DC Microgrid and Control System
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Lecture - 07
Power Electronics for Microgrid

Welcome to our course, NPTEL courses on the DC microgrid. Today we are going to discuss about the power electronics application of the power electronics in the microgrid.
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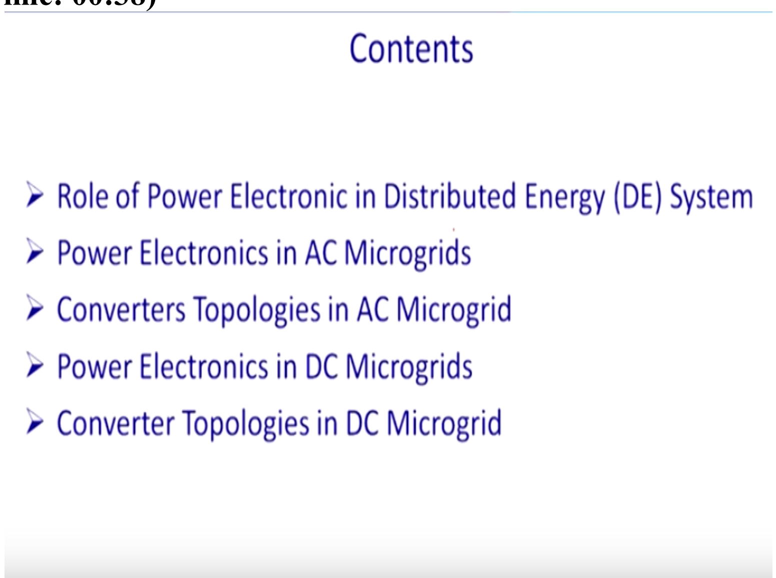

So this will be our presentation layout. Role of the power electronics and distributed energy that consisting of distributed energy sources and the storage element that will be the distributed energy system. And then power electronics in AC microgrids, converter topologies in AC microgrid and power electronics. Then we shall discuss about that what are the specific changes we require in power electronics to incorporate.

DC microgrid, we have seen that while using a DC microgrid we get rid of many AC to DC converter, as many as 3, 4 AC to DC converter in a particular topology we have shown in the previous classes and converter topologies for the DC microgrid.
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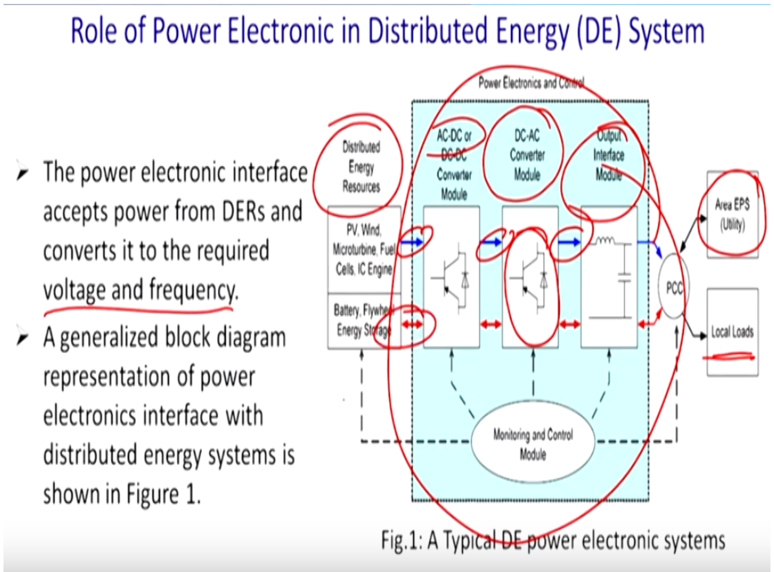

Now, role of the power electronics in distributed energy system. You see these are the distributed energy sources. These are the PV, solar PV or wind or micro turbine fuel cell. It may be diesel IC engine or the battery flywheel or the any other storage devices, thermal storage devices. Then it depends you know if it is a wind then it is AC and if it is a battery it is DC. If it is a solar it is DC.

So it can be AC to DC or DC to DC converter. AC to DC converter if the input is your variable AC for this you need to convert into the DC and if the input is variable DC for example, your solar it will change output voltage and current depending on the radiation and the temperature. So for this reason we require to have a DC to DC or AC to DC converter. Thereafter, essentially you require a DC to regulated AC converter.

And generally these are PWM converter and thus you will be injecting your harmonics into the system and their topological advancement here also there instead of the instead of this two level inverter we go for the multilevel inverter and thereafter you will have that filter to filter out those harmonics, high frequency harmonics, and ultimately you have a point of common coupling.

And these are the area of the utility where it will interact with the grid and you may have a local load also and you can dispatch power in bidirectional way. So this is something the overall role of the power electronics here. This block is the power electronics. So power electronics interface accepts power from DERs and converters. It is required for maintaining voltage or variable voltage and frequency.

The generalized block diagram representation of the power electronics interface with distributed system is shown in the figure. So input can be of different voltage and frequency and make it in a standardized we require the power electronics.

