Introduction to Smart Grid
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Lecture – 30
Operation and Control of AC-DC Hybrid Microgrid- II

Welcome to NPTEL online course on smart grid and we are continuing with the Operation and Control of AC - DC Hybrid Microgrid. In our previous lecture we have understood different type of operations merits of AC smart grid and the merits of DC smart grid as well as their limitations because of different type of sources in both and AC DC operation, as well as the loads which are commonly are of both AC and DC type.

And to avoid multiple conversions from DC AC DC as well as AC DC AC type we have created 2 different structures of operating AC DC microgrid in one structure the AC grid had both loads and generations are both AC DC loads. In case of DC grid 2 we had AC DC generations as well as AC DC loads and in case of structure 2 we forced all the DC sources and DC loads need to be connected to my DC grid whereas, all the AC loads and AC generations need to be connected to my AC grid.

So, that the multiple conversions from AC DC AC as well as DC AC DC will be minimized and after learning both the structures we understood the control schemes how the you know in a AC DC smart grid, they can complement to the main grid in both dispatch 10 and dispatched operations where in one case we expect our gen generators available to my micro grid or smart grid can vary it generations and inject different magnitude of real and reactive power to the grid to maintain it is voltage as well as frequency regulation and the other case we simply act as like a energy provider.

So, we operate all our generators set it is MPPT and keep on injecting energy to the main grid and being said that we do come across different other devices do play a very important role in AC DC smart grid and let us now focus on those devices in case of my AC DC hybrid smart grid.

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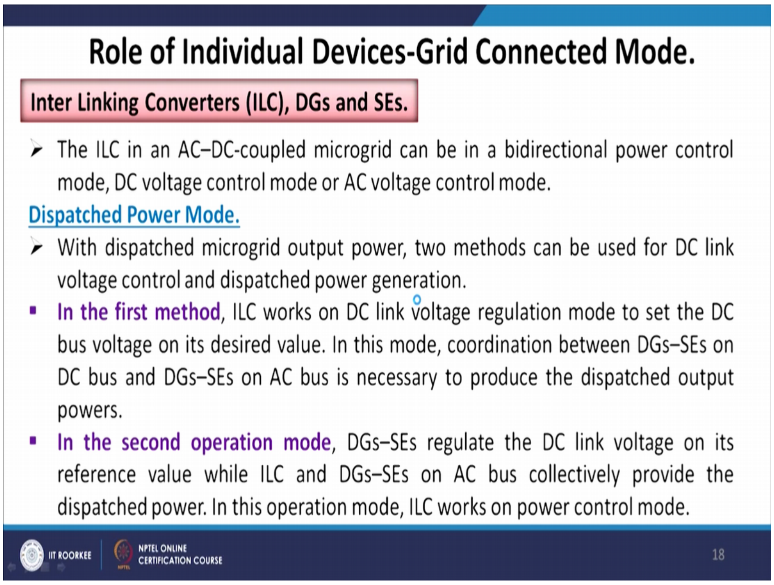

The first very important device is interlinking converters which ideally being conducted between my DC bus stand AC bus and secondly the distributed generators available in a hybrid grid as well as the storage elements. The interlinking converter in an AC DC coupled microgrid can be in a bidirectional power control mode DC voltage control mode or AC voltage control mode. So, very important the interlinking converter can act work on both AC voltage control DC voltage control as well as in power control mode.

Now, when we operated in a dispatched power mode where the system is connected to my grid and the generations need to vary as desired by the grid with dispatched micro grid output power, 2 methods can be used for DC link voltage control and dispatched power generation. In the first method inter linking converter works on a DC link voltage regulation mode to set the DC bus voltage on it is desired value in this mode coordination between distributed generators and the storage elements on DC bus and distributed generators storage elements on AC bus is necessary to produce the dispatched output power.

In the second method distributed generators storage elements regulate the DC link voltage on it is reference value while the inter linking convertor and the distributed generators and storage elements on AC bus collectively provide the dispatched power, in this operation mode the inter linking convertor operate in a power control mode.

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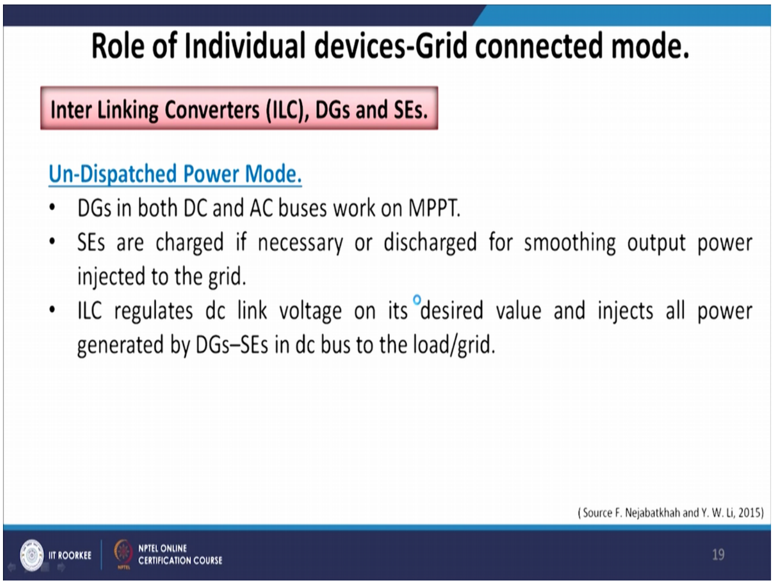

In case of un dispatched power mode distributed generators in both DC and AC bus work on it is MPPT because we are not going to encourage them to vary it is energy or power output. So, there will be allow to operate at it is MPPT mode storage elements are charged if necessary or discharged for smoothing output power injected to the grid. Inter linking convertors regulate DC link voltage on it is desired value and injects all power generated by distributed generators storage elements in DC bus to the load all the grid.

Now in case of a standalone mode means we have not been connected to the grid it is operating it is stand alone mode, DC bus voltage and AC bus voltage and frequency should be controlled simultaneously stand alone mode operation become challenge because both DC bus voltage as well as AC bus voltage and frequency should be controlled simultaneously.

