DC Microgrid and Control System
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Lecture - 20
Microgrid Control Architectures

Welcome to our lectures on DC Microgrid and Control System. Today, we are going to discuss about the microgrid control architecture, that is one of the important aspect of our microgrid.

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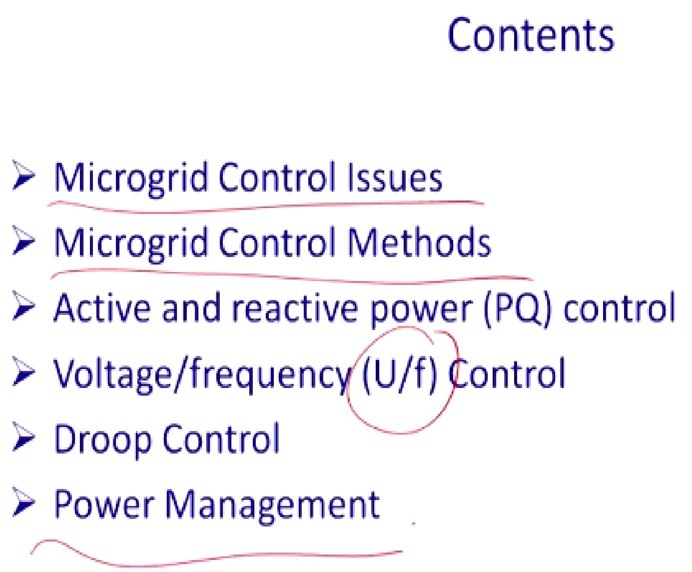

So our presentation layout will be the microgrid control issues, thereafter after microgrid control methods, active and the reactive power flow control, V/f control, and the droop control and thereafter power management. So this is droop control can be AC and DC and voltage and frequency control of course it is required to that AC microgrid.

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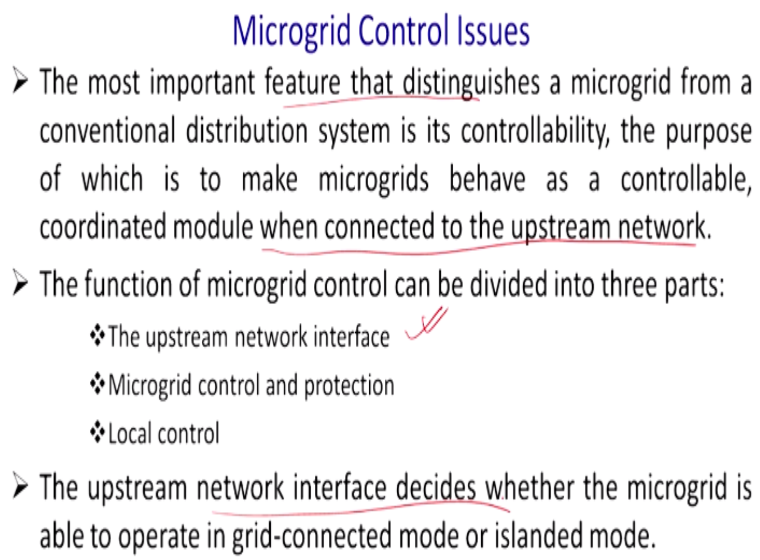

So most important features that distinguish a microgrid from a conventional distribution system is that its controllability. The purpose of which is to make microgrid behaves as a controllable coordinated module when connected to the upstream network. The function of the microgrid control can be divided into the 3 parts; the upstream network interface, we shall discuss in detail in next slides, microgrid control and the protections, and the local control.

The upstream network interface decides whether the microgrid is able to operate in grid-connected or the islanding mode. So many solar inverters generally does not able to in India if it is connected to the grid and generally dispatch power to the grid, if in certain region power goes off, then he has to stop, so it cannot feed the local power. So it is one of the capability that microgrid should have if the it is islanding mode, it should able to feed the local load.

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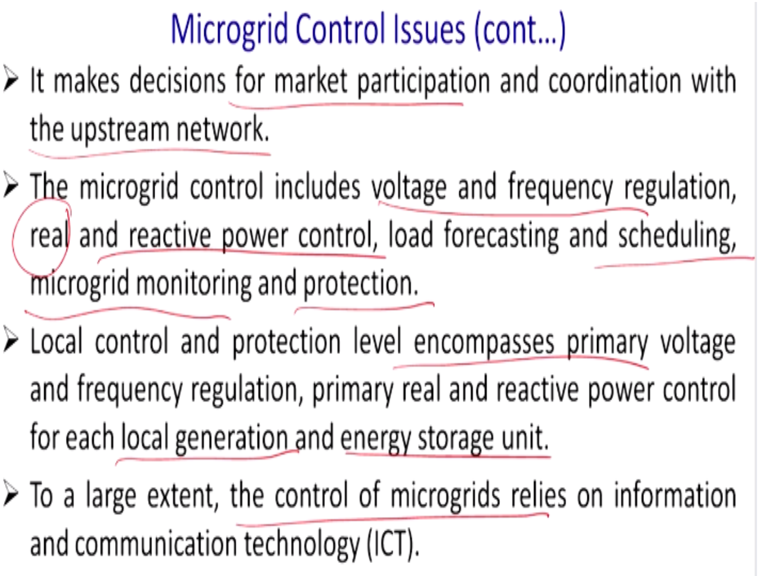

