DC Microgrid and Control System
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Lecture - 21
Microgrid Control Architectures (Continued)

Welcome to our lectures on the DC Microgrid and the Control System. Today we shall continue with our microgrid control architectures.

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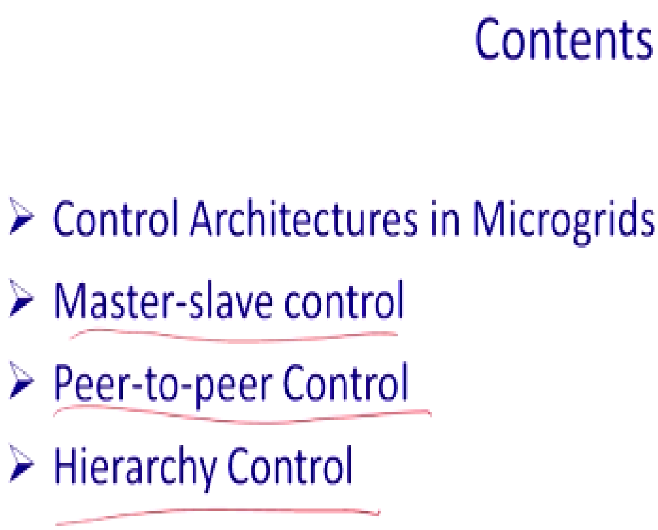

Our presentation layout today will be as follows. So that is control architectures in microgrids, then we shall take one special kind of control technique that is called master-slave control, and thereafter we shall discuss about peer-to-peer control as well as the hierarchical control or hierarchy control.

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Control Architectures in Microgrids

- Compared with a conventional power grid, microgrid has two different modes, grid-connected mode and islanded mode.
- The microgrid should be able to operate reliably in both modes.
- Depending on the roles of distributed generation in the microgrid, the control architectures can be either
  - Master-slave control,
  - Peer-to-peer control or
  - Hierarchical control.

So let us go to first the different kind of control architectures of the microgrid. So there is a basic difference between the control architecture of the basic grid, that is a conventional grid and the microgrid. Compared with the conventional microgrid, conventional grid, microgrid has 2 different mode, that is grid-connected mode and islanding mode, we have seen in yesterday's class.

So microgrid should be able to operate reliably in the both the modes, that is the one on the intentions of the microgrids, and depending on the role of the distributed generations in the microgrid, the control architectures can be either of this 3. So these are master-slave control where one will be the pilot inverter or the pilot source and other will try to synchronize with that, other we will have a peer-to-peer control, that is all will have some kind of flexibility, no one is given a greater priority, all will act with a synchronization with each other.

Thereafter we will have a hierarchical control, one will be given more importance than other, there will be hierarchies, so it is called hierarchical control.

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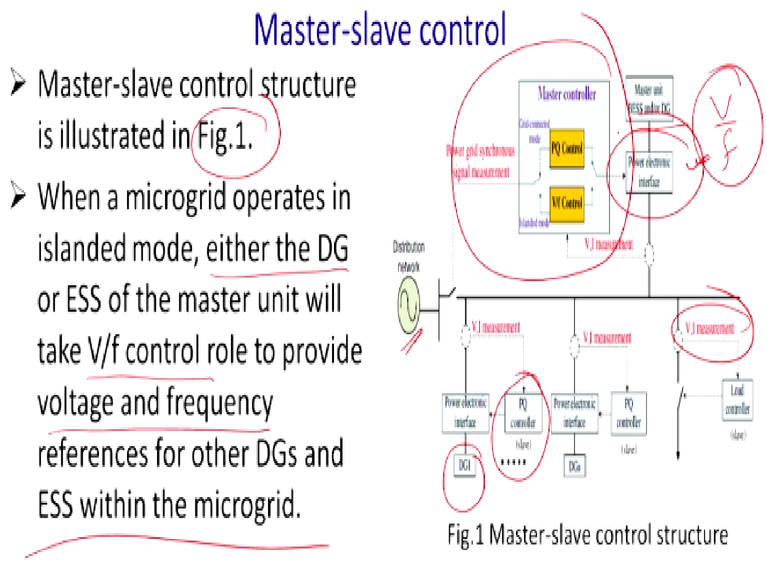

Fig.1 Master-slave control structure

Now let us understand first the master-slave control and it is illustrated in the figure 1. So you have a main grid that is a distributed network and here what happened you have a master controller. This master controller essentially can be of the 2 kind. If it is in a grid-connected mode, then it will go for the PQ control mostly, but there can be some exceptions; and if it is in the islanding mode, it will go for the it will it will go for the V/f control mode and it will have a master unit battery and the distributed generations.

