DC Microgrid and Control System
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Lecture - 18
Microgrid Operation Modes and Standards
Part – I

Welcome to our lectures on DC Microgrid and Control System. We shall continue our discussion with microgrid operation modes and its standard. So, that is something we required to work on it. So, we already have a grid code and all those things in a power system are quite standardized, but we require to form a standard for the microgrid.

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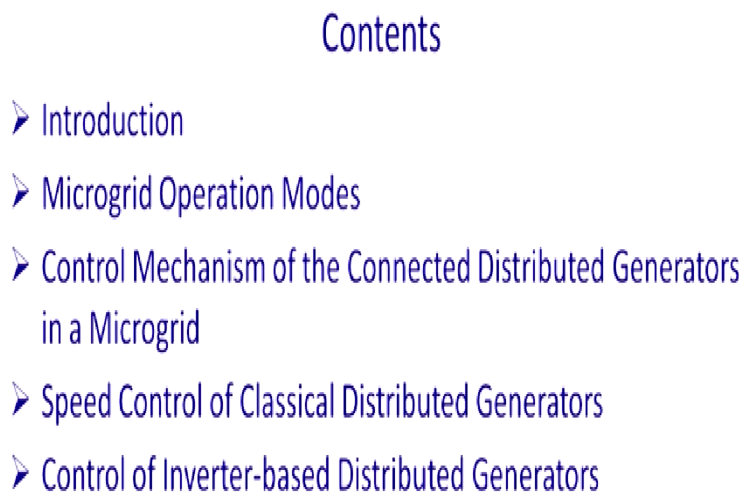

So, these microgrid operation modes we have already discussed in the introduction classes. We shall revisit it again and then we shall structure them in the different kind of operation mode and control mechanism for the connected distributed generation of the microgrid and speed control of the classical distributed generator and control of inverter-based distributed generators. So, these are the 2 methods we shall try to cover in our lecture.

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Introduction

- Small and smart grid energy systems are under continuous development to integrate massively renewable resources, microgenerators, and small energy storage systems (ESSs), as well as critical and noncritical loads in the control system of grids.
- The microgrids (μGs) are small electrical distribution systems that connect multiple customers to multiple distributed sources of generation and storage.
- The μGs are typically characterized by multipurpose electrical power services to communities that are connected via low-voltage networks.
- It is of great interest is that the hybrid power systems have the potential to provide reliable power supply to remote communities where connection to transmission supply is uneconomical.

Now, the small and smart microgrid systems are under continuous development to the integrated massively renewable energy sources and microgenerators and small energy storage as well as critical and noncritical loads in the control systems. The microgrids are small electrically electrical distribution systems that connect multiple customer to multiple distributed sources and with a storage element.

The microgrids are typically characterized by multipurpose electrical power service communities that are connected via low voltage networks, right. So, those are the things we have already discussed into our introductory class, but we wanted to revisit once we wanted to have a different kind of mode of operation. So, the there is a, so it a great interest of the hybrid power system have the potential to provide reliable power supply to remote communities for connection to the transmission supplies are not economical.

So, first micro gate was introduced in India, that was in 70s, where it was a place of pilgrimage. So, that was not a great success story either, anyway that comes later.

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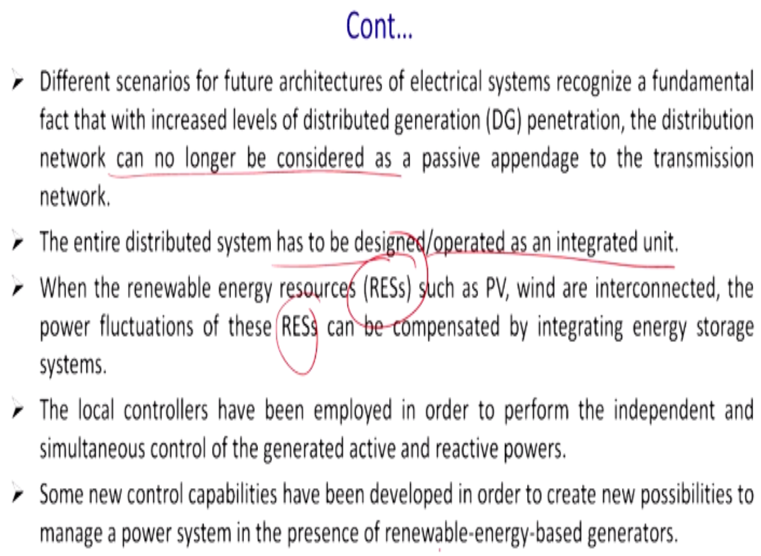

Different scenarios for future architectures of electrical systems recognize fundamental facts that with the increasing level of distributed generation, penetration, the distribution network can no longer be considered as a passive element or passive appendage of the transmission network. The entire distribution system has to be designed or operated as an integral system. So, previously we had a generator and the rest of the thing was a passive, but within a transmission distribution system also you have source, so we have to consider the whole as integrated unit.