Power balance should happen in both AC and DC bus means in the AC bus the source must be equal to load in case of DC bus again the DC sources or whatever the summation of sources must be equal to my load. So, the power balance for both AC bus as well as DC bus need to be maintained simultaneously.

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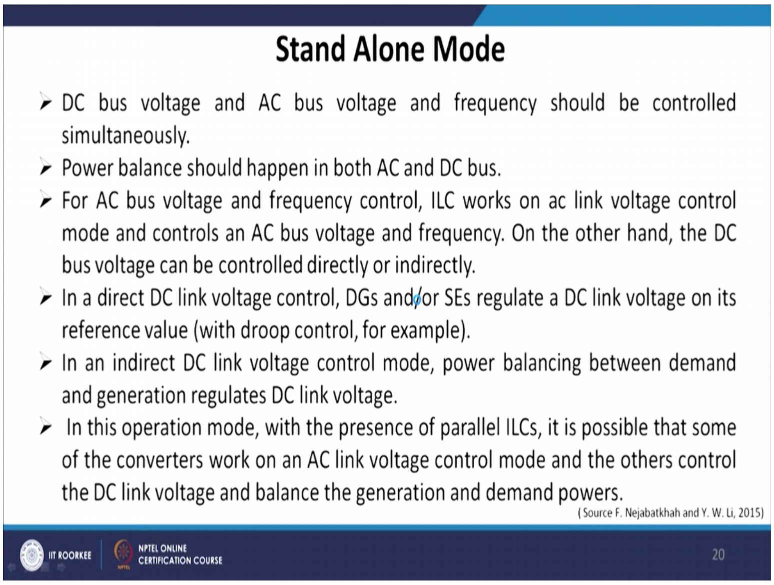

For AC bus voltage and frequency control interlinking convertor works on AC link voltage control and controls and AC volt AC bus voltage and frequency. On the other hand the DC bus voltage can be controlled directly or sometimes indirectly. In a direct DC link voltage control distributed generators and or the storage elements regulated DC link voltage on it is reference value for example, through droop control.

In an indirect DC link voltage control mode power balancing between demand and generation regulate my DC link voltage. In this operation mode with the presence of parallel inter linking converters it is possible that some of the converters work on an AC link voltage control mode and the other controls my DC link voltage to balance the generation and demand powers.

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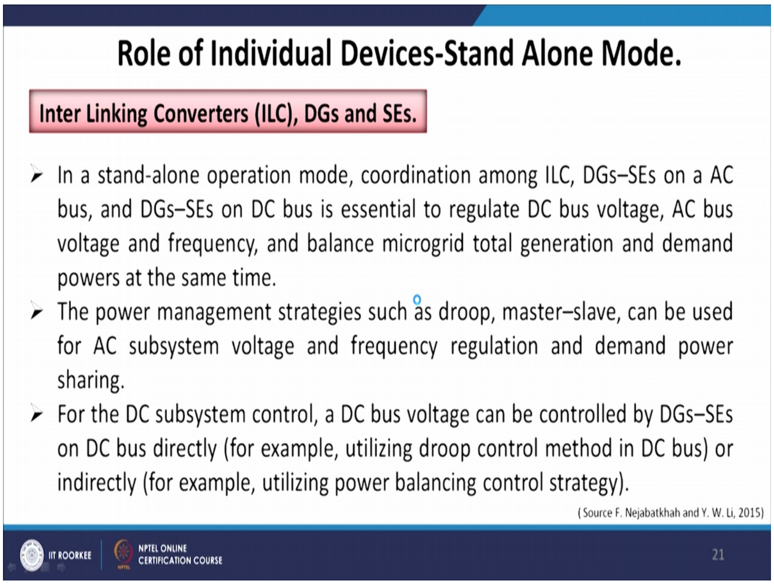

Now, during stand-alone mode of operation or islanded mode of operation how those devices interlinking converters distributed generators as well as my storage elements play an important role. Now, the in a standalone operation coordination among interlinking converters distributed generators and storage elements on an AC bus as well as the distributed generators and the storage elements in a DC bus is essential to regulate the DC bus voltage and AC bus voltage and frequency.

Interlinking capacitor, distributed generators as well as storage elements do take care of the complete DC bus voltage and AC bus voltage and frequency. Parallel they do also play an important role to balance your generations and demand at the same time. The power management strategies such as droop, master slave, can be used for AC subsystem voltage and frequency regulation and for the demand power sharing. For the DC sub system control a DC bus voltage can be controlled by distributed generation's storage elements on DC bus directly. For example utilizing droop control method in DC bus or indirectly utilizing power balance control strategy.

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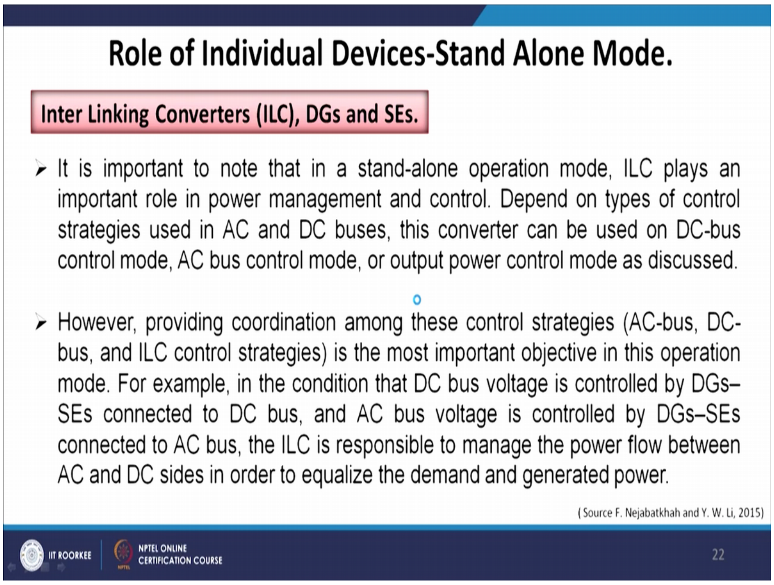

It is important to note that in a stand-alone mode of operation, inter linking convertors play an important role in power management as well as control depends on the type of control strategy used in AC and DC buses, this convertor can be used on DC bus control mode, AC bus control mode, as well as output power control mode.