Thereafter, you will have a power electronics interface and this power electric, from this power electronics interface, it will take inputs of the voltage and current and accordingly it will take decisions. So, this is the main part of it and these are auxiliary control or the slave control. You will have VI measurement and the power electronics in for interface of DG1 and so on and it will follow this master controller in toto, that is in a PQ controlling mode.

This we also have another generating unit or the or the energy storage unit so and also you can have a load with a controller with a load shedding scheme and thus also you have a provision of the measurement of the VMI. So thus what we can say when a microgrid operates in an islanding mode, either that DG or ESS of the master unit will take V/f control because flux remains constant at that case, road to provide the voltage and the frequency reference for other DGs and other ESS within the microgrid.

So ultimately, it will decide whatever V/f ratio has to be fixed and all those entities will follow it. So that is called the master-slave control and it is in the upgrade mode or islanding mode, it will go for the V/f control.

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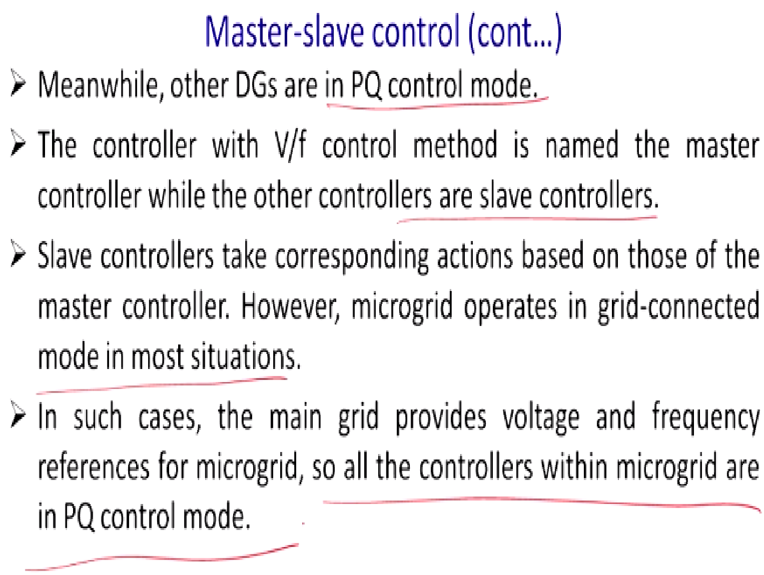

Meanwhile, the other DGs are in PQ control mode. So they will actually inject power and control them since its main is V/f, other will maintain the require reactive power and the real power in the system as desired by the V/f. The controller with V/f control method is named the master controller while the other controllers are the slave controllers. So only the master controller will work and set the frequency and the voltage of the bus, other will follow and maintain the PQ control to maintain those entities.

Slave control take the corresponding action based on this master controller. However, microgrid operates in grid-connected mode in most of the situation. So generally when you have a grid disturbance or nonavailability of grid, then only it becomes a microgrid and isolates itself in islanding mode. When grid is healthy, mostly it is the desirable and advisable to connect with the grid so that you can dispatch extra power which you have and generally what happens always you have a mismatch between the demand and supply and you will be utilizing your storage element for that purpose.

It is better to advisable that unless you use the storage element, and for this reason, it is also advisable to connect with the grid. So in that case when it is connected with the grid, in such cases, the main grid provides the voltage and frequency and thus your master controller will have to operate in the PQ mode, frequency reference of the microgrid, so all the controller within the microgrid will be in a PQ control mode. So, this is the basic difference in case of the islanding and the grid-connected mode.

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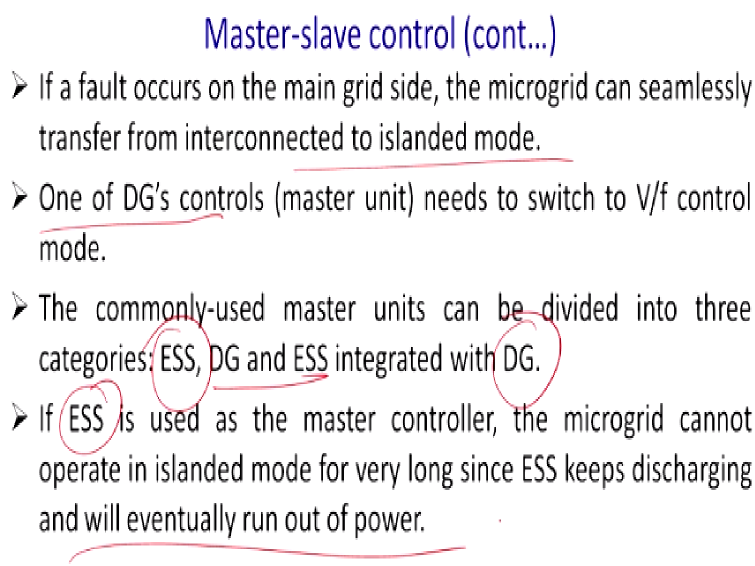

Now if a fault occur in the main grid side, the microgrid can seamlessly transform its interconnected to the islanding mode and it will change itself, that is all it is there and nonavailability of grid or any disturbances, so it will change over to this upgrade mode. One of the DG's control that is the master unit must switch into the V/f mode and that is predetermined. The commonly used master unit can be divided into the 3 categories.

