacts can get hard, which can have reliability implications.

So, the parasitic's of the power convertor component selection has implications in terms of both reliability and efficiency. And that has to be considered when you actually do the design, so that you are taking the overall picture into mind, rather than just a does this component work. Then will also to some limited extend look at modeling and control related issues of such a system.

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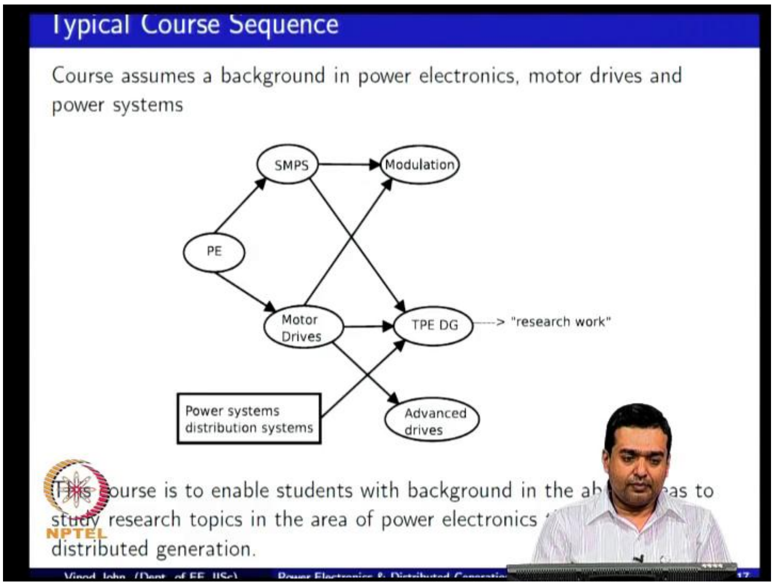

If you look at the typical background required for the course at IIC over here, we have a students who come in or masters degree or for research degrees, they would have already done courses in power electronics, they would have had courses in power systems. So, a introductory level you would have a power electronics course, you would have power systems course, which gives you some exposure to distribution systems, you would have done courses on switch mode power electronics, you would have done courses which help model motors, so you would have courses on motor drives.

And the idea of this particular course is to take in aspects of power electronics, some amount of machines and a power systems. And look at the issues, when you are actually interconnect a distributed generation source with the grid, also at IISE we have courses on details of the power converters, such as how do you modulate the power converter. You also have courses on advanced drives, where you look at details about control related modeling issues.

So, the idea was at this particular point the student can look at research related issues or some particular topic, which you may want to investigate in detail. And hopefully this background will give you the necessary tool to actually go in the direction of looking at power electronics and distributed generation.

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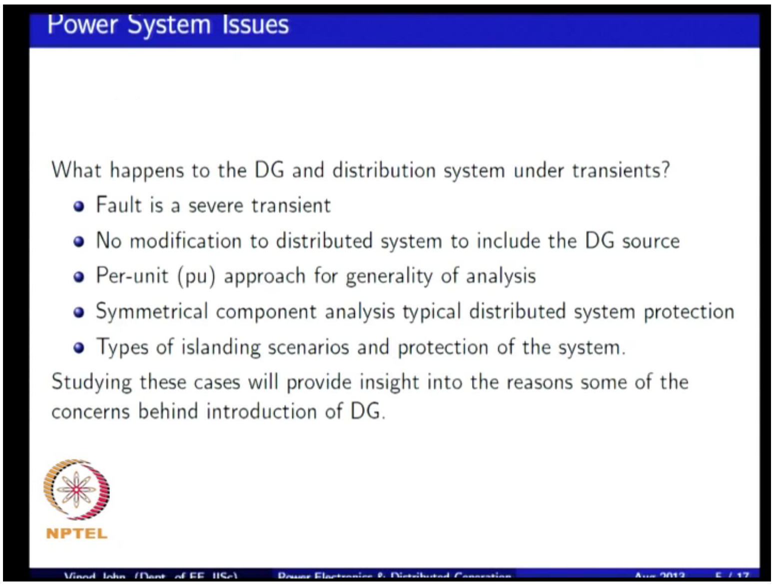

So, we talked about pre-aspects of a this course, so the first aspect was power systems related. And as we mentioned the fault is a severe transient and you need to actually deal with a fault in a power distributed generation system and one of the basic requirement would be that you have the existing distribution system with it is protection philosophy. And you do not want to modify the existing protection system, when you add in the distributed generation source.

So, suppose you have to rewire the whole distribution feeder, when you connect your solar inverter that would bring in a big cost to the overall society just, because a person wants to add a distributed generation source. So, you want your source to work intandan with the existing system and you do not want to modify the existing system, when you introduce the new sources. Some of the background that you would use, when you look at say for example, fault studies is you would typically do a per-unit analysis to actually evaluate what the fault levels are, what the voltages and currents in the system are...

So, the this would be something that you would have from your power systems background, you also make use of symmetrical components, extensively do analyze faults very common fault is a single phase fault. So, such methods are can be useful when you are analyzing distributed generation system and it is a impact on the existing system. Then another important scenario is when you have a additional source in addition to the main grid, which is represents the feeder coming in the substation.

If the feeder gets open for some reason, may be a upstream breaker is opened, then you have to consider what happens to the protection system. If now a new source is actually holding up portion of the feeder as an island, will the protection that was emphasize with to work with the original substation based protection, would it still work when you are operating as a island. So, these are some of the concerns that traditional utility engineers have, when people want to connect distributed generation sources, will the existing method working will it be severely impacted by adding the distributed generation unit.