However, providing coordination among this control strategies AC- bus, DC- bus and inter linking convertors control strategies is the most important objective in this operation mode for example, in the condition that DC bus voltage is controlled by distributed generators storage elements connected to DC bus and AC bus voltage is controlled by distributed generators storage elements connected to my AC bus.

The inter linking convertor is responsible to manage the power flow between AC and DC buses in order to equalize the demand and generation of the power. So, finally, the power balancing is possible through my ILC, now if you see the overall power management strategy we do have AC DC micro grid it could be either stand alone micro grid or a grid connected and in case of grid connected we have dispatched power output, un dispatched power output, in case of standalone we have DC bus control, voltage control and AC bus voltage control.

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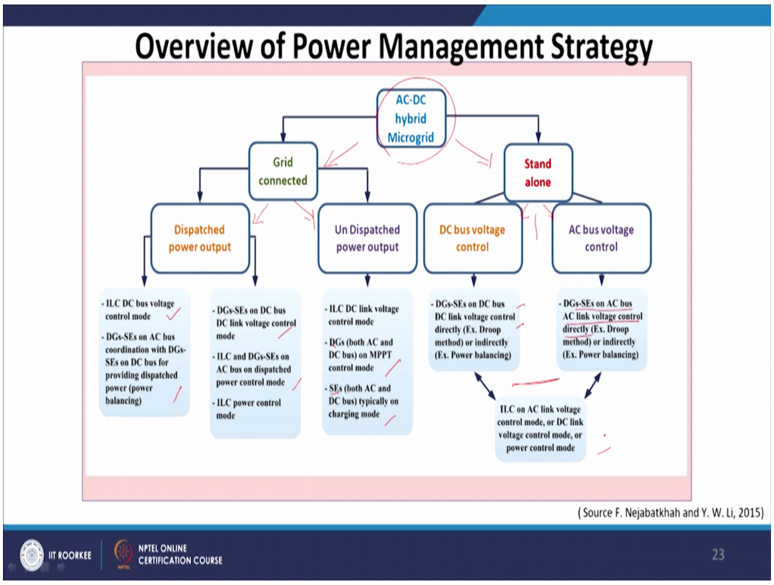

So, we can just have a quick look with the block diagram this is the key and it could be either grid connected or standalone and the grid connected either dispatched power or un-dispatched as we discussed and standalone could be DC bus voltage control or AC bus voltage control.

We can clearly see in case of dispatched either it could ILC DC bus voltage control mode, distributed generators storage elements on AC bus coordination with distributed generators storage elements on DC bus providing dispatched power balancing. So, you can operate in this mode or distributed generation storage elements on DC bus DC link voltage control mode, inter linking convertors and distributor generators and storage elements on AC bus un-dispatched power control mode.

In case of un dispatched in your inter linking convertor DC link voltage control mode, distributed generation both AC and DC bus on MPPT control mode because we do not allow them to vary much and the storage element typically on it is charging mode. Coming back to stand alone distributed generators on DC bus DC link voltage control directly, in case of AC bus voltage control distributed generation storage elements on the AC bus AC linked control directly please remember in both the cases inter linking convertors on AC link voltage control mode or DC link voltage control mode or it could be in power control mode.

So, this is the overall structure of your power management strategy for a AC DC micro grid both in grid connected as well as in islanded or isolated mode. Now, one very important situation that commonly being faced by your AC DC smart grid is the sudden variation in the loads, because the loads may come appear and vanish so, the variation in the load may lead to transient conditions power management during switching of transient operation modes.

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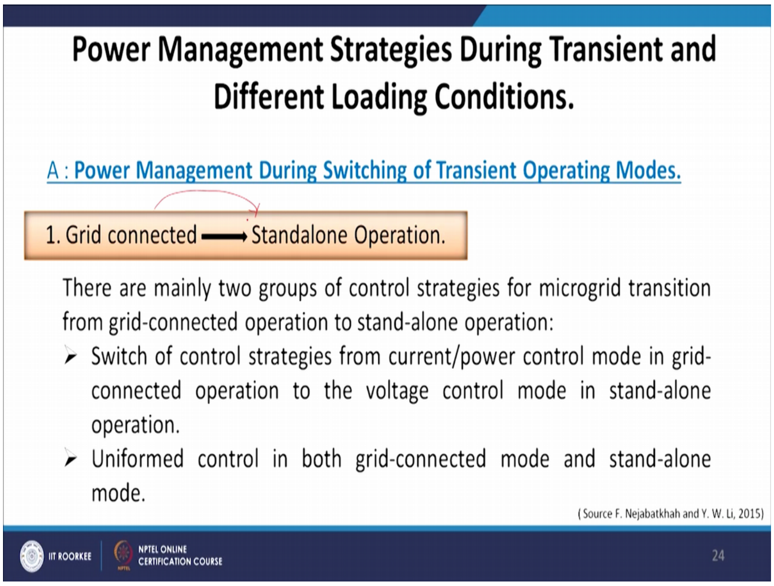

Now, imagine that we do have AC DC smart grid which is in connection with my utility grid everything goes well the control mechanism works well the load is keep on varying and it is very well managed as per the grid support mode operation if required and the voltage frequency regulation can be achieved everything goes smooth, but let us imagine due to some reason if the grid is disconnected means my AC DC smart grid is now going to operate from a grid connected mode to a standalone mode so, that is a huge shift from a grid to millenary mode.

Similarly when you come back when you like to come back to the main grid when you like to connect your AC DC microgrid after isolation to connect back to your grid also become a challenge. So, considering now we had the grid connected mode to your standalone mode of operation. How do you manage the power because switching of transient operating modes?

There are mainly 2 groups of control strategies for micro grid transition from grid connected operation to standalone operation, switch off control strategies from current or power control mode in grid connected operation to the voltage control mode in standalone operation. Uniformed control in both grid connected mode and stand alone mode so, the control strategies that we have adapted for the grid connected mode is not going to work exactly when it is islanded.

So, that is what an important issue need to be address switch off control strategies different control strategies are used in grid connected.