It can be the energy storage element, battery bank, DG's and ESS integrated with the DG, mostly solar and battery bank sometime because solar may not be available at the night, so for this reason, this confrontation is preferred and also it may be so happen if you have an energy storage element if somehow the battery life time is actually battery life time was less or something like that, then also this mode is not suitable for this is in combination of the DG and ESS is chosen for the master controller.

If that is what I am writing here, ESS is used as a master controller. The microgrid cannot operate in islanding for a very long time since ESS keep discharging and while eventually, it will go out of power and unless you have the excess DG generation to support you.

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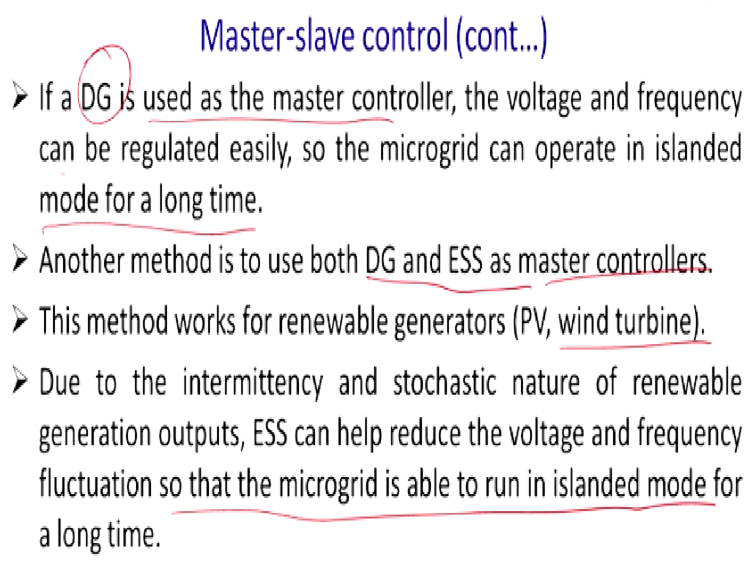

If DG, distributed generation, is used in the master controller, the voltage frequency can be regulated easily, so microgrid can operate in the islanding mode for long time, but there is only one catch, the availability of this DG power. So if it is solar, all of a sudden you got a cloudy day and your DG will not generate an output, then there is a very big problem there and if you set it as a in a PQ control in a as a master controller, and for this reason, you know this method many researchers are preferring is to both DG and ESS as a master controller.

This method works for the renewable generator, for example PV, solar photovoltaic, and the wind turbine. Due to the intermittency and the stochastic natures of the renewable generation output, ESS can help to reduce the voltage and the frequency fluctuations so that the microgrid is able to run in islanding mode for long time, so that is the desirable features and many microgrid follows and adopted that aspect.

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Master-slave control (cont...)

- If the energy capacity of the ESS is large enough, it can act as a master unit (V/f mode) to offer the specified voltage and frequency support for the islanded microgrid and adjust the power output to bring the frequency and voltage back to the scheduled values.
- If the energy capacity of ESS is small and limited, it can be integrated into the DC-link of a certain renewable power source as a combined master unit (V/f control mode) to provide the desired voltage and frequency support for an islanded microgrid.
- In this case a coordinated V/f and P/Q control strategy is required to realize the frequency regulation of the islanded microgrid.

Now if the energy capacity of ESS is large enough, but that comes with the cost, please keep in mind, it can set as a master unit or V/f mode to offer the specified voltage and the frequency support for the islanding microgrid and adjust the power output to bring the frequency and voltage back to the scheduled values, so that is something you have to keep in mind if you want to make your storage element as masters, capacity of the storage element will be quite big if the energy capacity of ESS is small and limited.

So generally this will be there as a practical problem and it can be integrated with the DC-link of a certain renewable sources such as the combined master unit of V/f control to provide the desired voltage and the frequency support for an islanding mode, so that is the combinations of the DG and the ESS. In this case, the coordinated V/f and the PQ control strategy is required to realize the frequency regulations of the microgrid. Then maybe this one is running in a v V/f control, but the DG may be running in a PQ strategy, that is also possible.