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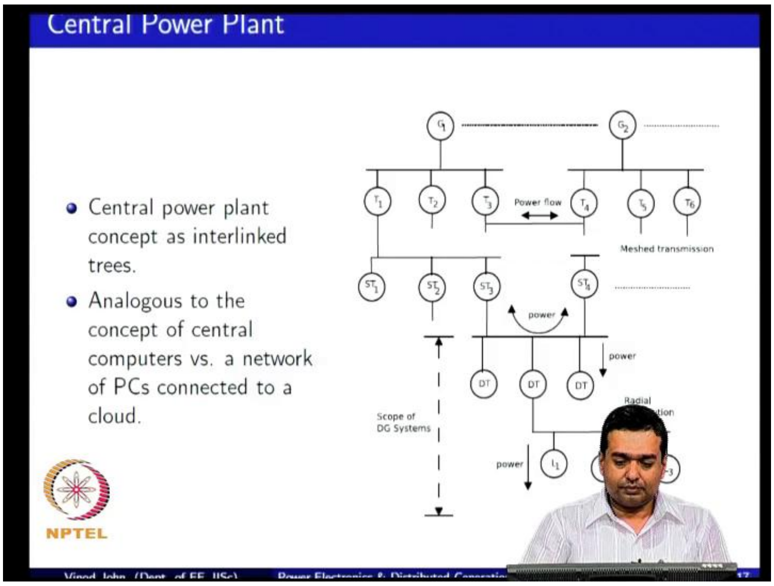

So, if you look at the structure of the power system people like to talk about a distributed generation as a something similar to the old centralized computers versus the newer network of computers to some extent that comparison might be valid. If you look at the overall power system, if you look at the sources in the traditional power system, they are shown as the generators over at the very top. Then you have connect the generators to the a meshed transmission system, where you have power flows, which can be bidirectional from one side to the other side.

You also have sub-transmission systems, which might be at a lower voltage level compared to the main power grid, which then connects to distribution systems. And traditionally you did not have the distributed generators connected to the distribution feeders and the power flow from on your distribution system from the distribution transformer, onwards was unidirectional. But, now when you have a DG source connected you are looking at the potential for bidirectional power flow, even on radial system, distribution systems and this has implications.

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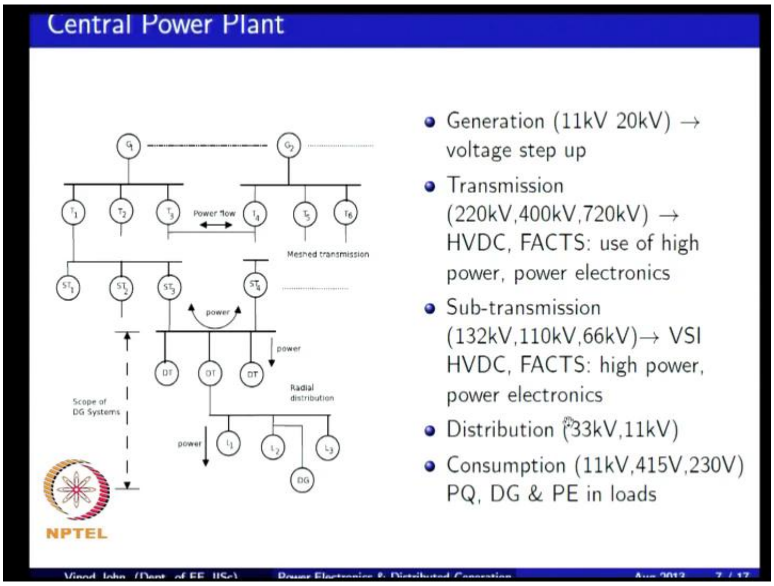

If you look at the voltages and the role of power electronics at the different levels of such a system, you have at the a traditional generator you might have a the generators operating at 11 k V may be 20 k V. And you step it up to the transmission level with a step up transformer, the role of power electronics at this level might be in the exitees of large sync synchronization, there might be some power electronics in the governor systems but, it is not a major player at this particular point in the generator.

If you look at the transmission systems, the voltages are a quite high, we are talking about 400 k V and when people talk about a ultra high voltage, we are talking about 220 k V etcetera. And at this level you have HVDC systems, facts systems, which use very high power electronics, you are sub-transmission system is at a slightly low voltage and even in this particular level you the role of power electronics would be in HVDC and facts at different voltage levels.

When you look at the distribution traditionally distribution is 11 k V can also be at 33 k V level and when it comes down to the consumption point it is typically 415 volts three phase or 230 volts single phase. So, the traditional role of power electronics has been in loads, later switch mode power supply, motor drive at the load level at the consumption point. But, when you are talking about distributed generation, you are talking about potentially connecting it at the consumption level or at the distribution level.

So, this is essentially the range of areas, where we people looking at distributed generation solutions. So, if you look at the way of interconnecting distributed generation systems, so people talk about now having a network of sources connected at the close to the loads. One thing when you have computer network, the constraints on the flow of information and the limits on those constraints are quite some challenging.

But, if you look at the constraints, that governed, the connection of distributed generation sources is not just the information required to control the source, you also have the physical circuit laws, which governed the power flow, you have the thermal management required to allow the power to actually come through. So, you have a lot more physical constraints in the network of energy sources.

So, I would say even though people talk about the analogy, it is actually much tougher problem, when you are looking at a network of energy sources and still that the stage of infancy compared to the mature level that the network of information systems are at today

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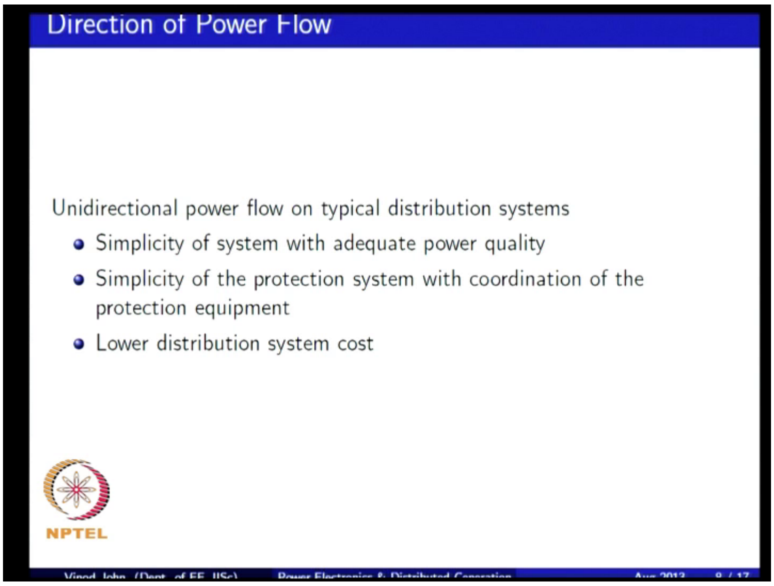

That the concept of unidirectional versus bidirectional power flow has a got a lot of implications, ((Refer Time: 18:50)) just again on the previous slide I just want to point out just because you have a lot of people associate distributed generation with solar energy or wind energy. But, that is not necessarily true all the time, I mean if you look at large wind farms they might be even though the individual turbine might be rated at couple of mega volts, the wind farm might be rated at 250 mega volts or 300 mega volts they would be connect connected to the sub-transmission or the transmission level.

