Power Electronics and Distributed Generation

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Lecture - 2
Distributed Generation Technologies

So, welcome to the second class on the course on topics in power electronics and distributed generation. In the last class we briefly covered some of the issues related to the course. One of the issues was about comparison of central power plant and the distributed generation for providing energy to a load and we looked at issues of complexity of protection, cost related issues, efficiency related issues, then reliability related issues and as you are aware, there are large variety of DG technologies out there. However, there is quite a bit of commonality in the way in which the power is eventually processed and fed to the grid or to the load and where especially when it comes to the interconnection with the low voltage system.

So, in this course, instead of focusing on individual technologies we will be looking at this broader issues, that are more common for independent of the particular technology. But we today in today’s class we will look at the, we will briefly look at the range of DG technologies that are out there. And in particular, we will look at what are the technology trends related to the power conditioning or a power electronic side aspect of it because the DG is a, can be considered as a bigger system. It might have sub-systems related to generation, it might have sub-systems related to the power conditioning, interconnection, protection, etcetera. So, will take a brief over view of DG technologies today.

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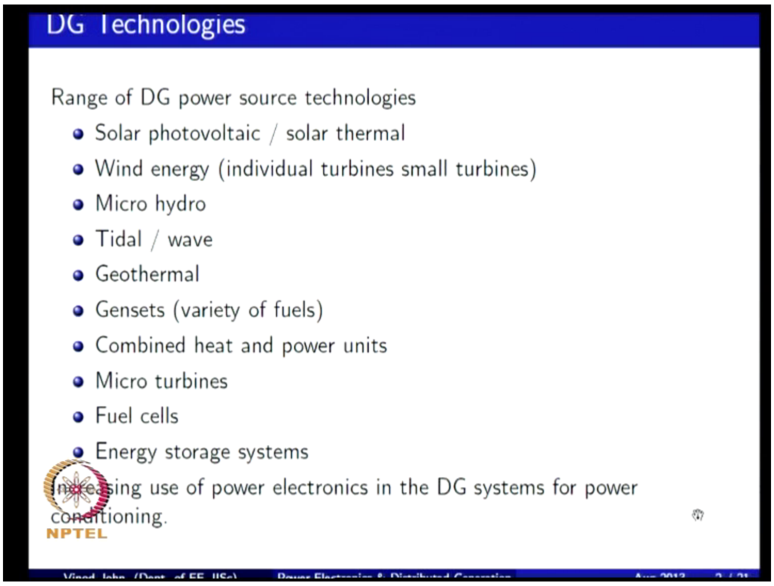

So, if you look at the DG technologies out there, quite prominent among them is a solar electrical, solar electric generation, both photovoltaic and solar thermal and it is one of the fastest growing electric generation methods today, older from a smaller base. Comparatively, wind energy is relatively mature, but if you look at wind energy at a distribution scale, you are talking about individual turbines or small turbines. The common way in which large amounts of wind energy is interconnected today is in the form of wind farms. We will also see micro hydro's getting a closer look for a variety of reasons. Then, you have tidal generation, wave based generation. You have geothermal energy systems in locations where geothermal energy is available.

But most common form of distributed generation out there is actually generator sets, commonly diesel generator sets and these generators need not just be fuel with diesel, there can be a variety of fuels and that makes it especially attractive. Also, the gensets can be modified to actually, not just provide electric output, you can have combined heat and power units where you co-generate electricity and also the thermal requirement, whereas cooling or heating.

You also have micro turbines, which is another way of generating electricity from a fuel source and you have fuel cells. You have a variety of energy storage system, systems, out there, batteries, ultra-capacitors, fly wheels, etcetera. And you can see, that there is increasing use of power electronics in the DG systems, especially for the power conditioning aspect.

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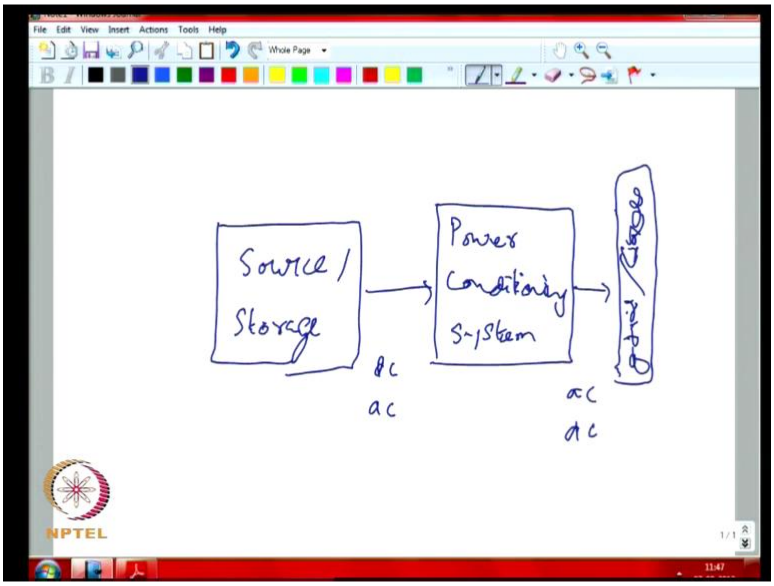

If you look at typical role of power electronics, you can think of a block, which might consider, might consider the source or the storage element. The output would go to a power conditioning system, the output would be fed to the grid. So, so the output would be fed to the grid.Often the source might be generating power at DC level or sometimes at AC. The power conditioning system it is leading, not only just be a power converter or an inverter, it can be a something like a machine. For example, you can have DC machines, AC machines, etcetera. Often you find induction machines being used with wind turbine.

So, you can think of machine as a power conditioning unit or a synchronized generator when you are having gensets. So, the power conditioning unit need not be power electronics. In fact, often machines are cheaper than inverters for a given power rating. So, often people look at machines much more closely rather than looking at inverter as the default option and here, it is commonly AC. Mostly, the AC at, you are considering low voltage, so you are talking about 415 volts, 50 hertz or 230 volt single phase grids. You can also have DC, off-late people are looking at DC distribution, especially in applications like data centers, etcetera. So, you can have combination of AC or DC depending on the configuration at the end application and that you have in mind.