When renewable energy sources such as PV, wind are connected, the power fluctuations of RESs that is renewable energy sources can be compensated by the by integrating the energy storage element. So, you can have a solar variation and fluctuation, wind variation and fluctuations. For this reason, we required to have a storage element. The local controller have have been employed in order to perform the independent and simultaneous control of the generated active and the reactive powers.

Some new control capabilities has been developed in order to create new possibilities to manage the power system in the presence of the renewable energy-based generator.

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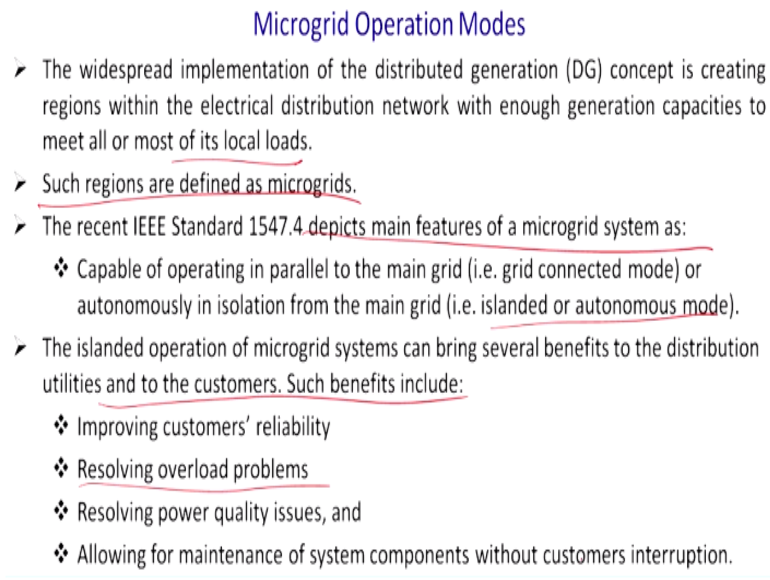

With widespread implementations of the distributed generations concept is creating the region within the electrical distribution network with enough generation capacities to meet the to meet all or most local loads, so that is something we require to plan it. So, what is a capacity installing capacity and what is the inhabitance capacity. So it should match either. So if you have a, it should not be actually total mismatching that doesn't make sense either.

Such region is and if there is self-sustainable energy and that is there to be set to be the microgrid and so the recent the IEEE standard 1574.4 depicts the main features of the microgrid system. Capable of operating in parallel with the main grid, that mean grid connected mode or autonomously in isolation with the main grid that is the islanded mode. Islanded operations of the microgrid system can bring several benefit to the distribution utilities and the customers.

Such benefits include the improving customer reliability, resolving overpower problem overload problem, resolving the power quality issues, allowing the maintenance of the component without the customer’s interruption. These are the few things that are the advantages of the microgrid.

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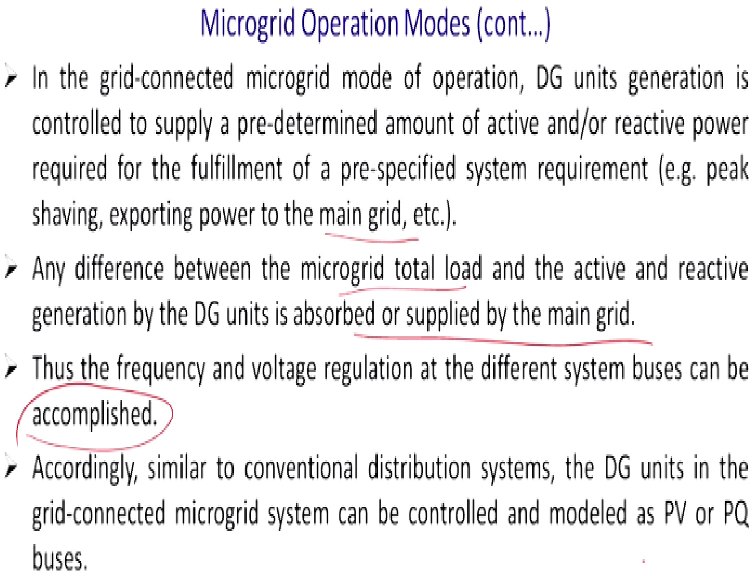

In microgrid in the grid-connected microgrid mode of operation, DG units generation is controlled to supply that predetermined amount of the active or reactive power required for the fulfillment of the specified system requirement. For example, the peak saving, exporting power to the main grid, etc, when the peak power is there, so that is something we require to plan accordingly. Any difference between microgrid total load and the active and the reactive generation of the DG unit are absorbed or supplied by the main grid.

