Introduction to Smart Grid
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Lecture – 29
Operation and Control of AC-DC Hybrid Microgrid- I

Welcome, to the NPTEL online course on Smart Grid today and, we will be talking about Operation and Control of AC-DC Hybrid Microgrid. As we all know during last few lectures, we covered important concepts related to AC smart grid operation and control and further we move to DC smart grid operation and control. And today we are wish to discuss very much in detail the challenges associated with operation and control of AC-DC smart grid.

Now, my dear friends the very important issue here, when we talked about AC smart grid, I mean we understood what are the control mechanism, operational mechanism, when it is connected to grid and, also in autonomous or islanded gird operation. And similar kind of analysis we have understood and discussed in detail related to DC micro grid, or DC smart grid too. But today we talk about a grid which has both AC smart grid as well as DC micro grid; DC smart grid in place.

So, imagine a grid which is which can act as both AC and DC smart grid, or they are together and, both AC-DC smart grid now can act in line with the utility, or the grid connected mode, or it can also operate in a islanded mode. Now why a why we are looking for AC-DC smart grid? Most of the generations in specific to PV and fuel cells, they do generate power in DC mode.

And then we need to I mean convert to AC, if you connect to a AC smart grid. Similarly if it is a wind generation that power wind generated at AC and, then we need to convert that to into DC, if it is a DC smart grid. Further the loads today are of both DC and AC type the most of them are of DC type.

But still we cannot ignore the AC types of loads which are very much important at industrial specific loads. And those loads need to be catered by both AC smart grid, as well as in DC smart grid under any given platform or conditions. So, if it is a DC micro grid, or a DC smart grid that DC loads can directly be connected whereas, AC load needs

conversion in case of AC smart grid AC load can be connected and DC load need to be converted.

So, we could see there is a bigger challenge of DC to AC and AC to DC conversion in case of AC grid and, AC to DC and DC to AC conversion in case of DC grid. And those conversions are more and more significant, in case of a independent AC or DC smart grid platform, so to gain couple of benefits and to avoid multiple conversions researchers thought of going for a hybrid grid, or a combination of AC-DC smart grid and that is what the today's topic is all about.

But we cannot ignore the challenges; now, there are very important challenges AC smart grid do operate with different control schemes, different operational schemes, DC grid operate in a different control schemes and operational schemes, when they go together what would be the common control scheme that need to be adopted, both in case of islanded as well as grid connected mode.

So, we will slowly proceed to our understanding in detail, what are the challenges and how that can be addressed. Certainly AC-DC smart grid is a real merit over individual AC DC smart grid, but the control challenges become severe and we will look forward to address those issues during next 30 minutes from now.

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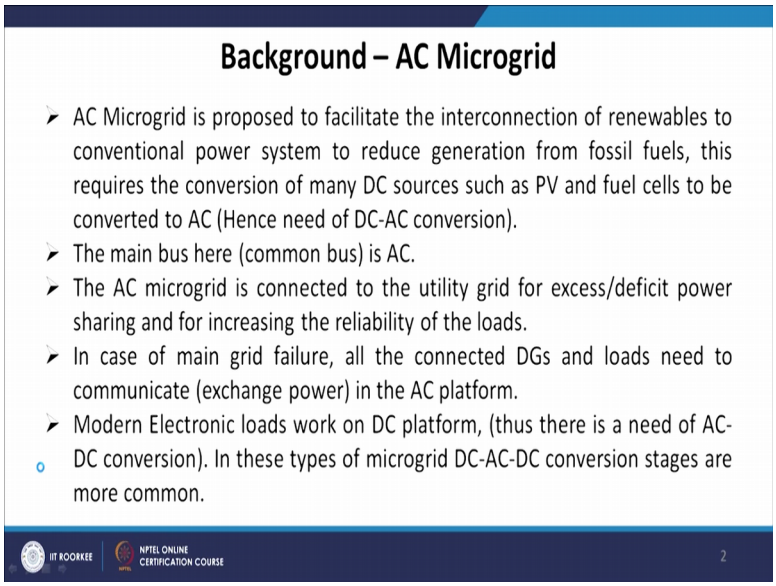

The background of AC micro grid is mainly proposed to facilitate the interconnection of renewable to conventional power system, to reduce generation from fossil fuels. And this requires the conversion of many DC sources such as PV and fuel cell to be converted to AC, and hence we need DC AC conversions.

The main bus in case of a AC micro grid is AC, the AC micro grid is connected to the utility grid for excess deficit of power sharing and for increasing the reliability of the load means, the AC smart grid has to be connected with the grid.