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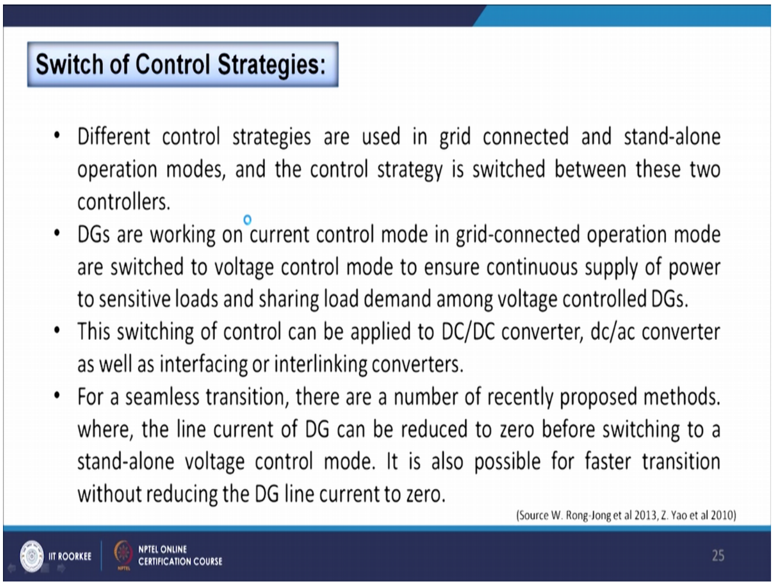

As well as in islanded mode of operation and the control strategies switched between these 2 controllers, distributed generators are working on current control mode in grid connected operation a switch to a voltage control mode, when it is islanded to ensure continuous supply of power to sensitive loads and sharing load demand among voltage controlled distributed generators.

This switching off control can be applied to DC, DC converters, DC AC converter as well as interfacing or interlinking converters. For a seamless transition from there are number of recently proposed methods where the line currents of distributed generators can be reduced to 0 before switching to a standalone voltage control mode. It is also possible for faster transition without reducing the distributed generation line current to it is 0 value.

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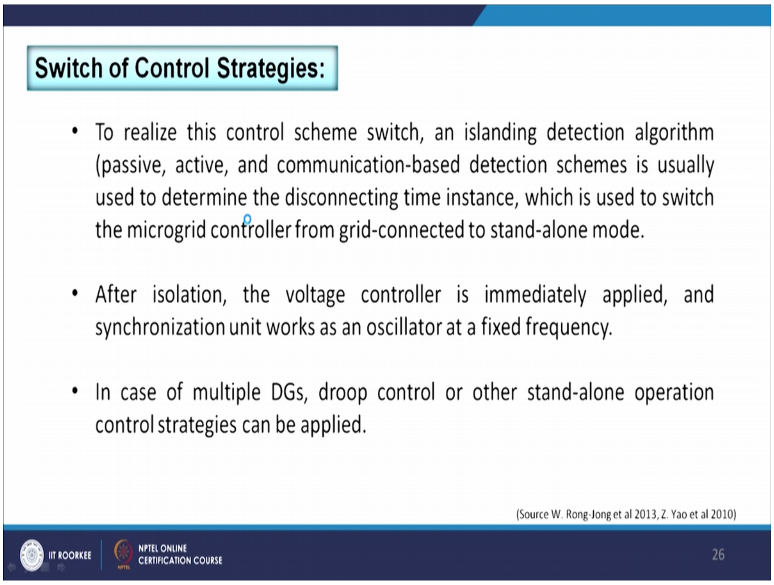

To realize this control scheme switch and islanding detection algorithm is required because you should know in priory that the system is going to get islanded. So, accordingly you can instruct your control mechanism in islanded operation. So, that detection algorithm either could be passive or active or communication based detection scheme is usually used to determine the disconnecting time instance, which is used to switch the micro grid controller from a grid connected mode to a standalone mode.

After isolation the voltage controller is immediately applied and the synchronization unit works as a an oscillator at a fixed frequency, in case of multiple distributed generators droop controller other standalone operation control strategies can also be applied.

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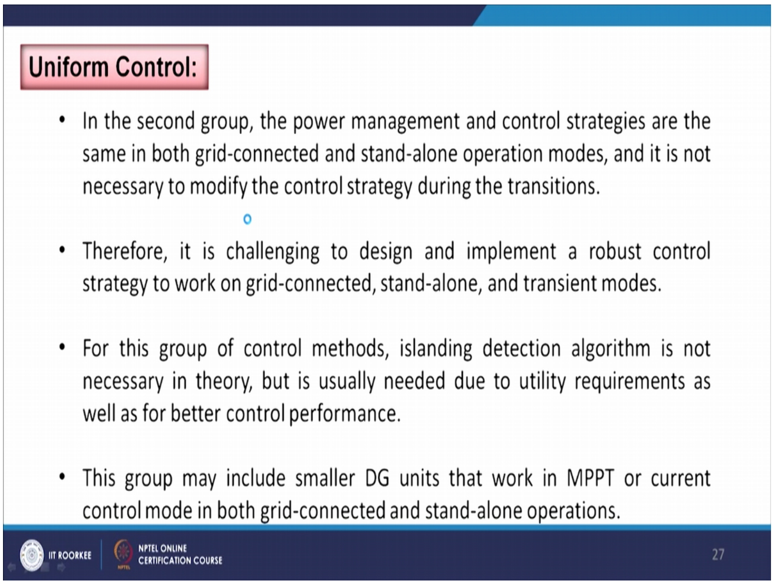

Now, in case of uniform control in the second group the power management and control strategies are the same in both grid connected as well as standalone operation mode and it is not necessary to modify any control strategy during the transition mode. It could be possible that you adopt to the same control strategy for both grid connected as well as isolated mode. So, that you need not change your control strategy trump a grid connected mode switching to isolated mode.

There for it is challenging to design and implement a robust control strategy to work on grid connected standalone and transient modes, for this group of control methods islanding detection algorithm is not necessary in theory at all, but it is usually needed due to utility requirement as well as better control performance because you need not worry much whether the system is islanded or not, but still we need to do it for better control performances.

This group may include smaller distributed generators that work in it is MPPT or current control mode in both grid connected as well as standalone operations. So, they keep on generating in MPPT mode whether it is grid connected or it even at isolated or islanded mode of operation.