So you don't bother it, so you just put it whatever extra to the grid. Thus frequency and the voltage regulation of the different system buses can be accomplished, so you don't have a problem on that. So, ultimately you supply to the main grids and main grid if rigid, so frequency is rigid. Accordingly, thus similar to conventional distribution system, the microgrid units in the grid connected microgrid system can be controlled and modeled as PV and PQ buses, that is an additional states first analysis.

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Microgrid Operation Modes (cont...)

- In the normal operation, the μG is connected to a main medium voltage (MV) distribution grid being either partially supplied from it or injecting some amount of power into it.
- Depending on the demand request, in the grid-connected mode, the main grid and local DGs may send power to the loads.
- As the MV grid sets the root mean square (rms) voltage, all DGs inside the μG can only generate currents but can be dispatched by the microgrid central control (μGCC) in order to provide power references.
- The control system in the local controller of the DGs is known as "PQ inverter control" and the DG is said to be in "PQ mode."

The nominal operation of microgrid, this is connected to the medium voltage distributed grid being either partially supplied or injecting some amount of power to it. Depending on the demand request, the grid-connected mode, the main grid, and the local grid may send power to the loads. As this MV grid sets the root mean square rms voltage, all DGs inside the microgrid can only generate current, but can be dispatched by the microgrid central control in order to provide the voltage preferences or the power reference. So, it can be the both.

The control system of the local control of the DGs is known as PQ inverter control and is set to be operating in the PQ mode.

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Control Mechanism of the Connected Distributed Generators in a Microgrid

- Today, large centralized facilities provide most of the electrical power around the world with fossil fuel, nuclear, and hydropower plants.
- These plants have good economies of scale, but they usually have to transmit electricity to customers far away, hence may affect the environment negatively.
- Using the RESs/DGs that are installed near the customer end reduces relatively electrical power losses on transmission lines because electricity is generated very close to the point of end use.
- This also decreases the size and number of power lines that must be constructed.
- The RESs/DGs appear as faster and less expensive option to the construction of large/central power plants with high-voltage transmission lines.

Today, a large centralized facility provides most of the electrical power around the world which is fossil fuel, nuclear, hydropower plant. These plant have good economic scale, but usually have a have to transmit electricity to the customer far away and hence affects the environment negatively and also it increases carbon footprint, etc, etc., you know very well. Using this renewable energy and DGs are installed near to the customer end reduces the relatively electric power losses on the transmission line.

So there is no hooking theft something like that, transmission line, because electricity is generated every close to the point of the end use. This also decreases the size and number of the power lines that must be constructed. So if you want to dispatch power, you would want to have a standby line and all those things that will have an extra cost. The renewable energy sources or distributed generations appear as a fastest.

The installation is very fast and less expensive option to the construction of the large or the central power plant with high-voltage transmission line. This is the advantage of the microgrid.

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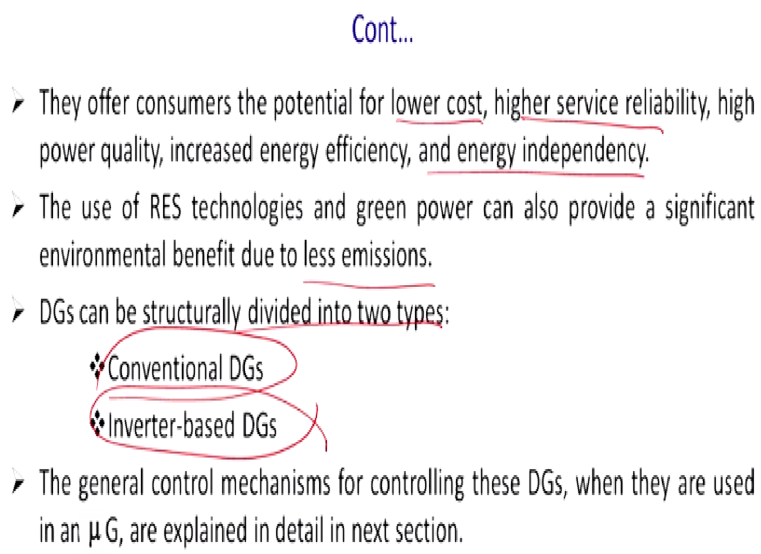

They offer consumers the potential for lower costs, higher service reliability, high power quality, increased efficiency, and energy dependency. Use of RES technologies and green power can also provide a significant environmental benefit due to less emission. So that is actually help us to reduce our carbon footprint.

The distributed generations are structurally divided into 2 types, conventional DGs and the inverter-based DGs. This general control mechanism for controlling these DGs when they are used in a microgrids are explained in the next section, that we are going to discuss now.