So, that as and when the load increases, you know we can take power from the grid and, when it is decreases we can share power to the grid. And that increases the reliability and the robustness of your AC smart grid, or AC micro grid. In case of main grid trailer all the connected DC and loads need to communicate in the AC platform, because this purely as grid for you. Modern electronic loads work on a DC platform and, in this type of micro grid; DC AC and for the DC conversion stages are more common.

Because you generate power with DC, connect to your AC grid, try to curtail your loads in DC so DC to AC, AC to DC. So, that those type of conversions are very common in case of AC micro grid.

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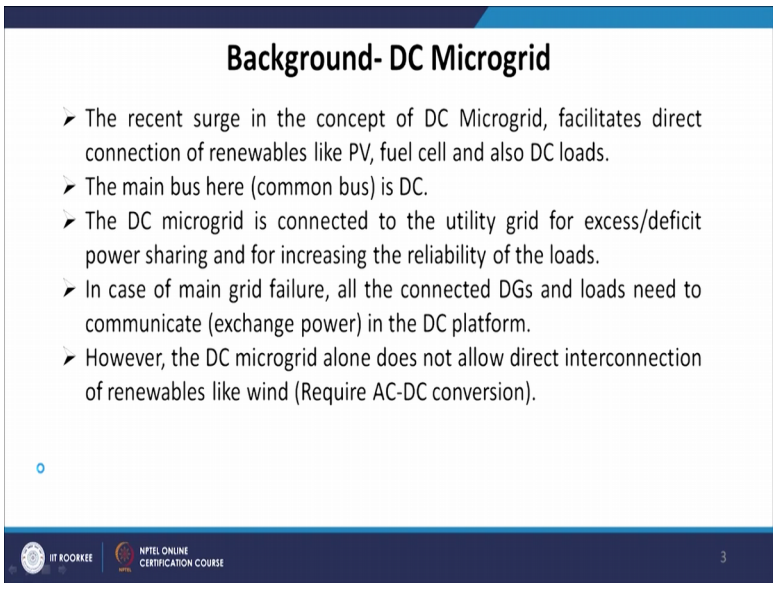

Now, similar let us see what is DC micro grid, in specific the recent surge in the concept of DC micro grid, facilitate direct conversion of renewables like PV, fuel cell also DC

loads means, just imagine you have a system where you have huge amount of PV connected, as well as you have the loads which are purely lightning.

And a DC micro grid is wonderful because, you can take all the energy in the form of DC and then cater all your loads in the form of DC, though the voltage uplifting or down grading has to be done, but certainly it is a purely DC platform the main bus which is DC. The DC micro grid is connected to your main grid to exchange power so that you know the reliability of the system can improve with variation of the loads.

In case of main grid failure we can operate in a islanded mode and, all the connected DGs and loads need to communicate and exchange power in the DC platform; however, the DC micro grid alone does not allow direct interconnection of renewable like wind. For example, if you have a DC grid in place and, you have wind generative those cannot be directly connected to your DC grid.

So, perhaps you require AC to DC conversion and being said that, we can have loads industrial loads, induction machines those are again AC in nature. So, again you need DC to AC conversion; so, in case of a DC smart grid or micro grid, you need to have AC to DC and DC to AC conversion which is very common. Now, if you move to AC DC micro grid, which is the combination of both AC as well as DC micro grid.

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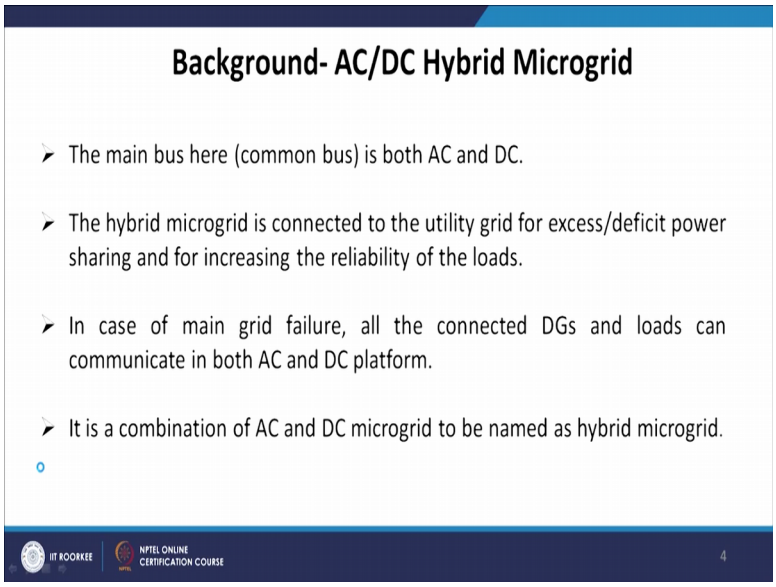

Then the main buses are a common bus common buses are of both AC as well as DC. So, you will have AC bus in place you will have DC bus in place ok, the hybrid micro grid is connected to the utility grid for excess, or deficit energy sharing, or power sharing and for increasing the reliability of the load. So, even this AC-DC micro grid hybrid grid has to be connected to migrate so, that the power exchange can occur as and when the load is keep on varying.