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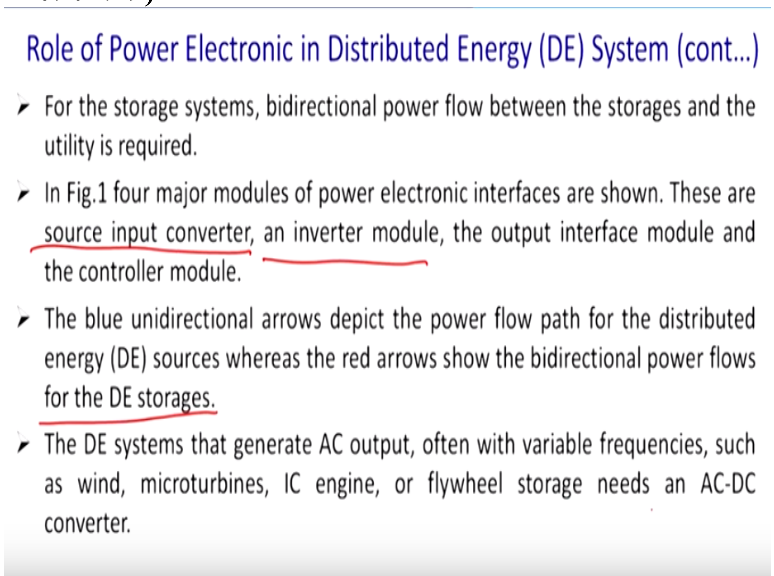

Now, for the storage system, bidirectional flow between the storage and the utility is required. So you can charge or discharge battery for the system if you require bidirectional flow. From the figure 1 four major module of the power electronics interface as shown. These are source input converter and inverter module, the output interface module and the controller module.

The blue, unidirectional arrow, you can refer, blue unidirectional arrow this one, this one, this one depicts the power flow path in a distributed energy sources whereas the red arrow shows the bidirectional power flow path with that DE storage. So these are the red arrows. So where battery is bidirectional and here is also bidirectional and it is bidirectional.

The DE system that generate AC output often with the variable frequency such as wind, microturbine, IC engines or flywheel storage needs an AC to DC converter.

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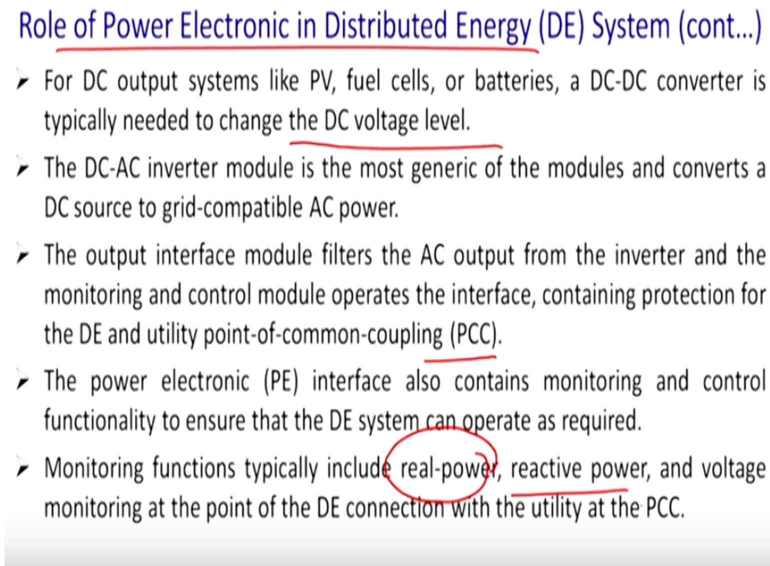

So the role of power electronics in a distributed energy system are for the DC output system like PV, fuel cells, or the batteries. A DC to DC converter is typically needed to change its DC voltage level. For example, solar has to track the MPPT and thus we require to have some MPPT voltage level and ultimately that may not be suitable for utilizing in a DC bus.

So again, you have to recalibrate and fit to the as a dc link as an inverter. The DC to AC converter module is the most generic of the module and converts a DC source to grid compatible AC power. The output reference module filter AC output from the converter and the monitoring and the control module operates the interface containing protection for the DE and utility point of common coupling.

The power electronics interface is also contain monitoring and the control functionality to ensure that these system can operate as required. So monitoring function typically include real power that is something PQ control, reactive power, voltage monitoring at the point of the DE connection with the utility at the PCC.

