**Introduction to Smart Grid**
**Prof. N. P. Padhy**
**Department of Electrical Engineering**
**Indian Institute of Technology, Roorkee**

**Lecture - 25**
**Operation and Control of AC Microgrid- I**

Welcome you all today for Operation and Control of AC Microgrid lecture. And in this section we mainly focus on what is AC microgrid and how the DGs can be controlled for a better operation of a microgrid. So, in this connection we will be first understanding try to understand the concept of AC microgrid and its control.

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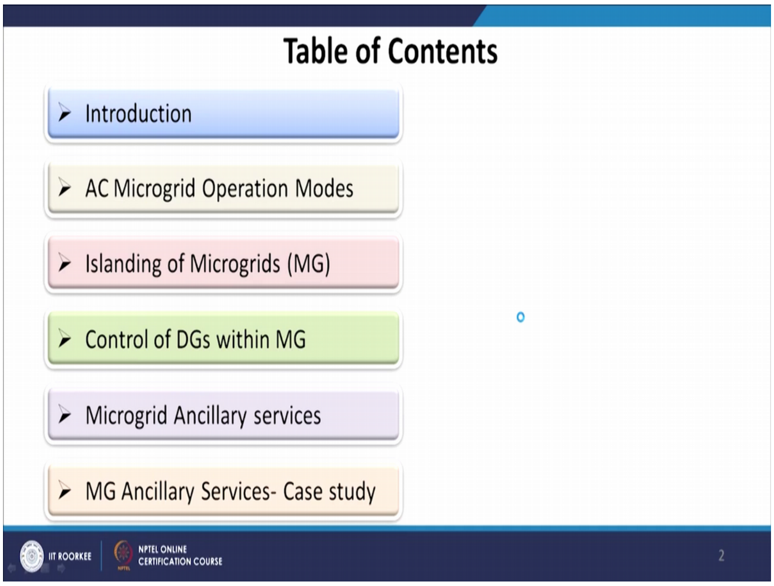


AC microgrid operation modes islanding of microgrids, control of distributed generation within a microgrid, microgrid ancillary services and few more case study to appreciate the fundamental fundamentals.

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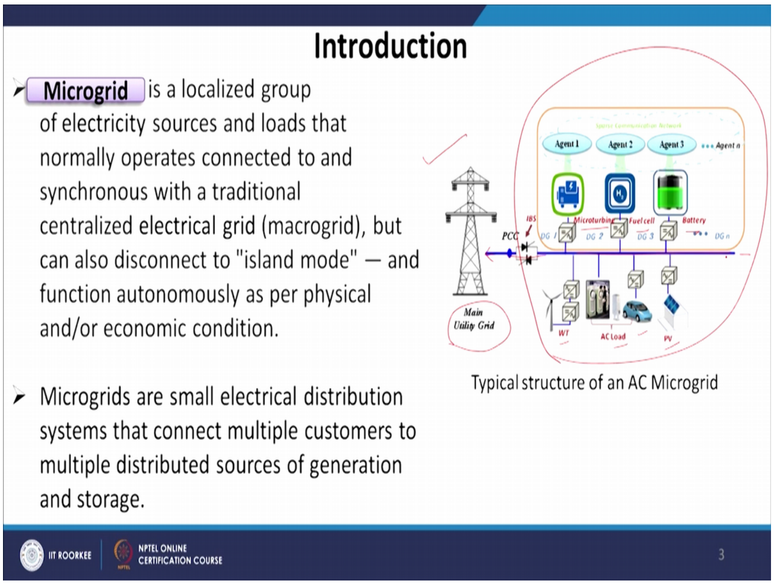


First of all we need to understand what is a microgrid. I mean microgrid do have different definitions, but one of the very basic fundamental way of explaining microgrid would be, microgrid is a localized group of electricity sources and loads that normally operate and connected to, and as well as synchronous with a traditional centralized electrical grid called microgrid. But can also disconnect if necessary to islanded mode and function autonomously as per physical and or economic conditions.

Now, let us consider a typical AC microgrid architecture we can see that the main utility grid, which I mean does exists in the system and this is my or our proposed microgrid. Now we can clearly see there are few wind turbines loads electric vehicles. And PV connected to my bus the blue line and further we have other type of sources from micro turbine fuel cell and battery.

So, here I like to focus on one point like in this AC bus, which has directly been connected to my utility grid which is also AC in nature. Now we have connected all different type of DC as well as AC sources the support of different interface converters and those feed power as well as energy to the AC grid and simultaneously we can connect AC loads as well as charge our electric vehicles through appropriate conversion from the AC grid.

Now, microgrids are small electrical distribution systems and they there could be either of a 100 kilowatts or maybe few megawatts, system that connect multiple customers to multiple distributed sources of generation and storage. So, please keep in mind microgrid is also a small distribution system with low capacity, and could manage to accommodate many different type of distributed generation along with storage simultaneously. Now there are two major operations that AC microgrid do face from time to time one is very common normal operation we called grid connected mode, and the other one is isolated mode or islanded mode.

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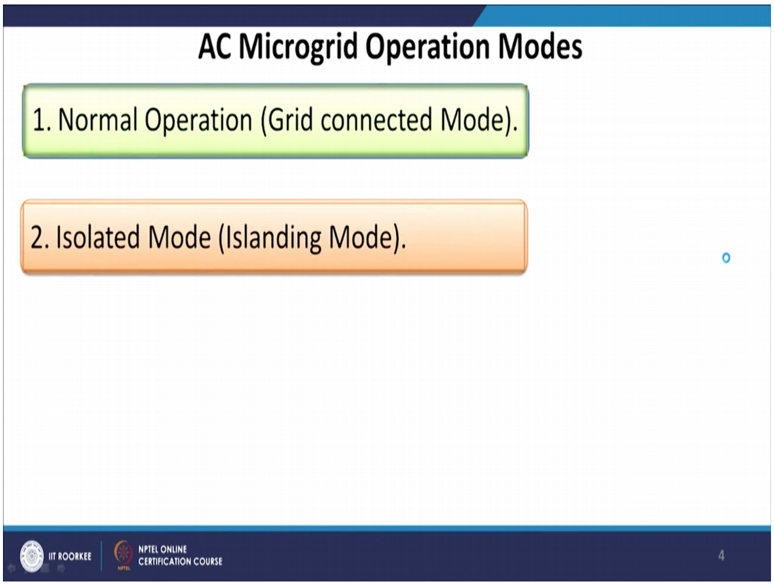