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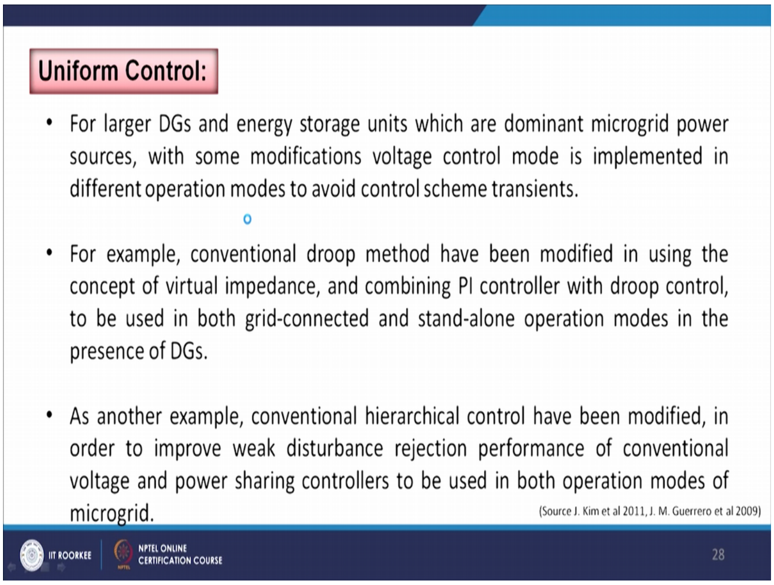

Now in case of uniform control for larger distributed generations and energy storage units, which are dominant micro grid power sources with some modification voltage control mode is implemented in different operation modes to avoid control scheme transients.

For example conventional droop method have been modified in using the concept of virtual impedance and combining PI controller with droop control, to be used in both grid connected and standalone operation modes in the presence of DG s. Uniform control is certainly an excellent way of handling your grid connected mode to islanded mode. As another example conventional hierarchical control have been modified, in order to improve weak disturbance rejection performance of conventional voltage and power sharing controllers to be used in both operation modes of micro grid.

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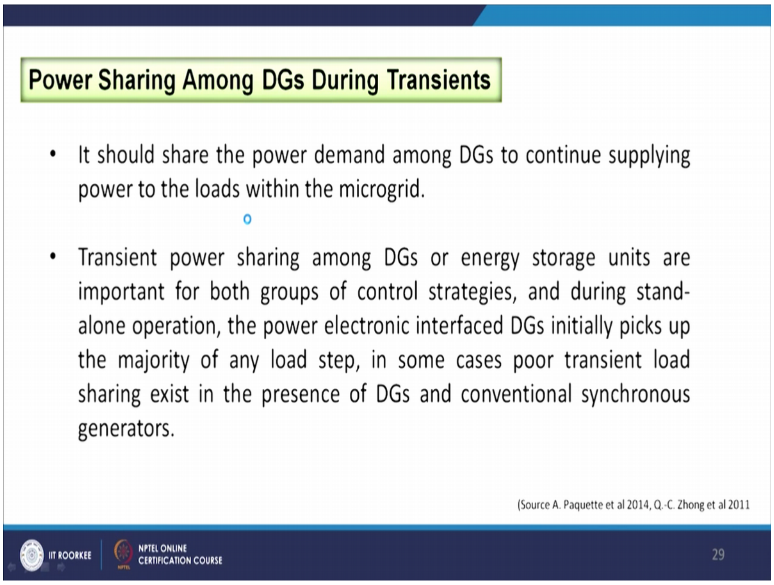

Now, how do you share your power during transient that is the biggest for example, the power sharing among the distributed generation not necessarily same when their grid connected mode and when their islanded how do you distribute their power. It should share the power demand among the distributed generations to continuous supply power to the load within the micro grid the main objective here the loads connected to your micro grid need to be protected or catered under any circumstances either their grid connected or it islanded mode of operation.

Transient power sharing among distributed generations or energy storage units are important for both groups control strategies and during standalone operation the power electronic interface distributed generators initially picks up the majority of the load step in some cases poor transient load sharing exist in the presence of distributed generators and conventional synchronous generators.

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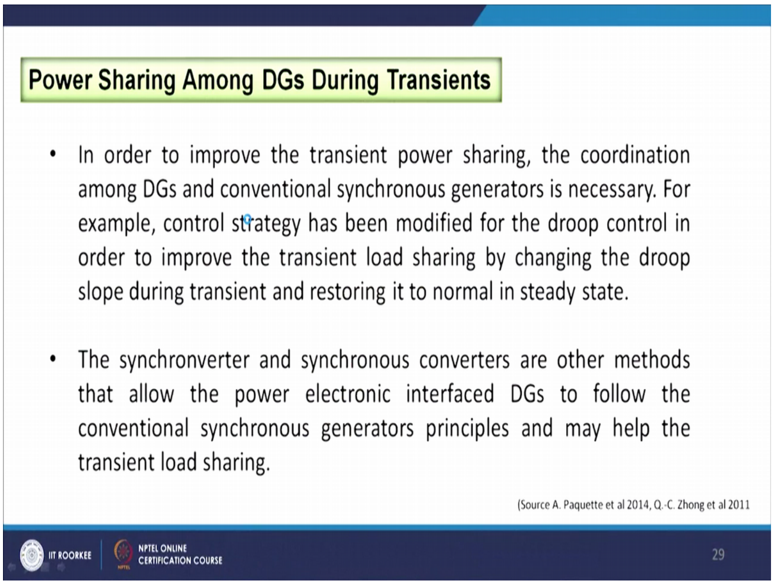

In order to improve the transient power sharing the coordination among distributed generators and conventional synchronous generator is necessary. For example control strategy has been modified to the droop control in order to improve the transient load sharing by changing the droops loop during transient and destroying it to a normal steady state value.

The synchronverter and synchronous convertors are other methods that allow the power electronic interface distributed generation to follow the conventional synchronous generator principles and may help the transient load sharing. Now the second important part is that when we like to connect your islanded AC DC smart grid to the grid how do we do it because the best practice would be that you keep on observing the voltage of the grid and once it is closure to my grid voltage then I can champion to grid connected mode from islanded mode.