So, the wind energy needed be distributed generation, a similarly if you look at some other newer solar power plans, they are rated at tens of mega volts especially at the large range. So, they can be considered as a more like centralized generation, rather than distributed generation, so when you are talking about the scope of DG systems, you are talking about the power levels that are compatible with the distribution feeders or at the consumption point.

And it is not about the type of source, it is not about solar energy or renewable energy, often you have a diesel generator sitting over here, which is sending power to the load and tt is a non-renewable fuel. But, it is distributed generation, because of the way in which it is connected and the fact that it is distributed in two ways, one is it is connected at the distribution level or at the consumption level. The second thing is geographically distributed rather than being centralized in large individual point centralized power plans.

So, it is good to have clarity on the difference between the type of source and whether it is distributed generation or not just because you have one variety of source it does not mean distributed generation. So, if you look at the issue of power flow in typical distribution system, you have simplicity of the system of the distribution system and if you look at a meshed system, where you have a possibility of power coming in from multiple sources.

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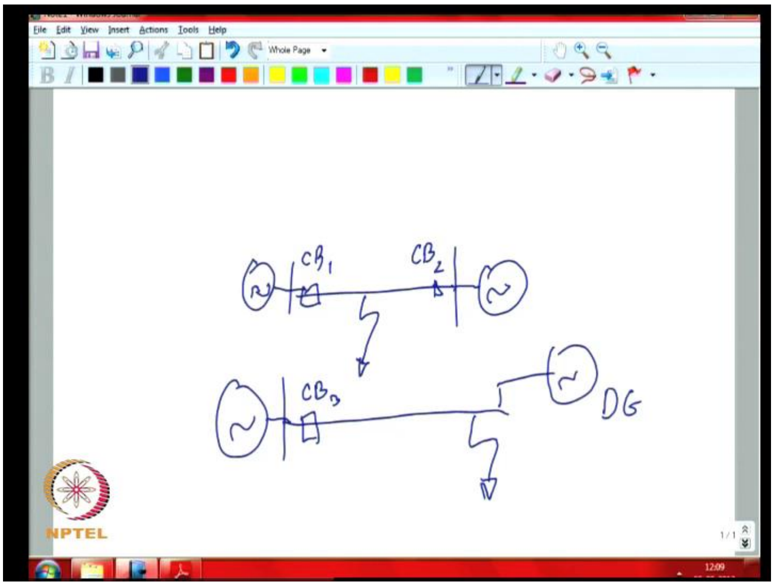

Then you have a scenario, where say you have two sources, suppose you have a fault over here at the center of the line, then to clave the fault you need to actually open say breaker 1 and breaker 2 to actually clear that fault. Because, just opening one breaker is not sufficient, you need to disconnect all the sources to actually clear the fault, if you look at the traditional distribution system, you might have a breaker at C B 3 and say you have a fault somewhere down on the feeder.

And you have to open just one breaker and you can actually clear the fault on the feeder, which means that there is lot of simplicity over here the protection equipment is actually reduced by half in this particular case, you need just one breaker compared to multiple breakers in the other scenario. And also as you proceed along this particular feeder, the ratings reduce as you go for the down the feeder as the loads are typically connected uniformly across the length of the feeder.

So, the rating or something which is much closer over here would be higher, the ratings that are towards the middle of the feeder would be lower. So, you have simplicity and cost reduction in a number of ways, so if you now connect say a distributed generation source over here. Then you have this issue that now to clear a fault that you had on the DG system you have the issue that you had in this previous case, where if you just open this breaker there is now the potential this DG source would actually feed the fault.

And then you have now the issue of being able to coordinate multiple DG sources, it is not just one potential source every customer on the feedback might potentially connect DG. And you need to make sure that those sources get disconnected, when the protection philosophy of the feeder has to actually kick in, so these are some of the concerns of not just simplicity. But, also the cost impact of trying to actually connect more sources into a distribution system.

And, so you need to actually now bring in the DG, such that you can have the existing distribution system. Because you cannot afford to put more protective devices or increase the cost of the existing feeder, you have to actually operate the DG in such a manner that it should not interfere with the existing protection philosophy of the feeder.

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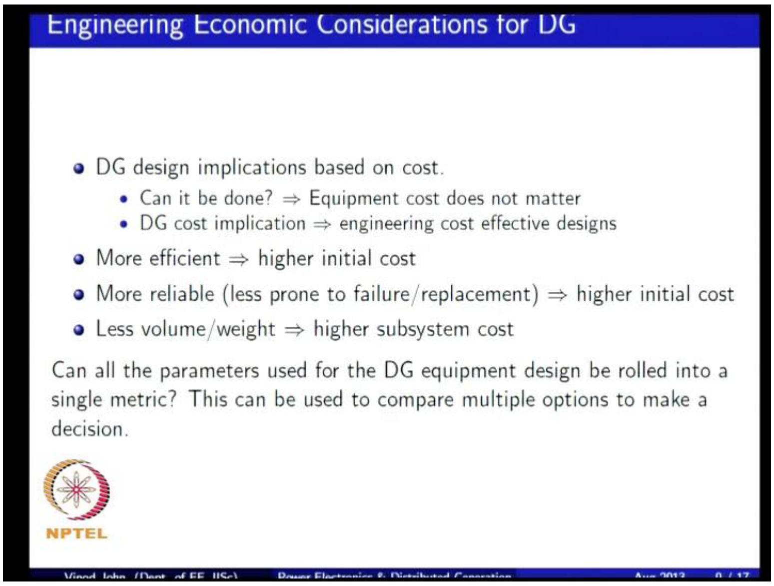

So, if you then look at the second aspect of what we will cover in this course, it is related to the engineering economic aspects of connecting a distributed generation source. And if you look at last year or two years back, they were people like to provide list of what are the grand challenges in facing humanity and one challenge was actually not just saying let us have solar power happens, but to make it actually cost competitive.