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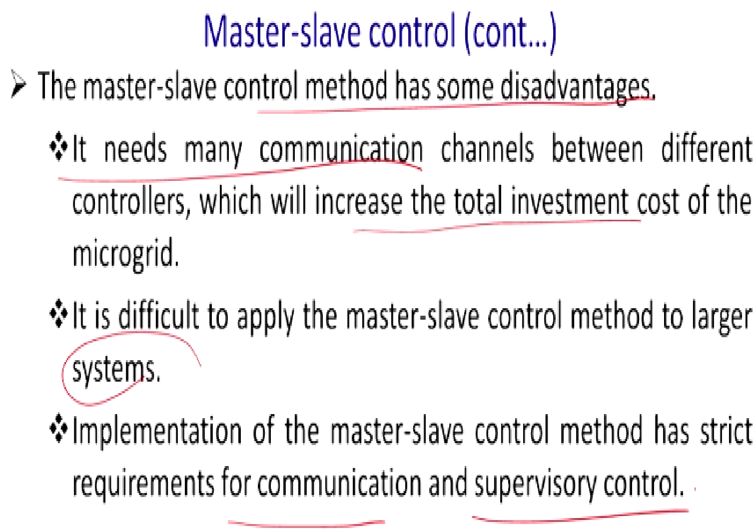

So now let us come across the advantage and disadvantage of the master-slave. The master-slave control method has some disadvantages. One aspect is that it should communicate individual DG's and ESS and thus you require a faster communication channel. So what does it say that it needs many communication channel as well as it required to be fast. Channels between the different controller which will increase the cost of total that is called CAPEX, increase the total cost of the microgrid, that communication has to be proper and it has to be communicated with all those subsidiaries.

It is difficult to apply master-slave control method to the large system because one-to-many connection will be there. Implementation of the master-slave control method has strict requirement for the communication and the supervisory control, so that is something we require to invest and not only power electronics, communication engineers and the communication aspects takes a big part of it.

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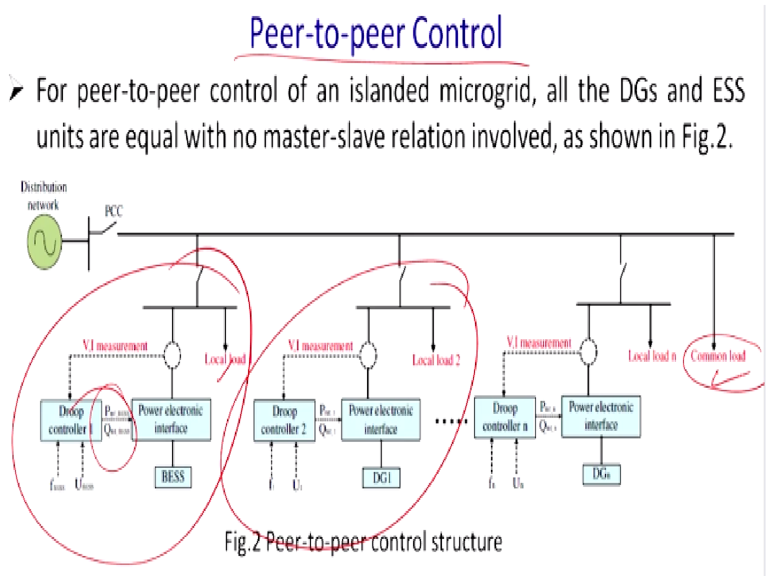

Now let us talk about the peer-to-peer control, so all are equally weighted. So what happen, we split it out microgrid into some nanogrids here and individual all have a control. So whenever there is islanding mode, so you have a local load and generally you have a group controller and that will actually talk with the power electronics interface and thus you may have a PQ control and you may have an energy storage and will feed the local load. Same for here, there is another micro nanogrid.

So it will talk with each other and ultimately will form another small nanogrid and there can be a common load, so it has to be connected whosoever this microgrid will have a power surplus will feed the common load. So individual control and feeding of the local load is a headache of the local control and only to meet the demand of the common load, they have to talk with each other and understand that what kind of power situation they are having and only the mic among this microgrid which has got a surplus power that will feed that common load, that is the way of walking on it.

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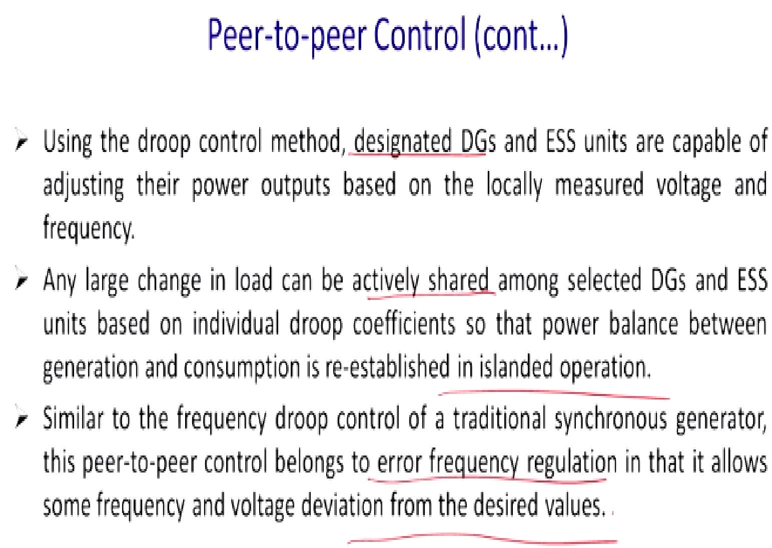

So we it uses very simple technique that is droop control method. Using the droop control method, designated DG's and ESS are capable of adjusting their power output based on the locally measured voltage and the frequency. So, you need not have to have a centralized control over the whole microgrid, individual portion of the microgrid can have a different voltage and the frequency, that flexibility it can have.