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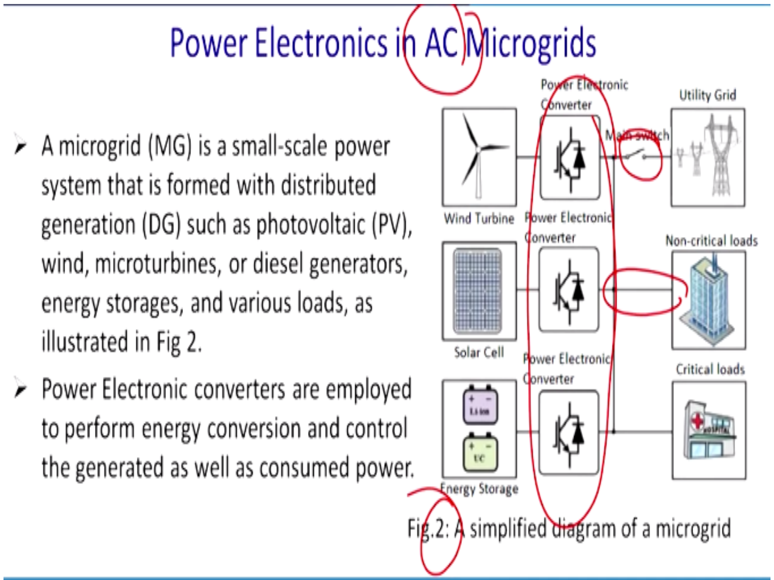

So this is the figure you know, you have wind turbine and you require to have a AC to AC conversion and if this grid is AC then you have a solar panel and from there you convert into the AC power and require to be synchronized and thereafter you have a storage element that is bidirectional. Once you have a extra (()) (8:26) you will stores the battery and that is required for the peak management and also in the emergency to feed the critical load.

This is the main switch. You can take power or dispatch power to the grid. And these are the non-critical load and it may be shut off depending on the kind of condition you wait to put it and these are the critical load and you require to turn it on always. A microgrid, this is AC microgrid. First we will discuss about the AC microgrid and try to see that what are the limitations of the AC microgrid then we will come to the DC microgrid.

The microgrid is a small-scale power system that is formed with the distributed generation such as photovoltaic, wind, microturbine, diesel generator, energy storage and various load as shown in this figure. The power electronics converter are employed to perform energy conversion and control the generate as well as the consumed power. So this is something that power electronics converter are going to do.

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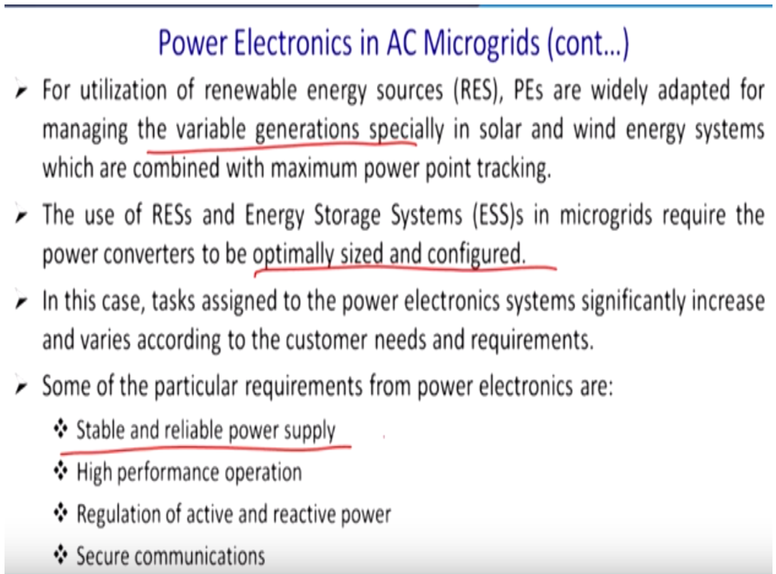

So for utilization of renewable energy sources, this PEs are widely adapted that is power electronics converters for managing variable generation supply in solars, wind system which are combined with the maximum power point tracking. You know not every voltage and current the solar generates the maximum power.

So we require to extract the maximum power because you know the efficiency of the solar panel is around 15% for the polycrystalline structures. So for this reason, losing some efficiency, it will be a great hindrance using the solar panel. For this reason solar power has to be tracked from MPPT. The use of RES and the energy storage system in microgrid require power converter to be optimally sized and configured.

You have to have a dynamical loading condition and thus you can increase the size of the you can actually optimize, reduce the size of the battery and increase the efficiency of the system. In this case the task assigned to the power electronics converter system significantly increases and varies according to the customer needs and requirement.

So of course customer can profile their way of consumption and accordingly it can optimize the energy efficiency and thus cost may become further and many criteria. Some of the particular requirement from power electronics are we want that microgrid to be operate in a stable and reliable power supply. It gives you the stable and reliable power supply. High performance operation.

That means it is free from the power quality issues. Regulations of active and reactive power and secure communication. It should be communicate to the other microgrid and disperse the power if they have a surplus and thus it can have a total management of the power in a particular locality. These requirements are important for the proper operation of the microgrids.