So, the big challenge is not just building a solar inverter that are actually 10's of 1000's of solar inverters there, the challenge is actually to make it cheaper than cold, we just actually a very cheaper source of power. So, if you can actually make solar energy lower cost, so without actually thinking about what are the implications of your power electronics or the source changes or the way you are doing interconnection, if unless you are able to boil it down to a cost you will not be able to address this issue of because the real challenges at the how to actually rolled into cost.

So, can be it done it can be done there are 1000's of people who have already done it and the issue is can it be done in a cost effective manner. And you have a number of traders in this particular consideration of cost, if you look at a typical system, if you want to make some component more efficient, you typically end up in a higher cost for it.

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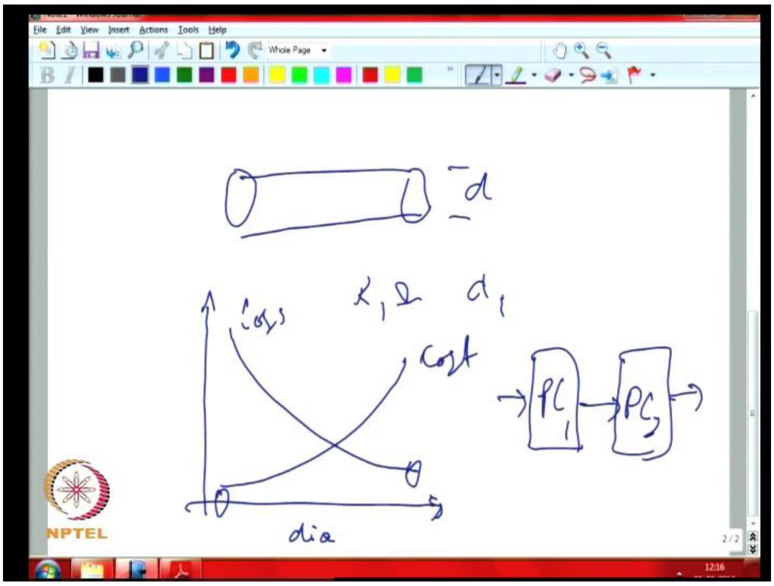

If you look at an example of say a simple wire, I mean if you have wire of some particular cross sectional area of diameter say d and you will have the resistance R 1 of a wire of diameter d 1. And, so just say R 1 ohms and d 1 is the cross sectional area of the wire and say you want to reduce the loss in that particular wire and you decide to double the diameter. So, if you double the diameter the area of cross section would go up by a factor of 4 so your resistance would come down by a factor of force.

So, you are at the handling the same level of current, your power loss would come down by a factor of 4. But, if you look at the cost of the copper that is use in that wire, which is twice the diameter, the volume has now gone up by a factor of 4, so you can see that your costs has gone up your efficiency has gone up, but your cost is gone up. So, if you look at the issue of cost versus if versus losses you have a situation, where if you look at some parameter may be the diameter if you are willing to pay a higher cost, then your losses can come down.

So, the question is the how much additional cost are you willing to tolerate to bring a loss down to some particular level. At this particular point you can actually increase the cost by a small amount and get a bigger benefit of loss reduction or efficiency improvement. Whereas, over here you might not get match in terms of efficiency improvement, but your cost has is going up quite rapidly. So, you have to actually make a engineering decision what is appropriate, even at the simple case of selecting a wire.

And similar implications are there when you are selecting magnetic components, where you are selecting capacitors, power semiconductors, which is etcetera, where there is a tradeoff between cost and the ratings of the components that you are selecting and this is one factor that you need to keep in mind. So, just improving the efficiency for ever will not take you in the right direction, you have to ask yourself this is efficiency improvement being coming in at the appropriate cost.

Not all situations of efficiency improvement is associated with increase cost, it might have a situation where you get both a increase in efficiency and a reduction in cost simultaneously. So, in that case it is a win win situation you have to go for it, suppose you have a power system, where you have power being processed in power converter one. And then it is being processed in power converter two and if by some simplicity of design you could actually merge it together and still retained the efficiency instead of processing it in multiple stages.

Then you might be able to see whether you can actually get lower cost because you are eliminating one big component and simultaneously you are reducing cost associated with a big component. So, you have situations where you definitely have to choose a design based on what would definitely give you benefit, but often in engineering you have situations like this, where you are looking at a tradeoff between what additional amount you are willing to pay and what is the benefit you are getting out of it.

Similarly, if you look at the issue of reliability, if you want to get improved reliability you may have to end up paying a higher cost. For example, if you in the case of a example about the wire that we just discussed, if you have a situation where, because of the increased losses in the narrow wire, your wire temperature is high that higher temperature would lead to poor reliability. So, if you the higher temperature poor reliability would mean that you would have higher failure rate and shorter mean times between repair etcetera. So, if you want to improve reliability you would then go and for a thicker wire, which means that you are paying a higher cost. So, if you look at again that the tradeoff that can potentially happen in such a situation.