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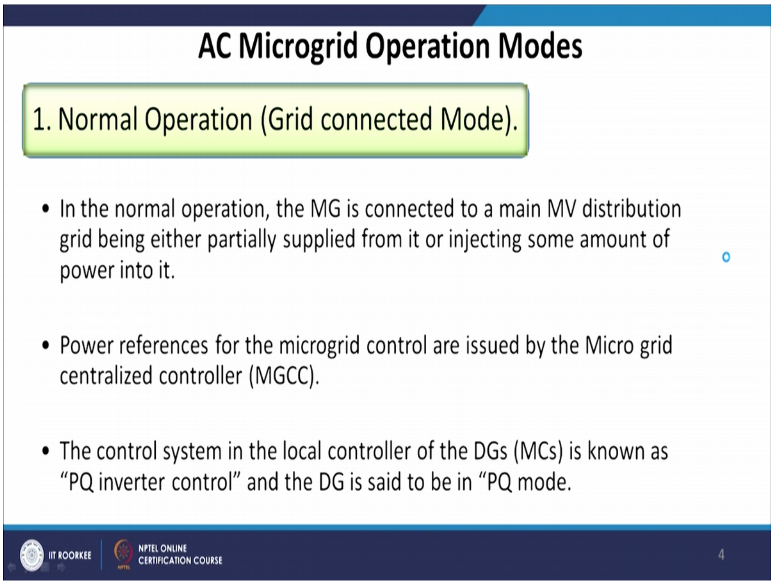

Now, in a normal operation the microgrid is connected to the main medium voltage distribution grid, being either partially supplied from it or injecting some amount of power to it. That means a microgrid which has been connected to your medium voltage distribution network, though it has its own generations to meet the local loads.

But sometimes it may take bit of energy from the main grid and when they do have excess energy they are capable of giving it back to the main grid. Now power reference for the microgrid control are issued by the microgrid centralized controller called MGCC. The control system in the local controller of the distributed generations is known as PQ inverter control and the dg is said to be at PQ mode.

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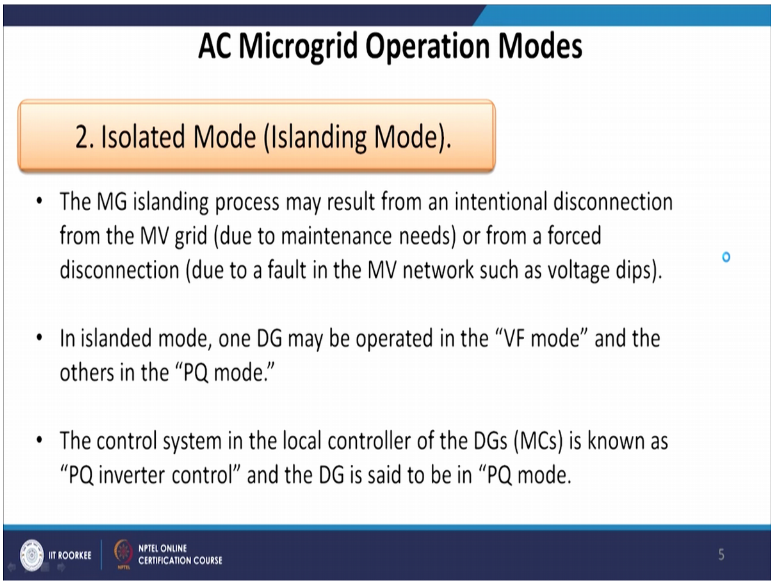


Now, in case of isolated mode of operation the microgrid islanding process may result from an intentional disconnection from the medium voltage grid or from a forced disconnection due to some fault or it could be a voltage dip. Now, in islanded mode one DG may be operated in the VF mode, and the other in the PQ mode. The control system in the local controller of the distributed generation is known as PQ inverter control and DG said to be in PQ mode similar to your grid connected operations.

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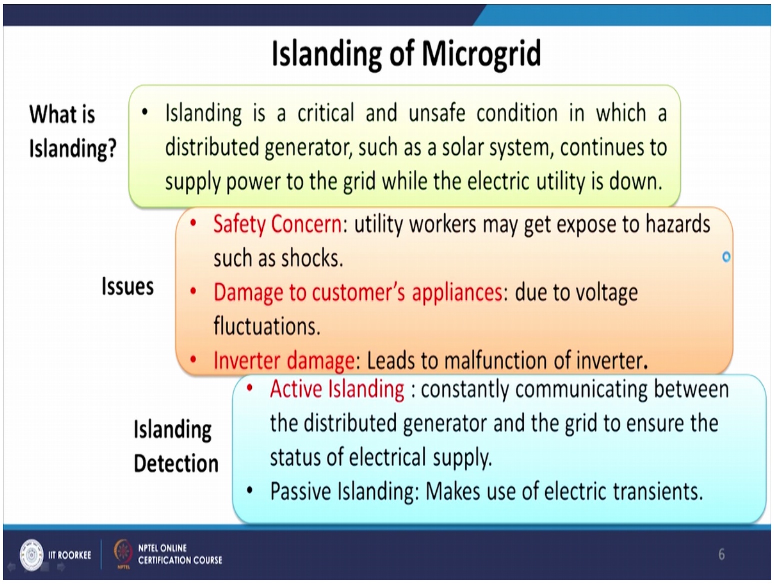


Now, let us try to understand what is islanding by the definition itself it says that something has been separated out or made independent. Islanding is a critical and unsafe condition in which a distributed generation such as solar continued to supply power to the grid while the electric utility is down. That means, we do have this is my main grid and this is my microgrid, they two are interconnected. And due to any reason if they are separated out all the sources connected to my microgrid is no more able to inject power if the system has not contained to islanded mode of operation means your grid is down as well as the generations are down.

But if you could manage to have a islanded mode of operation, then even though this minor grid is islanded. The source is connected to that islanded grid can continue to supply even they are separated. Now what are the main issues safety concern; utility workers may get exposed to hazard such as shocks, damage to customer appliances due to voltage fluctuations, inverter damage leads to malfunction of the inverters, islanding detection how do you know the system has been islanded or not.

There are two major one is active islanding and the other one is passive islanding. Active islanding constantly communicating between the distributed generator and the grid to ensure the status of the electricity supply, whereas passive islanding makes use of electric transient to know whether the islanding has occurred or not. Now moving back to control of the distributed generation in microgrid, which is slightly different than conventional generators.

If you look into a conventional thermal power generation, where the frequency keep on fluctuating due to the load and that can be controlled to meet out the desired frequency or the speed by giving extra energy or fuel to this power plant, whereas in case of microgrid we do have many generations, which do you know connect to the main grid through a converter system. And hence the control mechanisms are slightly different compared to a conventional thermal generator.

Now, distributed generations within a microgrid and their control are classified in this following manner.