In case of the main grid failure my AC-DC hybrid micro grid can act independently in an islanded mode of operation and, the all the diesel generator sorry DG distributed generators need to communicate to each other in both AC as well as in DC platform. It is a combination of AC and DC micro grid and very popularly named as hybrid micro grid, both AC and DC micro grids contain distributed generators, loads and maybe storage elements or storage systems.

So, you may have a AC micro grid or AC smart grid, which may have its own distributed generators, loads as well as storage systems. Similarly the DC micro grid may have all three components like distributed generators storage elements, or systems along with loads which are either AC or DC type.

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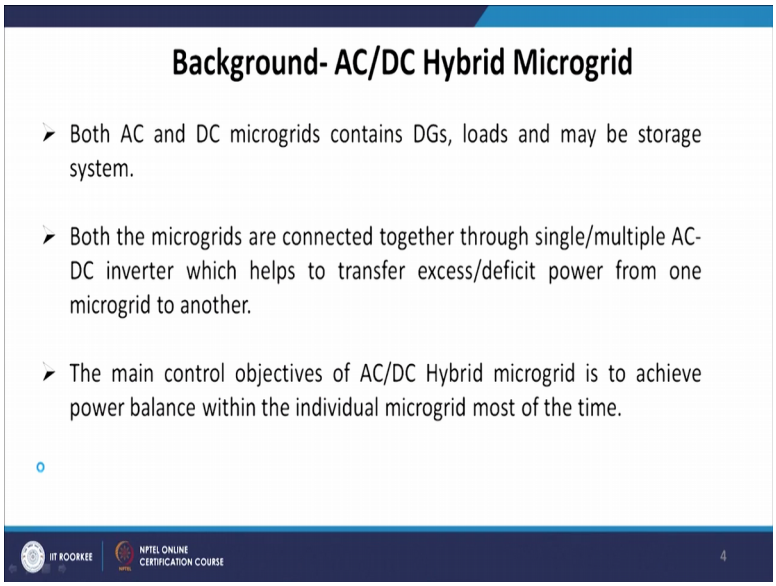

Both the micro grids are connected together through a single AC-DC inverter, which helps to transfer excess or deficit power from one micro grid to the other.

Now, please try to understand let us say my AC micro grid may have excess power that need to be transferred to my DC and, vice versa I may have a DC micro grid which may have excess power that can go back to my AC grid. The main control objective of AC DC hybrid micro grid is to achieve power balance within the individual micro grid in most of the time. Because, we have to balance your AC-DC micro grid even you are along with the grid, but you to balance your energy very frequently.

Now there are different type of architectures available in literature ah, but I feel very comfortable in picking up two very common architecture, perhaps that address all type of different architectures.

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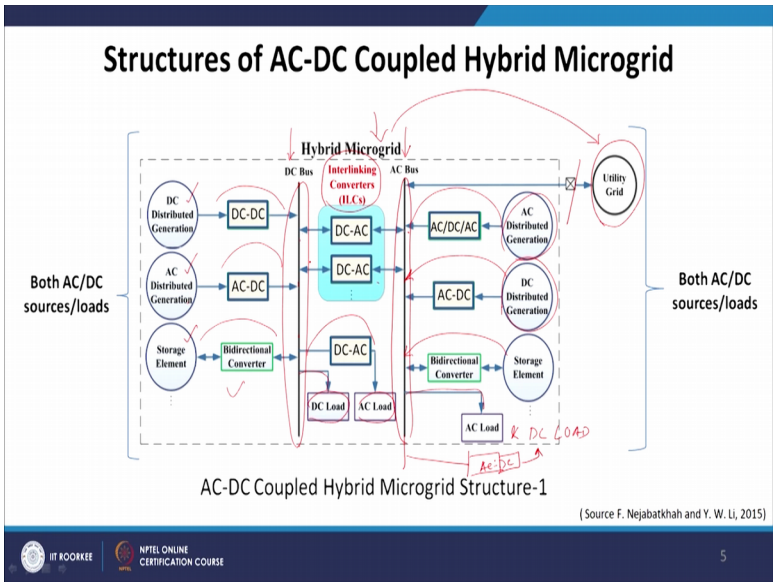

So, one of the very common architecture is AC-DC coupled hybrid micro grid we call it is structure 1 and, then we will see one more structure which is structure 2 in the later stage.