Any large change in the load can be actively shared among the selected DG's an ESS unit based on the individual droop coefficient, so that power balance between the generation and the consumptions is re-established in islanding operation. Similar to the frequency droop control, a traditional synchronous generator, this peer-to-peer control belongs to the error frequency regulations in case of the DC microgrid only voltage in that it allows the some frequency and the voltage deviations from the desired level and this concept also can be applied it to the DC microgrid.

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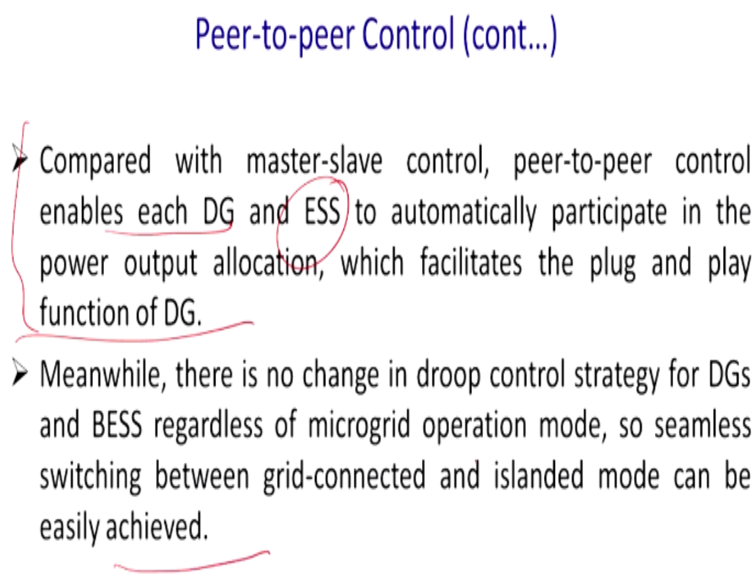

Now what happen compared with the master-slave control, peer-to-peer control enables each DGs, distributed generations, and ESS to automatically participate in the power output allocations which facilitate the plug-and-play function of the DG, that is one of the major advantages of the peer-to-peer connections. It allows plug-and-play type devices, so you can add on, and you can get rid of any load at your wish and without having much problem in overall microgrid and that aspect is generally missing when you have a master control.

So master control has to accept that communications and we got to have a processing whole unit and thus what happens it will take time to establish control and monitor. Meanwhile, there is no change in droop control strategy for distributed generation and the energy storage that is BESS regardless of the microgrid operation mode. So depending on the whether it is in an islanding mode or it is a on grid, it does not matter, droop control will walk according to the local frequency.

So simpler switching between grid-connecting and islanding mode can be easily achieved here and that is actually less complex because whenever there is a changeover, off grid to on grid, so you have to change the mode of operation of the master controller. Here, there is no requirement since it works with the droop control method, it will continue to work in a droop control method.

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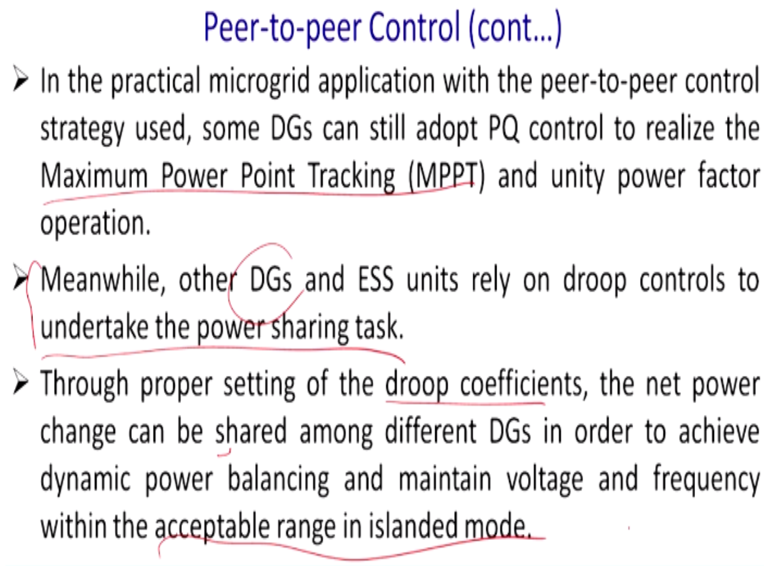

In practical microgrid applications with peer-to-peer control strategy mostly is used and preferred and some DG can still adopt PQ control to realize the maximum power point tracking and unity power factor operation, others for this other requirement, so it can go for it, other can go for the peer-to-peer control. Meanwhile, the DGs and ESS unit rely on the droop control to undertake the power sharing task.

