Introduction to Smart Grid
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Lecture – 28
Operation and Control of DC Microgrid- II

Welcome you all for today's lecture on Operation and Control of DC Microgrid. In our previous lecture we have seen different control schemes for DC micro grid and, now we will concentrate on a complicated scenario, where we may have one microgrid which is island it or in a system having multiple micro grids not necessarily one, but there could be n number of micro grids 1, 2, 3, 4 up to n and, how do they communicate and the control function need to be developed for that.

So, we can we could have one microgrid which is single islanding, or could be multiple islanding and with all those scenarios with both grid connected and islanded mode, we will try to understand what would be the best control mechanism suited for DC microgrid applications.

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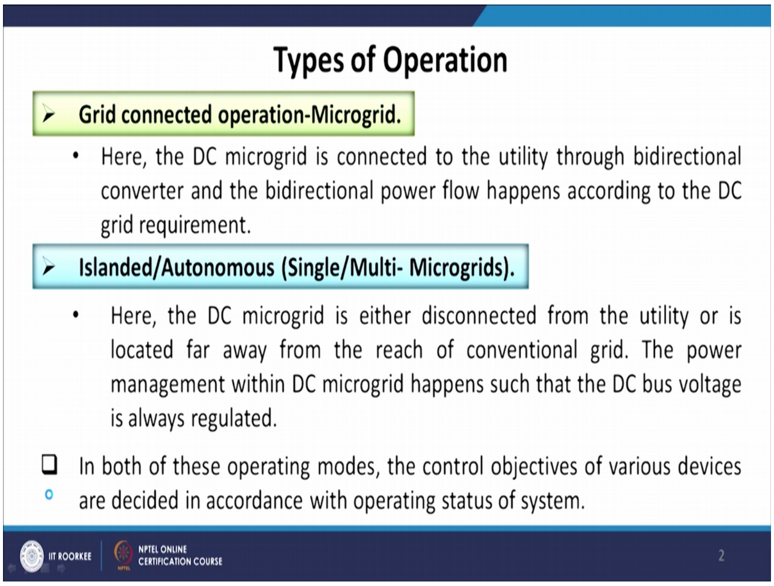

Now, as we all know there are or perhaps many times, I have discussed in my previous lecture there are two mode of operations one is grid connected operation of DC microgrid. And the other one is islanded or autonomous could be single or multi DC micro grids. Now, in case of DC micro grid, DC micro grid is connected to my utility through bidirectional converter and the bidirectional power flow happens according to DC grid requirements.

Here we do have the DC grid and my AC grid, or the main grid and they have been connected through a bidirectional converter, but the energy exchange from both the side is possible.

Now, in case of islanded mode or autonomous mode for both single as well as multiple DC micro grid, is either disconnected from the utility, or is located far away from the reach of a conventional grid. Means the grid which is been connected to my AC grid, but disconnected due to some issues technical challenges, or we do not have grid AC grid has never reach to the particular location and there are few communities need to be electrified so, we need to go for islanded mode of operation or autonomous mode of operation.

Now, the power management within DC micro grid perhaps such that the DC voltage is always regulated. Now, if you say that DC voltage is V DC may be 48 or 96, we have to make sure that at each and every bus the voltage is maintained to the desired DC voltage V DC or 48 or 96.

Now, in both these operating modes that is in case of grid connected, as well as in islanded mode of operation the control objective of various devices are decided in accordance with operating status of the system.

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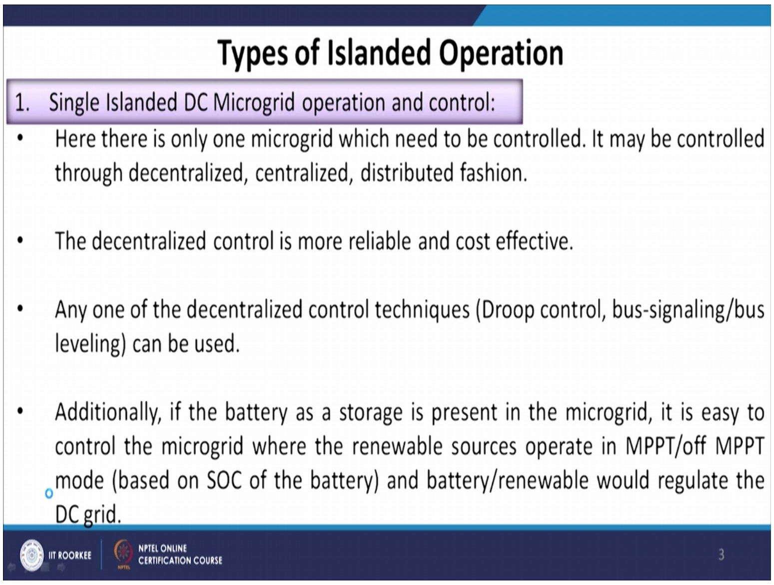

Now, let us concentrate on types of islanded mode of operation, where we have single micro grid single DC micro grid and, the second one where we have multiple DC micro grid in place. Considering single islanded DC micro grid operation and control here, there is only one micro grid which need to be controlled it may be controlled through decentralized, centralized, or distributed fashion.

The decentralized control is more reliable and cost effective, any one of the decentralized controlled techniques such as droop, bus signaling, bus leveling can be used. Additionally because if the battery is in place, then it is easy to control the micro grid where the renewable source operate in it is MPPT of MPPT mode, in the battery renewable would regulate the DC grid very important.

Now, if it is in islanded mode of operation; that means, the local lead load of the DC micro grid must be met by it is own generation, we always wish that my PV as well as wind generator connected to my DC micro grid; so, it produce maximum power. So, using MPPT approach I can extract the maximum power from both solar as well as wind, but the challenge here once we produce excess energy if my load is low, then the excess energy can be charged through my battery.

But once the battery is fully charged and still my load is low, then it is very difficult for me to accommodate the excess energy through MPPT available to me. So, that is what actually one need to and address and understand how those scenarios can be carried out.