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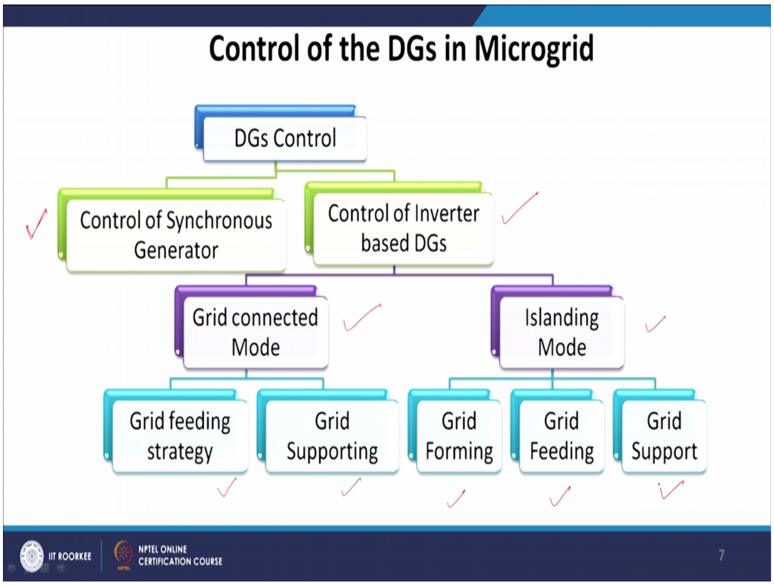


First of all we can have control of synchronous generator, and then we do have the major variety of control of inverter based distributed generator. The synchronous generator based which is classical as we all know, but as inverter based DGs are slightly different and will be focusing majorly on today's lecture.

Now, control of inverter based distributed generation once again they are of two types depending upon grid connected mode operation or islanded mode operation, and the grid connected mode operation do have two major type of control grid feeding strategy and grid supporting strategy. Whereas, in case of islanding mode we do have grid forming grid feeding and grid supporting mechanisms.

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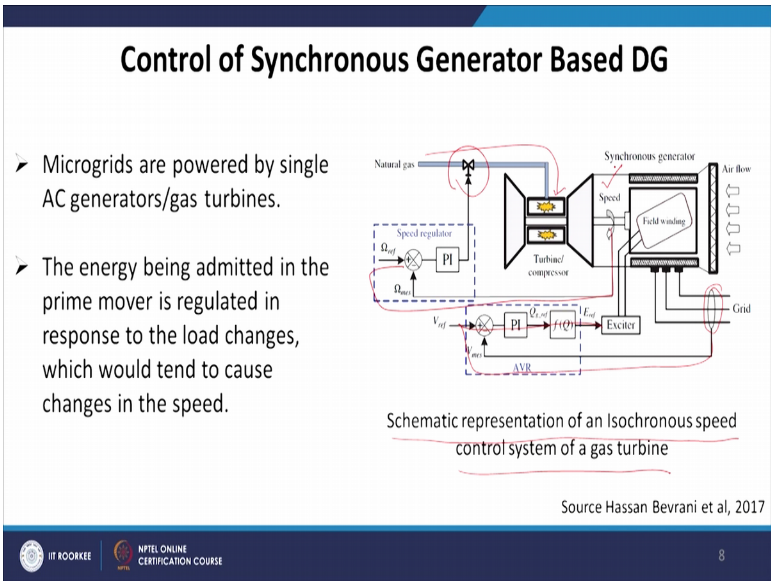


Now with this background let us consider one by one case and try to understand their functionality. Control of synchronous generator based distributed generator which is as simple as my thermal power generators. Now we could see a simple schematic representation of an asynchronous speed control system of a gas turbine, and you could see that the natural gas which is flowing to generate power for the grid. And the grid inputs are being fed further to my exciter. And one more interesting the speed signals depending upon its variation can come through speed regulator so, that the natural gas injection can vary to meet out my desire speed.

So, this is what the very simple. So, you detect the speed and where your input energy source could be steam, could be gas and based on that you can adjust your speed as per the desired frequency. Now microgrids are powered by single AC generators or gas turbines. The energy being admitted in the prime mover is regulated in response to the load changes, which could tend to cause change in the speed; if the load is changing your speed is changing and that can further bought to its desired speed through input changes.

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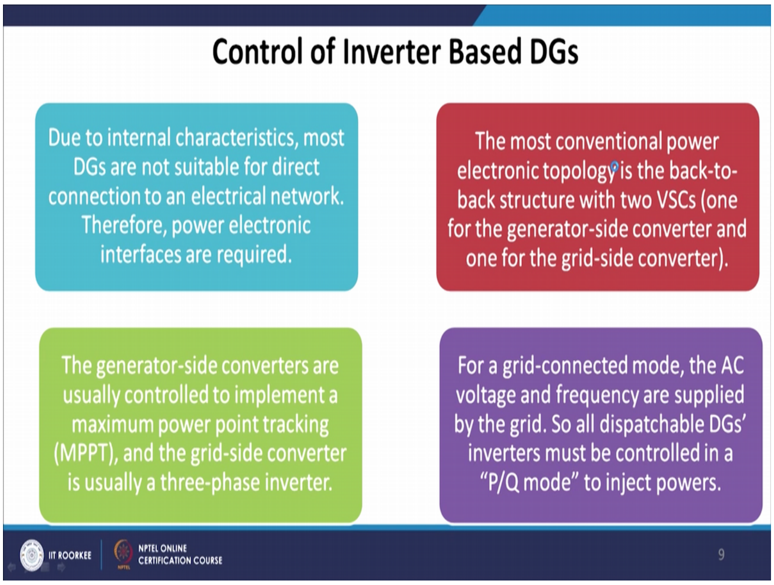


Whereas in case of control of inverter based distributed generators due to internal characteristic most distributed generators are not suitable for direct connection to an electrical network. In some of the cases we have to increase the voltage some of the time you have to convert the voltage type. Therefore, power electronic interface are required; the most conventional power electronic topology in the back to back structure with two VSCs one for the generator side converter and one for the grid side converter.

The generator side converters are usually controlled to implement a maximum power point tracking that is MPPT and the grid side converter is usually a three phase inverter. For a grid connected mode the AC voltage and frequency are supplied by the grid. So, all dispatchable DGs inverters must be controlled in a PQ mode to inject power. So, these are the following strategies we do follow in case of inverter based DGs.