So which will sync the power, which will take the power, that aspect like what you have seen in case of the parallel operation of the alternator in your basic electrical studies, same thing will be done by the droop control and is not only the AC microgrid, it is also for the DC microgrid, instead of a frequency and voltage, you will have the voltage only DC voltage, the proper setting of the droop coefficients through proper setting of the droop coefficient.

The net power can be shared among the different DGs in order to achieve the dynamic power balancing and maintain the voltage and the frequency within the acceptable range in the islanding mode. This is one of the another flexibility of this peer-to-peer control. So you have a droop control and thus you can actively share the different kind of load and you can vary this voltage and frequency within a limit and thus you have an acceptable range of operations within that, same features can be extended to the DC micro grid also.

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Peer-to-peer Control (cont...)

- The controllers in peer-to-peer control architectures can make decisions using local information, which can save a lot of money during establishing communication system and also minimize the system complexity.
- In addition the control method can fulfill the requirements for seamless transition between grid-connected and isolated modes.
- Peer to peer control can be applied easily for plug-and-play network.

The controller in the peer-to-peer control architecture can make decision using local information. So that is like taking information from the horse's mouth. So you are not sending the data, maybe the kilometers apart and that is what happened which can save lot of money during the establish establishing the communication system and also minimizing the system complexity because it will talk in a local loop.

In addition to the control method can we fulfill the requirement for seamless transmissions between grid-connected and the isolated mode and thus changeover is quite faster and easier and simplest. For this reason, we say that peer-to-peer control can be applied easily for any plug-and-play network, that is one of the major advantage of peer-to-peer network.

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Hierarchy Control

- In hierarchical control, a central controller is implemented to send control signals to each DG, ESS unit and controllable loads. A two-layer control structure is illustrated in Fig.3.

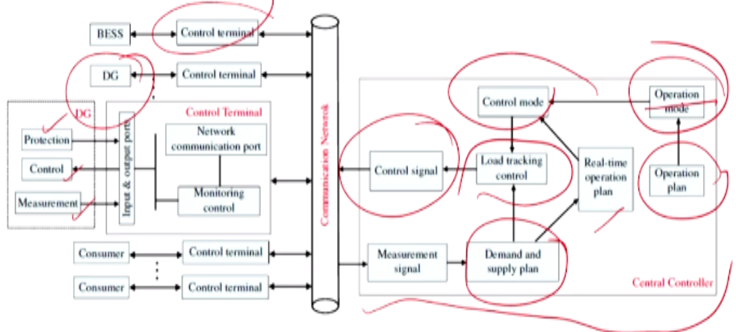

Fig.3: Typical two-layer structure

Now let us talk about another method that is called the hierarchical control. The hierarchical control, a central controller is implemented to use and send the control signal to the each distributor generator, electronic storage unit, and controllable load. The two layer structures illustrated, that is BESS, control element, DG control terminal, now you have distributed generations, protection control measurement, input and the outputs, now control terminal, network communication port, monitoring control.

Thereafter you have consumers, now you have a control signal, this is the brain of the hierarchical control. Now you have measured this all the signals, demand and demand and the supply plan, you see that what you get from the sources and what is a demand of the load at the time. Now there is a load tracking control, that means that it will actually say that how much load to be fed, then there is a real-time operation plan, and then you have operation plan in general that has been prefixed, so you define the operation mode from that point of time.

Then you got a control mode and but it can have it can overwrite by the real-time operation plan, say you have a data forecasting that some amount of irradiation will be there that time and thus this will be the generation forecasting, but and accordingly you have been chosen the operation mode, where all of a sudden you found that actually you had a problem with a grid and you require to go for the offline mode and that is that real-time operation plan, so you have to change the plan. This is the hierarchical control.