Now, I need your attention here let us say this is the DC grid or a DC bus and, this is my AC bus means, this zone is belongs to my DC micro grid, this section and this zone towards the right belongs to my AC micro grid. And then we have an important utility grid. Now, both AC DC hybrid micro grid can connect along with the utility and, during emergency this can also get disconnected and this can operate in your isolated or islanded or autonomous mode.

Now, in case of a DC bus we have all different type of sources that is DC distributed generations, AC distributed generation and SC that storage elements and, because it DC in nature the DC distributed generators can directly connected to DC bus through DC DC conversion. AC distributed generation can be connected to my DC bus through AC DC conversion.

And whereas, the storage element can be connected to my DC bus through bidirectional converter because, it may have to discharge its energy to the grid, when required as well as it has to charge as and when required so, that is what it means bidirectional conversion presence.

Now, in case of the AC grid similarly we so, have the grid is AC and, we have AC distributed generations. So, that can be connected to my AC bus. Similarly the DC distributed system can be distributed generation can be connected to my AC bus and, the storage element also can be connected to my AC bus.

Now, let us concentrate on the load side. Now, the loads can be either of DC and AC type. So, both DC loads as well as AC loads can be connected to my DC bus so, the DC loads can we catered directly whereas, the AC loads need to catered after DC AC conversion. Now, looking into the AC bus the loads could be AC and DC load.

And this AC load directly we converted here and, similarly we can have a conversion that is AC to DC and, then we can catered to the DC load. So, this option is also possible and we said that end of that both DC and AC bus will be connected through a inter linking convertor that is ILC. So, where the energy or the power exchange is possible from DC to AC type as well as AC to DC side. So, this conversation is possible to ILC's.

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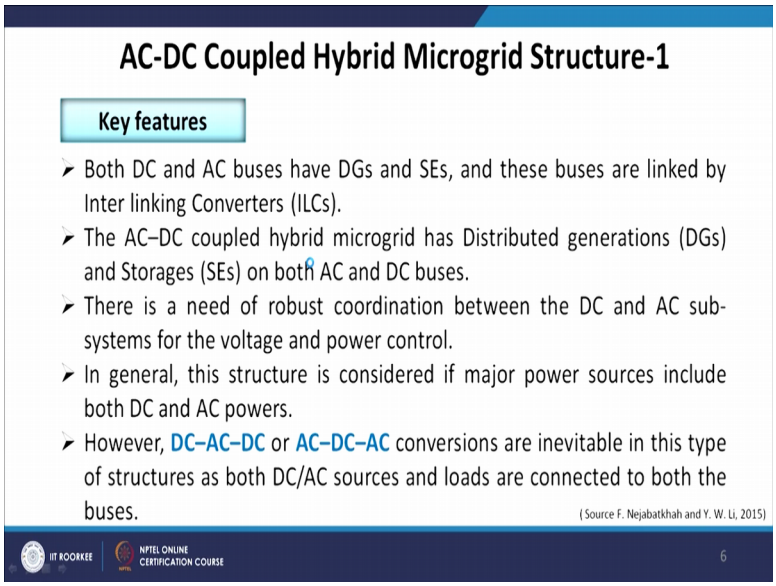

Now, in this structure one what are the key features? Both DC and AC buses have distributed generations, as well as storage elements and this buses are linked by interlinking converters that is ILC's. The AC DC coupled hybrid micro grid has distributed generations and, storage on both AC side as well as in the DC side. There is a need of robust coordination between the DC and AC subsystem, for the voltage and power control. In general this structure is considered, if major power sources include both DC and AC powers.

However, DC AC DC as well as AC DC AC conversions are invertible means you cannot avoid in this type of structure as both DC and AC sources and, loads are connected to both the buses. Because in the DC side you have DC AC loads, as well as DC AC generations or sources, along with storage. In case of AC grid, you have AC DC distributed generators, AC DC loads as well as you storage elements.

So, I mean the conversion from DC AC DC as well as AC DC AC is certainly cannot be avoided, but we can also imagine some structures of or the architectures of AC DC micro grids, or smart grids where we may connect all the DC sources to a DC bus and, all the AC sources to a AC bus and, very carefully we can distribute the loads DC load to the DC side and AC load to the AC side, that is one of the wonderful I mean the structure one can ever imagine.