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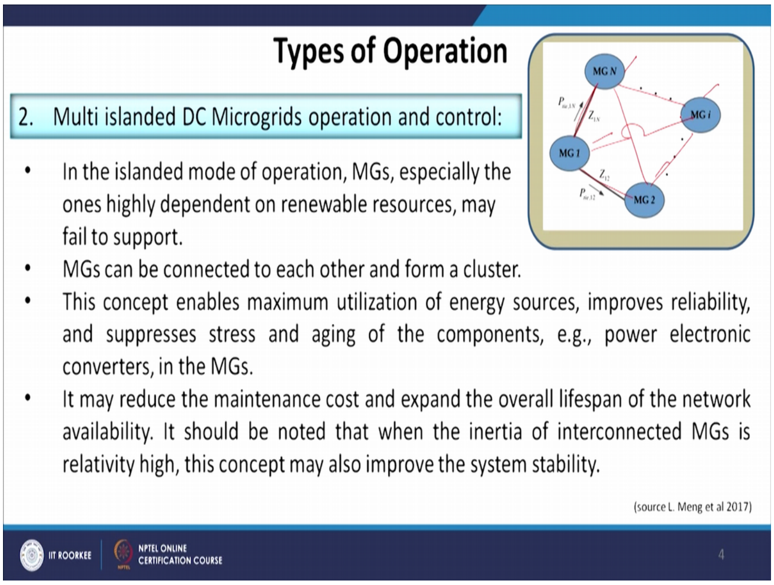

Now, in case of multiple islanded DC microgrid. Let us say instead of one microgrid, we may have multiple micro grids in place, where the Thailand power flows between one microgrid to other in anyway. In the islanded mode of operation micro grids especially the ones highly dependent on renewable sources may fail to support, micro grids can be connected to each other and form a cluster.

We may have 10 residential buildings and each residential building maybe a microgrid to me and all of them work through a community. This concept enables maximum utilization of energy sources, improve reliability and suppress stress and aging of the components example power electronic convertors in the micro grid. The very important part of multiple islanding operation is that, as I mentioned that once my load is low and the generation is blindly available to me.

I have to store those excess energy through my battery, but once it is as high as 90 percent of the state of charge, then settle in a battery of that particular microgrid may not be able to take those excess energy available to me from both wind and solar operating at MPPT. But if I do have multiple microgrid connected those excess energy may go to the other micro grid which may be shortage of energy; so, those exchanges are possible.

So, it is more efficient way where multiples micro grids operate in a cluster or together. It may reduce the maintenance cost and expand the overall life span of the network availability, it should be noted that when the inertia of interconnected micro grid is relatively high, this concept may also improve the system stability.

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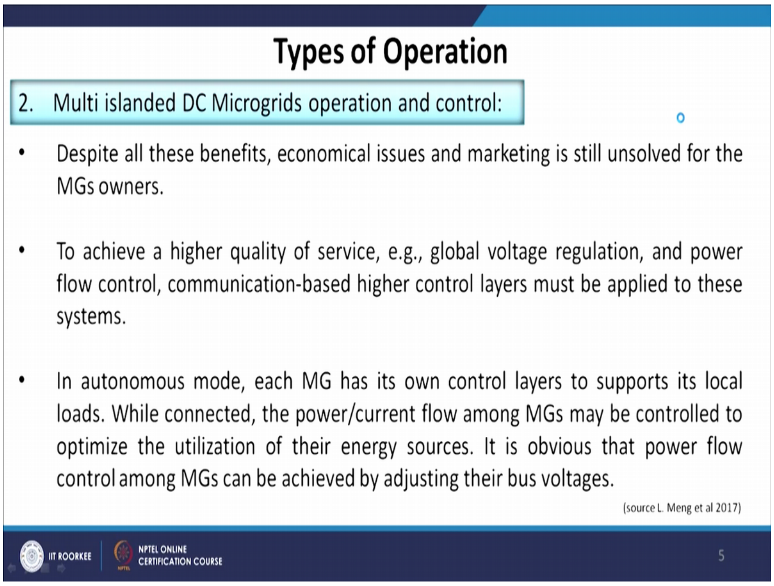

Despite all these benefits economical issues marketing is still unsolved for micro grid owners. To achieve a higher quality of service, example global voltage regulation power flow control communication based higher control layers must be applied to those systems, technology need to be very well developed and they required to be developed to handle such, cluster based micro grids operating in islanded mode.

In case of autonomous mode each micro grid has it is own layer of supports, it is local loads while connected the power current flow, among micro grids may be controlled to optimize the utilization of their energy sources. It is obvious that power flow control among micro grids can be achieved by their bus voltages means, if you wish from the micro grid 1, the power should flow through the micro grid 1, then we have to adjust the terminal voltage of both the micro grids in such a manner that power can flow, because as we know the power flow between two buses is proportional to the terminal voltage of the both the buses.

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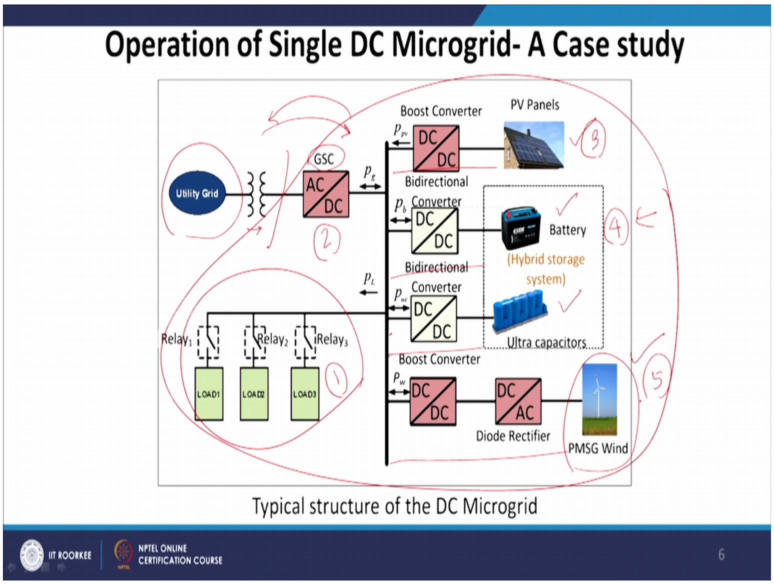

Now, this is a typical structure of a DC micro grid and I will show you later stage how this experimentation work. So, this typical structure claims that we have a PMSG wind turbine connected to my DC grid, ultra capacitor connected to my DC grid; hybrid energy storage system connected to my DC grid both battery and ultra-capacitor, then we have PV panels connected to my DC grid and we do have loads connected to DC grid, we have utility grid and which is AC in nature.