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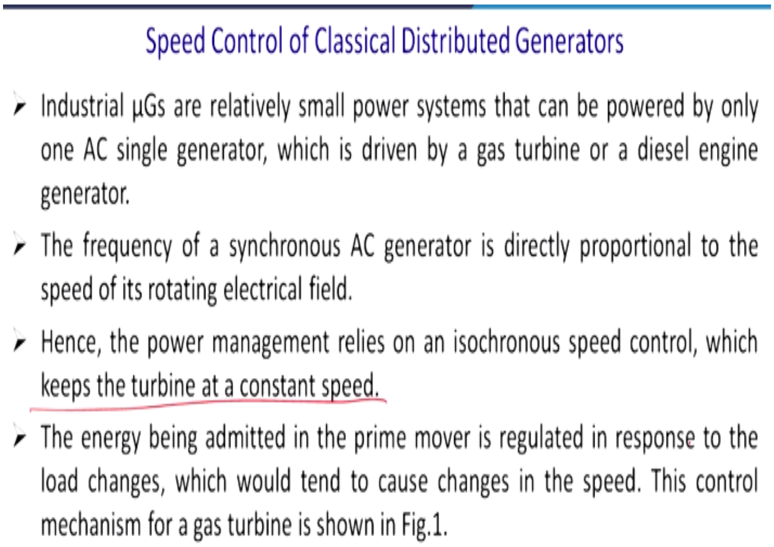

So, industrial microgrids are relatively small power system that can be powered by only the single AC generators and which is driven by the gas turbine or the diesel generator, that we have seen in our household applications. The frequency of the AC generator is directly proportional to the speed of the rotating electric field. Hence, the power generator, power management lies on the isochronous speed that we do have to rotate at a constant speed control, which keeps the turbine speed at a constant operation.

The energy being admitted to the prime mover is regulated in response to the load change, which would tend to cause a change in speed. The control mechanism for the gas turbine, it has been shown in the next figure.

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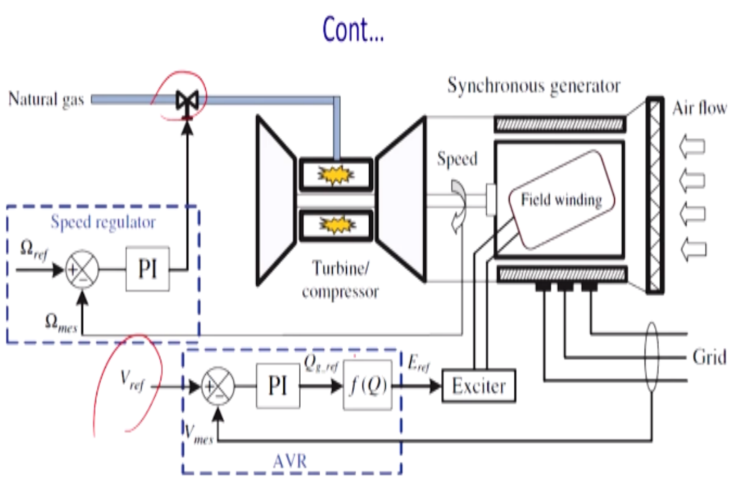

Fig.1 Scheme of an isochronous speed control system of gas turbine

So, this is a natural gas which you are burning, your speed controller. So, you have a reference speed regulator and reference measured speed. You have PI controller. Ultimately, you will change the input of the throttling valve. You have a turbine or the compressor and that will be actually generating the direct talk and that will rotate the crank and you have a field winding and you have an airflow that will actually control also the control the fan into the turbine or the ignition of a turbine.

So, Vref is basically, you have a Vref, you have a V measure, then they had a PI controller, ultimately it is the Q reference and then it is If and that will change this exciter of the, that is supply to the field winding, that will be changing based on the voltage requirement and that will be the output, the exciter.

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- Any increase in load decreases the speed (Ω). The kinetic energy in the large inertia contributes to compensate the speed in few instants.
- Moreover, energy is quickly admitted to the prime mover to maintain the speed at the set point (Ω_{ref}) by the speed regulation using a simple proportional–integral (PI) controller.
- Any decrease in load increases the speed, but energy is quickly reduced to the prime mover to maintain the speed at the set point.
- An automatic voltage regulator (AVR) is used to control the output RMS voltage of the machine (V_{mes}) by regulating the voltage across the field exciter (V_{ref}).
- In case of a load change in the network, the power system's inertia can perform energy balance with detection of the variation in system frequency.

In case the load decreases, the speed increases. The kinetic energy in the large inertia contributes to compensate the speed within the few instants. Moreover, energy is quickly admitted to the prime mover to maintain the speed of the speed at the set point. The speed regulation is using a simple proportional controller, since it is a mechanical controller and it is quite slow in operation.