If you could manage to connect all the DC source to DC grid, all the DC loads to the DC grid and, AC source to a AC grid and AC load to AC grid so; that means, both the grids are taking care of their own a common bus characteristics, for both generation load and the bus. If it is purely AC or purely DC and further they can be connected to ILC's where the exchange of power is possible as and when required, that is centrally an efficient way of imagining the smart grid structure.

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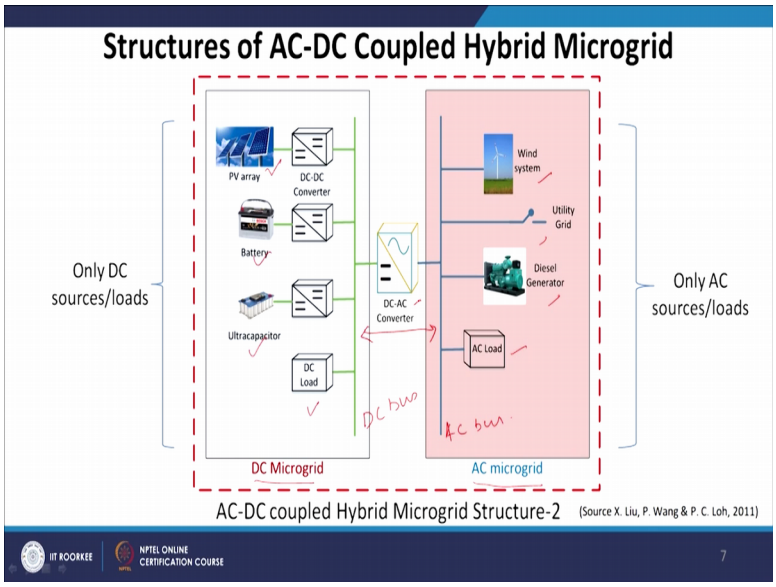

And this is another structure we call it is structure two where you all can see this is my DC micro grid, the left half and, the right half is my AC micro grid. And we can clearly observe that the PV battery, ultra-capacitor and DC loads all DC characteristic based generations and loads are connected to my DC bus.

Now, similarly if you look at the right side the AC micro grid all the AC loads, diesel generators, utility grid wind system, which are purely AC operational connected to my AC bus, an perhaps they have been inter linked through DC-AC conversions. And this is one of the very efficient structure, where we have DC one side and AC side previously, you have seen one more structure where AC bus can accommodate all types of generators as well as loads and DC bus also can accommodate all type of generations and load both the structures are very important.

Now, in case of structure 2 there are few merits that let us discuss, mainly AC sources and loads are connected to AC network whereas, DC sources and loads are tied up with the DC network.

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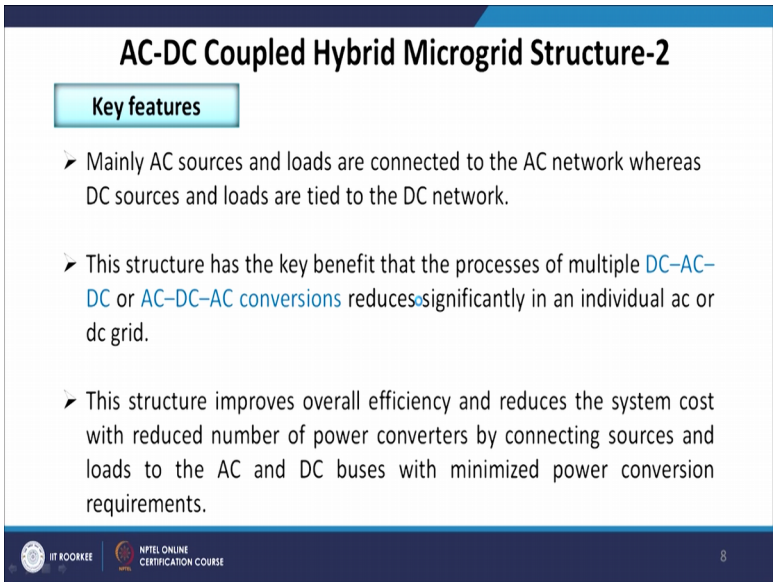

This structure has the key benefit that the process of multiple DC-AC-DC and AC-DC-AC conversion will certainly be reduced significantly, because of an individual AC and DC grid. This structure improves overall efficiency and, reduces the system cost with reduced number of power converters by connecting sources and loads to the AC and DC buses with minimized power conversion requirements. Now, slowly let us move in to the control strategies and power management schemes.