So, this is my DC grid; so now through GSC the power can move from main grid to DC grid, as well as it can go from my DC grid to main grid as and when excess power is available to me in my DC grid. Now, the question is once this grid is isolated, or disconnected from the grid under that circumstances the DC grid has to operate in an islanded mode. Under those circumstances how do I control my all the energy sources, such that my DC micro grid can operate efficiently.

Now, there are so, many devices within a micro grid DC micro grid. So, the important is my the converter between utility grid and DC micro grid wind generations.

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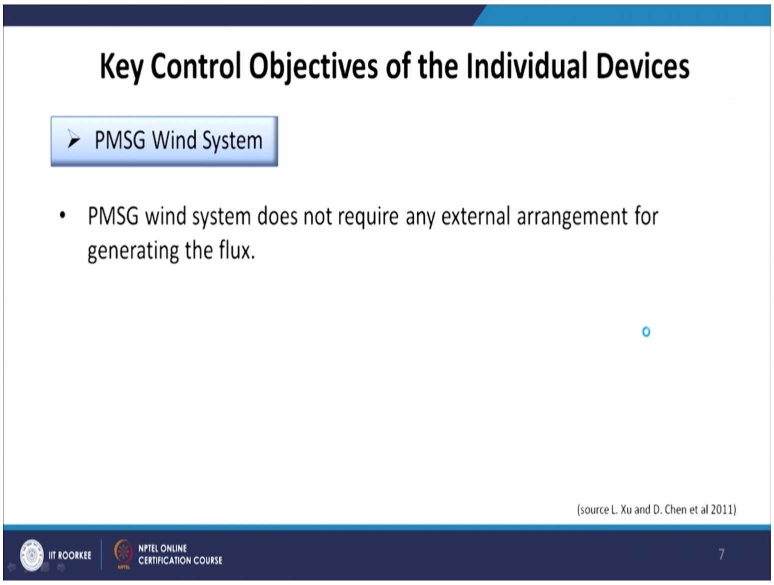

Now, let us detail focus on the wind systems, then we will move to other devices like ultra capacitors, battery storage PV and the convertors. As well as the loads so, majorly we have load is one of my component as we have seen load 1, we have GSC converter 2, PV 3 battery as well as ultra-capacitor as a hybrid energy system 4 and my wind 5. We will take one one component at a time and slowly discuss about their features.

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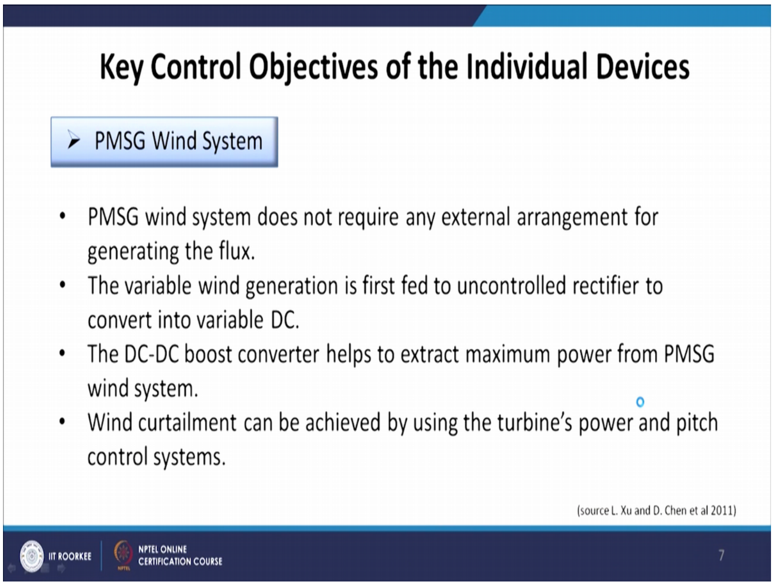

PMSG wind system, PMSG wind system does not require any external arrangement for generating the flux. The variable wind generation is first fed to uncontrolled rectifier to convert into variable DC, the DC-DC boost converter helps to extract maximum power from PMSG wind system. Wind curtailment can be achieved by using the turbines power and pitch control system.

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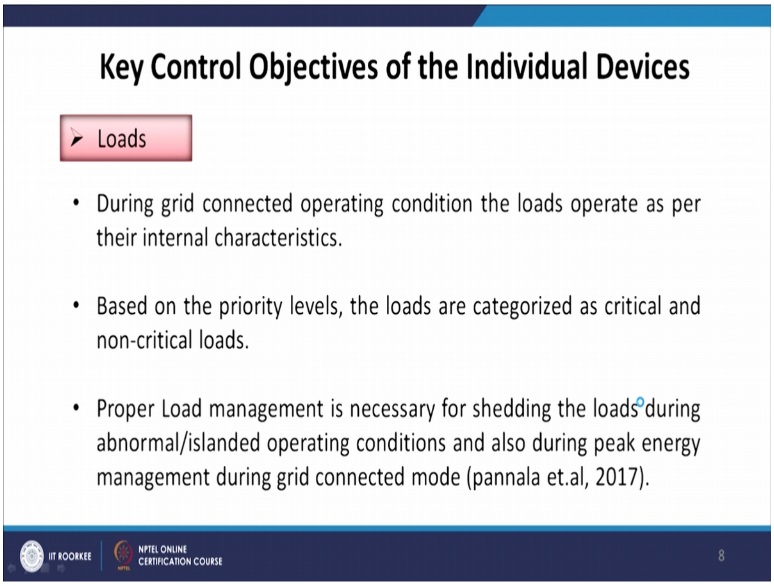

Concentrate on loads now; during grid connected operation conditions, the loads operate as per their internal characteristics based on priority level, the loads are categorized as critical and non-critical loads. I like to emphasize on a very important point. Now in case of DC micro grid, when the loads are connected along with a battery storage.