Any decrease in the load increases the speed, but energy is quickly reduced to the prime mover to maintain the speed at a cost endpoint. An automatic voltage regulator that is called AVR is used to control the output of the RMS of the machines machine by regulating the voltage across the field exciter Vref. In case of the load change in the network, the power system inertia can perform the energy balance with detection of the variation in the system frequency. That is a way it will operate.

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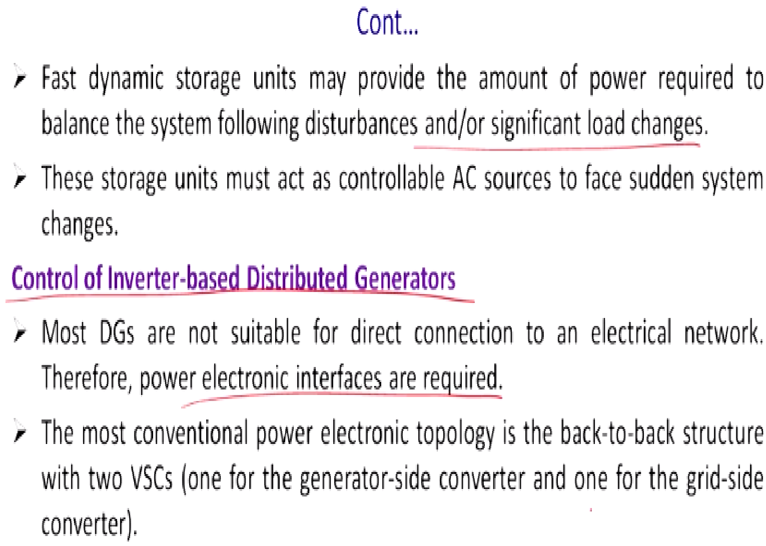

Now, fast dynamic storage unit may be provided that can be battery or ultracapacitor. The amount of the power required to balance the system following distrurba, following disturbances or significant during the load change, so it can be flywheel, it can be battery and depending on the kind of energy it will fluctuate. The storage unit must act as a controller of the AC sources for the face to face the sudden system changes.

Now, let us come to the inverter-based distributed generator and this system has got an inertia and takes lot of time to have a control, but this system is a low inertia system, it can act very fast, but there is a problem in it. Most DGs are not suitable for direct connection of the electrical network, and since it is a for example, if it is a solar, it is generating DC and if you get may be AC. Therefore, power electronics interfaces are required.

Most of the conventional, most of the most conventional power electronics topology is the back-to-back structure of this 2 current source converters or generator-side converter and for the grid-side converter, these are the 2 converts.

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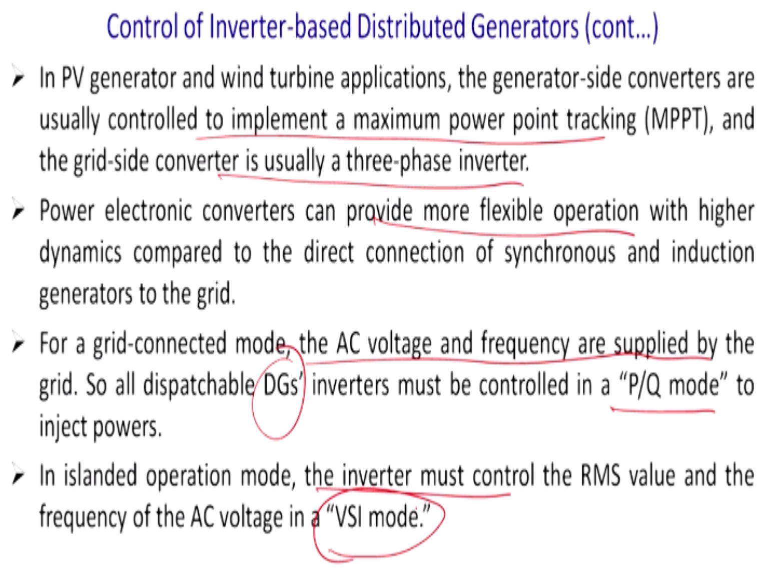

The PV generator and the wind applications, for example, the generator-side converters are usually controlled to implement the maximum power point tracking of the MPPT. So, we have seen the MPPT tracking for the wind as well as solar. So and the grid-side converter is usually a three-phase inverter and that will be connected to the grid. The power electronic converters can provide more flexible operation with high dynamics compared to the direct connection of the synchronous of the induction generator to the grid.

For a grid-connected mode, the AC voltage and frequency are supplied by the grid. So, all dispatchable DGs or distributed generator inverters must be controlled in PQ mode to inject power into the system. We have discussed PQ mode in previous in few lectures few slides ago. So, please revisit that IB. In the islanding operation mode, the inverter must control the RMS value of the frequency of the AC voltage and it is called VSI mode.