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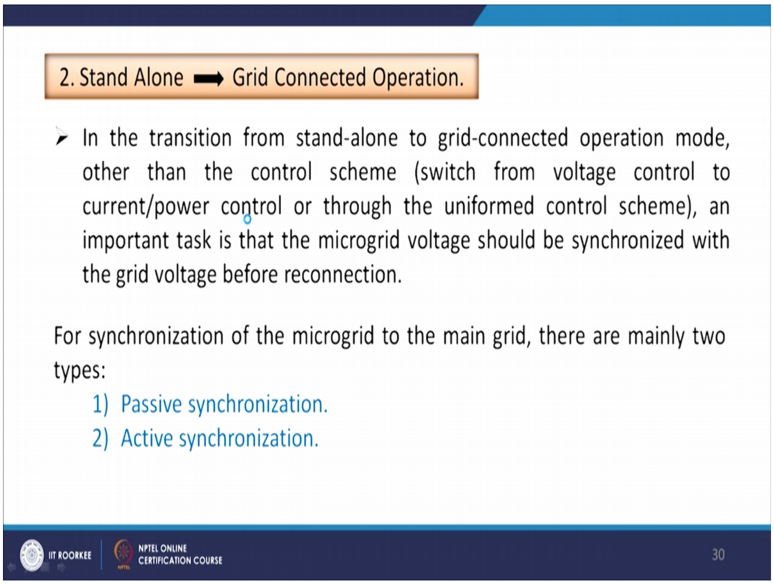

Now, in the transition from stand alone to grid connected operation mode other than the control scheme switch from voltage control to current or power control or through uniformed control schemes and important task is that micro grid voltage should be synchronized with the grid voltage before connection that is fine the control schemes which are in operation in the islanded mode of operation need to be revisited when it is con connected to my grid, but before that one of the most important part is your voltage synchronism means when you operated a islanded mode of operation so, not necessary your voltage of operation is same as the grid voltage.

So, you have to make sure there is a voltage synchronism between your grid and the main grid. So, that they can be connected to the grid my AC DC micro grid can be connected to the main grid so, that voltage synchronism become an important challenge and how do you know that both the voltages are same or close to each other. For synchronization of the micro grid to the main grid there are 2 types of synchronization, one is passive synchronization and the other one is active synchronization.

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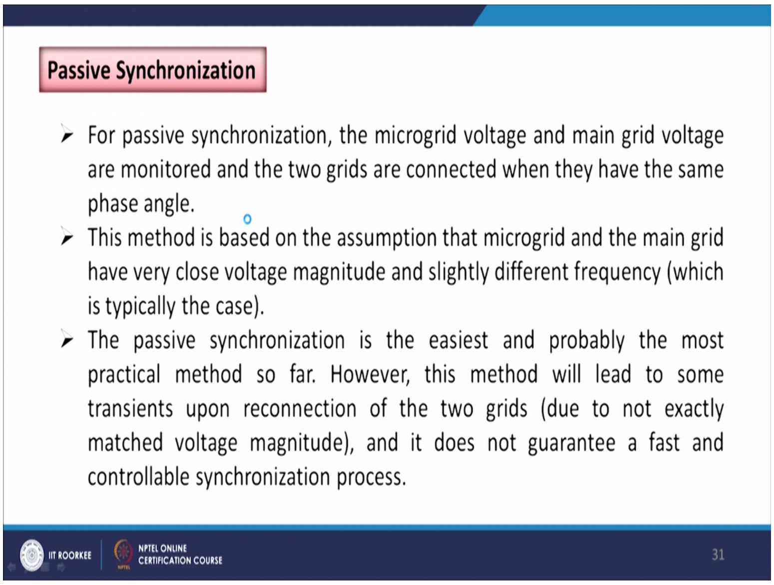

In case of passive synchronization the micro grid voltage and main grid voltage are monitored and the 2 grids are connected when they have the same phase angel. So, these 2 are monitored when they have the same phase then they are allowed to get connected in case of passive synchronization.

This method is based on the assumption that the micro grid also do operate in the same voltage level of the main grid and they are very close to each other whereas, the frequency may be slightly different. So, the voltage magnitude is considered to be same and the frequency is different.

The passive synchronization is the easiest and probably the most practical method. So, far; however, this method will lead to some transient upon re connection of the 2 grids and it does not guarantee a fast controlled synchronization process.

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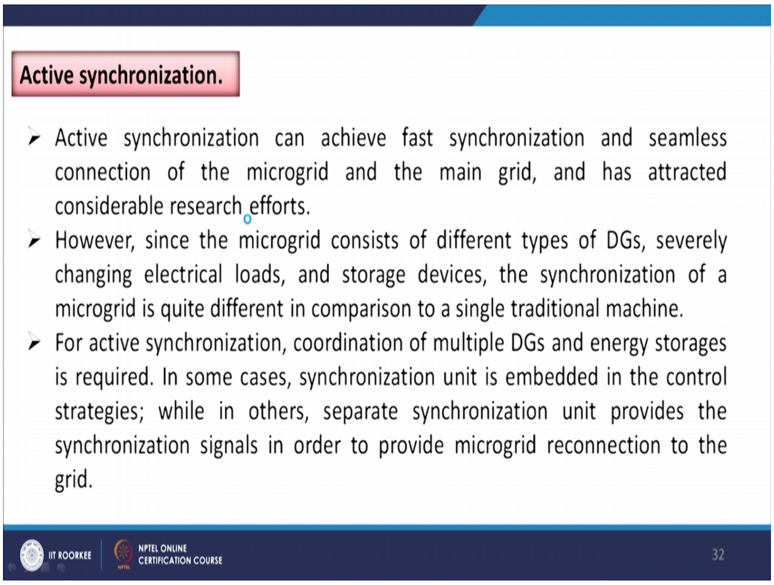

In case of active synchronization which is slightly advanced active synchronization can achieve fast synchronization and seamless connection of the micro grid and the main grid and has attracted considerable researcher effort today so any research related to active synchronization become a hot topic.

However since the micro grid consists of different type of distributed generators severely changing electrical loads and storage devices the synchronization of the microgrid is quite different in comparison to a single traditional machine. For active synchronization coordination of multiple distributed generators and storage elements is required in some cases synchronization unit is embedded in the control strategy while in other separate synchronization mechanism is placed compared to my control mechanism.