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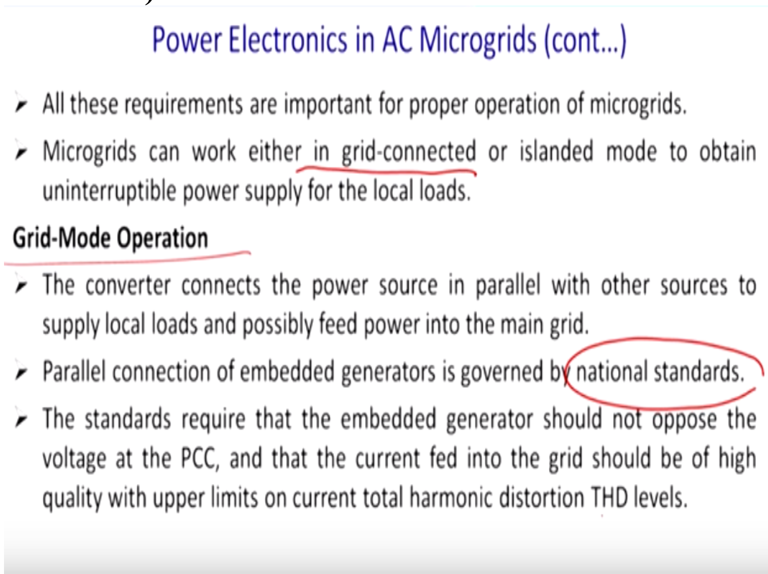

Microgrid can work either in grid-connected or islanding mode to obtain uninterruptible power supply for the local loads. So grid mode of operation, the converter connects in the power source in parallel with the other sources to supply the local load and possibly feed power into the main grid when there is a power surplus. Then we state that it is the grid mode of operation.

Parallel connection of embedded generator is governed by the national standard that is a grid code of a particular the country. India has its own grid code. The standard requires that embedded generator should not oppose the voltage at the PCC and the current fed into the grid should be of high quality with proper limit on the current or the total harmonic distortion.

So we have to when you are connecting and you are supplying to the grid, we have to ensure that your power since you are using the power electronic devices and thus you have a switching and you may have a problem of the power quality and that does not happen when you are supplying to that (()) (13:49) where you have an internal problem. When you are connecting to the grid it may affect to the other customer.

For this reason the power quality norms require to be maintained. Standard also require that the embedded generator including the power electronics converter should operate an islanding features. Due to some reason if grid is not operated it can feed the local load.
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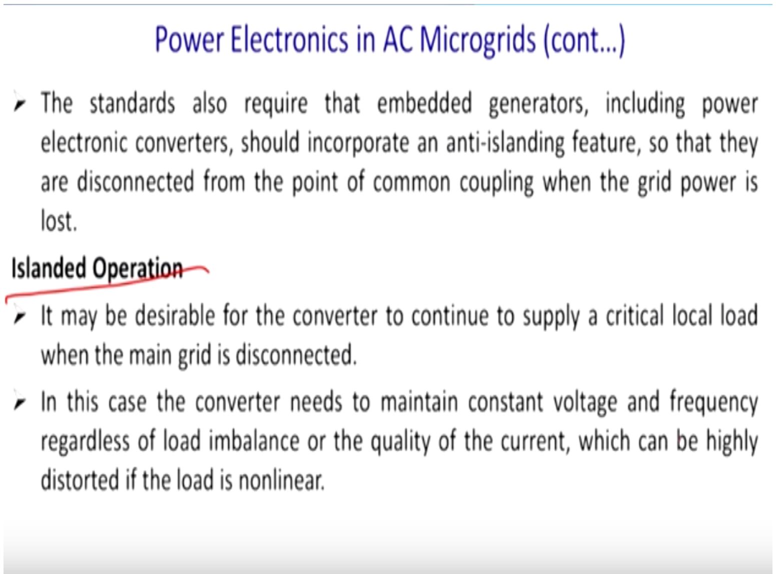

So that they are disconnected from the point of common coupling when grid power is lost or any reasons it has been switched off. So islanding operation what does it do? It may be desirable for the converter to continue supply the critical load when main grid is disconnected. Then it will go to the islanding mode of operation. It will cut the non-critical load and only fit the critical load.

In this case converter needs to maintain a cost and voltage and frequency regardless of the load imbalance or the quality of the current which can be highly distorted if load is nonlinear.

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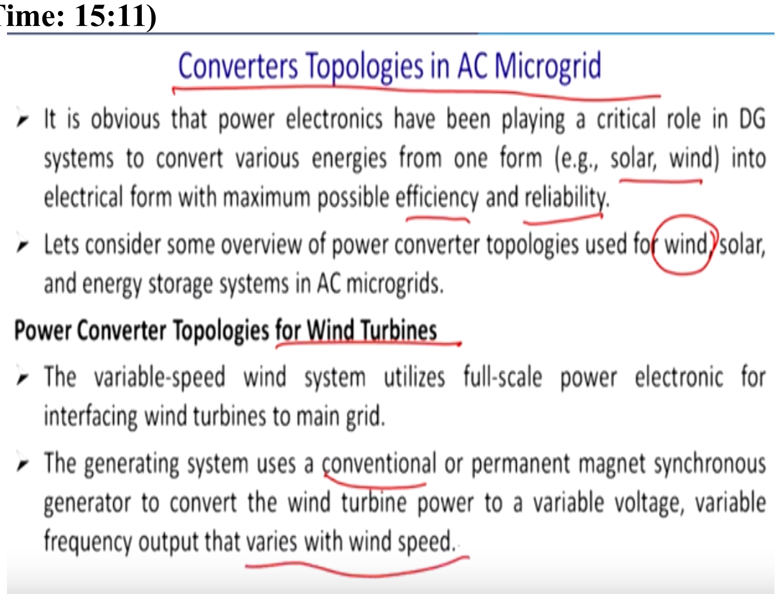

So it is obvious that power electronics, now we talk about the converter topologies and the power electronics in AC microgrid that we will be using. It is obvious that power electronics have been playing a critical load in distributed generation system to convert various energies from other form like solar, from the electrical energy that means solar wind into the electrical form with the maximum possible efficiency and the reliability.