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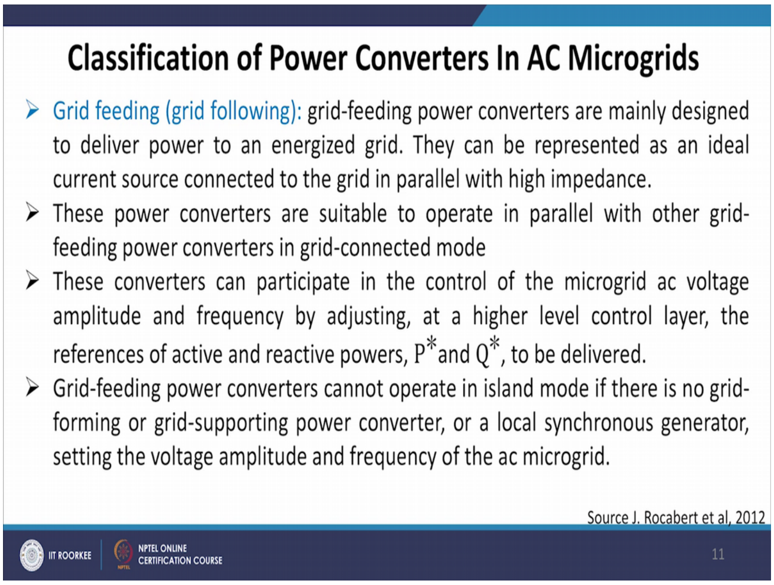


Now, classification of power converters in AC microgrids: let us consider one by one first one is grid feeding or grid following. I need your attention at this stage because these are the fundamentals before we go for any control strategy of microgrids, we need to understand what is grid feeding thoroughly. Grid feeding power converters are mainly designed to deliver power to an energized grid. They can be represented as an ideal current source connected to the grid in parallel with a high impedance. These power converters are suitable to operate in parallel with other grid feeding power converters in grid connected mode.

These converters can participate in the control of the microgrid AC voltage amplitude and frequency by adjusting at a higher level control layer the reference of the active and reactive power P and Q that need to be delivered. Grid feeding power converters cannot operate in island mode, if there is no grid forming or grid supporting power converters.

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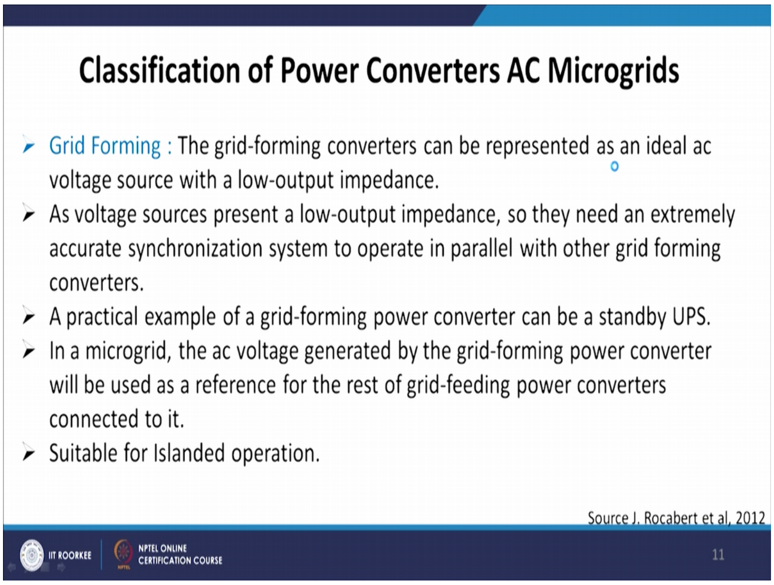


Now, classification of power converters AC microgrid; let us say grid forming the grid forming converters can be represented as an ideal AC voltage source with a low output impedance. As voltage sources present a low output impedance so, they need an extremely accurate synchronization system to operate in parallel with other grid forming converters.

A practical example of a grid forming power converter can be a stand by UPS that we all commonly use in our residences. In a microgrid the AC voltage generator by the grid forming power converter will be used as a reference, for the rest of the grid feeding power converter connected to it. It is very much suitable for islanded mode of operations.

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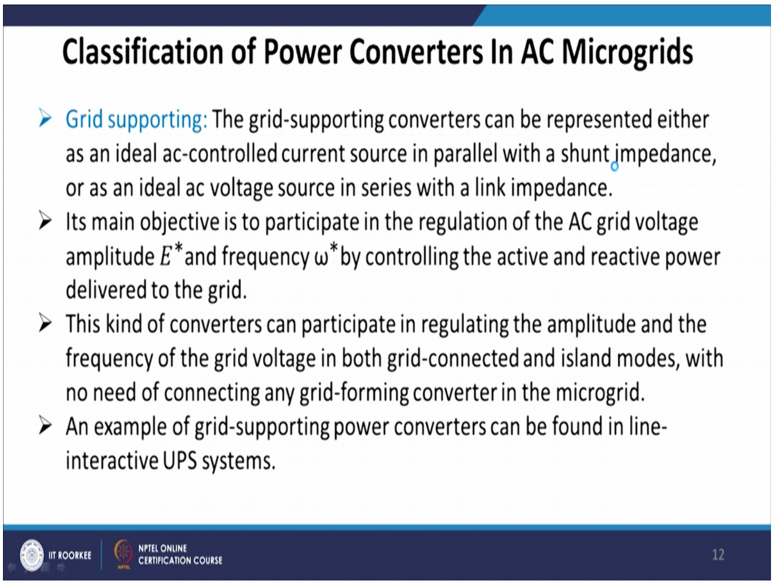


Now, let us move to the second one that is grid supporting. The grid supporting converter can be represented either as an ideal AC control current source, in parallel with the shunt impedance or as an ideal AC voltage source in series with a link impedance.

Its main objective is to participate in the regulation of the AC grid voltage amplitude E and frequency omega by controlling the active and reactive power delivered to the grid. This kind of converters can participate in regulating the amplitude as well as frequency of the grid voltage both grid connected and islanded modes, with no need of connecting any grid forming converters in the microgrid. An example of the grid supporting power converter can be found in line interface ups systems; grid feeding strategy for passive generators.

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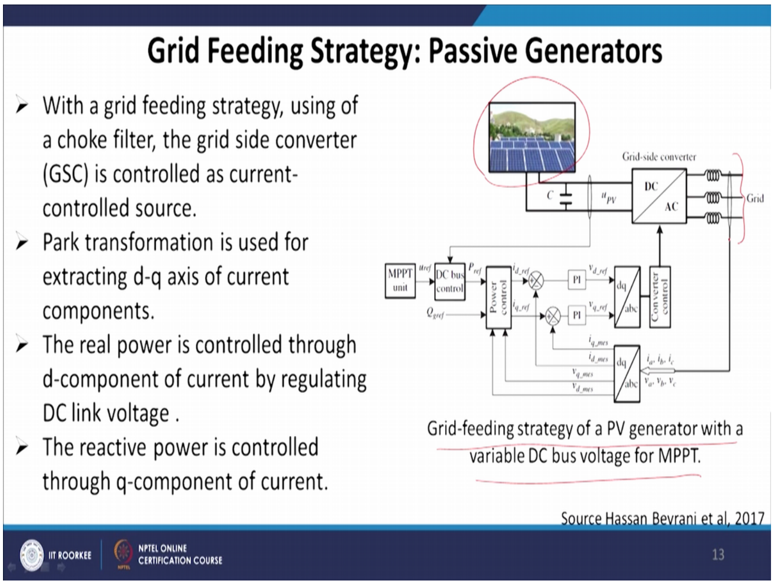


With a grid feeding strategy using of a choke filter the grid side converter that is GSC is control as controller source, park transformation is used for extracting DQ axis of current components. The real power is controlled through d components of current by regulating DC link voltage whereas; the reactive power is controlled through Q components of current.