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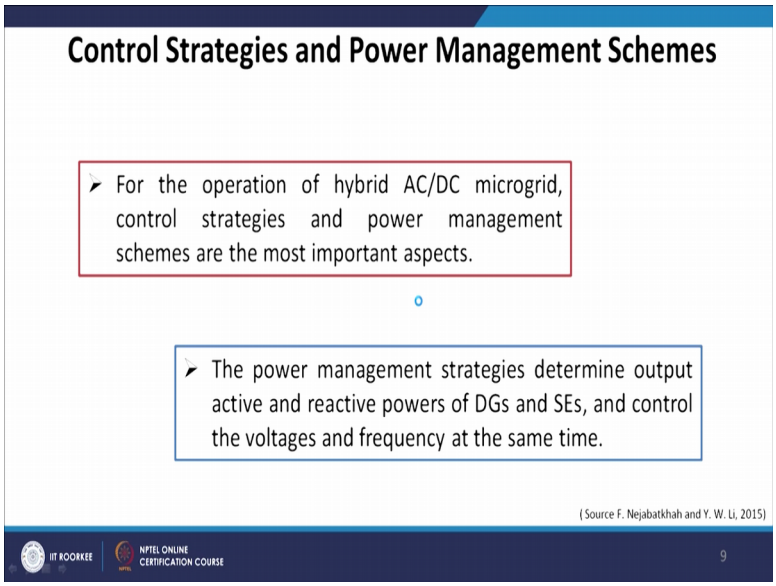

Now, for the operation of hybrid AC DC micro grid, control strategies and power management schemes are the most important aspects. The power management strategies determine output active and reactive power of the generators connected to my AC-DC grid, from the diesel generator and storage elements and, control the voltage and frequency at the same time.

Now, you see when we get into the DC side DC micro grid control operation, where we realize that the frequency element is missing. So, the droop characteristic need to be redesigned, in case of AC all options are possible to me, but in case of hybrid now have to see what would be my common control characteristic that can take care of both the grids simultaneously.

Now, what are the challenges that we do see, when we integrate both AC and DC smart grids together, we realize the benefit now the challenges. Due to the absence of global variable because, we do not have a common variable to take care of both DC and AC, which can be used for power sharing voltage and free voltage regulations, or frequency regulations.

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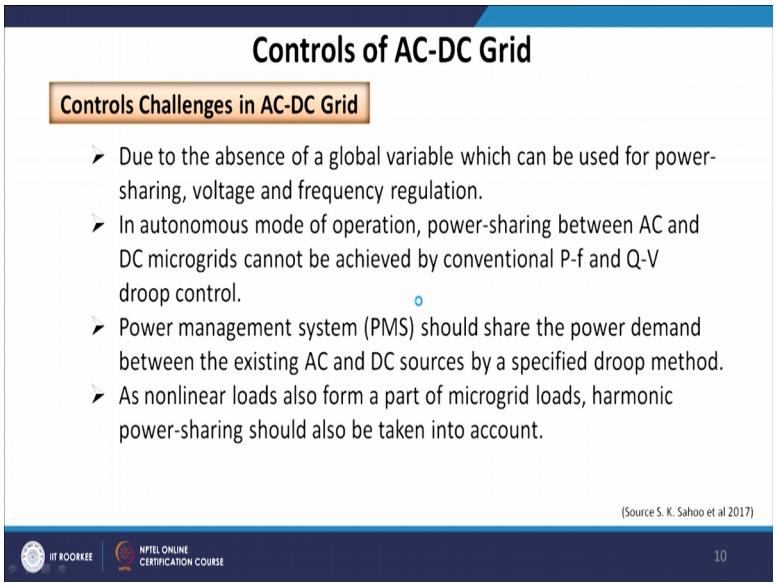

In autonomous mode of operation when it is islanded power sharing between AC and DC micro grids, cannot be achieved by conventional P-f or Q-V droop control characteristics. Power management system that is PMS should share the power demand between the existing AC and DC sources, by specified droop method. As non-linear loads are also part of this micro grid, harmonic power sharing should also be taken it account between the grids. A trade of between reactive power sharing and voltage regulation become important.

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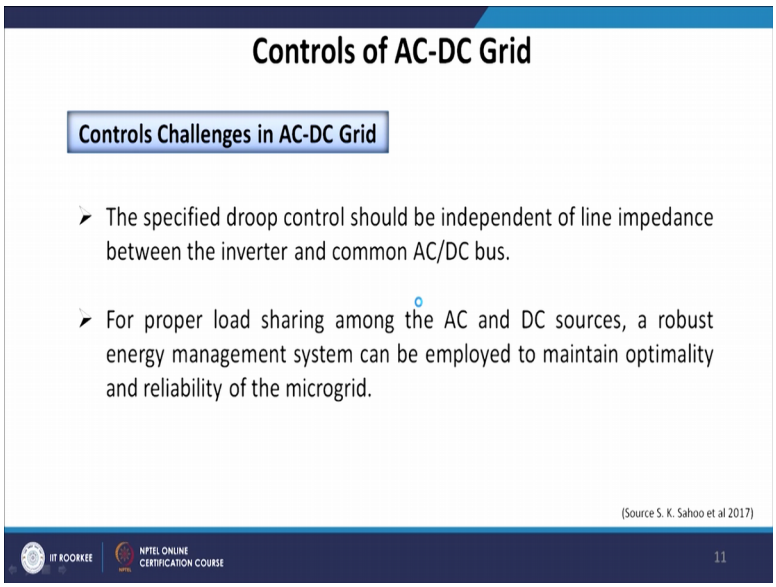