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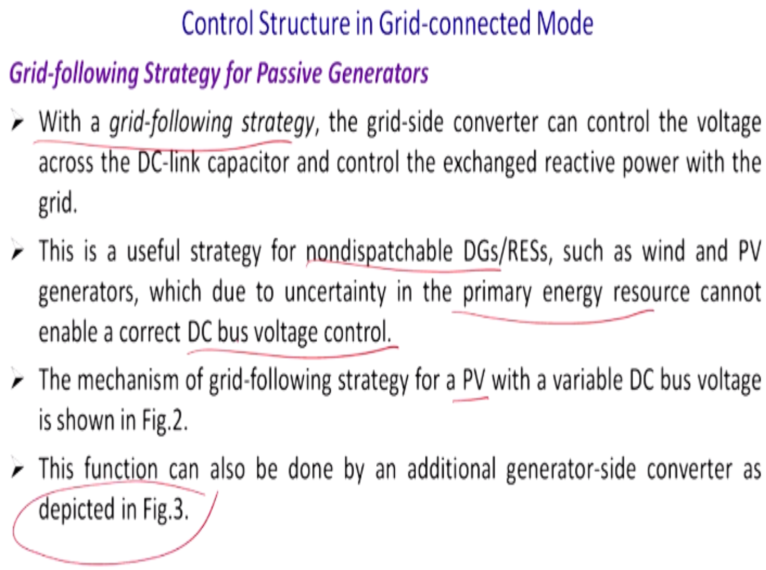

Now with a grid-following strategy, so this is kind of strategy let us understand. The grid-side converter can control the voltage across the DC-link capacitor and control the exchange of the active power with the grid. So, this is the, this is with the grid following strategy. This is a useful strategy for nondispatchable DGs or the renewable energy sources such as wind and PV generator, which due to uncertainty of the primary energy source cannot be enabled to correct the DC bus voltage control.

So, this is something sometime happens. So, you have a primary energy source has some problem. The mechanism of the grid-following strategy for the PV for the solar with a valuable DC bus voltage, it will be shown little later and function and this function can also be done by additional generator-side converter as shown in the figure 3.

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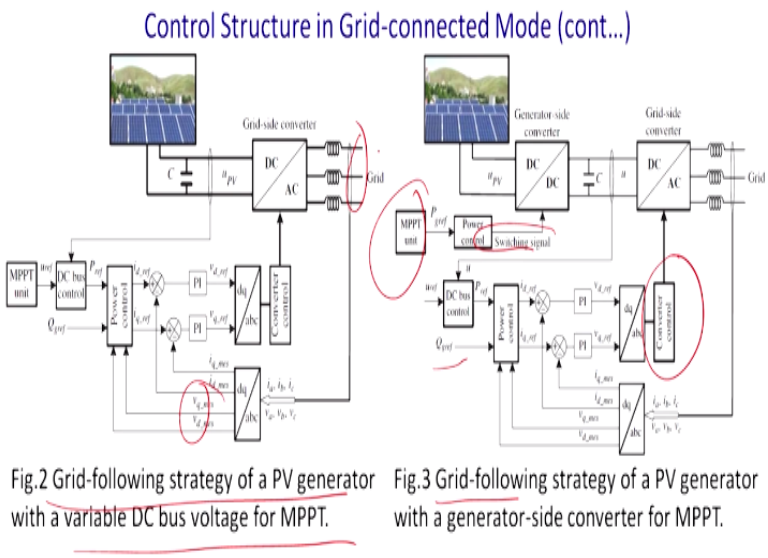

So, see this one is essentially a grid-following strategy of the PV generator with variable DC bus for the MPPT. So, you have a solar panel. They had a capacitor, thereafter you got an input to the DC bus and you sense this is MPPT unit and this is a DC bus control and thereafter you will have a power control. From there, you have a reference of id and iq where you allow this DC bus to fluctuates and you track the MPPT.

So, thereafter, you got a Vdq reference Iq reference, you take you mix up this currents ABC and we have VBBC, you convert to the dq measures and Iq measures and Pq and Vq goes here and this will be compared fed to the PI controller and thus this becomes your reference for the d-axis and the q-axis. The grid-following strategy is that you know with the variable DC bus voltage, this voltage E is connected to the grid and ultimately so power will come and maintain this voltage here.

Ultimately you try to inject the power from that one, that is called a grid-connect strategy. Another is, another is grid-following strategy, while you don't you require to maintain the constant DC bus voltage and also the MPPT voltage, that in this case, you have MPPT voltage, you will have a power control, that is switching signal and you have extra DC to DC converter and thus your voltage here is fixed, and since there you have DC bus control, you have a power control, Q reference, that is id and iq and you have a PI controller.