As I told you when we have excess energy, those can be stored if the load is being catered, rest of the energy can be stored in my battery. Once the battery is heavily stored maybe 90 percent of a source, when the MPPT operating point may be shifted to other mode, because we cannot extract maximum power, we have to lower it is output now.

Now, when in the evening time let us say if it is a PV connected islanded DC micro grid during, evening times when the load is more I do not have PV, I have to discharge my battery, but the storage cannot be discharged less than 10 percent of SOC which is very expensive and the battery life may go down. So, under those circumstances I need to very carefully curtail my loads, I have to very carefully curtail my loads based on it is important, whether it is critical or non-critical to match the generation available to me and the loads.

So, indirectly the storage energy must be matched to my critical loads during peak hours, when renewable generation is not available. Proper load management is necessary for setting the loads, during abnormal islanded operating condition and also during peak energy management during grid connected mode. The next important is G-VSC we call it is grid voltage source converter connected between both AC grid and my DC microgrid.

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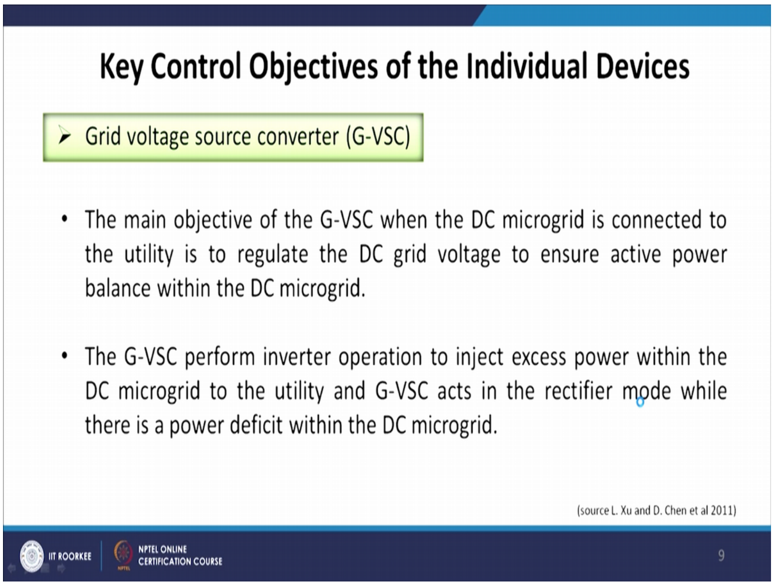

The main objective of G-VSC when the DC micro grid is connected to the utility is to regulate the DC grid voltage to ensure active power balance within the DC microgrid.

The G-VSC perform inverter operation to inject excess power within the DC microgrid to the utility and, G-VSC act in the rectifier mode while there is power deficit within the DC micro grid. Means you get the AC power convert to DC and fit to my DC micro grid, or when it need to be given back to my AC grid DC to AC conversion and connect to your utility grid of the main AC grid.

Now, the next component is hybrid storage system, where we have seen that we have a storage that is battery along with ultra-capacitor, they both go together because of their complementary applications.

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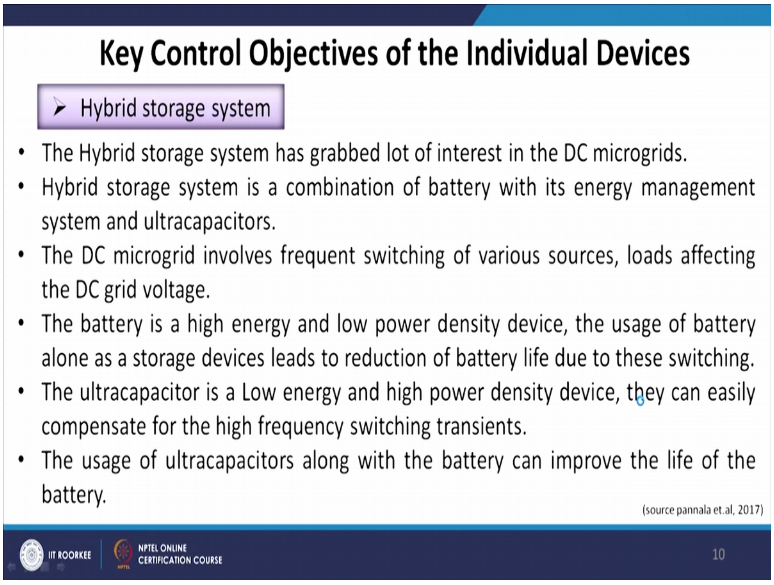

The hybrid storage system has grabbed lot of interest in DC micro grid, hybrid storage system is a combination of both battery with it is energy management system and ultra-capacitor. The DC micro grid involves frequent switching of various sources and, loads affecting the DC micro grid voltage. Because if you look into a very residential complex, because DC micro grid is you know especially is applicable to a in a low network, where the energy or the power requirement is in kilowatts.

And the load is keep on changing and the load is keep on changing and, that may disturb my DC bus voltage of the DC micro grid. The battery is a high energy, but low power density device and, the usage of battery alone as a storage device leads to reduction of battery life due to the switching.

So, now what happens if you keep on changing the load, then your battery starts discharging frequently the different steps and, that may spoil the life of the battery and that can be protected in the presence of ultra-capacitor . The ultra-capacitor is a low energy, but high density device they can easily compensate for the high frequency switching transient.

So, way both together can handle many high frequency transient that may occur switching transients in the system. The usage of ultra-capacitor alone with the battery can improve the life of the battery, in the presence of ultra-capacitor which can handle high frequency switching transients; so, that the battery life can be improved.

But when we talk about a battery we need to have a Battery Energy Management System; BEMS.