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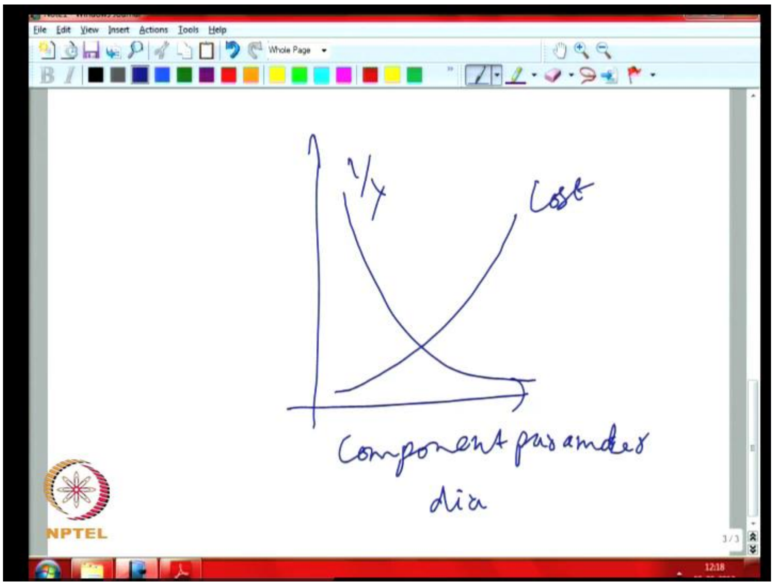

You are looking at a say a tradeoff such as a some component parameter, such as the diameter and on the one hand if you are looking at the if you are increasing the diameter your cost is going up. But, your mean time between failures say 1 by lambda would actually come down because you are having a more reliable component, so you also have this tradeoff between reliability and cost. So, if you are designing a power electronic component and you wanted to lost for, so many years.

If you reduce a cost there is a chance that you would in the component may fail before it reaches the decide a life time. And often in power generation systems you are talking about power plans with 20 or 30 years of life, so can we meet the life of say for example, you build a damn, you wanted to lost for 50 years or 100 years, if we are talking about a nuclear power plant, you are talking about 40 to 60 years. So, depending if you were looking at a wind turbine people looking at wind turbines, which can lost for 20 to 30 years.

So, if you look at solar panels, solar panels can actually lost for a long time, the question is will the electronics that go along with the panel, last for as long as the panel does. So, this issue of tradeoff between reliability and cost also exists, there might be other considerations too such as what is the weight or volume of a component. For example, if you want to make something more compact or extremely light weight, you may have to end up paying more.

And applications such as say transportation the place where the lot of emphasis on volume and weight. For example, if you had a solar converter and you wanted to install it in your hostel and if the solar inverter was the size of almera, you would say no it cannot enter my room and the solar inverter is, so big. Where as if it is the size of may be a cell phone or a laptop, then you do not mind having a panel outside your window because it is not taking much space.

Similar I mean, so you want to have there is a benefit of reducing your volume and weight. For example, when you talk of a application like, transportations say aircraft or a satellite, size and weight is extremely important, so when you want to fly somewhere the aircraft that company that take you there will weigh your baggage. And see whether it is under 20 kilo grams, if is smaller than 20 kilo grams then charge they will charge some extra for carrying a heavier bag or if your bag is too big, they will not allow you to check it in.

So, they operate under tight constraints of size and volume and the implications of size and volume say on a per converter sitting in a aircraft or a satellite is it will cost more fuel consumption in the aircraft. So, there actually a cost impact of size and weight, which needs to be considered when your designing your engineering system and you can see that you make a purchase decision based on say initial cost. But, if you forget about efficiency or reliability or how what the size or weight is then you are not actually taking in the overall picture.

So, you need to actually Rollin the different aspects of design, including efficiency, reliability, weight, transportation constraints, the reliability has implications on how often you do servicing. So, many of this things have to be rolled in to a single metric and then you make a comparison the design that you are doing is it heading in the right direction or not.

So, the metric that you would used might give more weight age to save weight and volume, may be in a aircraft application it might give more weight age to efficiency and reliability and say a application such as long duration industrial power systems. So, that can be different ways of weighting things then but a methodology to actually bring this all together is important for any engineering design.

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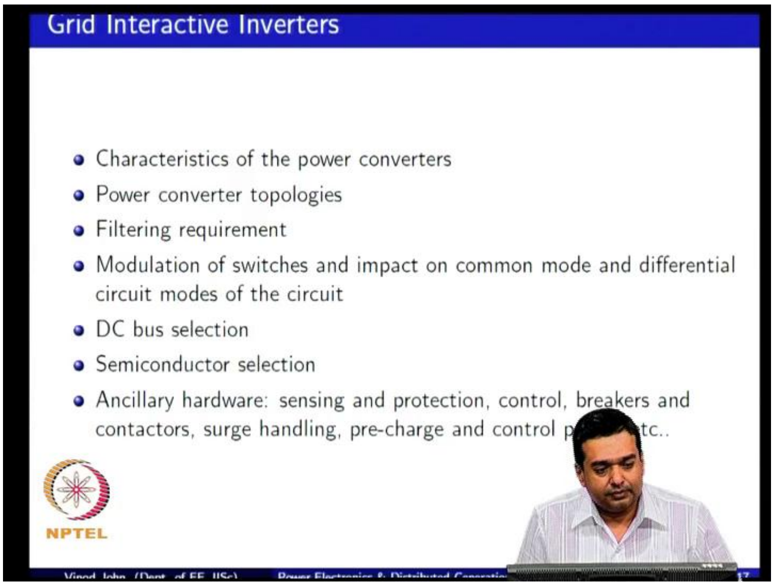

The third part of the course is about the power electronic details will be looking at the characteristics of power converters, the topologies, the requirement of filtering, the output of the power converter you do not want your neighbors, a computer to shut down every time, your solar panel under roof generates power. So, you want a tight filtering and you want it to be compatible with the things that are there around you.

So, we will look at filtering the way you model they switches what does it is impact on a common mode and a differential mode, bases. And will look at a things like how to select the DC bus, often if you use a voltage resource converter you are talking about how to select the DC bus, primarily the DC bus capacitors for such a power converter, how do you select the semiconductors, this has a implications on not just that temperature of the semiconductor junction.

But what is the cycle life of say a given package of the semiconductor, also with a any power converter, you it is not just the main power circuit components there are lot of ancillary hardware, you have sensors, you have protection components in your power converter, you have your controller, it might be small analog controllers or more sophisticated, digital controllers, you have breakers and contactors that need to operate when you are running the power converter, you need to handle surges, you might have some surge protectors, you need to pre-charge your power circuit components. And you also need to provide control power to your circuits boards that are there within your power converter. So, all these ancillary components are important for proper operation of the power converter.