Let us consider some overview of the power converter topology used for wind, solar and storage devices in AC microgrid. Power converter topologies for the wind turbine. The variable speed wind turbine utilizes full-scale power electronics for interfacing wind turbine to the grid and one of the advantages of wind, it is available throughout the day and night that payout factor is quite high.

The generating system uses conventional or the permanent magnet synchronous generator to convert wind turbine into a variable voltage, variable frequency output that varies with the wind speed.

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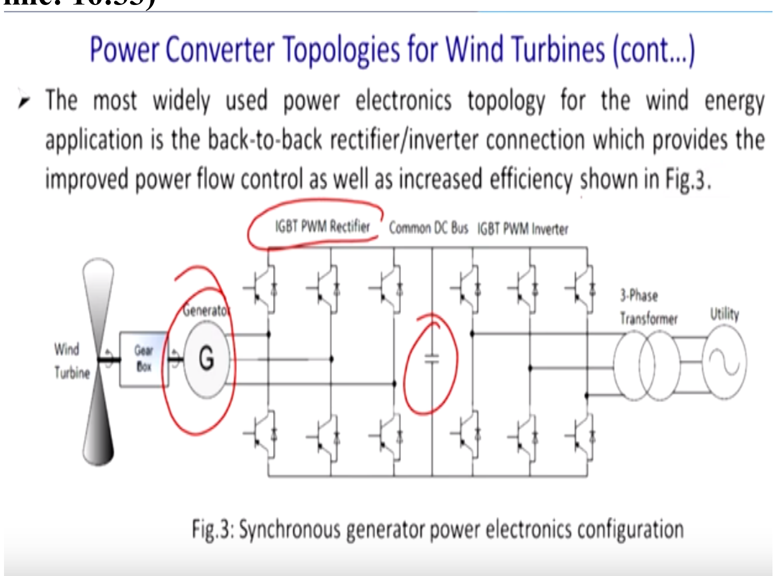

So this is a case of mostly this will be a PMSG. Otherwise you will have a DFIG that is permanent magnet synchronous generator and then since it is a variable speed **it is** it require to be rectified and generally rectification has been done with the control rectification because this require to have a MPPT tracking. Accordingly it has to run at a particular speed and that will generate the MPPT voltages and thus you have a common dc link voltage. Then you convert. This is a grid side inverter.

Then it will inject power to the grid with the necessary PQ control that when it will control the flow of real and the reactive power as required by that grid current. So most widely used power electronics topology for the wind turbine application is the back-to-back rectifier inverter connected with the inverter connection, which provides the improve power flow control, as well as increase efficiency. So that we can show in the next figure anyway.

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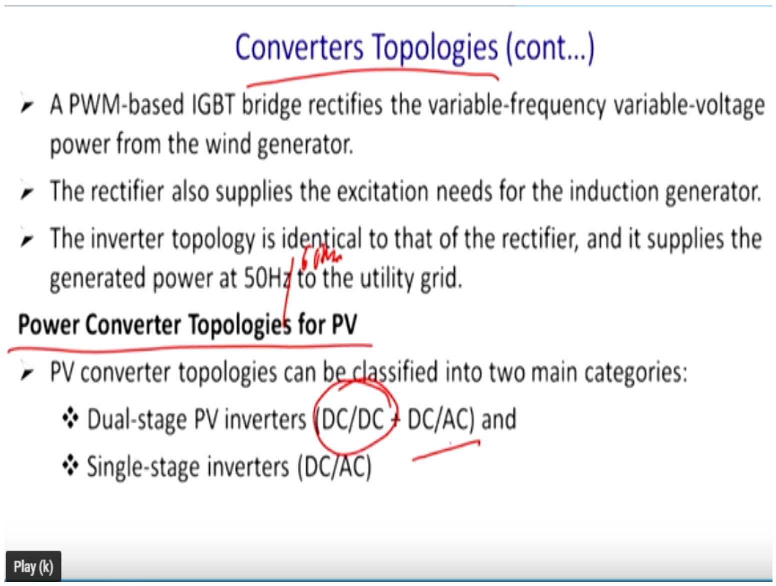

So this is the PWM technique it will be using in case of converter topologies. A PWM based IGBT bridge rectifier the variable frequency variable voltage power from the wind generation has been used. The rectifier also supplies the excitation needs for the induction generator. The inverter topology is identical to that of the rectifier and it supplies the generated power at 50 hertz or 60 hertz as prescribed by the grid or the utility.