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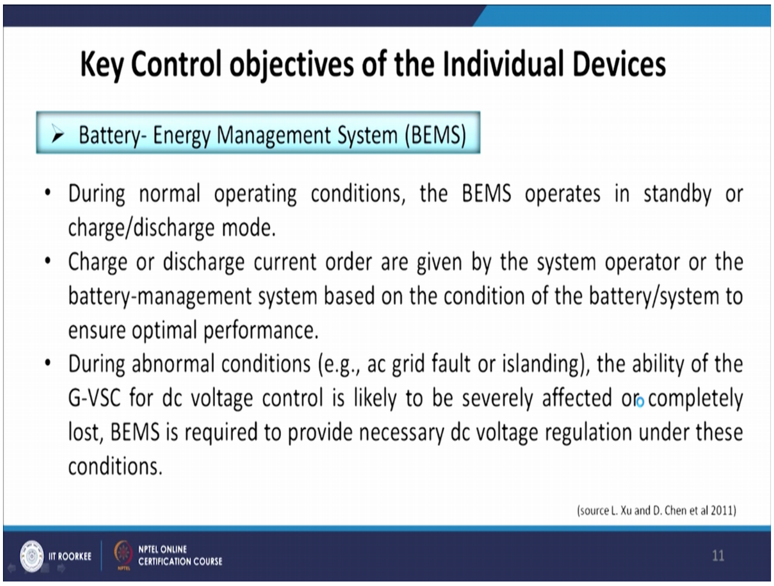

During normal operating conditions the BEMS operates in standby or charge discharge mode. Charge or discharge current order are given by the system operator, or the battery management system based on the condition, or the battery system to ensure optimal performance. During abnormal conditions that is grid failure or islanding, the ability of the G-VSC for DC voltage control is likely to be severely affected or completely lost.

So, BEMS is required to provide necessary DC voltage regulation under this conditions. Photo Voltaic; PV systems.

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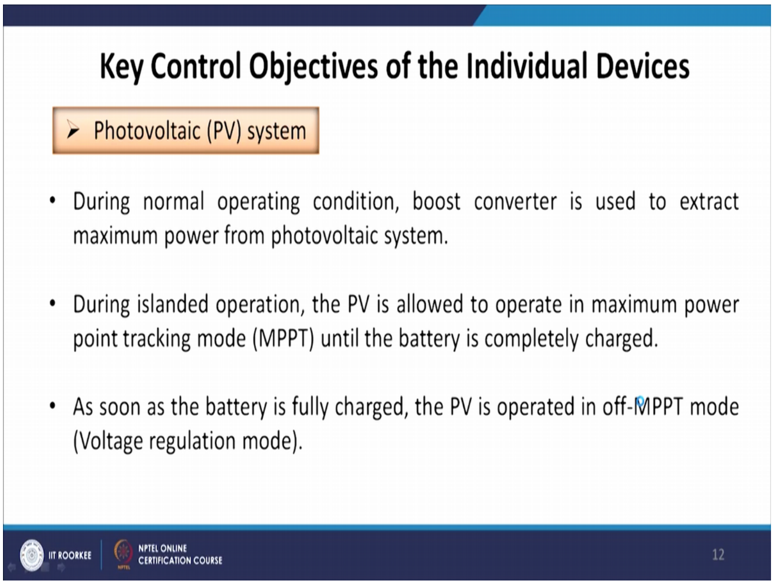

During normal operating condition, boost converter is used to extract maximum power from photo voltaic systems. During islanded mode of operation, the PV is allowed to operate it is MPPT mode until the battery is completely charged. As soon as the battery is fully charged, the PV is with the PV is operated at off MPPT.

Because you cannot operate to extract maximum power at that point, because your battery is not going to take anything it has been fully charged. So, we have to operate your PV in voltage regulation mode. So, it will really reduce its generation and operate in voltage regulation mode.

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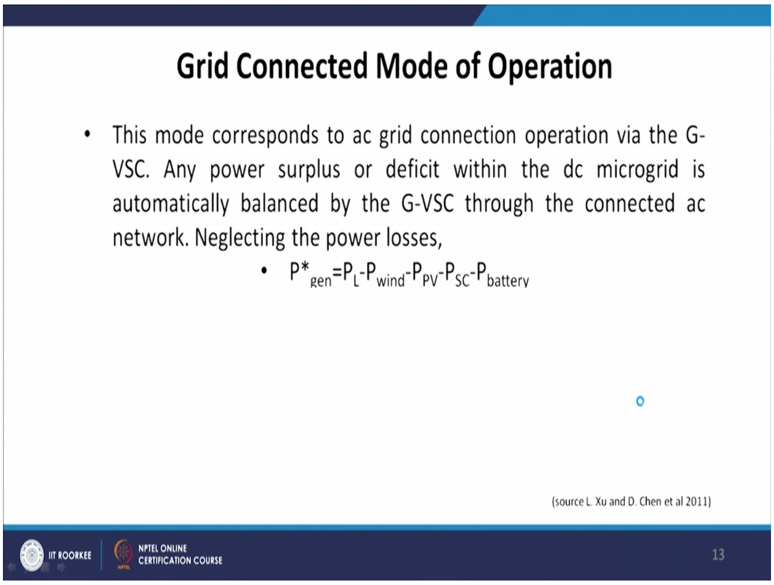

The mode correspondent to a AC grid connection operation via the G-VSC any power surplus, or deficit within the DC microgrid is automatically balanced by G-VSC, though through the connected AC network neglecting the power losses.

So, at this point ignoring the power loss now the P generation which is nothing, but my P load minus the power coming from wind, the power coming from PV, the power coming from super capacitor and, the power coming from battery. And the rest will come from my main grid at which the DC microgrid is connected.

Now, P G-VSC P wind PV, PSC and P battery refer to the power input to the DC grid from G-VSC. The wind turbine photovoltaic system, super capacitor and the battery here system, P L is considered to be the power consumed by the load.

So, please remember this P generation is nothing, but my P G-VSC so, the power which is coming through grid voltage source converter is to match the difference between the load and the generation which is present within my DC microgrid, the mismatch will be managed by P G-VSC.