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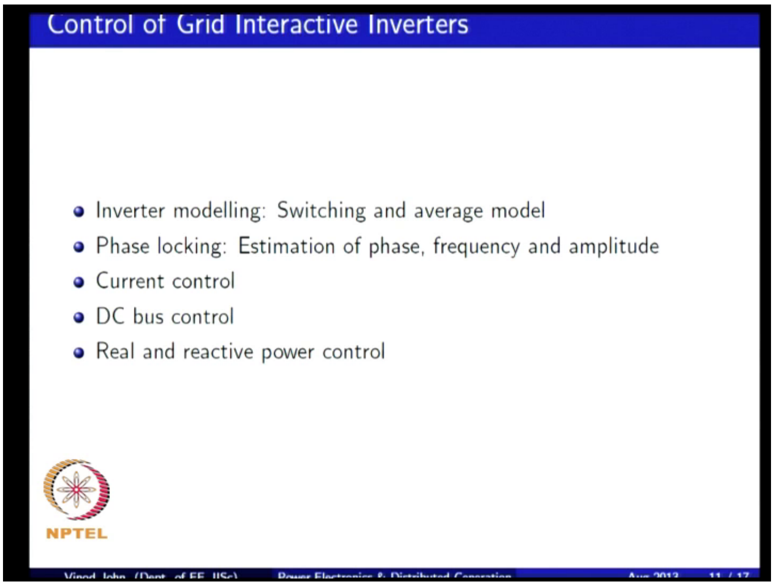

If you look at the control related aspects to some extent we will look at the switching and average models, some of the important requirements are to be able to do things like phase locking, how to controlled the current that is coming out of your distributed generation unit, how do you control the DC bus, how do you controlled the real and reactive power coming out of your power conditioning unit. So, these are issues that are control related which we will try to address some extent.

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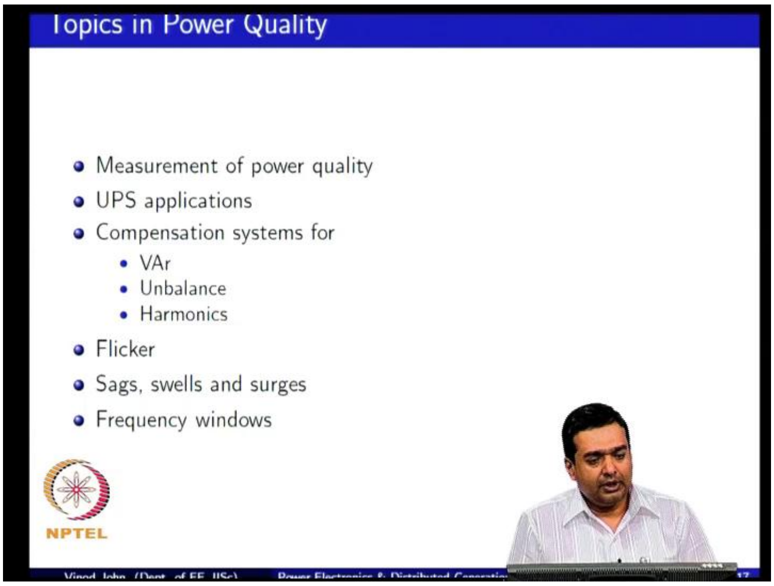

If you look at a power quality related issues, one of the first question is how do you measure what is a power quality. And will have some discussion about that and as important to make a justification to add equipment, which is addition power quality issue such as UPS. You also have power quality is not just an issue from the customer side, so a customer side power quality issue is that a power cut or a outage.

Where as you can also have power quality from the provider side, where customer load is drawing a lot of harmonics or a customer load is highly unbalanced. So, it is a power quality issue which is impacting the provider, so power quality is not just one sided issue it, you have to look at it from both sides from both the loads and the sources. And ensure that overall the system is in good shape. You also have issues like flicker, which comes up when you have a periodic power injection in to a node, you have to deal with sags, swells, surges in a real grid. And you also have to look at what are the ranges of frequencies that you need to operate and how to operate within that particular range appropriately.

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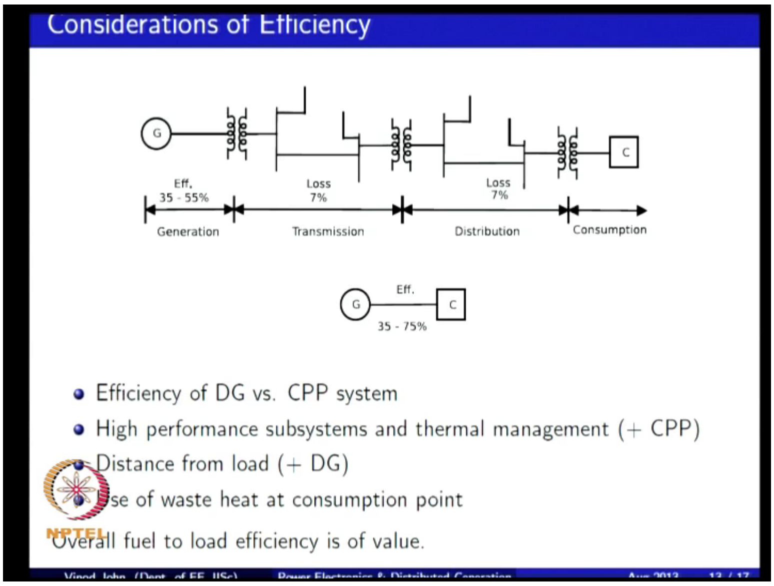

If you look at the issue of efficiency of a the distributed generation versus the centralized generation, you can have a variety range of efficiency over here depending on the type of plan, whether it is a just a boiler or running a turbine or it is a got different stages of which can help improve efficiency or whether it is a natural gas power plant. Where you can have improved efficiency, you also have losses in transmission systems, losses in the distribution system.

And then finally, at the consumption point you are talking about over all power from the fuel to the actual a energy that is delivered, you are talking about something in the range of 20 to 40 percent. If you have a generator source, which is sitting to close your point of consumption, you can have if you are just providing the electrical energy output to your load, then you could have similar levels of efficiency. But, in addition to the electrical energy that is being provided to the load, if you can make use of the waste heat in the load for some purpose.