So now we talk about the power converter for PV. So power converter topologies can be classified into the two main categories. This is the dual stage PV inverter. That means first you have a DC to DC converter that will track MPPT. Generally it is a boost converter. Thereafter, you have an inverter that will convert that DC into the grid voltage or you may have a single stage DC to AC converter. So this is the power flow diagram.

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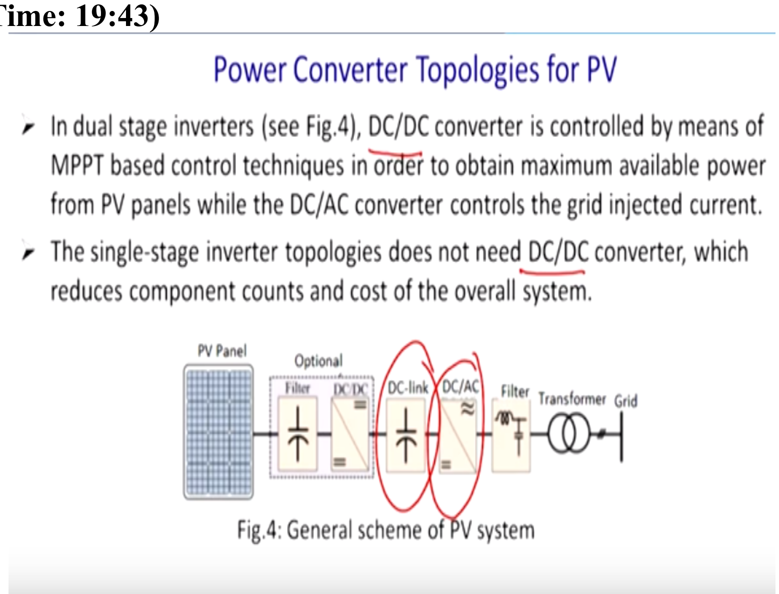

You have a DC panel. Thereafter you have to have a small filters, mostly capacitors. So because of the input current switching has to bypass So you have a DC to DC converter. Essentially you get a dc link and this task of this DC to DC converter is to maintain, is track the maximum power point.

Then this AC to DC converter or inverter will generate the voltage and the frequency and the other power quality issues TST as per the grid norms and it will be fed to the filters to meet the grid requirement and it will be connected to the utility. This is the dual stage converter. In dual stage inverter DC to DC converter is controlled by means of the MPPT based technique in order to obtain the maximum variable power from the PV panel while the DC to AC converter controls that grid injected current.

This single stage inverter topology does not need DC to DC converter, which reduces component count and cost of the overall system.

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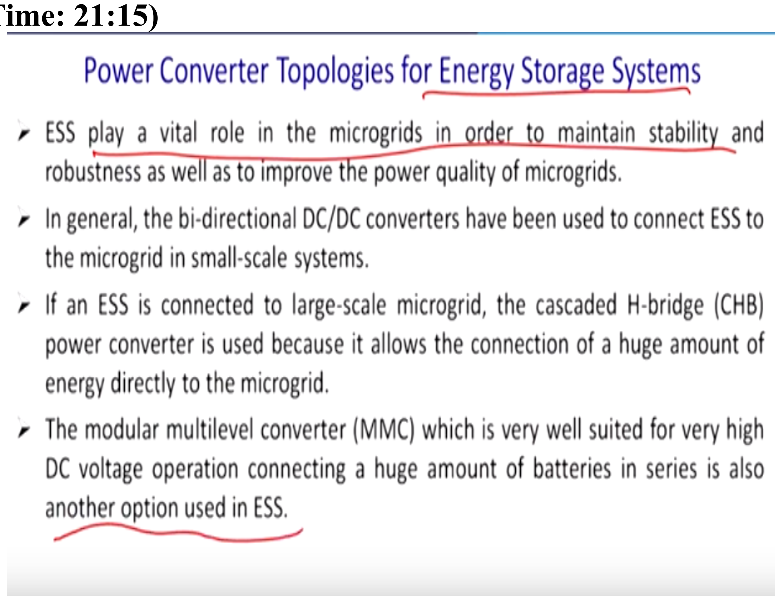

Now comes to the topologies actually require for the energy storage and it has to be a bidirectional DC to DC converter. As discussed ESS play a vital role the microgrid in order to maintain the stability and the robustness as well as to improve the power quality microgrids. In general the bidirectional DC to DC converter has been used to connect these ESS that is energy storage devices or system to the microgrid in small-scale system.

If an ESS is connected to a large-scale microgrid, the cascade H-bridge power converter is used, because it allows the connection of a huge amount of energy directly to the microgrid. In modular multilevel converter MMC which is very much suitable because it has a independent DC sources as a panel is suited very much but DC voltage operation connecting the huge amount of batteries in series also another option too as used in ESS.

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Power Electronics in DC Microgrids

- In DC Microgrid power converters used to interface source and loads and also an interface to AC grids.
- A dc microgrid decouples the frequency, voltage and phase of the various AC generation and consumption element in the microgrid by use of suitable power electronic converters.
- Fig.5 illustrates that a DC bus based microgrid. The interface between each energy source and dc bus has a power electronic converter (a DC/DC or an AC/DC) converter.