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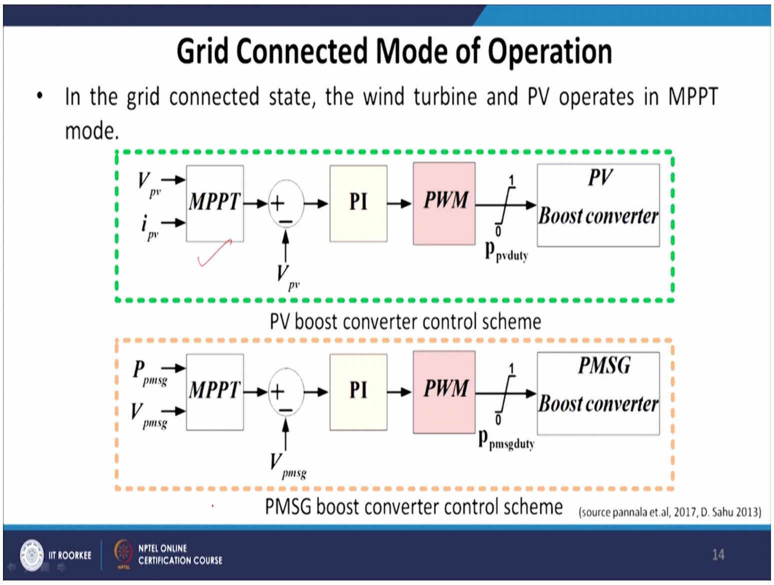

Now, in the grid connected state the wind turbine and PV operate in MPPT mode. Now, you could see the MPPT mode of operation for both the PV, boost converter control schemes and, boost converter control schemes for permanent magnet synchronous generator; MPPT mode of operation. This is the structure will discuss very much in detail when we move forward this to give an idea, how the wind turbine and PV operates in MPPT mode.

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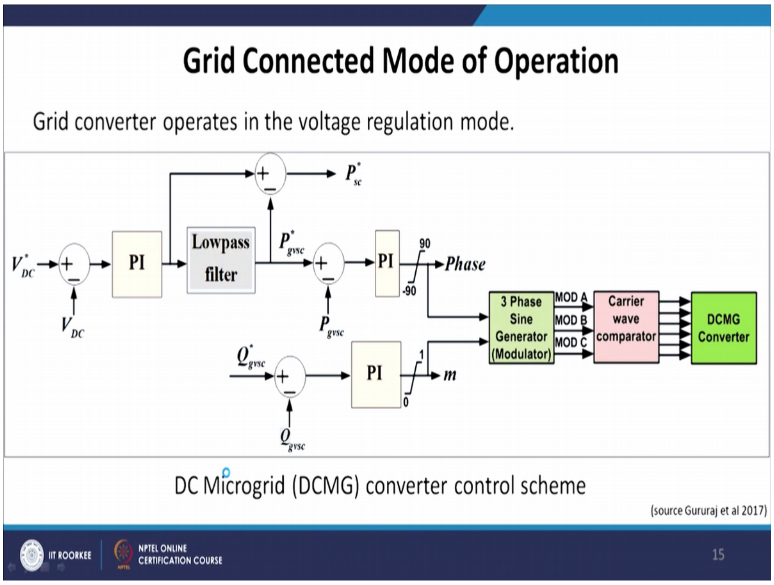

And this is my DC microgrid converter control schemes, you could see the DC microgrid converter and this is the V DC, which is important variable in my given system this is coming from my gvsc all the variables and the control scheme is in place.

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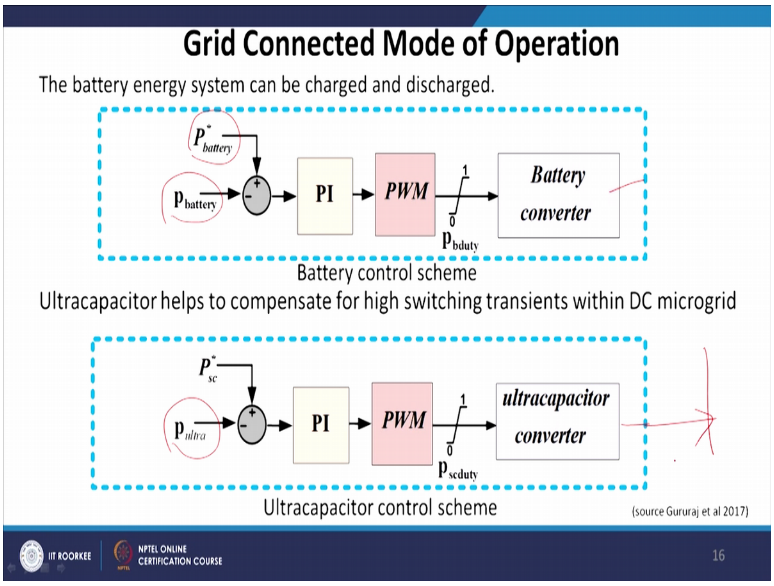

Now, the battery control scheme once again very important, we have P battery feedback P and we do have battery converter. So, each and every device is connected to my DC grid through converter and, you can see the ultra-capacitor scheme, similar to P battery we will have P ultra and connected to my ultra-capacitor converter and, then it can be connected to my DC grid.

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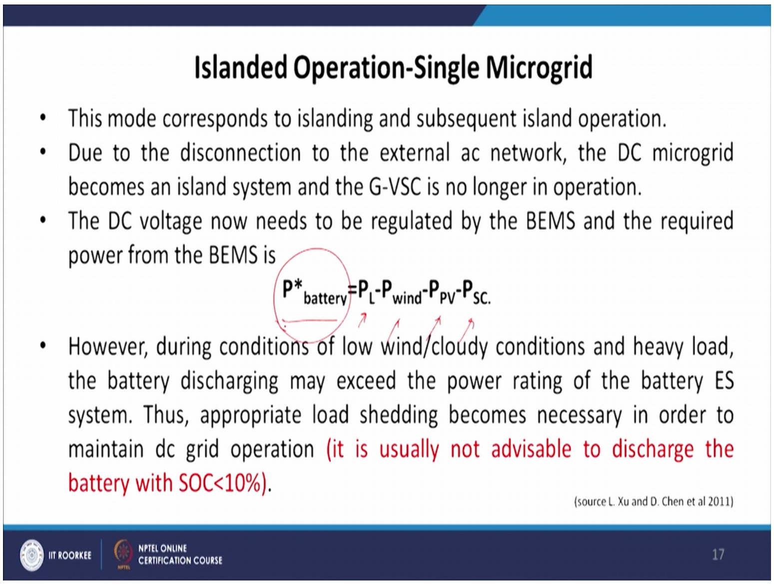

The islanded operation of a single microgrid, this mode correspond to islanding and subsequent island operations. Due to disconnection to the external AC network; the DC microgrid becomes an islanded system and the G-VSC is no longer in operation.