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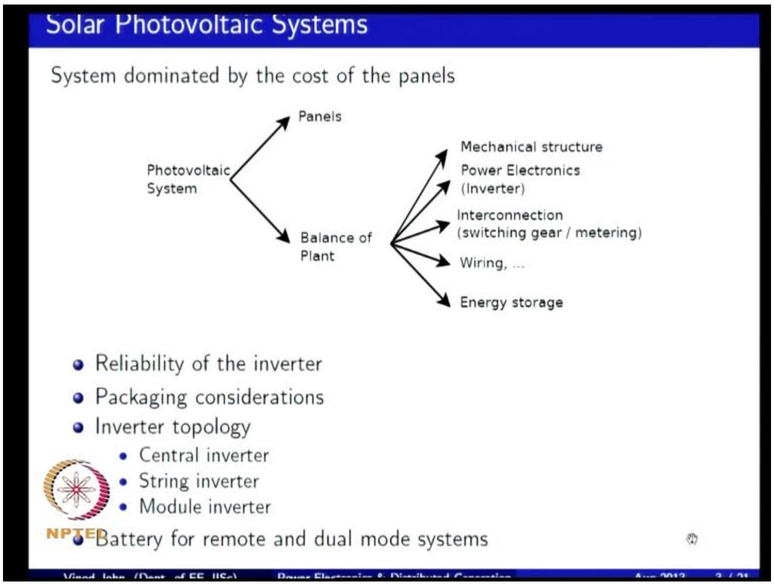

If you look at, if you look at the, the dominant technology, that is emerging today, it is actually the solar electric generation and the photovoltaic is an important part of the solar electric generation. And the cost of the photovoltaic system has been dominated by that of the panels. And if you look at the photovoltaic system you have the panels, you have the, you have the panels and the balance of plant and one-third of the cost typically goes into the panels and the remaining into the balance of plant. In the balance of plant you have the mechanical structures for mounting the panels, you have the power electronic inverters, the interconnection, which could be switchgear metering required for measuring, how much power is actually generated, either be wiring requirement from the panel to the power conditioning system. And from there to the outside.

You, depending on that type of application, you may also need energy storage in the, in the system and so what I mentioned is, that the panel cost is the dominant cost. Today, if you look at the overall cost of photovoltaic system, today people are talking about cost and the range of, one and one and a half lakhs per kilo-watt for the overall system with panel cost today being of the order of, as cheap as 50000 rupees per kilowatt; 4 years back it used to be, panel cost by itself would be the one and a half lakhs. So, you can see, that the panel cost reduced drastically by a factor of at least 3 over the last 4 years.

If you look at the remaining aspects, the costs have not fallen that drastically. The cost of power electronics in such a system is actually on the smaller side. It is typically in 10 to

15 percent range. So, you might say, for a kilowatt you might pay up to 20000 rupees. So, you might say, then the entire focus should be on the panels and the electronics is secondary.

But the main issue was, if you look at from a reliability perspective the cost of the life of the panels is expected to be about 20 to 30 years, whereas if you look at the reliability of electronics today, it does not last that long. If you look at one end of the spectrum, today's laptops, cell phones, etcetera, they get obsolete in a couple of years and things stop functioning. Even high end electronics, you might be able to work for a longer duration, but you might have to replace some semiconductors or capacitors, etcetera. So, if you look at typical systems, you are talking about, say may be 5 years or may be 10 years. But you can see, that if you have cost of a system, which costs 20000 rupees, but it has to be replaced every 5 years, the overall life time cost can actually accumulate quite a bit.

If you look at the details of the inverter topology in this photovoltaic system today, the earlier topology was centralized inverter where you take all the panels, you connect, you connect the panels together in arrays and you bring them to a single inverter and use that inverter to actually send power out to the grid. So, you have issues of, if the inverter for some reason is down, then you do not have any power that is sent out at all. The second thing is, if you look at the maximum power point at which the overall array can work, it would depend on how the cells are connected together. You might have issues of things like partial shading, which might not allow the array to go at its best performance.

So, people have looked at connecting strings on one particular inverter and having parallel such inverters, so that approach is called the string inverter approach. People are also looking at having one inverter per module, which means, that you could actually operate at the best power level on a per module basis. So, so there has been an evolution in the topology of the inverter, but people look at advantages and disadvantages of going across this particular spectrum.

An important part of the inverter is also packaging consideration. For example, if you have a solar inverter, which is sitting indoors, the thermal issues are relatively mild compared to a solar inverter, which you want to mount along with your module outdoors or if the entire central inverter has to set outdoors, you have to deal with it and package it in a manner, which will handle the heat, the dust, humidity, etcetera outside, which makes thermal management more challenging. It can, which in turn would affect the reliability. So, packaging consideration of the inverter is also an important issue.

So, the other aspect is, if you look at the larger solar photovoltaic insulations today, commonly it, across the world people are looking at grid connected, but in situations where you are operating in a remote situation where you do not have the grid or if you have a grid, which, where the power quality of the grid is not good, you need energy storage. And people are looking at dual mode systems, which mean, that you can operate either in a grid connected mode or in a standalone mode disconnected from the grid.

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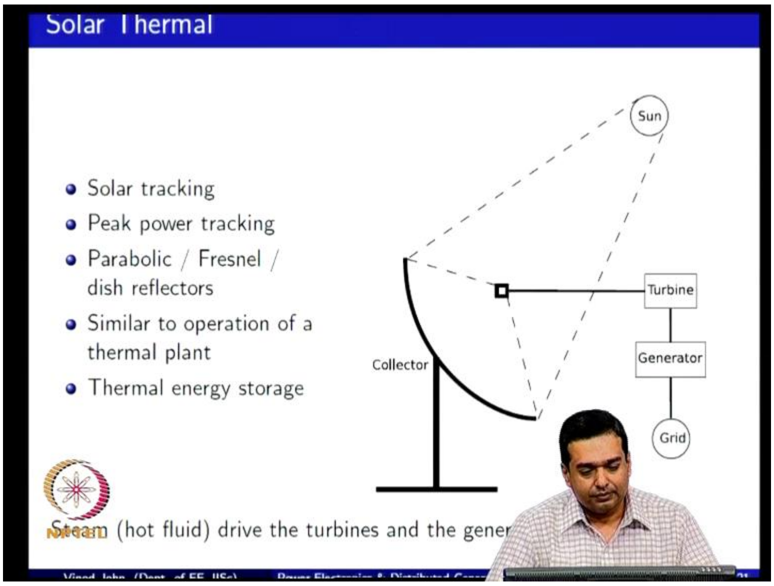

If you look at the solar thermal electric technology, it consists of large reflectors, which concentrate the solar thermal energy and make use of some fluid to actually dry a turbine and a generator and send the power to the grid. So, in many ways it is similar to the technology of the traditional generator depending on how much power is collected.