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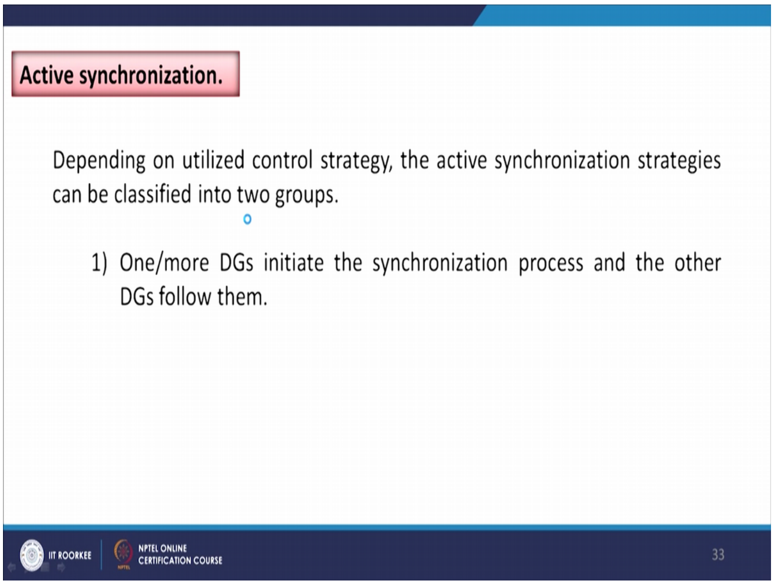

Depending on utilized control strategy the active synchronization strategy can be classified into 2 groups, first one or more distributed generators initiate the synchronization process and the other distributed generators has to follow. Second one all distributed generators take part in the synchronization process simultaneously.

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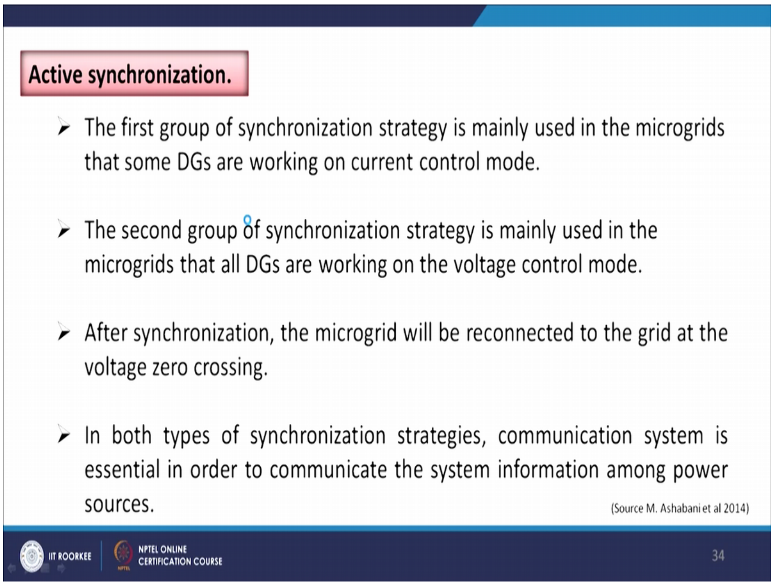

The first group of synchronization strategy is mainly used in the micro grid that some distributed generators are working on current control mode. The second group of synchronization strategy is mainly used in the micro grid that all distributed generators are working on a voltage control mode after synchronization the microgrid will be re connected to the grid if the voltage 0 crossing. In both type of synchronization strategies communication system is essential for any active synchronization communication system is must to communicate the system information among different power sources.

Now, if the loading conditions are keep on changing then in a hybrid microgrid as you all know the AC DC microgrid which has been connected to my main grid and the loads of the AC DC micro grid keep on changing.

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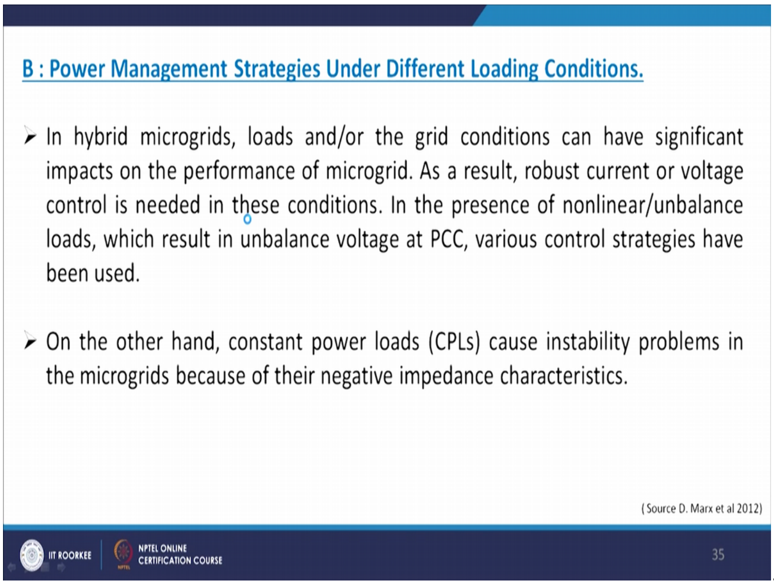

And in a hybrid micro grid loads and or the grid conditions can have significant impact on the performance of the micro grid. As a result robust current or voltage control is needed in this conditions, in the presence of non-linear unbalanced load which results in unbalanced voltage at my point of common coupling various control strategies have been used. On the other hand constant power load CPLs cause instability problem in the micro grid because of their negative impedance characteristics.