From there, you got a control over current and similar thing is fed here. One advantage is there, you are maintaining a constant DC bus voltage, thus modulation induction is fixed. Most of the cases if the if you assume that grid-side has a constant voltage, but here, your modulation index will vary to give injection of the power.

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Control Structure in Grid-connected Mode (cont…)

- With a grid-following strategy, using of a choke filter, the grid-side inverter is controlled as a current-controlled source.
- Direct and quadrature components of currents are calculated by a Park transformation for power calculation.
- Generated real power variations of the DG cause a DC-bus voltage error, which is corrected via the DC bus control by adjusting the reference of the real power (P_{ref}) injected to the grid.
- The reactive power output is also controlled using the PI regulator by adjusting the magnitude of the inverter reactive current output.
- This inverter can operate with a unit power factor or can receive a set point (from the μGCC) for the output reactive power.

With a grid-following strategy, using a choke filter, the grid inverter is controlled as a current-controlled source. So, that is the current-controlled source it will act. Direct and the quadrature components of the current are calculated by the Park transformation for the power calculations. Generated real power variations with the DG causes the DC bus voltage error, which is connected via DC bus controlled by adjusting reference of the real power and injected to the grid.

The reactive power output is also controlled using the PI regulator by adjusting the magnitude of the inverter reactive current output. So, this is something we will do. Then the inverter can operate with the with a unit power factor and can receive a set point of the micro GCC for the output reactive power. This is the mode of operation for the grid-connected mode.

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Grid-following Strategy for the PQ Mode

- With a grid-following strategy, the inverter operates by injecting the available power at the primary source into the grid since the DC bus voltage is constant.
- In the DGs with the possibility of increasing/decreasing the amount of primary power, an additional active power reference can be used by the local controller (P_{gref}), to make the generated active power variable.
- These kinds of DGs are dispatchable and their control system is known as "PQ control," as illustrated in Fig.4.

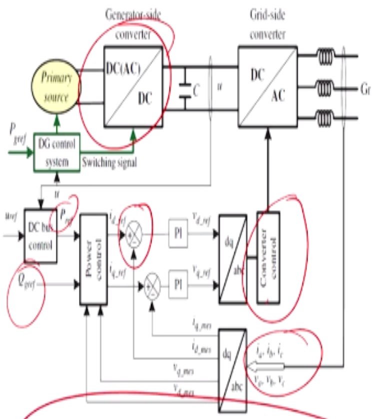

Fig.4 Grid-following strategy of a dispatchable generator in the PQ mode

And in a grid-following mode, you see that is a primary source, and you have a Pg reference and you have variable DC and thus you have to maintain the MPPT control and you will control also that DC bus voltage and then you have a power reference that is Pref and Qref and now you take the inputs from your grid side currents and voltages, you feed this voltage element here, please recall our previous lectures on modeling, and thereafter you have Idref and Iqref and you will feed to this and you generate Vdref and Vqref.

Thereafter Dq and ABC to the converter control and that will feed to the AC inverter. With the grid-following strategy, the inverter operates by injecting the available power at the primary source to the grid since this DC bus voltage is constant. The DGs, generally we operate in this sport mode, but we require extra DC to DC converter and the distributed generators with the possibility of the increasing and decreasing the amount of the primary power.

An additional active power reference can be used by the local power controller that is gref. So, this one is gref, to make the generated active power variable. This kind of DGs are dispatchable and their control system known as the PQ control and this has been illustrated here.

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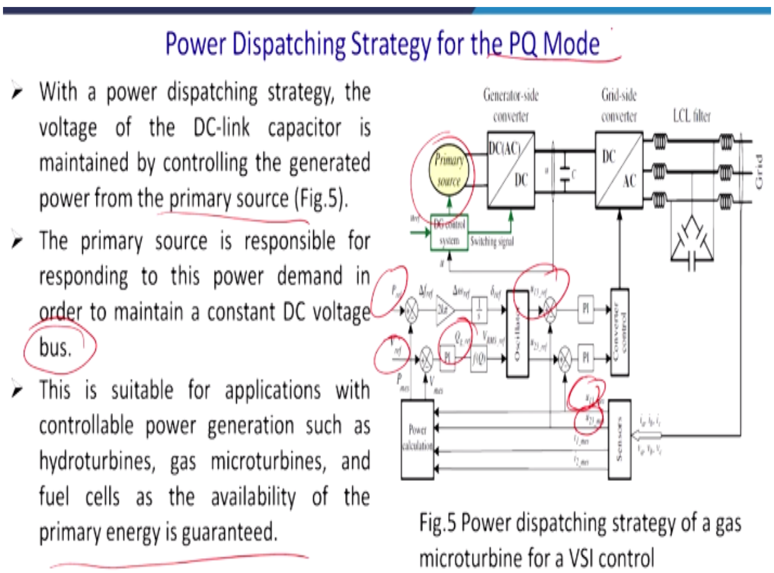

Now power flow strategy in a PQ mode. With the power dispatching strategy, the voltage of the DC-link capacitor is maintained by controlling the generated power from the primary sources. So, this is the primary source. So, you got a DC system, you got pulses, and this one will try to maintain the constant DC bus voltage and you sense this is a line filters, you sense the currents, and thereafter this is a measured value of voltage and current and thus.