Typically, solar tracking is done in this technology, which means, that depending on the time of day you would actually track the sun. You have also to track the peak power that can be extracted from such a system so as to fully utilize it. You have a variety of technologies for the dish collector, you would have parabolic collectors, you have dish reflectors, you have fresnel reflectors. Fresnel reflectors are essentially, small planes, which together form part of a dish, so it is more easily handled.

So, the operation of such a system is similar to what you would do with a thermal plant, where you have hot fluid, you generate and use that to run a turbine and then generator and the power level depends on what is available from the sun. People are also looking at the possibility of storage in such a system where you can make use of the collected energy during the day and you store it as stored thermal energy in things like molten salts and then you use that energy to drive the turbine at a time, at night time when the solar energy is not available. So, people are looking at possibility of storage even with solar thermal technology.

The reason people are looking at solar thermal closely is that the cost of solar thermal is actually lower on cost of energy bases compared to the photovoltaic and the efficiency of the conversion is also typically higher in the photovoltaic system. You are talking about efficiencies of 7 to 14, 15 percent for common commercial selves depending on whether it is amorphous or crystalline, etcetera, whereas you could get efficiencies of the order of 25 percent in the solar thermal. So, you end up having better cost of energy, so it is, it can be quite cost effective.

And the challenge in the solar thermal system is to make it truly distributed. Often the solar thermal system is actually large insulations where you have large collection points from which you generate power almost on centralized bases. It is difficult to scale many of these collector tracking systems, so that you could put it on, say, individual roof tops or on commercial establishment. So, to make it truly distributed is actually a challenge.

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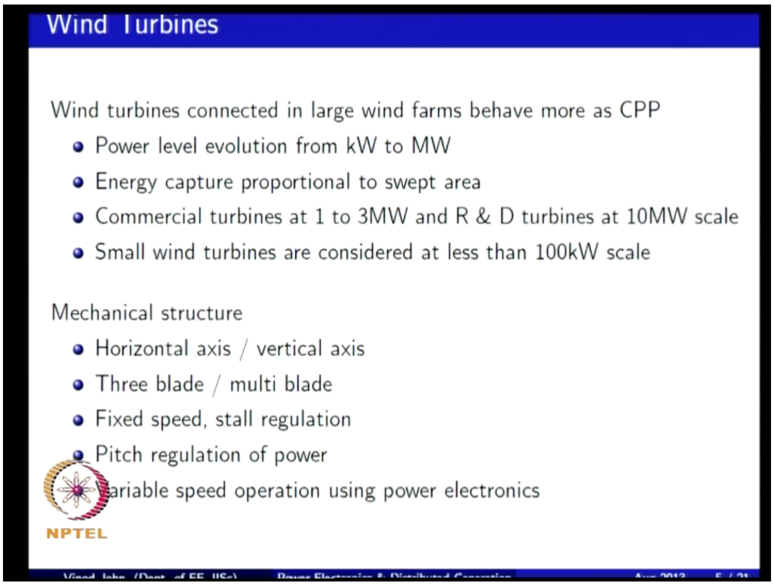

If you look at the wind technology today, this compared to the photovoltaic is much more mature. In India, I think, today, the amount of energy generated from wind technology is actually comparable to, for example, nuclear power. So, it is, I would say, fairly mature in terms of what capacity is out there. If you look at the evolution of these wind turbines, it started off with some things, things in the order of kilowatts in the eighties to megawatts today on individual turbine bases.

If you look at the wind turbine, the reason why it has scaled up to higher power level is, if you look at the energy captured by an individual turbine, the energy captured is proportional to the area covered by the blades of the turbine, which is proportional to, say, the dimension square like radius square. Whereas, if you look at the material, that goes into the constructions, it is proportional to the dimension. So, you have cost that scale with dimension, but energy, which scales the square of the dimension. So, if you make it larger, you could actually bring down the cost per unit of power produced.

So, the limits on how big it gets is actually related to constraints, like how strong a material you could actually use for constructing the turbine to make it even bigger or you could have limits on what could be the speed beyond which your caustic noise becomes too severe. So, even though it is rotating at slow rpms, the turbines, the tips speed can almost reach to, close to the speed of sound. So, you could have really loud noise coming in from things like the tips, ((Refer time: 19:24)), etcetera. So, the limits on how large you can go is actually limited by the technology of the materials, that and that goes into the turbine.

And today, commercial turbines are available in the 1, 2, 3 megawatts quite commonly and there are research turbines prototypes, that are installed in the 10s of megawatts on per turbine bases. People have looked at individual turbines, that go up to 25 megawatts, etcetera. If you look at the small wind turbines, you are considering turbines, which can be connected to the distribution. Typically, you are talking about small turbines, which are rated at less than 100 kilowatts.

In terms of the mechanical structure of wind turbine, you can have a variety of mechanical configurations. You can have the common varieties, the horizontal axis, what we commonly see, you can also have vertical axis turbines. The commonly seen turbines are the three bladed turbines; you can have multi-bladed turbines. If you look at the really old turbines that were used for pumping water, etcetera, you would see a large number of blades and they would rotate at lower speed, but have a sufficient arc to pump water. You can actually also reduce the blades; you can have two bladed turbines. People have actually built prototypes of single bladed turbines. If you have just two blades it is easy to carry just in one dimension, single blade, again reducing components. So, people have looked at a variety of blade configurations.