As I have mention the AC grid and the DC microgrid connected through G-VSC grid voltage source converter. So, they can exchange power from AC grid to DC grid as well as from the DC grid to AC grid, depending upon the energy level, most of the time if the energy shot in my DC grid, it can take energy from AC grid and if excess energy is available to me if my battery is charged the PV and wind operated MPPT.

The battery is no more able to charge so the excess energy can be diverted to AC grid instead of moving to a other mode of operation of my PV. So, but if it is islanded then they have to locally balance their energy in a different way. Now, during islanded mode of operation the G-VSC has no role to play, because it has been disconnected from your AC grid.

The DC voltage now become regulated by BEMS and required power from the BEMS means, when it is been disconnected the local DC grid will be controlled, whenever there is excess energy or the load is keep on varying the PV is at MPPT. So, the balancing will be done through my battery, or the battery as well as ultra-capacitor together can meet my load variation.

So, the PV and wind at MPPT grid has been disconnected and load variation can be matched through my battery as well as ultra-capacitor through the hybrid energy system. So, that you can see the P battery which is the P load minus P wind P PV and P super capacitor. So, the energy that has to come from battery must be equal to the difference between, the load power from the PV power from the wind and power for the super capacitor. So, battery play a very important role during islanded operation of a DC microgrid.

However, during conditions of low wind cloudy conditions and heavy load the battery discharging may exceed the power rating of the battery, because the load is such the battery has to completely discharge, but as you know because to maintain the life of the battery you cannot discharge beyond, or less than 10 percent so, that we need to take care, it is never be advisable for the battery to do discharge to meet your load requirement below 10 percent of associate that need to be taken care.

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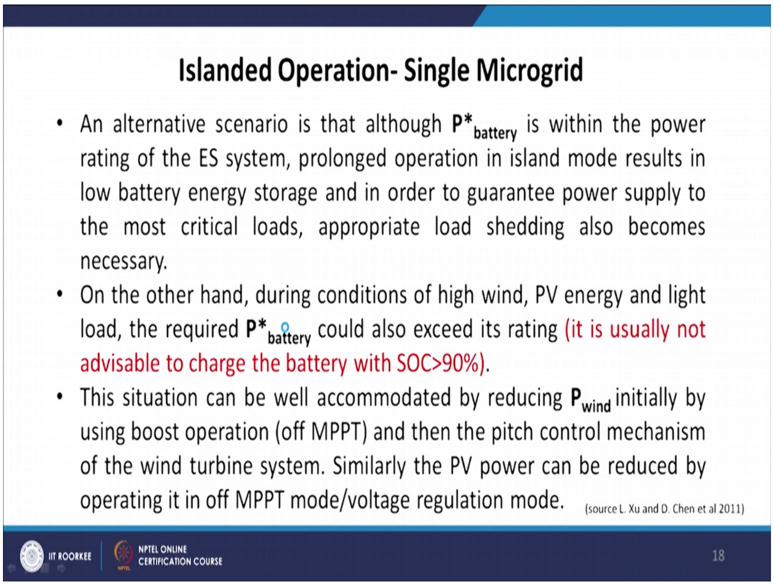

An alternative scenario is that although the P batteries within the power rating of the ES system, prolonged operation in islanded mode result in low battery energy storage and, in order to guarantee power supply to most of the critical loads appropriate load shedding also become necessary means. If your battery is not able to discharge or not able to maintain your load requirement.

And to meet your load if you have to reduce your SOC far below 10 percent, or may be close to 10 percent, it would be rather advisable you can curtail some of the loads in the DC microgrid important loads can be protected, low important low priority loads can be curtail so, that my battery need not discharged to such a level which is below 10 percent at any given point of time.

And other hand during conditions of high wind, the V energy and light load the required P battery could also exceed it is rating means, you produce excess energy through wind and PV and your load is at light load positions, one thing I like to make it clear at this point, I mean unfortunately we do have excess renewal available to us, when we do not experience the peak of the system.

During night hours the wind energy is maximum, but it is not a peak hour similarly during daytime, the PV operate it is maximum point, but it is not a peak hour. So, during those hours the energy lead to be stored through the battery and, the battery will keep on adding it is charging value and may exceed 90 percent of charging, or 90 percent of SOC which is still not an advisable approach.

So, once again under the circumstances this situation can we well accommodated by reducing the P wind, initially by using boost operation that is do not operate your PV at MPPT and, then pitch control mechanism of the wind turbine system. Similarly the PV power can be reduced by operating it to of MPPT and move to voltage regulation mode, I like to highlight two very important point here, when you have excess energy from PV as well as from the wind and not able to store, then you move PV to it is voltage regulation mode from MPPT to off MPPT, that is the voltage regulation mode.

Similarly for the wind you can move from MPPT to off MPPT using pitch control mechanism.