Now, if you look at the grid feeding strategy of a PV generator with a variable DC voltage for MPPT. Now the setup is as simple as you have the PV generators connected to my grid and as a passive generator it can feed energy through controlling D and Q component of current.

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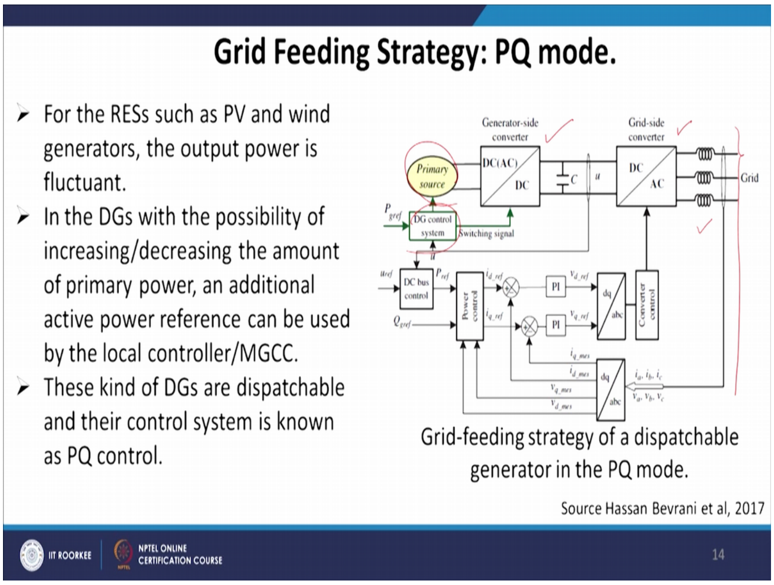


Grid feeding strategy for PQ mode of operation for the renewable energy sources such as PV and wind generators, the output power is flat fluctuant. In the DGs with the possibility of increasing or decreasing the amount of primary power and additional active power reference can be used by the local controller that is MGCC; now, the grid feeding strategy for a dispatchable generator in a PQ mode the block diagram, which has been shown in details.

So, we have grid then we have grid side converters generator side converter and my primary source followed by dg control system. Now if you look into this kind of distributed generators are dispatchable and their control system is known as PQ control.

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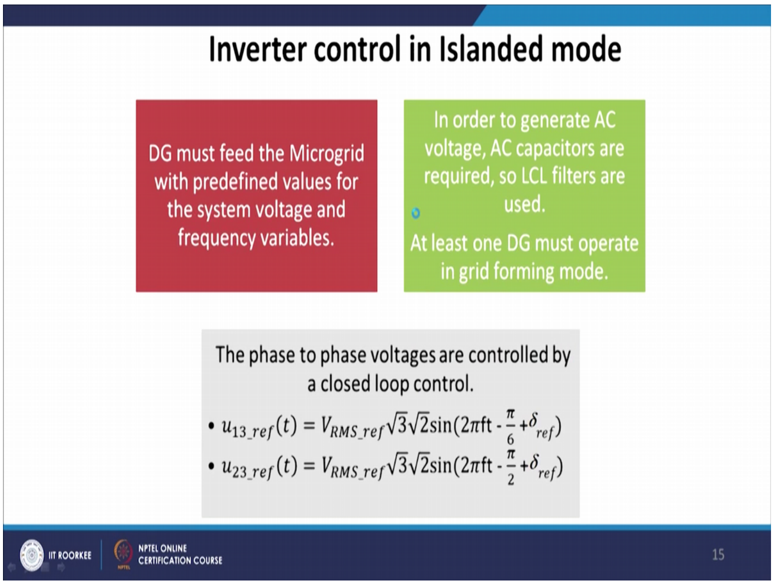


Now, the inverted inverter control in islanded mode distributed generator must feed the microgrid with predefined values, for the system voltage and frequency variables.

In order to generate AC voltage, AC capacitors are required. So, LCL filters are commonly used, at least one distributed generator must operate in grid forming mode regularly.

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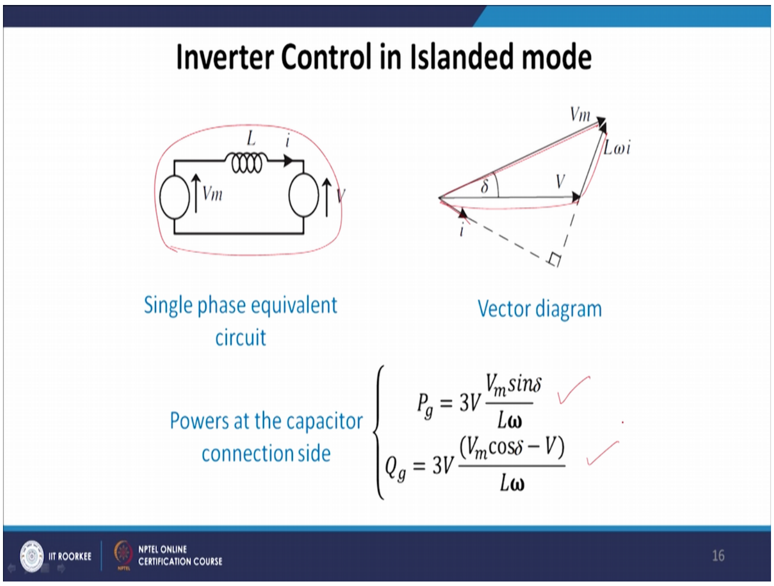


Now, in case of inverter control in islanded mode we can see the single phase equivalent circuit, and the vector diagram voltage lagging with its phase the drop and the final voltage. Now in case of the power at a capacitor connected side can be obtained the real as well as a reactive using these two expressions.