Then you can actually have better overall fuel to induce efficiency and such systems are typically called co-generation systems. And the comparison of efficiency between the centralized and the distributed is not that straight forward for example, if you have a centralized system, because it is a very large power source. You can actually a make use of generators, with high performance, components with a better cooling etcetera to actually improve the efficiency at the large centralized generator making use of the economies of scale.

Where as you may not be able to increase the cost of this generator to that extent, so you have some advantages, because of higher performance of system and thermal management, in the centralized method of generation. But, if you are looking at from a distance point of view, you have definitely advantages for the distributed generation type of sources. And making use of the waste heat at the point of consumption with will actually give you a big boost in terms of increasing your overall efficiency.

In fact, professor Amulya reddy who use set up the center for sustainable studies in IISE, he had a acronym he used to call it defenders, which is development focused end user oriented and service directed energy sources. And such sources fit in more with the distributed generation parade and the idea is that say if you are providing, say writing institution to a rural household there is definitely development, that is possible more work that such a person can do and provides a direct service. So, there are advantages to the distributed generation parade, even when the some of the initial cost might up to be higher. And over all the fuel to load efficiency is a important aspect to be kept in mind when you are looking at or comparing these systems.

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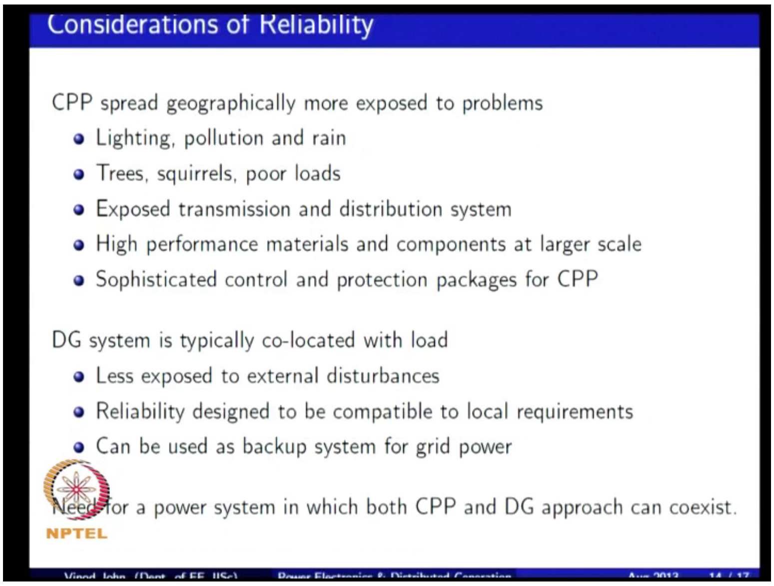

Another aspect is about reliability, when you are look comparing the centralized approach versus distributed approach, the centralized power system is covers a much wider area. So, it is a geographically more exposed to problem such as environmental or lightening, rain, pollution and etcetera, so you can have faults, because of a number of reasons such as this or your distribution systems, might have, tress that are closed by which cause periodic faults, you might have students and birds coming and sitting in and you have situations such that, you would have poor loads on your distribution systems.

For example, on a distribution feeder you might have may be a hundred distribution transformers and from each distribution transformer you might have milli tens of load. So, you are and each consumption load might be household or commercial establishment and each household you might have 10 or milli tens of loads, so if you are looking at the actual load connection to the physical distribution system it is a very large number. So, even if your load has a failure of once in 5 years, if you have milli 1000 of loads these faults are occurring all the time.

And you need to be able to deal with that especially when it is trader around in a large geographical manner. And, so you are your transmission and distribution system traditionally is more exposed to the problems, but on the flip side you can make use of higher performance materials and components on a larger scale you can have more sophisticated, control and protection packages in the centralized system, where it might be justified based on economies of scale. Where as in DG systems, it is code typically code located with the load, which means that it is less exposed to external disturbances.

And, so you can tune your reliability to match your load requirement, rather than make it all very high or all very low you can actually try to match the reliability requirement of the source with the load. And often DG is also people use it as a backup system, when you do not have power from the grid, so overall if you look at a from the efficiency perspective and from the reliability perspective. What I believe is important is not that one method of a addressing generation will solve all problems, it is a way in which you need to design your system.

Such that boost centralized and distributed generation has they have to co-exist, so it is not that the centralized system would go away and you would have only distributed sources or you would never have distributed sources and everything is solved in a centralized manner you need to have engineering architecture, where both systems can actually co-exist.

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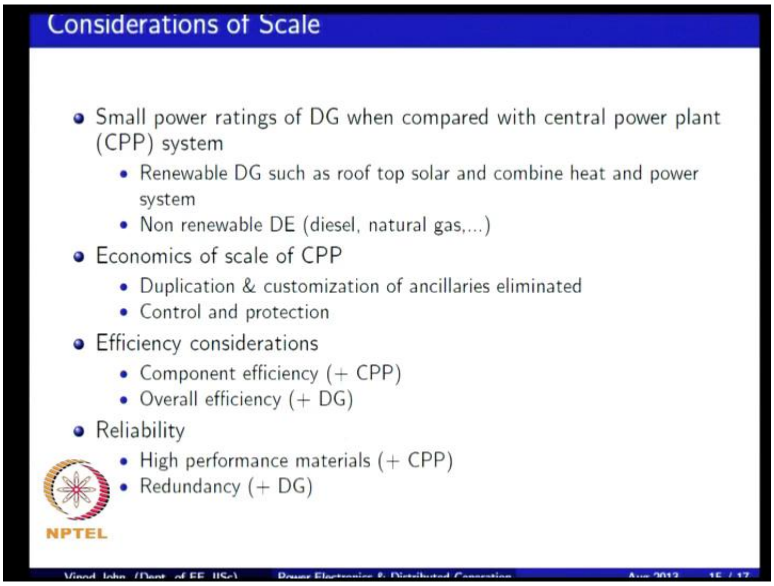

So, we looked at it from a efficiency and reliability perspective, if you look at the typical upfront cost perspective. Scale actually favors centralized power plant, where you have larger ratings of the centralized power plants, where as the smaller ratings of the DG unit. So, you have benefits of efficiency economies of scale up to some extent, once you go to very ((Refer Time: 50:26)) then again you have problems, but when you talking about typical DG and centralized systems, you are talking about benefits of efficiency of scale for the centralized systems.