In terms of operation, the earlier turbines used to be fixed speed, stall regulated. What you mean, what it means is, that the speed would be dependent on the grid frequency, the motor that is connected and the gear box, and the limitation of power would come in by the design of the blade. So, for example, if the wind power becomes more, the blades were designed to stall rather than capture the increased speed of the wind. So, they are called stall regulated turbine.

The other option with the blade is, rather than keep the blade at a fixed position and design the blade to stall, you could physically change the pitch angle of the blade. So, if you have excessive power you could actually increase the pitch angle and let the power not be captured by the wind turbine. They are called pitch regulated blades.

You could also, off late people have looked at variable speed operation, this is what is commonly the state of the act today where you not operate at a fixed speed, but you operate at a speed, which gives you the best energy capture. So, even at low speed you can actually operate at a lower speed and capture the best possible energy under low speed conditions. When you go to high speed, you pitch out the blades and reduce the amount of power that is captured.

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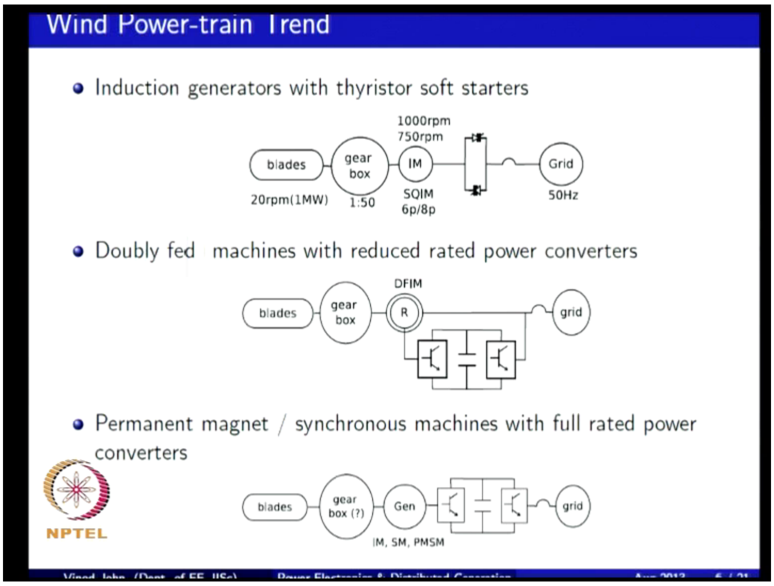

If you look at the powertrain, the powertrain of a wind turbine is essentially the main part of power flow starting from the blades where you have the energy from the wind being converted to the mechanical energy, typically through a gear box, a step up gear box. So, if you are having blades that are rotating at, of the order of 20 rpm, you, and say, your machine over here is running at, of 50 hertz, say at 1000 rpm you would need gear box, which is having a ratio of, of the order of 1 is to 50. So, there is a large, a speed step up ratio, that is required for the gear box and when you talk about 20 rpm it means, that in a in a minute you have 20 rotations.

So, for one rotation it takes 3 second for the blade to go round, which appear slow, but because the dimension of the blade is really large, of the order of 50, 70 meters, etcetera, the tip speed is actually quite large even with a slow rotational speed of the blade. So, you typically have a gear box and the earliest technology where was, you would have a fixed induction machine used, that is used to connect the output of the gear box to the electric grid. And the electric grid being 50 hertz, it means, that the synchronous speed of the machine is fixed once you fixed the pole number of the machine. You could have, may be, a couple of fixed speed points depending on the pole number. You could have a

6 pole slash 8 pole machine. You would also typically add back to back connected ((Refer time: 24:41)) to limit inrush during startup of the machine, etcetera and this was the typical early configurations of wind turbine.

If you look at wind turbines today, the state of the art, you replace the induction machine, the school cage induction machine with a doubly fed machine. So, you have windings on both, the strator and the rotor. The strator is connected to the grid and rotor is connected to the grid through back to back power converters. So, this type of configuration is what is called the slip energy recovery scheme and doubly fed machines. The power handled by the rotor is proportional to the slip speed. So, if your slip speed is small range, say, 30 percent of your nominal speed, then the power rating required by these power converters would be smaller percentage, one-third of the power required for, the rated power of the over overall turbine, which means, that you would need smaller rated converters over here and this is actually state of the art.

If you look at commonly available commercial turbines today, there would be doubly fed machines with back to back connected converters with the rotor energy recovery scheme. If you, if you look at what the people are looking at today, as you go to higher and higher penetration levels of the grid and when you are dealing with weaker grids, people are looking at, instead of handling just the rotor power with a power converter, you replace it with now a fully rated power converter, which can handle the entire power. And now, if you have a fully rated power converter, which handles the entire power, then the generator can be replaced with, may be a synchronous machine or a permanent magnetic machine, which has higher, which can have higher efficiency than an induction machine.

Also, if you design now a special machine which can run at lower electrical frequency, then it means that potentially you can eliminate the gear box because this particular machine can be made to run at a rated speed of may be 20 rpm itself rather than at 1000 rpm or a higher rpm. So, you can potentially eliminate large elements such as a gear box in such configuration and this is being looked out more closely by, by many manufactures as potential as turbines, that can be installed on, especially in the condition when you are having high penetration of wind turbines already in the system and you want to install more turbines or when you have weak grids where the power that is put out by the turbine can actually cause problems to the grid. Then, having a fully rated power converter will allow rapid control of power flow, which will help stabilize the grid.