Thus it makes decisions for market participations, whether we will sell the power to the main grid and coordination with the upstream network, that is actually the how it will sell, what is the power quality, all those issues. Microgrid control include voltage and the frequency regulation, of course you cannot sell, if you are willing to sell power, you are not allowed to sell power at different voltage and the frequencies, so it has to be with your grid frequency as well as grid as well as in a desired power factors, you cannot inject power factor at any power factor.

So for this reason, you require to have a real and the reactive power control and also we required to have a load forecasting. So you know that where the peak will come in load and if required load scheduling, that mean some can you shift some amount of load where your power is more where actually you have excess generations, and microgrid monitoring and so thereafter you required to monitor it properly whether physically as well as sensor levels, and thereafter its protections, fault and different kind of aspects.

Now local control and protection level encompasses primarily voltage and the frequency regulations, primary real and the reactive power control for each local generation and energy storage unit. To a large extent, the control microgrid real relies the information on the communication technology because it has to communicate between 2 different sources as well as load, there might be a miles apart if it is not if it is, they might be actually some kilometers apart if it is not hundred or thousand miles apart.

So for this reason, we require to have different kind of communication networks Zigbee or whatever may be.

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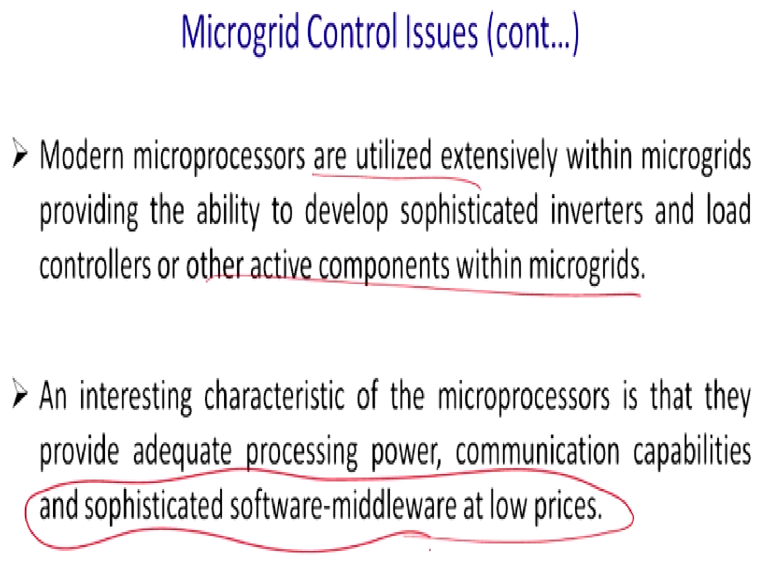

The modern microprocessors are utilized extensively within microgrid providing the ability to develop sophisticated inverter and the load controller or other active component within microgrids. An interesting characteristic of microprocessor is that they provide adequate processing power, communication capabilities, and sophisticated software-middleware and the low prices, so that is something it has been achieved we can say and thus the scope of this microgrid has en enhanced.

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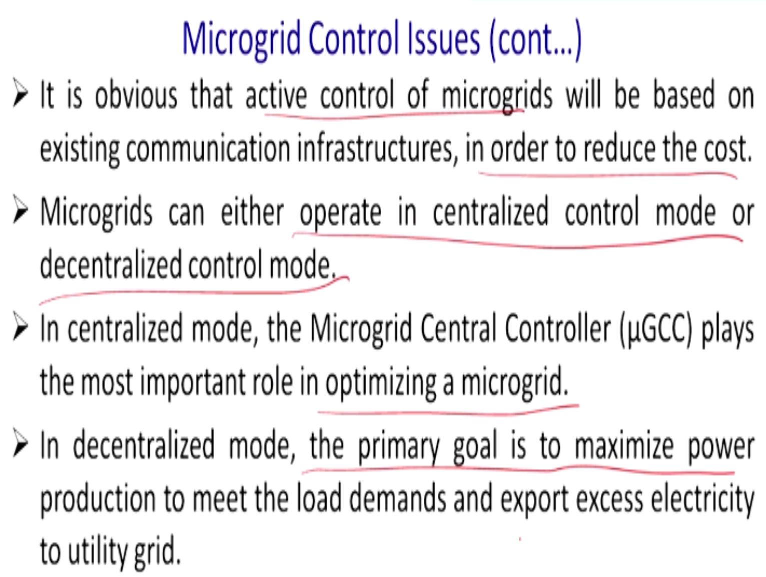

Now, the control issues of the microgrids. It is obvious that active control of microgrid will be based on that existing communication interface or the infrastructures in order to reduce the cost. Already if you have a SCADA, you will be using SCADA. If you already have a

Zigbee, you will be using Zigbee. Microgrid can either operate in centralized control mode or decentralized control mode. In centralized mode, the microgrid control plays the most important role in optimizing microgrid.