If you look at renewable DG systems like, roof top solar or combined heat and power systems, they or of a lower rating, typically may be for a household or commercial rating. So, you cannot use the level of sophistication or the advanced materials, you may not be able to use hydrogen cooling for example, to cool the conductors of a residential synchronize machine, where as you could actually easily use that it is typically used in a large centralized generator.

So, whether it is D again, as we mentioned the DG does not have to be always in a renewable did not always be a centralized power, I mean solar roof top solar it might be a small diesel generator that you have a in your commercial establishment, which you use as a generation source, either as a backup or it might be use for some additional functionality depending on the type of a interconnection or power conditioning device.

So, again if you look at the economics of scale issue for each distributed generation system, you need to actually duplicate control and protection. And, so you have some impact over there, but it is becoming less important now a days, as you have a sophisticated digital controllers, which can handle not control of the DG unit, but also many aspects of the protection can be integrated in to a single processor. So, the you can actually have quite sophisticated protection and control methodologies one at lower power scales with a the newer digital controllers.

If you look at efficiency from the component efficiency point of view from the machine efficiency point of view, you have advantages from the centralized power method of generation. Whereas the overall efficiency, especially if you are making use of waste heat you have advantage distributed type of solution, again when you look at the reliability from the use of high performance materials or cooling, you have advantages to the centralized power plant, but reliability is not just a having high obtained.

But, if you look at reliability in terms of redundancy you have say for example, if one large generator in a cold plant or a goes down, you lose a large amount of generation. Whereas, if one turbine out of 250 turbines come down in a wind form, you might use 2 mega watts out of 250 mega watts, so the redundancy actually gives you benefit in some of these methods.

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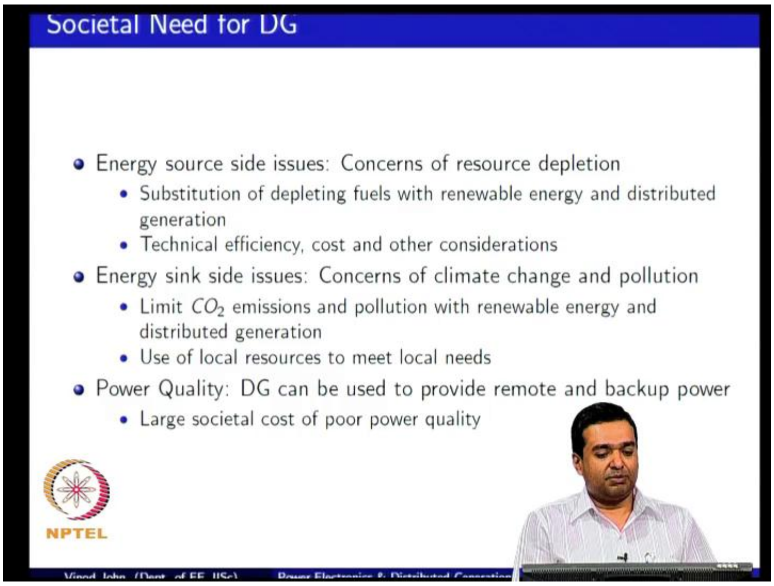

So, if you look at the societal needs for distributed generation, there are many issues, which makes energy a pressing topic it is a issue from the source side. Where you have concerns of resource depletion, you have concerns from the sync side after you make use of a the energy how do you deal with things like carbon dioxide, which is essentially at the same climate change issues. You also have issues of power quality is there energy at all in the first place, I mean this way big societal cost for of poor power quality or lack of electricity being available is actually a big cost.

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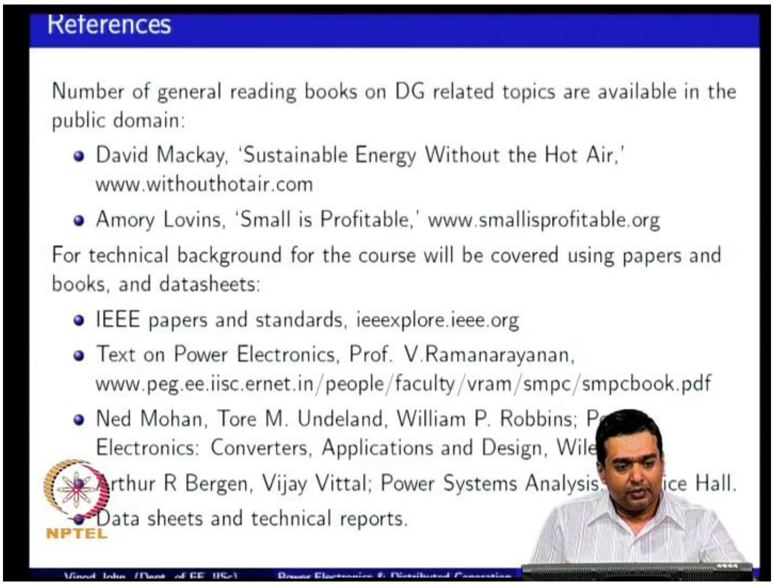

So, over all for this course we do not have a standard text book, we will be looking at papers from generals, we make use of data sheets or technical reports from companies, you can make use of your power electronics or your power system, text book that you use in your under grad or in your courses, that you have done in your first and second semester. The first couple of books are one by professor David MacKay.

And the second by Amory Lovins they are actually more general reading you do not need to have much technical background to actually read these things may be your can ask your parents or relatives to also read at they may be able to comfortably read to those books. So, this is similar in line to the smallest profitable similar to small is beautiful paradine that EF shoemaker used to had a book or a smallest book beautiful.

So, this is the overall introduction for the course, in the next class we will look at specific distributed generation technologies and how power electronics has a important role in those technologies.

Thank you.