The specified droop control should be independent of line impedances between the inverter and the common AC-DC bus, for proper load sharing among the AC-DC sources, a robust energy management system can be employed to maintain optimality and reliability of the micro grid.

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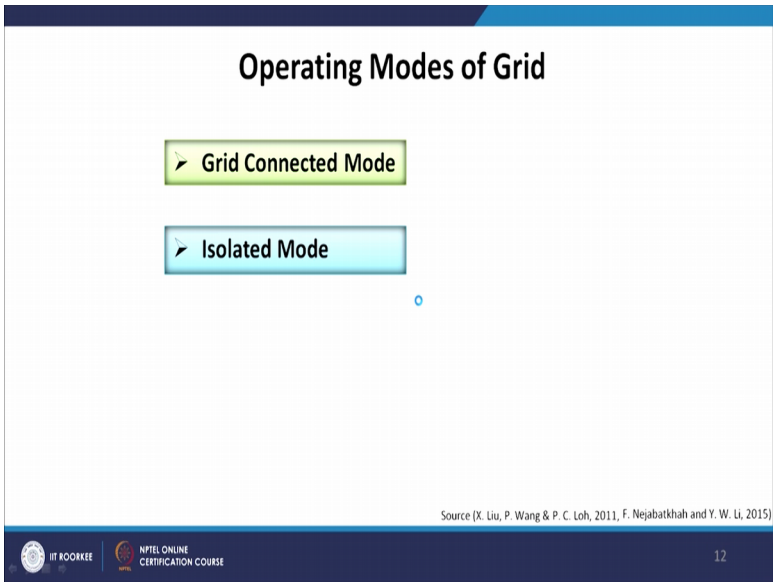

Now, let us see what are the operating modes of the grid there are two modes as we all know, one is grid connected the other one is isolated.

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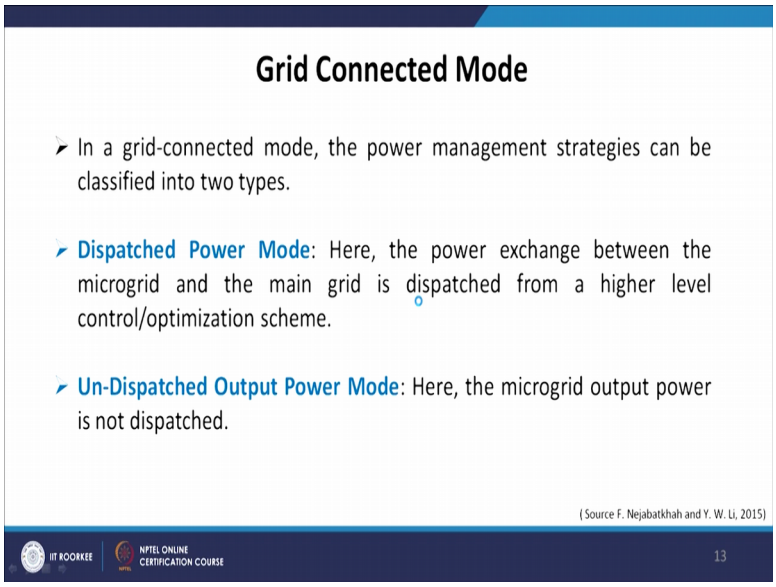

Now, in a grid connected mode the power management strategies can be classified in two ways, one is dispatched power mode and, the other one is un dispatched output power mode. Now, let us focus now imagine we have both AC and DC smart grid, or micro grid in place together and both AC-DC micro grid is now being connected to my utility, or the main grid.

Now, the power man in a strategies because, as and when the grid needs power, or we have excess power in your AC-DC smart grid that need to be given to my grid and, when it is shortage, or deficit then we need to take it from the main grid. Now, during that grid operation there are two challenges with me here.