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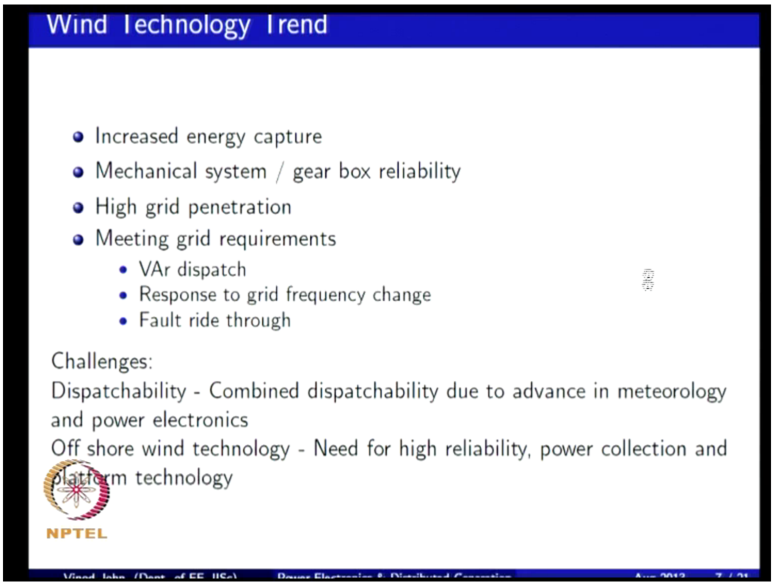

So, if you look at the technology trend, that was there, it is, it is going in the direction of one increased energy captured from the wind. The second is to improve reliability. For example, if you can eliminate the gear box, then the issue of gear box reliability goes away. You also have high grid penetration issues. For example, not all parts of the world have the best wind resource. If you look at India where you have the best possible wind resources available, you are talking about places like, may be Gujarat, Tamil Nadu, etcetera, you already have a large number of turbines. So, if you want to put more turbines in such a location, then you need to have better ways of dealing with the grid and you. So, that is another way.

A trend, which is demand requirement, which is being imposed from the grid side, so meeting some of the requirements like dispatching a reactive power to support the grid responding to grid frequency changes. So, if the grid frequency rises suddenly, you could cut down on the power that is send out to the grid and helps stabilize the grid. Obviously, the turbine cannot increase the power beyond what is already available from the wind, but you can actually reduce the power and still operate.

Also, another issue that has become important is fault ride through. So, for example, if you have a fault under a grid and all the power converters shut off, then you lose a large amount of generation at one go. But, so you need to have turbines and with power converters that can actually stay in there and the fault protection logic of the power system operates. And power system protection typically operates in the many fundamental cycles time frames. So, you are talking about hundreds of millisecond, whereas if you look at the protection of Igbt's in power converter, you are talking about microsecond range. So, you need to operate your power converter without tripping for many hundreds of milliseconds range, which is a challenge.

Also, another challenge is to look at, whether you could make use of advanced meteorology. So, you have better weather prediction, better prediction of what the wind conditions are and use that to actually plan on how, how much wind power will be there, which means how much other resources would be needed. So, combined dispatch ability is something that people are looking at especially with power electronics you could actually adjust things at a faster rate.

Also, people are looking at offshore wind technology, large number of installations out there. In the world, if you look at the load centers of the world, the bigger cities of the world in India, Bombay, say Cochin, Chennai, Kolkata, they are all coastal cities and those are the load centers. So, if you look at London, New York, etcetera, you have the power generation source sited close to the loads, then you have better possibility of feeding the load from a source that is close by. So, the offshore wind technology is actually quite appealing.

However, with offshore technology you need higher reliability. For example, if you have a turbine, which is down on land, you can send a service person to go and repair it, whereas if you have a turbine, which is sitting in the Arabian Sea, in monsoon season, the rough sea might prevent you from repairing it during the monsoon season. So, you would have, you need higher reliability for actually doing things like proper servicing.

And power collection is also an issue. At sea you need to collect the power and transmit it to the land typically through sub-sea cables or some form of a DC conversion and transmission, etcetera. People are also, there are also mechanical challenges of how to install the turbines in water. People are looking at the technology from offshore oil and gas platforms to and making use of that to actually use that in wind, offshore wind technology.

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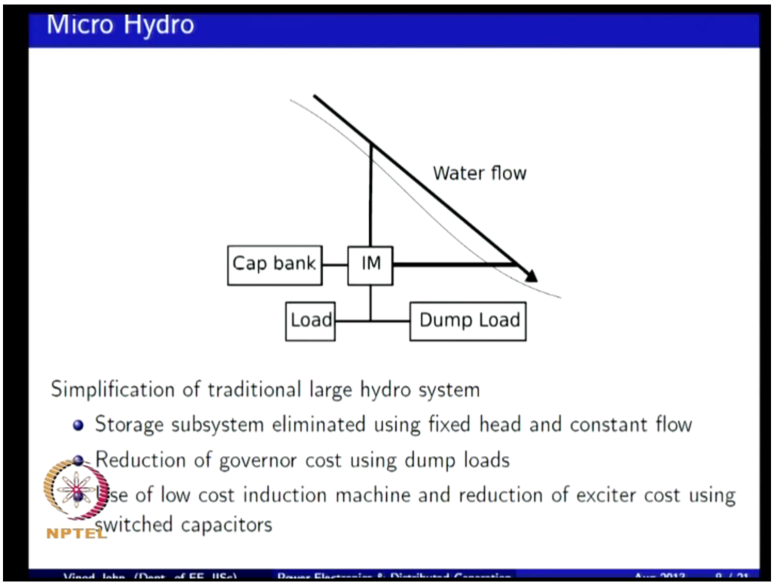

Another technology, which is the, is coming up and is quite appealing is micro hydro. If you look at the large damns, there is a, already the best sites are taken. In the Indian context you have a large damn, you submerge a lot of land and then, there are rehabilitation and relocation issues. So, micro hydro is actually quite appealing in that context where you are taking the traditional hydro system and trying to simplify it. And if you look at the simplification, the big, the big cause in hydro is actually the civil, the construction of the bank and the land submerge, etcetera. So, if you can eliminate the construction of the damn that eliminates the fairly big cost.

So, if you eliminate the damn construction, what you are doing is, you are taking water at an increased height and taking a pipe and draining it out at a lower height where such possibility exist. And making use of a fixed head you do not have storage, but you have a fixed head depending on the height of the intake and the outlet. The second reduction of cost can be in terms of, say, to control the power.

In a traditional dam you have governors, which regulate the amount of water that is going in, which would regulate the amount of power that is generated. So, if you have a fixed height and if you are not having a governor, it means, that your power output is constant. And if you have loads that are connected, which are variable, if you can have dump loads such that the some of the load, actual load plus the dump load is constant, then you do not need a governor. You are always operating at constant power output from the machine because the total load is constant. So, you could potentially eliminate another costly system, such as the governor.