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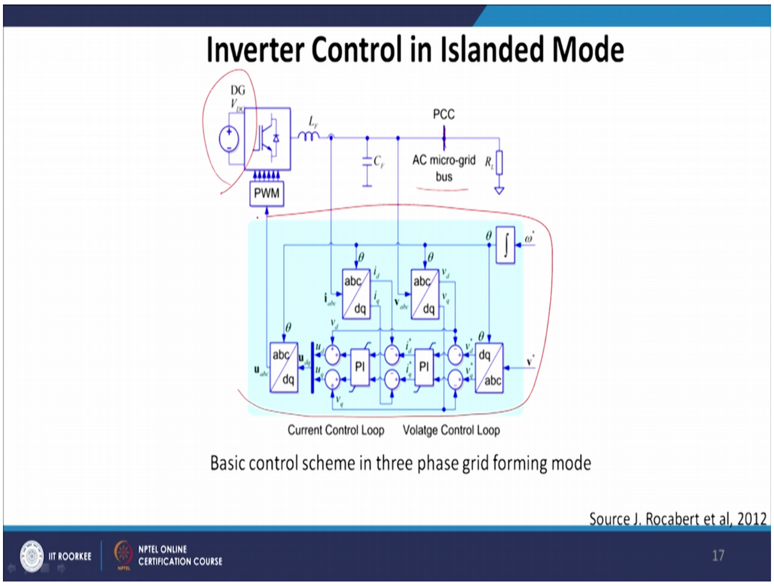


Now, inverter control in islanded mode the basic control sys scheme in three phase grid forming mode; now we can see this is my AC microgrid, this is my PCC distributed generators and the complete control loop for both current as well as voltage.

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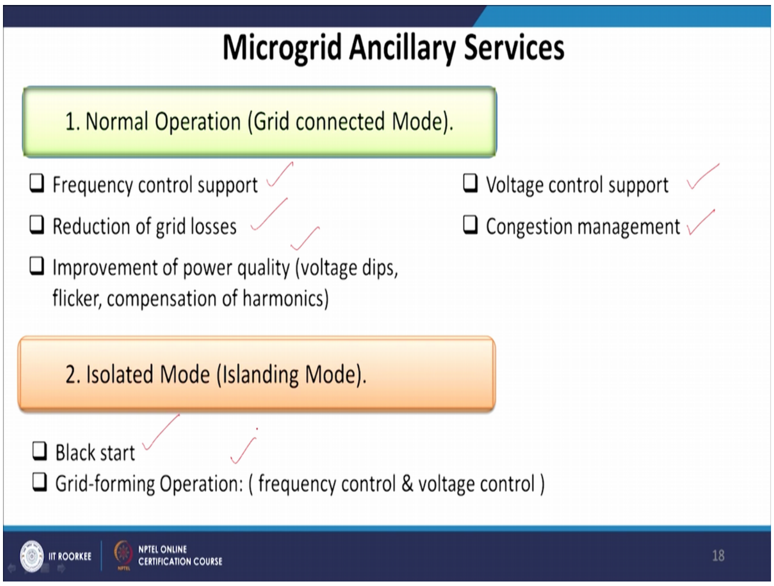


One of the very important aspect that is microgrid ancillary services how microgrid can help the system to have ancillary services such as our frequency. Normal operation that is during grid connected mode microgrid can provide frequency control support because the frequencies keep on changing based on the load.

So, can microgrid support or complement the frequency variation. It expected to reduce the grid losses. It is expected to improve the power quality that is compensation of harmonics, voltage control support and finally, the congestion relief or management for low voltage networks. Now in case of islanded mode that is a isolated mode it can be used as a black start and black start as well as grid forming operation for frequency control and voltage control.

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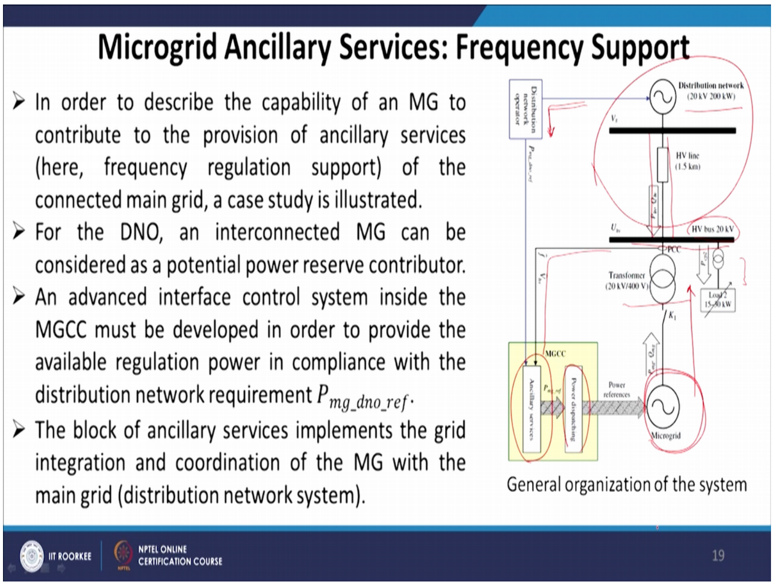


Now, in case of a frequency support in order to describe capability of an microgrid to contribute, to the provision of ancillary services of the connected main grid a case study is illustrated. For the distribution network owner or operator an interconnected microgrid can be considered as a potential power reserve contributor. An advanced interface control system inside the microgrid MGCC must be developed in order to provide the available regulation power in compliance with the distribution network requirement that is P. The block of ancillary services implements the grid integration and coordination of the microgrid with the main grid that is my distribution system.

Now, if you look at the arrangement this is my classical distribution system of let us say 20 kilo volts and the capacity of 200 kilowatt and then we feed further high voltage connected to my high voltage bus. So, ideally we do have a high voltage bus which is of

20 kv and then we can connect different type of loads we do have transformer setups and this is my microgrid setup here.

Now, the energy is flowing through this way and we can also allow the microgrid energy to flow, with reference to the ancillary support system required by the distribution system. Now from the distribution network we can read the power and the voltage at different buses through MGCC, the ancillary services can be predicted and power dispatching scenario can be redesigned so, that the overall ancillary services can be gained by my distribution network. So, microgrid is acting as a ancillary provider to my distribution system for a given environment or circumstances.