In DC microgrid power converter used to interface the source and the load and also an interface to AC grids. The DC microgrid decouples the frequency, voltage and phase of the various AC generations and consumption element in the microgrid by use of suitable power electronics converter. Now, figure 5 we illustrate that the DC bus based microgrid or DC microgrid, the interface between each energy sources and DC bus has a power electronics converter to maintain a required DC bus voltage.

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Power Electronics in DC Microgrids (Cont...)

- Each of these converters centrally dispatched in order to regulate energy flow in or out of the dc bus, or they may be droop controlled in order to share power in a distributed manner.

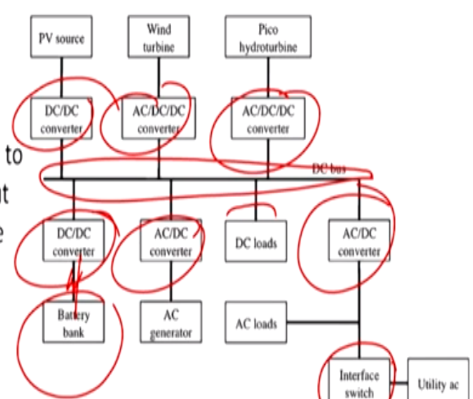

Fig.5: A simplified Schematic illustration of DC Microgrid

So this is the DC bus and ultimately you have PV and thereafter you have a DC to DC converter. You have wind. Then thereafter you got a AC to DC thereafter DC to DC converter. You may have a Pico heart hydro turbine or micro Herbert hydro turbine you may have a Pico hydroturbine or micro hydroturbine. You may have a AC to DC to DC converter.

Thereafter you may have a battery bank that has a bidirectional power flow. You use DC to DC converter. You may have a AC generator as a backup. So there you may have a AC to DC converter. You may have a DC load and thereafter you may have AC to DC converter and that feeds the AC loads. So it is DC to AC converter or inverter, an interfacing switch and also it will send the power back to the utility.

So this is the structures of the microgrid and these elements are the DC microgrid and these are the power electronics devices. So these are the entities of the power electronics and it has huge implication. Each of these converters centrally dispatching power to regulate energy flow in or out of the DC bus or they may drop control in order to share the power in a distributed manner.

Now, let us see that two topologies of bidirectional DC to DC converter.

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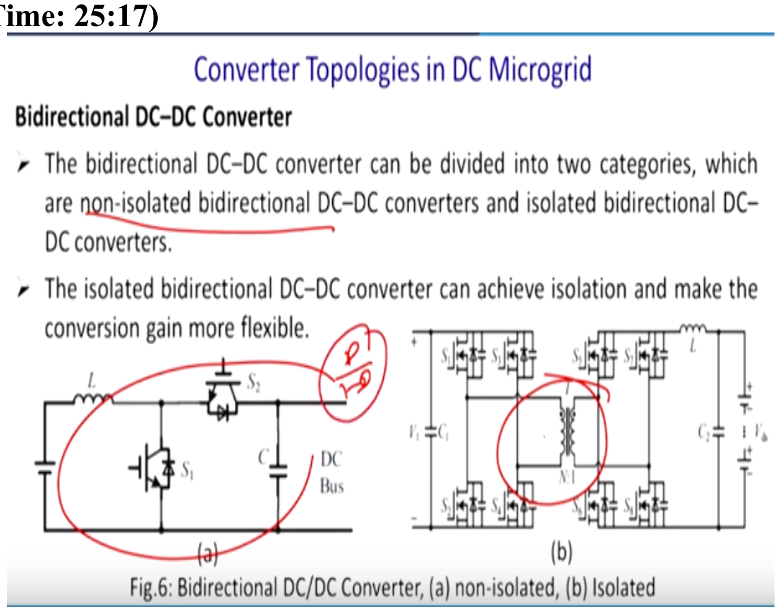

Fig.6: Bidirectional DC/DC Converter, (a) non-isolated, (b) Isolated

One is nonisolated, another is isolated. So bidirectional DC to DC converter can divided into two categories, which is non isolated. That means source and load does not have galvanic isolation. And another topology **is** has a galvanic isolation by high frequency transformer that is called isolated DC to DC converter. So isolated bidirectional DC to DC converter can achieve isolation and can make conversion game more flexible.

Because here you have to control the duty cycle by this two switches and mostly these two switches are complementary in the logic and you know that actually the transfer function will be given by D/1 - D here and here you can also play with the trans ratio. Because once you require to buck it a high voltages generally current sometime become discontinuous and in that case the control system loses its predominance.

So you have to ensure that that is bucking ratio or the boosting ratio are not so high.

Otherwise it leads to the discontinuous mode of conversion. You require to have a sufficiently amount of the high current. But here you can play also with the transformers trans ratio and thus your ratio of the bucking and boosting some part you can play around with your transformer. But from that it gives you a galvanic isolation.

Thus if there is only any disturbance in the input side does not transmit to the load side and vice versa and it is protected from the search and other devices, other anomalies. So the non-isolated DC to DC converter which we have seen works as a boost converter when battery is discharging and works as a buck converter when power is reversed.