Then, you could also, for example, replace the machine. Induction machine is cheaper than a synchronous machine, so replace the synchronous machine with the induction machine, which means, that then you have a cost reduction in terms of the exciter not being there. The excitation, in this case, is then provided by a bank of capacitors, which would itself be a self-excited induction machine. So, for a variety of these reasons people are starting to look at a possibility or small hydro where it is possible.

In India you are talking about the Western, Eastern Ghats. So, in the monsoon season, when water is available you could generate power. Similarly, in the Himalayan mountain range you could actually generate power with a small hydro and people are looking at these as possible solutions.

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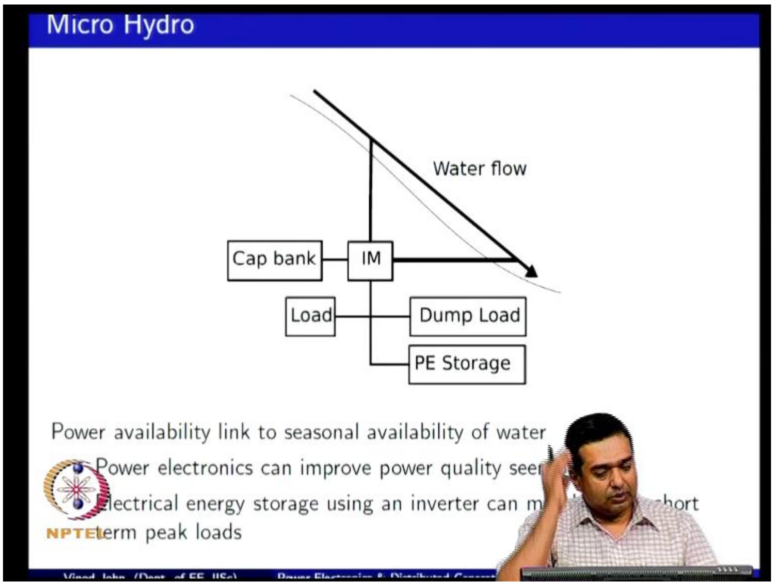

So, if you look at what would be the role of power electronics potentially in such a system, you could say, for example, if you take a load, typically it is not just real power, you might also need reactive power, which means, that the total output of the induction machine, the voltage would not stay constant even though the total real power stays constant. If you add more inductive watts from the load, your voltage might drop, which means, that you cannot have just a fixed capacitor, you would have, need a bank of capacitors also by rapidly responding to the load requirements.

You could improve the power quality from, say, a power electronic connected converter that is used in parallel. Also, if you have limited, some amount of storage available in the power converter, if the load is on a transient bases, for example, on a startup of the load you need a higher level of power than in what is available from the machine. Then, potentially, the storage element could provide a transient power requirement keeping the average power coming in from your, your induction machine, the micro hydro and the power electronic device providing you the dynamic power requirement as an when required.

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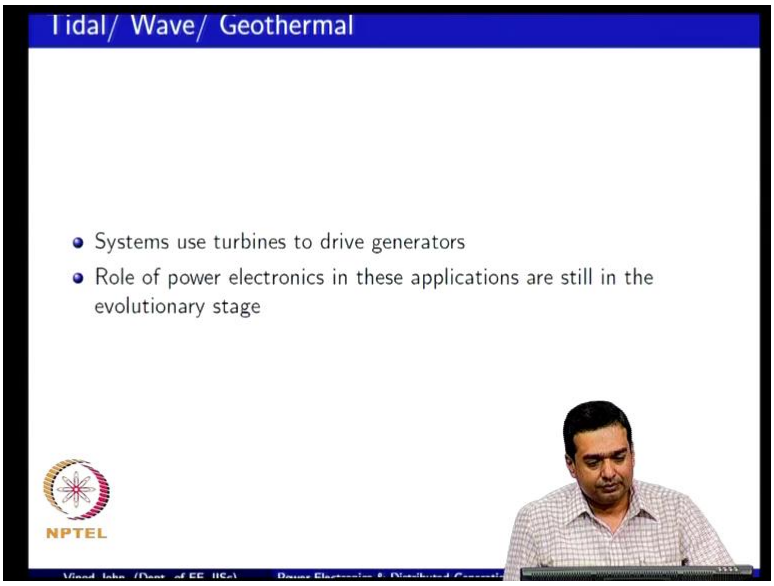

If you look at a wave and a tidal energy, these are similar to, in a way you can think of it as something that is similar to wind. Wind is a fluid, which is not that dense; water is a fluid, which is much more dense. So, if you look at the turbine required in a tidal application, the diameter of the blades in the real turbine would be much smaller because the power density available in the flow of water is actually much higher. So, so so you can think of, there is some similarity to what is being done in wind and what could be done in the tidal or the wave turbines. Also, you have the typical effect that the water flow does not change as dynamically as the change of a wind.

So, if you look at the tidal regions and wave energy regions in India, the Gulf of Kutch is a good location in India for potentially harvesting wave or tidal energy. Similarly, the Pak strait, Gulf of Munnar area, they are good locations for potentially harvesting tidal and wave energy. The challenge in these systems is, that you have now turbines, which are submerged in water. So, it is exposed to sea water, which has salts, it was quite a corrosive environment. So, packaging is an important consideration.

If you look at geothermal, again depending on where the resources are available, I think in India there are geothermal stations in the Himalayas, a smaller bases. So, depending on where the resources are available people are looking at the possibility of geothermal in all these systems. You have turbines, that are that drive generators to produce power. And if you look at role of power electronics in these applications, it is still in the evolutionary stage in starting stage.