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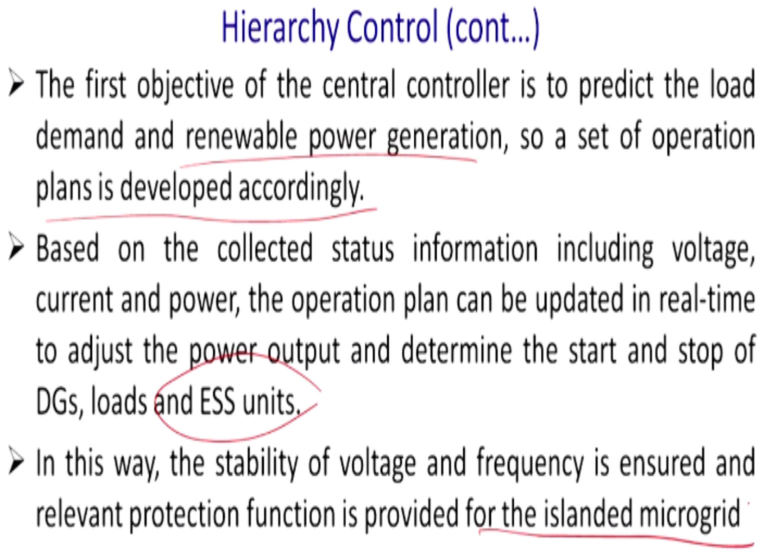

So let us understand that how does it work. The first objective of the central controller is to predict the load demand and the renewable power generation, so a set of operation plans is divided accordingly. Based on the collected status information including the voltage, current, and the power, the operation plan can be operated in real-time to adjust the power output and determine the start and the stop of DGs and the loads and the ESS units.

So all those things has to be count, you know the state of charge of the ISS units, thereafter how much local generation is there and what is the forecasting, all those issues has to be captured her. In this way, the stability and the voltage in the frequency, and in case of the DC microgrid it is the voltage, is ensured and relevant protections is provided for the islanding mode.

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Hierarchy Control (cont...)

- In hierarchical control scheme, physical communication channels are required for mutual communication between DGs and top-level controller.
- If one channel fails to work, the entire microgrid fails to operate normally.
- Another type of hierarchical two-layer control structure is shown in Fig.4.

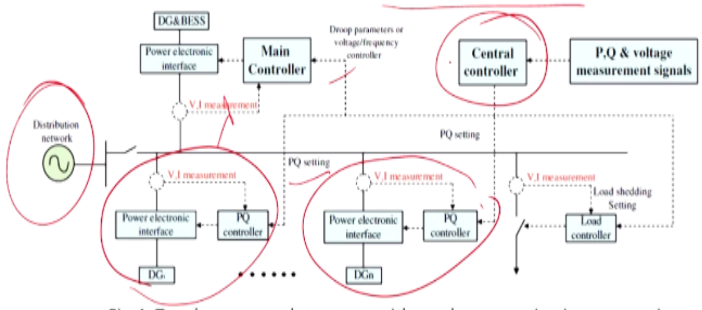

Fig.4: Two-layer control structure with weak communication connection

So let us see this figure 4. So this is your main grid and you have a main controller and main controllers will work with the DG and BSS and power electronic interference VS Department. Thereafter, it will sense the signal to this local load and the sources. Same way, you have another central controller that will actually give you the measurement of the PQ and the voltage measurement and that will set to control another set in a PQ setting and another microgrid that maybe consisting of the loads and the A, so it will go for the load shedding scheme.

So it has a different kind of hierarchy, so this will have a main control, ultimately to have a PQ control that will be desired. Here you will have a load shedding scheme. So, you can split it like that, so not all this mi nanogrid will be given a same kind of task, you will be differentiate the task. So, hierarchical control is one way, one of the way of this master-slave control, but we apply a different kind of control to the different microgrid.

In in hierarchical control scheme, the physical communication channels are required for mutual communication between the DGs and the top-level controller. So, it is not the communication channels are missing, so that is what I was saying. This is all one of the way one of the way to the master-slave controller, but there is a little difference in between. If one channel fails to work, the entire microgrid fails to operate normally, that is one of the vulnerability of this kind of hierarchical microgrid. Main channel fails, everything will go down, shut down.

Another type of the hierarchical structures are two-layer control structure that is generally preferred and that gives a redundancy and the flexibility, so that is that is shown in the figure. This is the main controller and there is another central controller. So, some will be given a task to PQ control and other issues, some will be given the load sharing scheme, and they will talk with each other definitely some time, but task is segregated and you if one channel fails, still you fails, still you can operate this microgrid and still you persist to keep operating.

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Hierarchy Control (cont...)

- In this control structure, only weak communication is needed to coordinate the central controller with local controllers of DGs.
- In this method, transient power demand-supply balance can be achieved by low-level controllers of DGs, and the top-level central controllers are capable of modifying the steady-state operating points of low-level DGs and managing the load based on the variation in both DG outputs and load demands.
- Even if communication fails for a short while, microgrid can still maintain normal operation during the period of fault.

In this control structure, weak communication is needed, so you do not have to take a very fast bandwidth communications to coordinate the central controller with the local controller of the DGs. In this method, transient power demand-supply balance can be achieved by the 2-evel controllers, these are distributed generations and the top-level center controller are acceptable of modifying the steady-state operating point of the 2-level distributed generations and managing the load based on the variations in both distributed generator output and the load demand.