In decentralized mode, the primary goal is to maximize the power production to meet the load demand and export the excess electricity to the grid, so you will sell the power when you have an excess.

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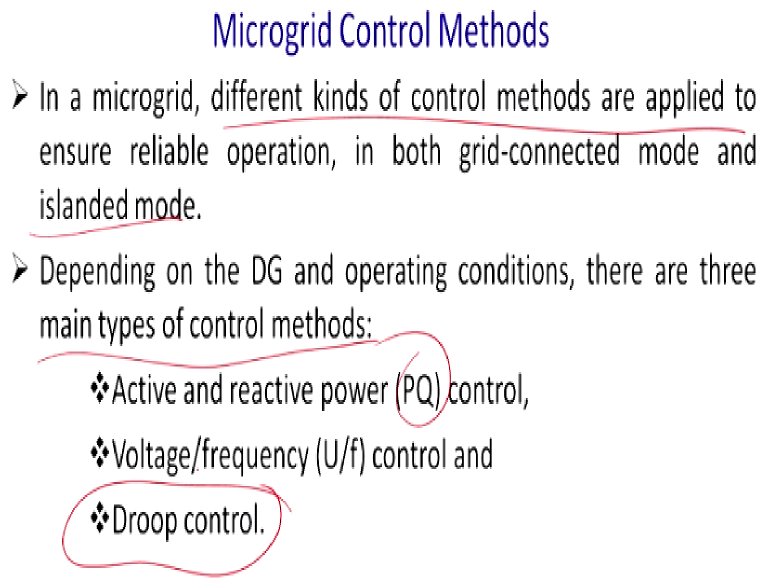

In a microgrid, different kinds of control methods are applied to ensure reliable operation in both grid-connected mode and islanded mode. Depending on the distributed generations and the operating condition, there are mainly 3 types of controls. One that is active and the reactive power flow control, that is PQ control, thereafter voltage frequency control, and the droop control, droop control can be both AC as well as DC.

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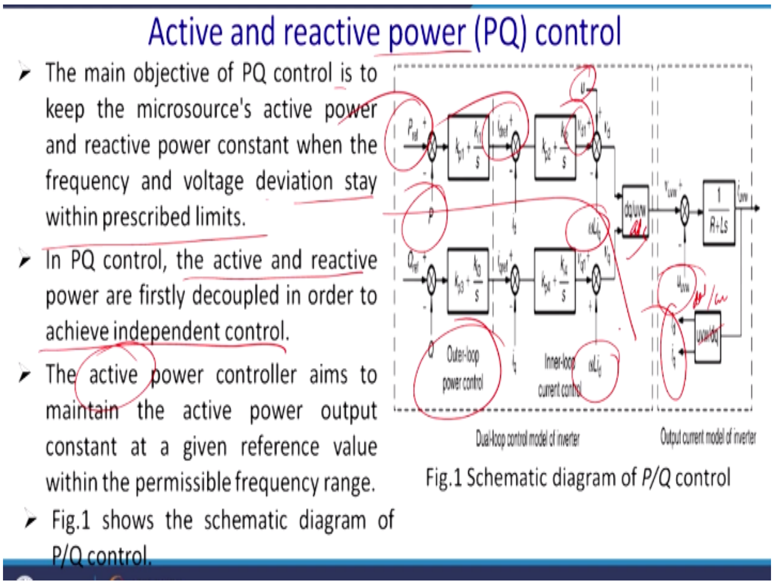

So let us see first the active and the reactive power flow control. So you have the P reference. You should have seen the our 20th, 19th lectures how generate the P reference and you have an actual power generation and you feed it to the PI controller, ultimately you generate this, actually d-axis reference of the current, and then you subtract with the actual d-axis current of the maybe the inverter.

Then you feed it to the PI controller and ultimately you got the VD1 and that VD1 has to be subtracted from the input U and thus you got the reference VD, you can convert into d-q to uvw or abc frame of reference, generally German style uvw and we may write abc also, same thing, and same way for the reactive power flow control you for (( )) (08:40) control Qref and you got a PI controller that will be the outer loop.