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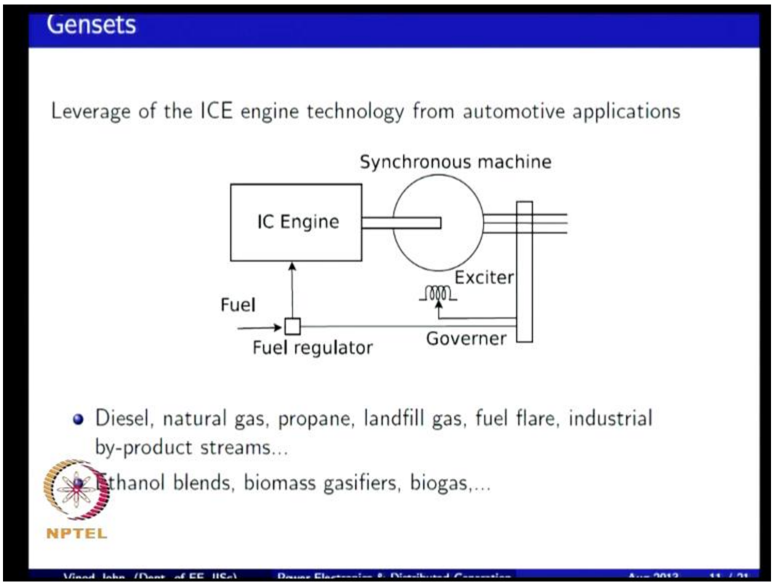

If you look at the most common distribution generation technology, that is actually out there, it is the gensets that are commonly used. If you go to any commercial area of the Indian city you would have people who have gensets outside their shops. If there is a power outage all the gensets will turn on. So, there is actually a very large installed capacity of gensets out there, though not connected to the grid, it is, they are acting as backup systems.

The cost of the genset is quite low because it leverages the IC engine technology from automotive applications and so the cost is actually quite low. And if you look at the system, you have the fuel. The fuel can be a variety of fuel, diesel, natural gas, propane. It can also be the landfill gas fuel, that is flood out in some chemical processing, industrial by-products, etcetera. It could also be agricultural by-products, ethanol blends, biomass, gasified biomass or biogas. So, you could have variety of fuels. And in the genset what you do is, you try to provide a fuel so as to regulate the speed the output of your machine, so that you maintain 50 hertz frequency required by the AC grid or the load.

So, you would have this particular machine operating at constant speed depending on the required frequency, say, say if this is 50 hertz, you would have the corresponding speed depending on the pole number of the machine. You will also have an exciter system. So, with stand-alone loads you are ensuring, that you are maintaining the required load voltage or if you are operating it connected to the grid, you are using the exciter system to control the reactive power flow from the machine to the outside.

So, one constrain that you can immediately see is, that irrespective of the load that is connected or the power that is sent out, the IC engine has to operate at a fixed speed at light load or full load depending on the frequency, that is to be generated at the output, which is in a way an area where power electronics can come in and that is, essentially, by allowing the IC engine to operate at variable speeds.

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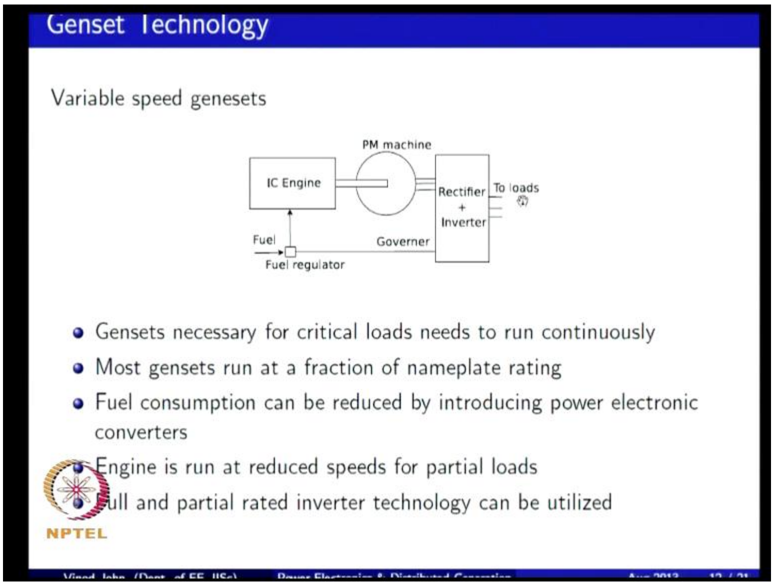

So, you take the output from the IC engine through a machine, rectify it and then you use an inverter to provide the fixed frequency, which means, that potentially, now at light loads you can run your IC engine at a much lower rpm. So, reducing the fuel consumption in the IC engine, so you could see that. Also, in many time, many applications, your genset might need to run continuously if you want to provide backup in a rapid bases.

So, if you start a genset, even fast starting gensets, you are talking about, may be 10 seconds for it to start up, if you want to transfer to a genset in time duration shorter than 10 seconds, then you would run the genset at almost close to no load, and whenever there is a disturbance you would transfer to the genset. Also, many times when you size a genset, you will size it for your maximum load and most of the time you will be running it at a partial load or at a light load, which means, that you are not making the best possible use of the genset in terms of operating at the best possible efficiency point. And by being able to run at variable speed you can actually operate over the best efficiency for a given power that is being generated.

So, also when you run a genset at a fixed speed, your acoustic emission is actually related to the speed of the, of your machine. You can see, when you drive a vehicle at high speeds, the sound from your engine goes up quite a bit. If you can actually run it at low speed, say, the sound can come down. So, for a variety of reasons this variable speed genset technology is actually quite appealing and there are manufacturers out there who offer variable speed gensets.

You can also say, for example, in this particular slide you look, at a machine, a permanent magnet machine, which is rectified along with an inverter to actually feed the loads. You can also have full and partial rated generators, rated generators, similar to what we discussed in the wind application by having things like doubly fed machines to actually feed loads and even that has been manufactured in Bangalore, actually has started building a doubly fed machine based variable speed gensets.