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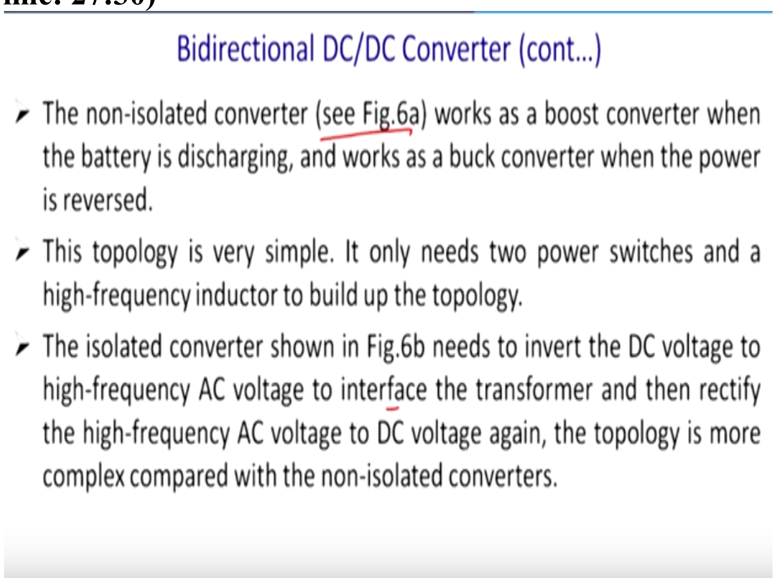

And you can have a different altogether just opposite topology. That depend on the kind of way you are using it. Generally bus voltage are higher, battery voltage are lower. So once you are charging this bus from the battery, so it require to be buck and once you have fitting battery to the bus, it require to be boosted and for this reason you require a boosting.

But it may so happen you got a bus voltage lower and your battery that higher voltage you can do the reverse operation. The topology is very simple. Advantage of the topology is very simple in case of the non-isolated AC to DC converter. It only needs to pause switches and high frequency inducted to build the topology. And we can incorporate the soft switching action into it and as thus we can get a very high efficiency into the system.

Isolated AC to DC converters shown in figure 6b convert DC voltage into the high frequency AC, voltage to interface the transformer and then rectify the high frequency AC into the DC. Again this topology has a more complex operation, more switches. And of course, there are more challenges but there are lot of advantage to this topology.

One is power handling capability can be anything and for the full bridge configuration, it can handle a power as big as a megawatt level. Then it has got isolation. Protection is fully ensured and you can play around with this actually stepping up and the with a transformer ratio and thus stepping up and the stepping down, it can be easily managed unlike that direct DC to DC converter or non-isolated DC to DC converter.

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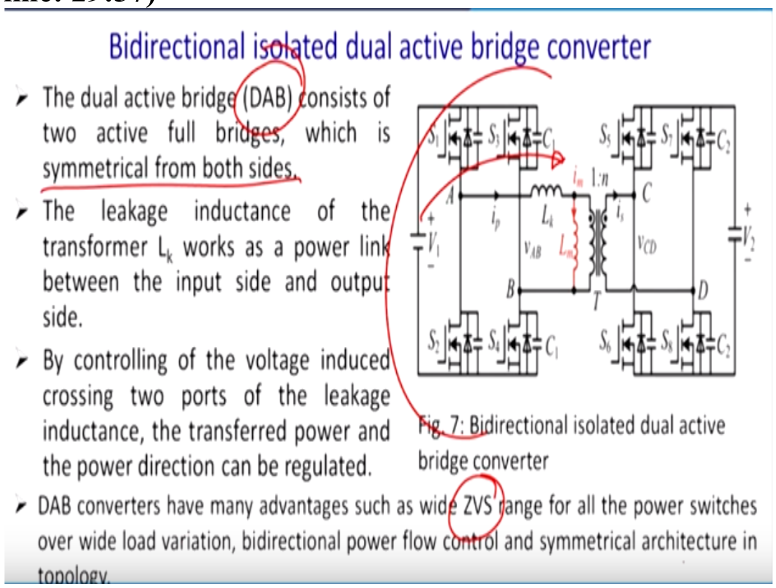

So the dual active bride, we shall abbreviate here DAB consisting of two active full bridge which is symmetrical for both side. The leakage inductance of the you can see that you can have a mirror image that side. Leakage inductance of the transformers L k works as a power link between the input side and the output side. So this is the, by controlling the voltage induced crossing the two parts of the leakage inductance, the transformer transferred power and the power direction can be regulated.

So you can change, this bidirection you can change this point to this point by switching and it will be charging and just reverse you can do from this point to this point also you can do when you are actually discharging your battery. DAB converters have many advantages **as** such as ZVS that is zero voltage switching that is soft switching. Range for this power switches or wide variation of the load.

Bidirectional power flow control and symmetrical architecture in topology. Thank you for your attention. We will continue with the AC to DC converter in a microgrid on the power electronics application in the AC microgrid in next class.