Then you got Iqref, then you multiply with the Id with the omega and that will be substituted by the PQ 1 and that value you required to put it, there is a cos reference, it is omega x iLq has to be subtracted and that value will be VD and ultimately you get because you want that it will be unity power factor and you will have you will be RMS value and this value will be essentially the different 3 voltages, ABC, and that is actual voltages and thereafter what happens you will feed it to the filters.

Thus you got a filter current that will be in ABC or the UVW frame and you transfer to this just difference, that is really actually UVW to the d-q frame and you get the IdIq. The main objective of PQ control is to keep the microsource active power and the reactive power constant when the frequency and the voltage deviation stay within the prescribed limit, so that is a grid code, so you have to follow that grid code.

The PQ control, the active and the reactive power are firstly decoupled in the d-q axis in order to achieve the independent control, but there is a cross term that is omega x iLq and omega x iLd. The reactive power control aims, sorry first let us take active power control. Active power control aims to maintain the active power output constant at a given reference value with the permissible frequency range and it has been shown this part of the figure. Figure shows the PQ control.

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Active and reactive power (PQ) control (cont...)

- The active power controller aims to maintain the active power output constant at a given reference value within the permissible frequency range.
- The reactive power controller aims to maintain the reactive power output constant at the given reference value within the permissible voltage range.
- If microgrid operates in the grid-connected mode, the main power grid is responsible for maintaining the voltage and frequency of the microgrid.

The active power control aim to maintain the active power output constant and at a given reference with a permissible frequency range as I told you, and the reactive power control aims to maintain the reactive power output constant at a given reference value within the permissible voltage range and generally it controls also the sanks. The microgrid operates in the microgrid-connected grid-connected mode.

The main power the main power grid is responsible to maintain the voltage and the frequency. So, it is the job of the, with a rigid system that is the grid, will maintain the voltage and frequency and we required to just follow it.

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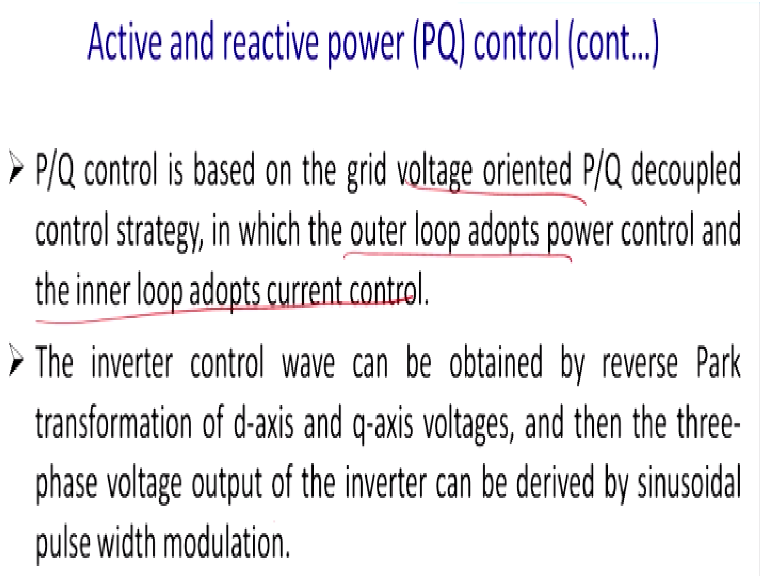

So PQ control is based on the grid voltage oriented PQ decoupled control strategy, in which outer loop adopts the power control and inner loop adopts the current control. Please go back and see that how does it work. So here, you have output current for the inverter, here the dual loop for the inverter. The inverter control wave can be obtained by the reverse Park transformations of the d and q-axis voltage and then the 3 phase voltage output of the inverter can be derived by the sinusoidal pulse width modulation or any other technique so that is the choice of the particular design engineer.

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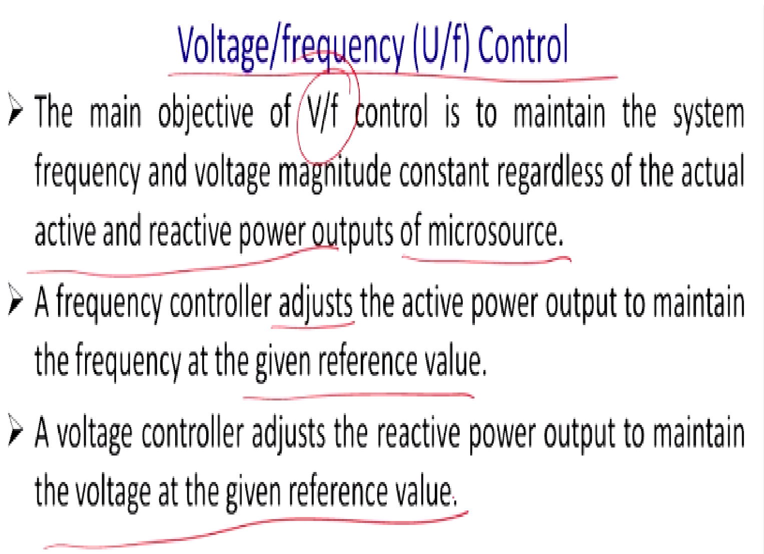

The main objective of V/f control, now let us talk about the V/f control. We have discussed about the PQ control. Now we will talk about the voltage/frequency control. It is to maintain the system frequency and the magnitude cost and regardless of the actual reactive power real and the reactive power output of the microsources. So you require to maintain this thing constant.