You have a reference power and you got you have a calculation of the voltage and current and you got a reference power. Thereafter, you got a voltage reference in the grid side and you will inject the you will subtract that value, thereafter you got a Q reference. Mind it if sag does not occurs, so this low does not work. So it will work, come into the picture if there is a voltage sag or soil or voltage disturbances sometime.

So, then you integrate over it and ultimately, and you got f and q, so you got a reference for 1 and 3 and 2 and 3 and then you feed it to the PI controller with this voltage reference, you and voltage reference between the line 1, 2 and line 2, 3 since it is a three-phase (( )) (26:10) system to line, sensing 2 line voltage is sufficient. So, from there, you feed it to the ABC to d-q frame and ultimately it will feed to this AC inverter. The primary source is responsible to this power demand in order to maintain the constant DC bus voltage.

This is suitable for application with the controllable power generation such as hydroturbines, gas turbines, fuel cells, and as cells as availability to the primary energy standard. So, this is quite familiar and it has been practiced ion many kinds of operation, this PQ mode of operation.

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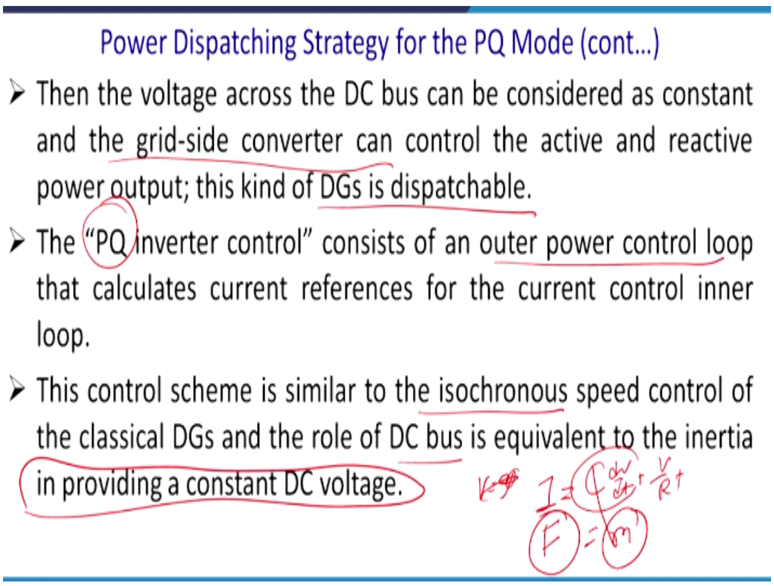

Now, the power dispatching strategy for the PQ board, so we required to dispatch power that is the whole intention of this renewable energy sources. So, the then the voltage across the

DC bus can be considered as a constant and we are maintaining constant by DC to DC converter. The grid-side converter can control the active and the reactive power output, this kind of DGs are dispatchable.

The Q inverter control consist of an outer power control loop that calculates the current reference for the current controller inner loop, just go back and you can check it. So, ultimately, you know here you have this controller and so you are feeding it and this is the PI controller, so coil coppering, it is generating that. This control scheme is similar to the isochronous speed of control in case of the classical DG, so it has a synonymous in that sense, but it has got no inertia.

So, this is one of the challenges of this speed for the classical DGs and the role of the DC bus is equivalent to the inertia and is providing by the DC voltage constant. So, DC bus, DC voltage constant, it is something like the it is the capacitors. Please recall you have force voltage energy. So, in there, you have a voltage equal to you know you can write or you can have a force current analogy.

So, in this case, you can see that since the voltage control holder source of force current energy comes into the picture and thus in volt uh thus force current analogy, capacitor is considered as an electrical mass. So, in this case in this case, this DC bus voltage will provide the required inertia. So, ultimately due to the current analysis you know if you write current, so you will find that current is you can refer RLC circuit is what you can have current and the force analysis you can do.

Then you will find if you have a same kind of parameters coefficient analysis, you will find that mass in force will have a same kind of aspect in current because it is Cdv/dt + you can write it this equations V/R + this thing So, ultimately you can differentiate it, you can write in terms of the integration of it. So, mass and the capacitor will be synonymous here in case of the force current analysis and thus in this case DC bus voltage will provide the inertia, which is provided by this inertia by the providing mass system.

Thank you for your attention. I will continue to do the classes on the modeling on the micro microgrid in our next class. Thank you.