Even if the communication fails, if data is lost for the short time, that doesn't have any problem. So fails for the short time, the microgrid still maintain the normal operation during the fallout time period.

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Hierarchy Control (cont…)

- Fig.5 shows a three-layer type of control structure. The top-level operation and management system of the distribution grid (OMDG) is responsible for monitoring the real-time operation status of the microgrid group, which consists of multiple microgrids.

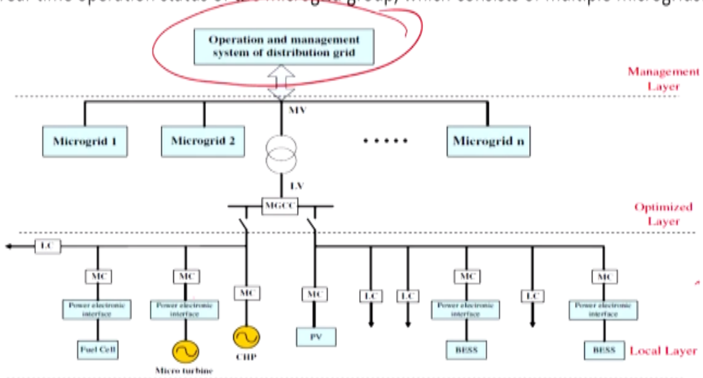

Fig.5 Three-layer control structure

So, this is the hierarchal control. Figure 5 show shows the same. This is a management layer operation and the system distribution grid that depends that is that works mainly on the predicted datas and accordingly you set the mode, thereafter you had a micro different kind of microgrid, thereafter you got a low voltage side and the and in between you got a one microcontroller, one this controller, so there are so many controller, with that there is a local layer, and this layer is optimized layer and accordingly you can switch on a different mode and will decide which layer to be considered.

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Hierarchy Control (cont…)

- The middle-level µGCC is in charge of monitoring the operation status such as the key node's voltage and frequency of each microgrid in the islanded mode, power flow through each branch, current output and power reserve margins of each DG and ESS, load condition and so on.
- In addition, the µGCC can optimize the economic operation of each individual microgrid and provide ancillary services through the proper regulation of the ESS and DGs, including load following, operational reserve as well as frequency regulation and voltage control

So based on these discussions what we can say that the middle level microgrids in charge of the monitor and operation of such status as key to the node voltage or frequency of each microgrid in the islanding mode, power flow through the each branch of the current output and the power reverses the margin of the each DGs and the coordination between the load and so on, this has been done by the middle level.

In addition, this kind of microgrid can optimize the economic operation of each individual microgrid and provide ancillary service through the proper regulation of the ESS and DGs including the load flowing, operational reserve as well as the frequency regulations and the voltage control.

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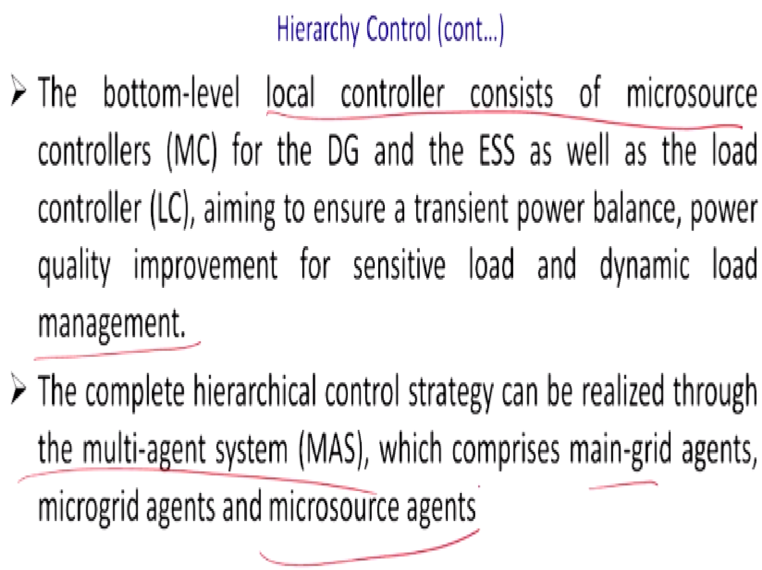

Moreover, the bottom-level, the local control consists of the microsource controller for the DGs and ESS as well as the load controller LC, aiming to ensure that transient power balance if there is any sudden (( )) (30:50) of the power, so that will ensure that transient power balance and it improves the power quality problem and the dynamic load management. The complete hierarchical control strategy can be realized through the multi-agent system which in abbreviation we said is MAS, which comprises of the main grid agents, microgrid agents, and the microsource agents.

Thank you. Thank you for your attention. We will continue our discussions with a different hierarchical topology of the microgrid in next classes.