A frequency control adjusts the reactive power output to maintain the frequency at the given reference value. A voltage control adjusts the reactive power output to maintain the voltage at the given reference value.

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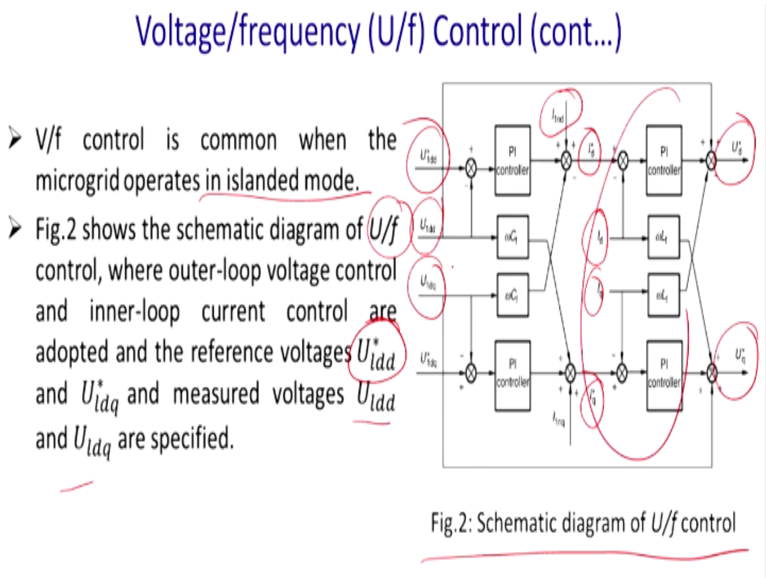

So see that how does it work? You got U1dd. So you got a PI controller, that is a reference and you got actual U1dd, then you subtract that you got a value and then you will subtract it from this I1nd and thus you got a d-axis current, and similarly for the q-axis current, so you will multiply with omega CF and you subtract and here you will multiply with omega CF and you subtract and thus you get the IQ. So this is the actual value of Id and Iq and that will be multiplied with the voltages and ultimately you will have a Ut start and Eq start.

So V/f control is a common when it operates in an islanding mode, so you have disconnected your connections from the grid. The figure 2 shows the schematic diagram of V/f control or U/f control where the outer loop controls the inner current loop are adopted with the reference signal Uild and the U star ld are the measured voltage and this terms are the actual voltages. So this is the schematics for the U/f control or the V/f control for microgrids and generally it is preferred in islanding mode.

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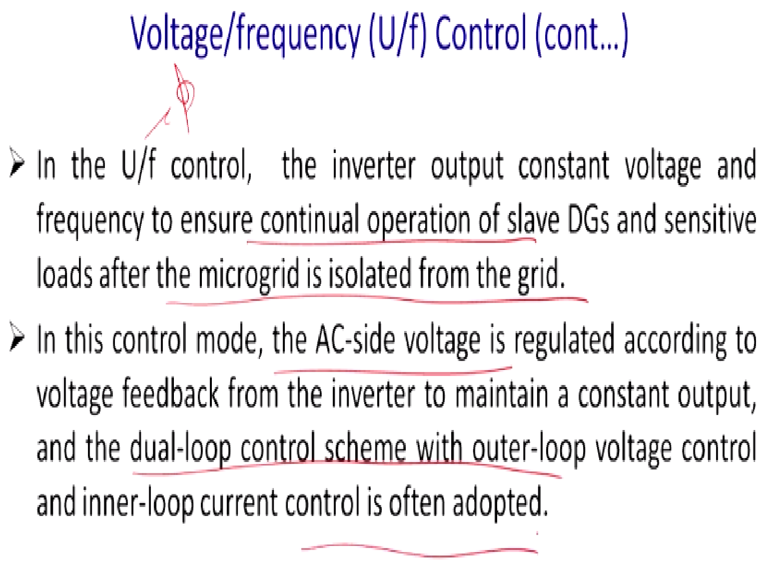

In U/f control or the V/f control, the inverter output inverter output constant voltage and constant frequency that will ensure continual operations of the slave DGs and sensitive loads after microgrids are being isolated from the grid, so that is something we required to issue, but what happen if you control the V/f, then what happen essentially the flux become constant with integration of the frequency.