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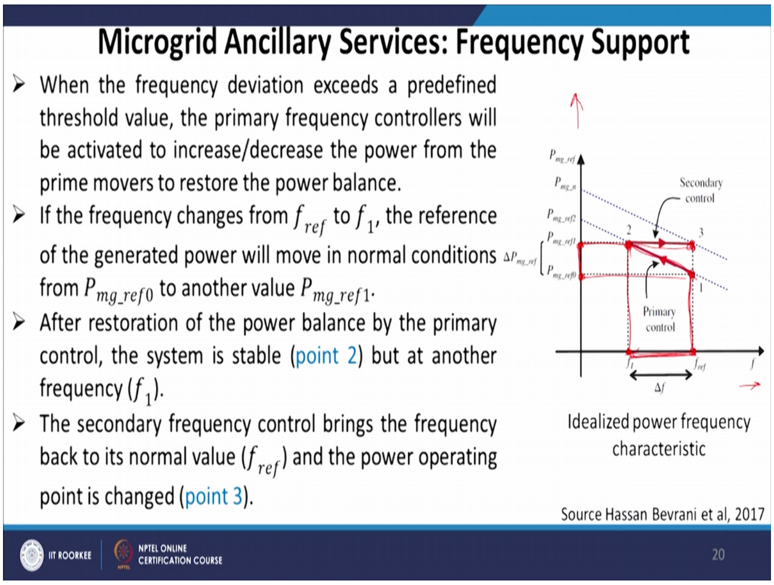


Now, if you look at when the frequency deviation exceeds a predefined threshold value, the primary frequency controller will be activated to increase or decrease the power from the prime movers to restore the power balance. If the frequency changes from let me consider this diagram, now let us say if the frequency is varying from f reference this point to another frequency that is f 1 and now because the power during f reference was my P mg at this point.

Now, when the frequency dropped due to an increase in P is at this point. Now this is my P characteristic and this is my f characteristic now due to an increase in power the frequency dropped or indirectly frequency drop leads to increase in power. Now that if the frequency changed from f reference to f one the reference of generator power will move a normal condition that is from this point P mg reference 0 to P mg reference 1.

Now, what has happened that we have operated with the desired new power requirement, but the frequency is now changed. After restoration of the power balance by the primary control the system is stable at this point, but with another frequency f 1, but not at f reference now to move to the f reference with increase in power. Now I have to move through secondary control to the location 3 such that now I have attained the new power as well as the previous frequency at this location.

Now, this one moving from 1 to 2 is my primary control scheme and again further improving the system from 2 to 3 through secondary control, where the increased power as well as the previous frequency being preserved. Now the secondary frequency control brings the frequency back to its normal value f reference and the power operating point is changed to point 3.

Now, this is the very ideal power frequency characteristic.

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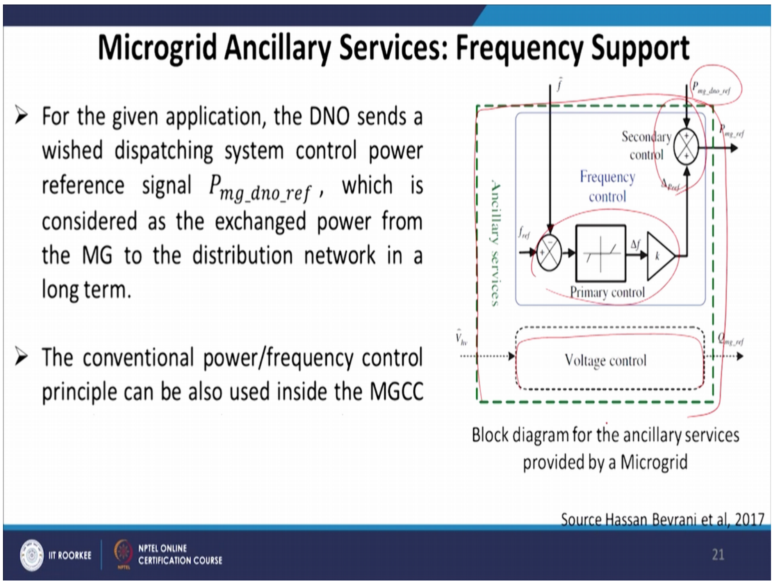


Microgrid ancillary services for a given application the DNO sends a wished dispatching system, control reference signal that is P mg dno reference which is considered as a exchange power from the microgrid to the distribution network in a long term. The conventional power frequency control principle can be also used inside the MGCC. Now this is a another setup where we can see this is my primary control and the secondary control where the P mg dno reference is being received, and voltage control scheme simultaneously we can say the whole setup works for my ancillary requirements provided by a microgrid.

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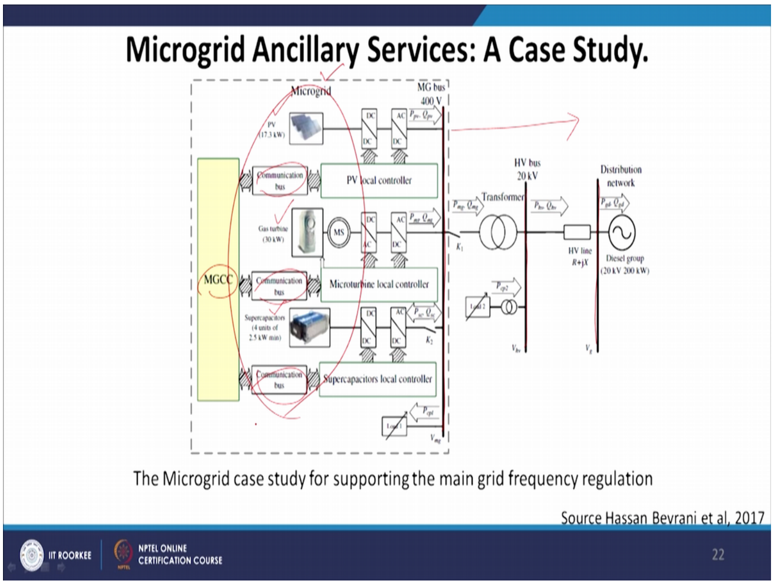


Now if you consider a microgrid ancillary services a very simple case study, especially to support the frequency regulation. Now you can see there is a distribution network and we have high voltage bus, and this is overly my microgrid where we have PV gas turbine, super capacitors they all connected to the grid along with MGCC through communication buses.

Now, as and when there is a frequency regulation issue, the microgrid can support or optimize its own generation so, that the frequency of the overall distribution system at which the microgrid is been connected can experience a better frequency regulation.

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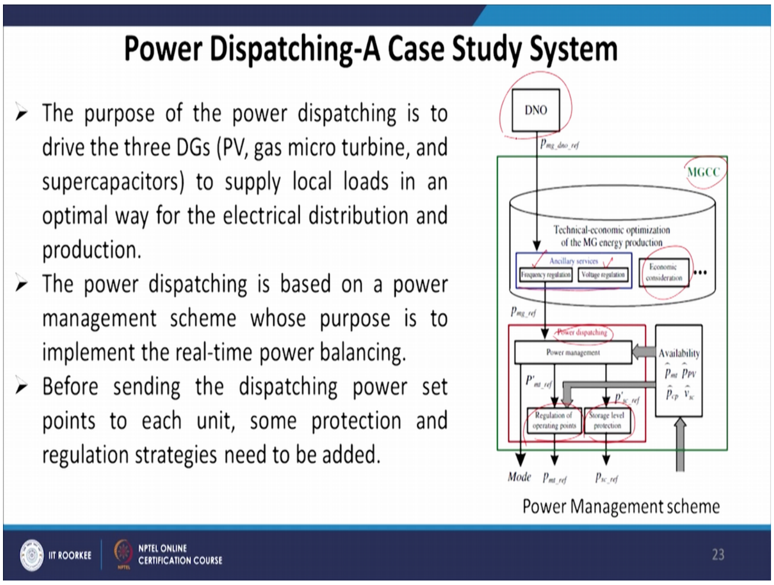


Now, if you look into the power dispatch scenario, the purpose of the power dispatching is to drive the three distributed generators to supply the local loads in an optimal way for the electrical distribution and production.