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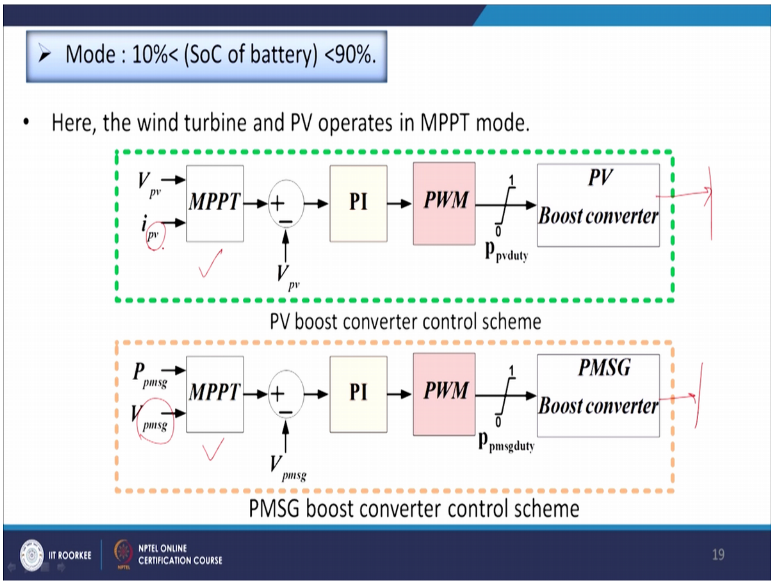

Now, when the SOC the battery which is within 10 percent to 90 percent of the wind turbine and PV operates in it is MPPT mode, you could see that is both are connected to my DC grid, operate at MPPT and this is for my permanent magnet synchronous generator wind turbine and, this is for my PV generators.

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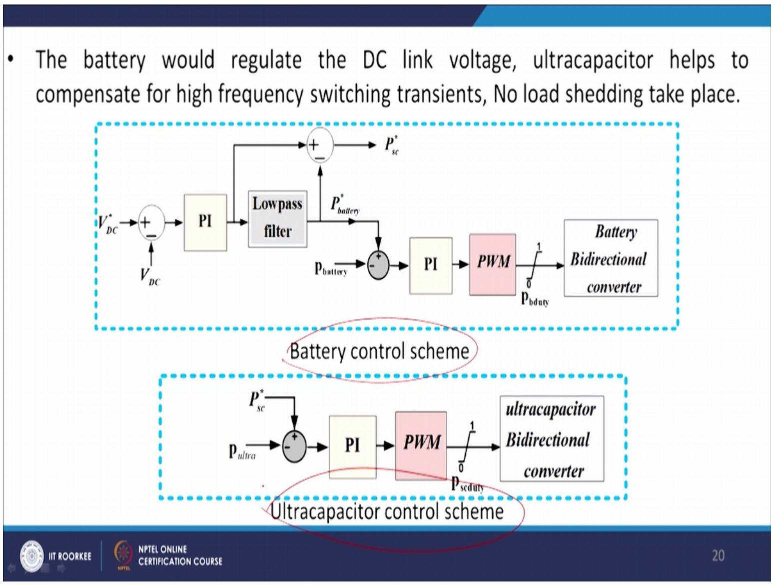

Now, the battery would regulate the DC link voltage ultra-capacitor helps to compensate, for high frequency switching transients and low loading no load shedding takes place.

So, this is one of my the concept of battery control scheme, we will discuss very much in detailed once you progress and today's lecture mostly reported and referred to the following literatures.

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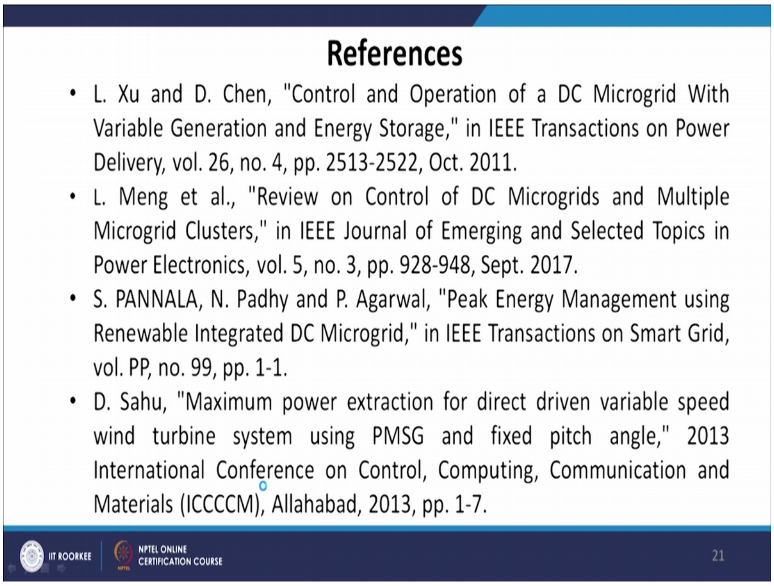

So, you are advised to please refer those articles to understand more on operation and control of DC microgrid. So, I like to summarize at this stage that the DC micro grid, operation and control become a challenging task, when it is operated with grid and without grid it is more challenging, when it is not with the grid, because the G-VSC is no more able to translate power from DC grid to main grid.

So, the DC grid has to balance it is power locally and, there are two scenarios where the load is more generation is less one more scenario where generation is more and the load is less. Now, when generation is more load is less under those circumstances the battery can come back and extract all the energy from the PV or wind generators and, keep on storing.

But when the storage become beyond 90 percent, then it become a critical challenge, we cannot anymore allow your PV and wind generator to operate it is MPPT mode, they have to go for off MPPT mode through pitch control as well as voltage regulation mode.

Where ever if the generation is low load is high the battery will start discharging it is energy, but when it is below or close to 10 percent of SOC, it is not advisable to fully discharge it is better to disconnect some of the non-important loads to balance the power within a DC microgrid, but when it is connected to main grid the challenge is little less because, as and when energy is required for the DC microgrid, it can take power or energy from the AC grid and, if excess energies available that can be given to the AC grid.

So, the main merit of G-VSC, if it is in place between AC and DC grid, then both my PV and wind generators, or can operate at MPPT mode, excess energy can go to battery or it can go to main grid, but when it is islanded mode we cannot afford to operate PV and wind generator at it is MPPT. So, the operation control mechanism both at islanded as well as it grid connected mode become an important issue.

So, I request all of you to please focus, the importance control mechanism for DC microgrid, which is slightly different compared to AC microgrid mainly due to absence of frequency.

Thank you very much.