So if you ensure that, then all the machines and all those elements will operate fine. Otherwise, this torque will change and all those things will be a big issue. In this control mode, the AC-side voltage is regulated according to the feedback from the inverter to maintain the constant output and the dual-loop control scheme with the outer-loop voltage and control and inner current loop control is often adopted. So this is the inner current loop control and this is outer voltage loop control.

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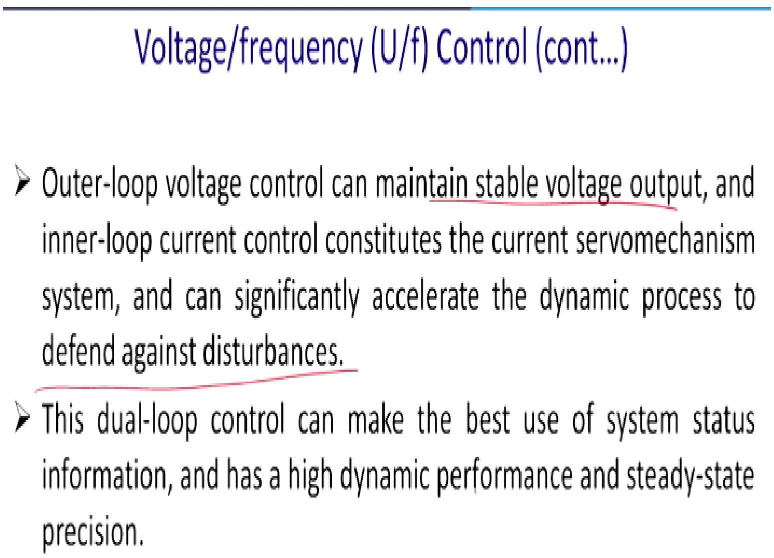

The outer voltage loop control can maintain the stable voltage output, and the inner current loop control constitutes the current servomechanism and can significantly accelerate the dynamic response to defend the disturbances. If all of a sudden the voltage sags, so this faster current loop will act and mitigate those disturbances. The dual-loop control can make the best use of the system status informations and has dynamic performance in the steady state with a quite good amount of precisions.

So it will ensure that again it reaches the stable state after the disturbance is over into the same state where it was with a quite high level of precision, that is the advantage of the dual control.

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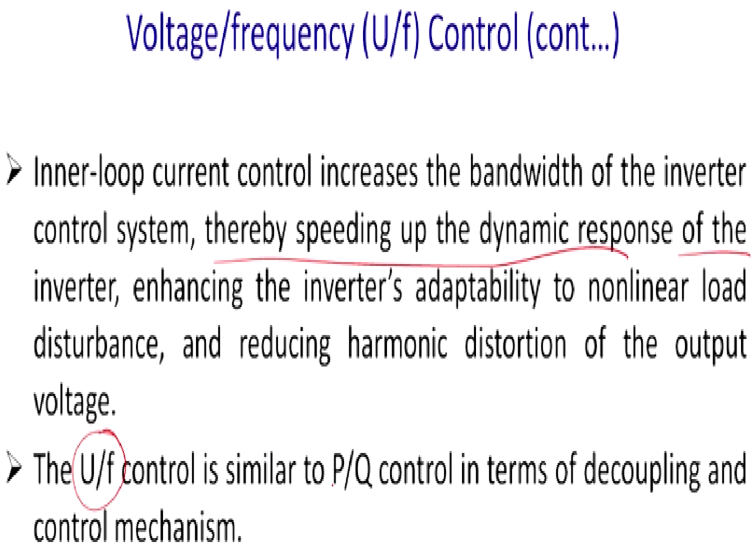

Inner control, inner-loop control current increases the bandwidth of the inverter control system since the switching frequency will be high, for this reason you know you require to have a quite high bandwidth and thereby speeding up the dynamic response. So it can take very fast actions, if it is operating at 10 kilowatts, then you have bandwidth over 10 kilo Hertz and while your power supply has a supply frequency of the 50 Hertz.

So it can acts and is thousands times faster of the inverter, enhances that inverter's capability to nonlinear and load disturbance and reducing harmonic distortion of the output voltage and others power quality issues. You can go for selecting harmonic eliminations and other. So V/f or U/f control is similar to the PQ control in terms of the decoupling because you have splitted in DQ frame and what general it is applied for the islanding mode, where PQ control has been applied for the grid connected mode.