Now, the power management system where the main focus is what would be the optimal mix of the generators connected to my microgrid to behave such a manner that we can claim that the optimal dispatch is being carried out for the system. Now once again this my MGCC system in place then we have ancillary services both frequency and voltage regulation we do have many economic considerations and followed by the power dispatching regulation of operating points and storage level of protections.

So, this mechanism is overly monitored and controlled by DNO and this is very commonly known as power management scheme of a microgrid connected to a distribution system. The power dispatching is based on a power management scheme whose purpose is to implement the real time power balance. Before sending the dispatching power set point to each unit some protection and regulation strategies need to be added.

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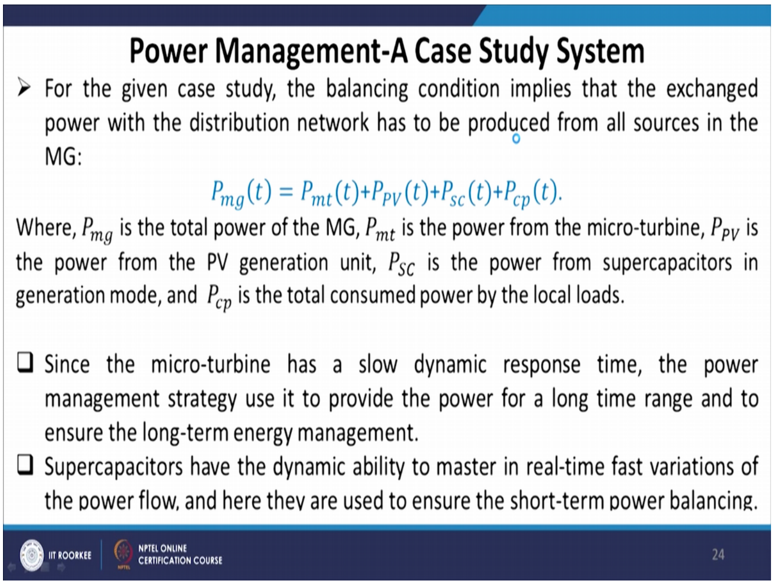


Now, if you wish to manage the power for a given case study the balancing condition implies that the exchange power with the distribution network has to be produced from all sources in a microgrid. Now the P mg the total power of the microgrid will be from the source as well as from the loads. So, it is power from the micro turbine, power from the PV generation, power from the super capacitor as well as the total consumed load or critical loads.

Since the micro turbine has a slow dynamic response time, the power management strategy use it to provide the power for a long time range and to ensure long term energy management. Whereas, in case of super capacitor it has the dynamic ability to master in real time fast variations of the power flow and here they are used to ensure the short term power balancing.

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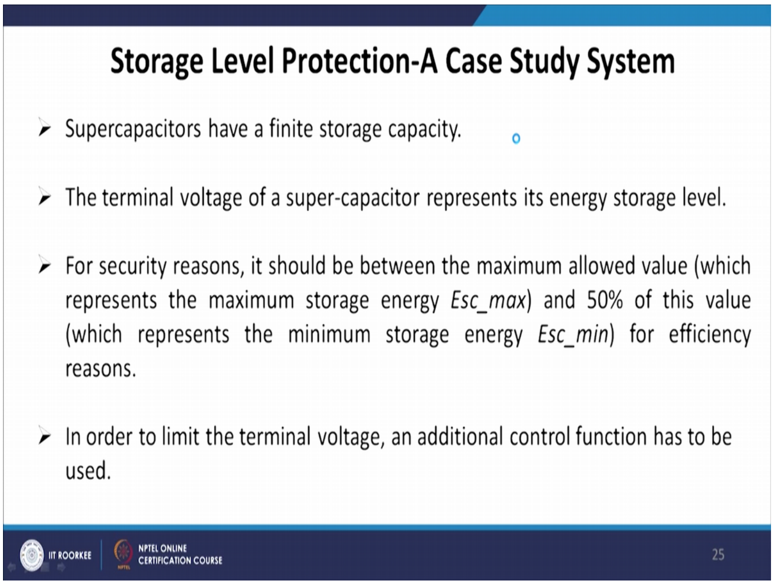


Now, storage level protection was quite interesting, where super capacitors have a finite storage capacity. The terminal voltage of a super capacitor represent its energy storage level. For security reason it should be between the maximum allowed value which represents the maximum storage energy and 50 percent of this value for efficiency reasons which represents the minimum storage. In order to limit the terminal voltage an additional control function has to be used.

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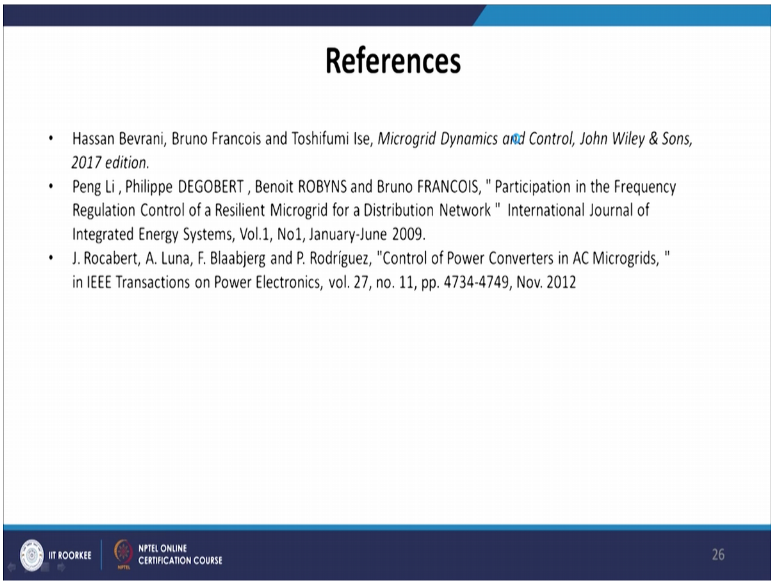

Now, these are the reference which has been used for this lecture. And I may request all the listeners to please refer to the supporting materials.

Thank you.