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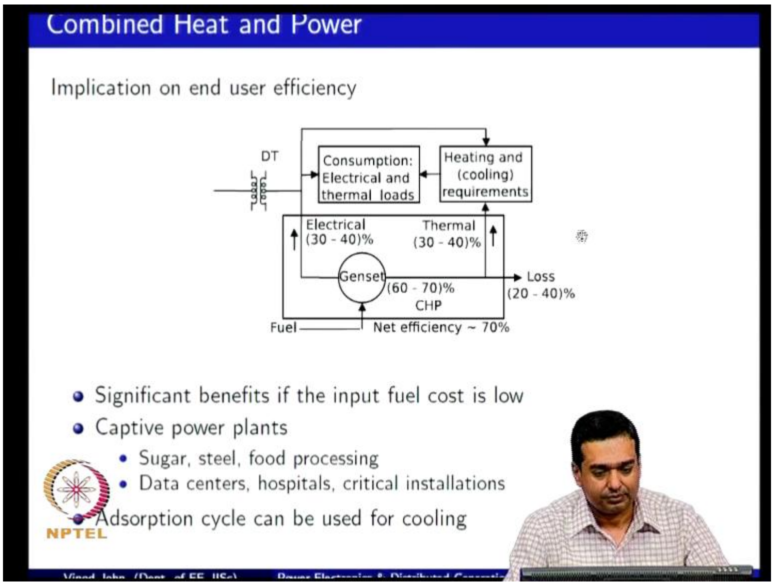

The another appealing aspect of genset is when you are not just looking at the electrical output from the generator, but if you can potentially make use of the waste heat that would be invariably generated from the engine. So, if you look at the efficiency of conversion from fuel to electrical, you are talking about numbers in the 30 to 40 percent range. So, if you are only generating electricity you are just making use of this part of the energy that is there in the fuel and there is a large amount of waste heat. So, if you could actually tap the waste heat for, say, heating requirement or also for cooling requirement, then you might have traditionally the heating being done or conditioning being provided by a compressor, which might actually consume electrical energy.

Now, because now the heating or cooling requirement is from the waste heat, the electric consumption can actually come down. So, that becomes an added advantage, which means, that now your fuel to your end use of both electrical and thermal energy can go up, even above 70 percent compared to the 30 to 40 percent if you are just looking at making use of the electricity.

Obviously, now for this you now need to have additional systems, like heat exchangers, chillers, adsorption chillers, etcetera and they are used for a variety of applications. For example, when your common application of such combined heat and power is in, say, production of sugar where you have to actually boil the juice, the extracted sugarcane juice to actually concentrate it at higher temperatures, lower pressures, to actually get the sugar.

So, you could actually make use of the waste by this way to actually drive your, your genset and then make use of the electricity to produce little to meet the requirements of the plant and make use of the waste heat to actually raise the temperature of your syrup that is being concentrated. So, their applications in sugar, steel, food processing.

You also have data centers, which need cooling your hospitals where you need both, hot, hot water cooling critical insulations. If you look at the cooling requirement, typical cooling that would be done in, say, a refrigerator is with a compressor. So, that is one way of achieving cooling. The way, for example, our body cools itself down is by adsorption cooling where essentially, it depends on the phase change where you sweat and your sweat becomes, vaporizes from the liquid states and the phase change actually cools down your skin.

So, you have similar adsorption cycles with special fluids like lithium bromide, ammonia, etcetera, which can be, which can actually make use of the waste heat to actually provide cooling to your end requirement So, you could actually make use of the waste heat from the genset along with things like adsorption chillers for combined heating, cooling and power.

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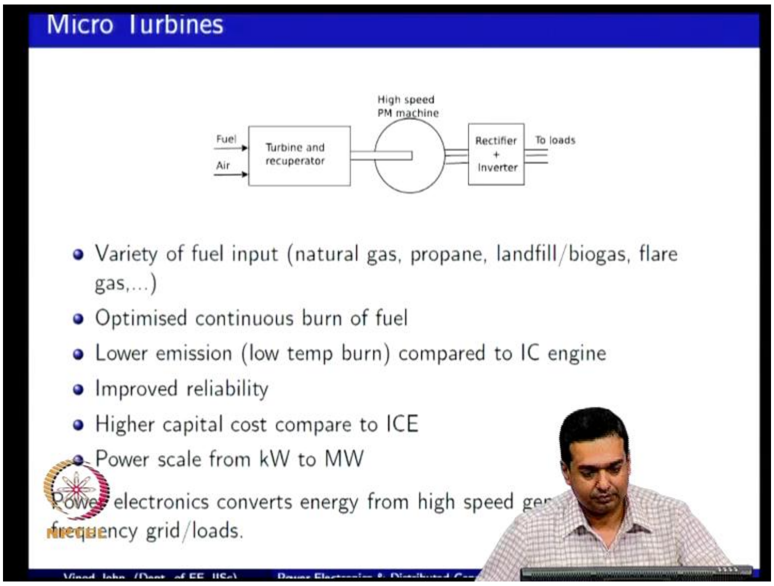

If you look at other technologies related to, which consume fuel, that technology is the micro turbine technology. If you look at its difference with the IC engine, IC engine is producing pulses of power each time you ignite the fuel in the cylinder, whereas in a turbine you are continuously burning the fuel in the turbine combustor. And again, the micro turbines can be used with a variety of fuels because it is a continuous burn. You can optimize the burn to reduce emissions and pollution and because of the continuous burn you can also have uniform power generation rather than pulsed power that is being generated or pulsed talked that is being generated, you can improve the reliability.

However, the capital cost of a micro turbine is more than the IC engine because it is not able to leverage the technology that is commonly there in automotive applications. In fact, we can think of a micro turbine as a scale down jet engine. So, its power scale can be from kilowatts to megawatt range and once you have the output of the micro turbine, the turbines are spinning at fairly high rpm, tens of thousands of rpm. So, you typically have machine, you can have a high speed permanent magnet machine, which, which generates AC. You rectify it and then you use an inverter to actually feed power into the grid or feed the load at 50 hertz.

So, in the next class we will look at some of the other possibilities such as fuel cells storage. And, today we have looked at a range of technologies of distributed generation. If you look at the role of power electronics in the system, it is actually increasing over time, and the role of power electronics is to improve the energy, conversion efficiency, the energy capture, to improve the type of power quality that is output from this, the DG systems, to improve reliability. To meet a variety of such requirements role of power electronics is actually increasing in these DG systems. So, we will, tomorrow, in the next class we will discuss a few more DG technologies and take it from there.

Thank you.