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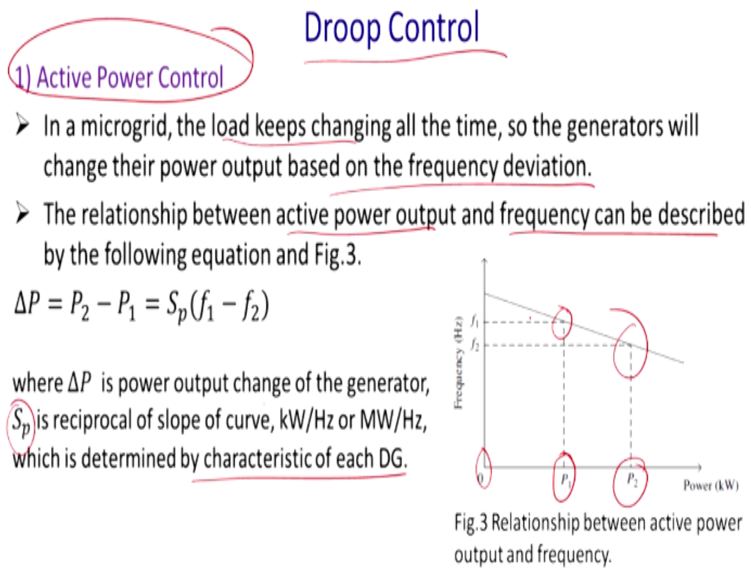

Now another is the droop control and it is basically the first part will be the active power control. In a microgrid, the load keeps changing all the time, so load is something that prerogative of the uses. This can change the load as they require. So generator will change their power output based on the frequency deviation. So once load is more, you will see that there is a deviations in the frequency, and based on that, they have to increase the power.

The relations between the active power output and the frequency can be described by the following equations in the figure 3. This is the frequency in y-axis and this is the P1 and this is a P2. You can see that del P = P2-P1 = Sp is the function into f1-f2, where del P is the power output change of the generator and where Sp is the reciprocal of the slope curve of kilowatt per Hertz or it depends on the inertia or megawatt per Hertz, which determines the characteristics of the generator, how it will droop.

If you load it, how its actually the power will come down. So and note down, it will generate this much of frequency once you have loaded to the P1, it will generate 50 Hertz. If you go to the P2, it will generate 49.5 Hertz, something like that it will continue.

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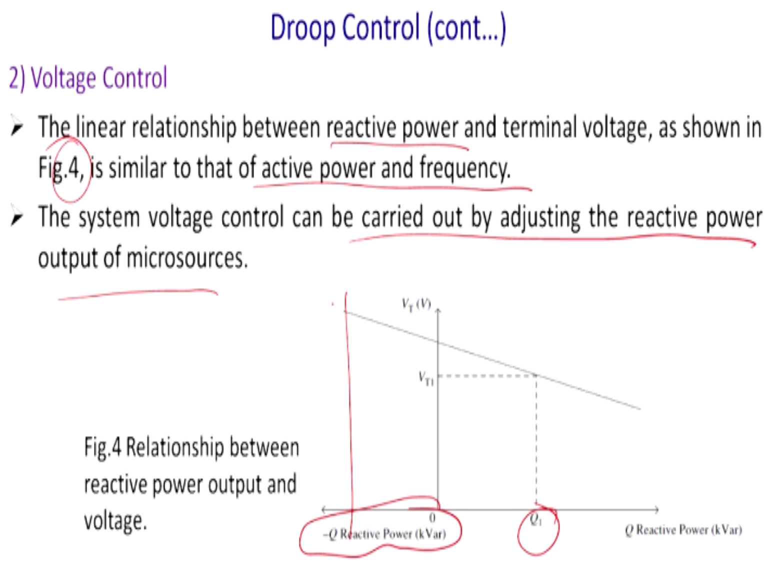

Same strategy can be applied for the voltage control, mainly this has been used for the DC microgrid. The linear relationship between the reactive power and the terminal voltage shown in figure 4, so you can see that Q will, negative Q also try to increase the voltage similar to that of the active power with the frequency. So, thus voltage can be maintained by actively controlling the VQ, but then you will sacrifice the power quality, that is for power you will have a problem little bit with your power factor.

The system voltage control can be carried out by adjusting the reactive power reactive power output microresources. So this is the reactive power, it is minus and thus you can have, when you achieve the reactive power, this will be the terminal voltage and it is a lying reactive power, and once you load it, voltage will come down, and again if you can inject minus VQ, then you can also soil up the voltage, that is also possible.