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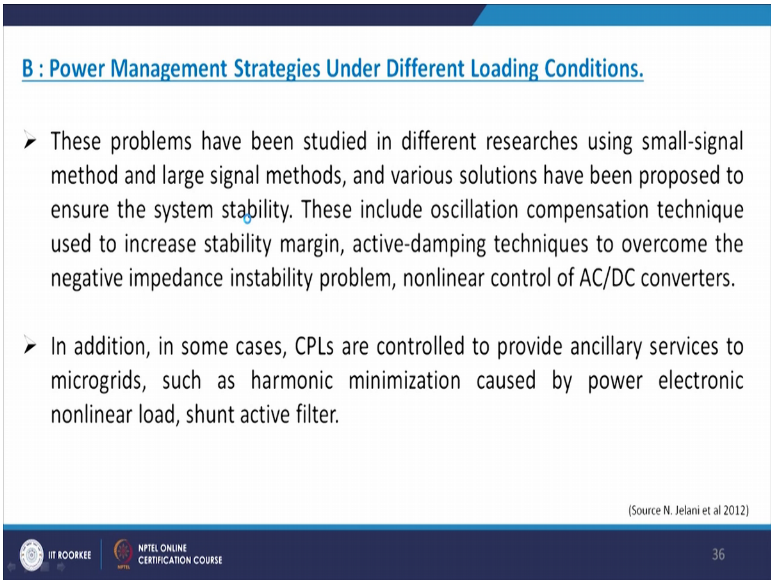

This problems have been studied in different researches using small signal method and large signal methods and various solutions have been proposed to ensure the system stability this includes oscillation compensation technique used to increase the stability margin active damping techniques to overcome the negative impedance in stability problem non-linear control of AC DC converters.

In addition in some cases CPLs are controlled to provide ancillary services to micro gird such as how many minimization caused by power electronic non-linear loads shunt active filter etcetera, with this we need to know understand that because of the varying loading conditions the CPLs which affect the microgrid stability frequency and voltage dependent loads can influence the microgrid stability at large.

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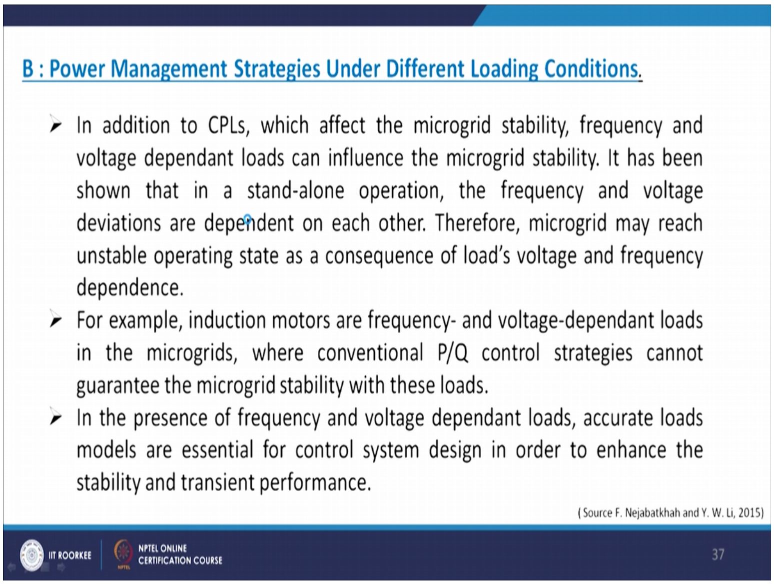

So, one is moving from the grid connected mode to islanded mode and islanded mode to grid connected mode the control strategies certainly takes an important role whether to continue with this same control strategy or change your control strategy if you have to change then add whether it is through active synchronization or passive synchronization and finally, when you look into the different loading condition the challenges how the power management need to be performed.

It has been shown that an standalone operation the frequency and voltage deviation are dependent on each other, therefore, microgrid can reach unstable operating state as a consequence of load voltage and frequency dependence for example, induction motors are frequency and voltage dependent loads in the micro grids where conventional p q control strategies cannot guarantee the micro grid stability with this type of loads.

In the presence of frequency and voltage dependent loads accurate load models are essential for control system design in order to enhance the stability and transient performance. Now the lot of lot of work has to be achieved in AC DC micro grid operation and control in specific, because we have seen the very important challenge here the loads and generations may connect your AC DC microgrid either to the respective AC or DC bus or they may be connected differently means the AC bus may have AC generations DC generations as well as AC loads and DC loads whereas, in case of DC microgrid we can have AC generations DC generation connected to my DC bus as well as AC load DC loads connected to my DC bus.

This is a common structure one whereas, you can go for the structure 2 where all the AC loads are connected to AC bus AC generations connect to my AC bus and the DC generation connected to DC bus and DC loads connected to my DC bus and this both AC DC bus connected through interlinking converters for exchange of powers.

Now, because of that the complexity of control strategy gets complicated and different techniques need to be adopted especially when you move from grid connected mode to islanded mode and islanded mode to grid connected operations interlinking converters, distributed generators, as well as storage elements do have to play an important role in parallel to any control scheme that is being adopted, a lot of future research areas currently going on.

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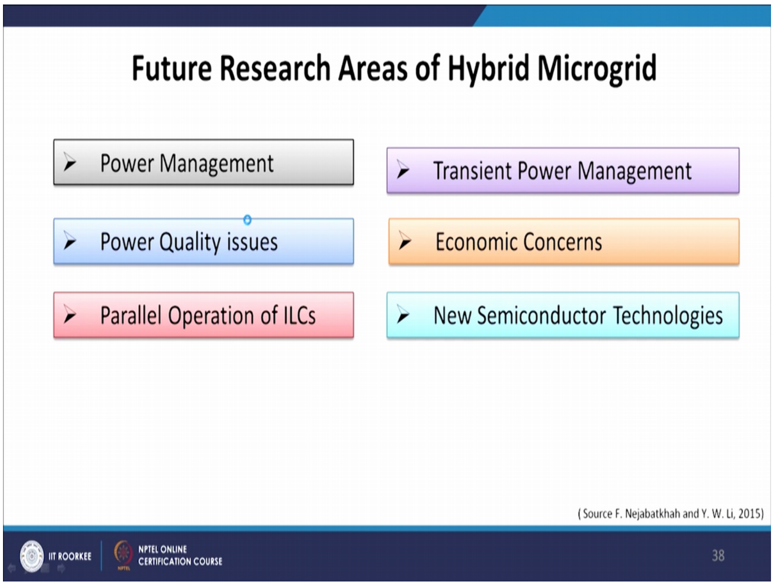

In case of hybrid micro grid and to mention few of them power management challenges, power quality issues, parallel operation of interlinking converters, transient power management, economic concerns, new semiconductor technologies and communication system.

Thank you.