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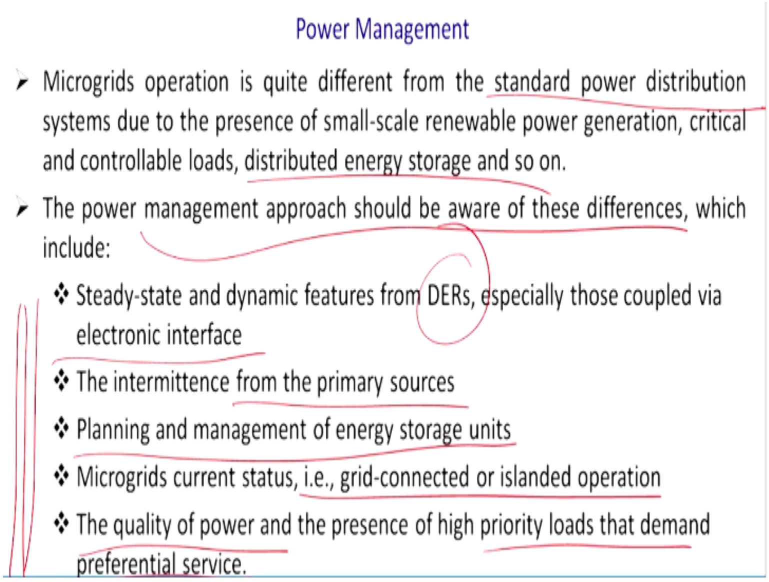

So the microgrid operation is quite different from the standard power distribution system due to presence of the small-scale renewable power generation, that is one of the basic understandable, loads are not features only their source also, critical and the controllable loads, distributed energy storage, and the so on; there are many variant, many entities. So power management approach should be aware of this differences which include, these are the following.

The steady-state and the dynamic features of the distributed energy resources, these are the energy storage and the distributed generators, especially those coupled via electronic interface, by electronic interfaces, intermittence from primary sources, planning and management of the energy storage units, microgrid current status, that means the grid-connected or islanded operations, the quality of power and presence of high-priority loads that demands that demands the preferential service that can be a critical load or any other entities.

So these are the few aspects you know we required to consider for the power management. For examples if it is an hospital, operation theater will be consider the critical load, you cannot have a load shedding there. So based on that, you have different kind of consideration while go for the power management.

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Droop Control

1) Active Power Control

- In a microgrid, the load keeps changing all the time, so the generators will change their power output based on the frequency deviation.
- The relationship between active power output and frequency can be described by the following equation and Fig.3.

$$\Delta P = P_2 - P_1 = S_p(f_1 - f_2)$$

where ΔP is power output change of the generator, S_p is reciprocal of slope of curve, kW/Hz or MW/Hz, which is determined by characteristic of each DG.

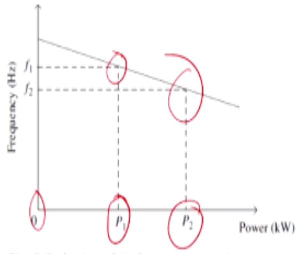

Fig.3 Relationship between active power output and frequency.

So as microgrid design to be an autonomous system, the operation is supported by the power energy management system and some smart features are expected to be present, that is the active load control mainly. The power and the energy management system is responsible for managing different DER that is distributed energy res resources and the storage element called DES are connected to the grid.

Accessing and monitoring microgrid frequencies and nodal voltages as far as other power qualities indices, THD, power factor these are the entities that has to be monitored and maintained. Planning and operation of the microgrid in standalone, when actually it is cut off from the grid and the emergency condition, you may have a cut off due to some issues like thunderstorm, your grid connection is off, you can still can feed your critical load. Planning and operating microgrid in standalone in the emergency condition.

Deciding the moment to connect and disconnect microgrid, when you find that there is an excess of power, you should be able to connect it; when you have when you can self-sufficient, no point of connecting the grid, you can run it offline mode and microgrid from the main grid. Considering operation optimization by internal and the external data, that is something also very important. So we have to see that how much generation is there, an external data may be what is the tariff that this power company, utility company is giving to you.

So we have to consider the operation optimization based on internal and external data. Internal load, internal generations, there are external tariff, and all those consideration will come into the picture while forecasting. Improving dynamic response because you have a fast-acting power electronic devices, maintaining stability and the nominal values for state variables, so that is something you should consider in a power management and current.

There are so many these state variables generally are the current through the inductor that is which you have sent, so voltage across the capacitor that should be readily available for the control. These are the few topic, few issues to be considered, and you know what actually we require to revisit is that this there are 3 aspects while our control, this is for the U/f control or the V/f control, mainly it is used in islanding mode. You have a PQ control, mainly it is used in a grid-connected mode.

These are mainly the choice. Another topic is the droop control where you have a real power control and thus you control over the frequency and you have reactive power control, thus you have a control over the output voltage sometime, and you can see that how reactive power changes the output voltage and accordingly you can change the injecting the reactive power and change the reactive voltages, and thereafter based on these 3 control strategy, you have to design your power management control accordingly.

So this is the something we require to keep in mind. We will apply PQ control, you may apply aha V/f control, you may apply droop control; and these are all for the hybrid microgrid or AC-DC microgrid, and generally group control alone can be applicable while voltage for the DC voltages in case of the DC microgrid. Thank you for your attention. We shall continue through our discussions on the DC Microgrid.