Now, the main grid can use that AC-DC micro grid, as a you know component to get major benefits of it is own voltage control and frequency control mechanism. Let us say my system is suffering with loads my excess loads. So, I have time shortage of power so, I can take energy from the AC-DC micro grid. And similarly I am excess frequency and, I can give back to my micro grid for storage and charging them.

So, that is one way of so, where actually the generations of the AC-DC smart grid can be controlled, where is in case of un dispatched output power mode, we perhaps feel that we give all our energy operate all my generators in MPPT mode and, you know whenever you have excess power you try to feed the grid, you try to feed the grid.

So, the most important is dispatch power mode where you your generators of the AC-DC, as well as the storage they keep on varying to meet the grid requirement. And in case of un dispatched output power mode, where you do not do much you fix your generation at their MPPT mode and, keep on generating and if your loads are less, then you give to the grid. So, that is what both the methods are very commonly used.

Now, in dispatched power mode the power exchange between the micro grid and the main grid is dispatched from a higher level control, or optimizing scheme. Whereas, in case of un dispatched output power mode, the micro grid output power is not dispatched.

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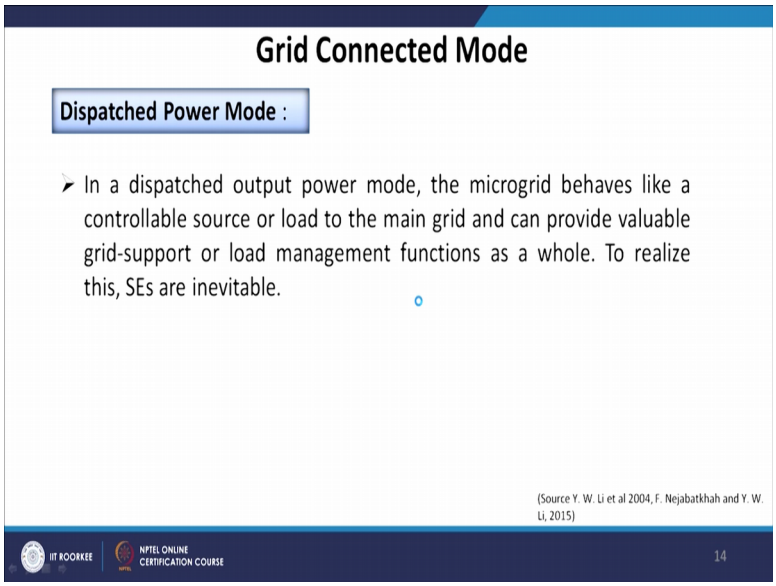

In case of dispatched power mode, the micro grid behaves like a controllable source or load to the main grid, as I mentioned earlier. All the loads or generators connected to my AC-DC hybrid micro grid act like a controllable source or a load.

So, that the main grid can provide I know that it can provide the valuable support to the main grid and, to realize this storage elements are invertible means. If you like to vary your generations as well as load of your AC-DC micro grid, to meet certain requirements of your main grid, then the storage has to be there, because all the variations because the discharging and charging of storage can perhaps meet out better requirement of your main grid.

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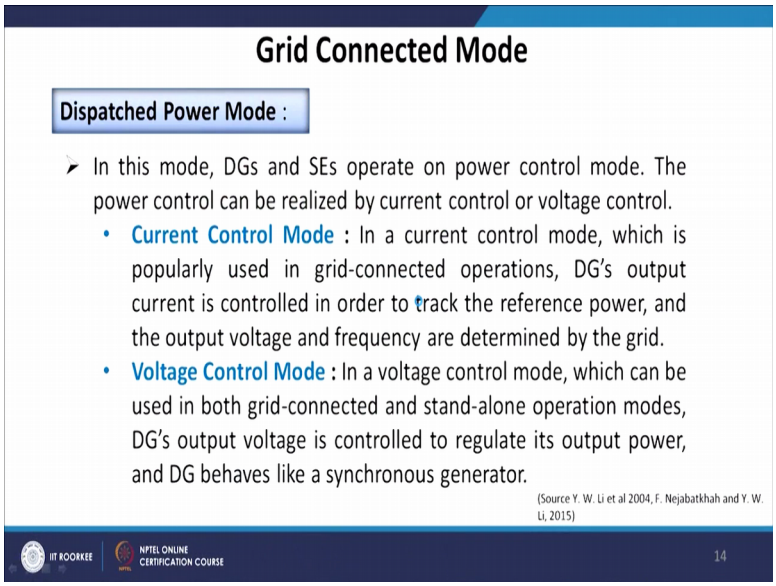

Now in case of a dispatched power mode, distributed generators and storage elements operate on power control mode. The power control can be realized by either current control, or voltage control. Now, in case of current control mode, which is popularly used in grid connected operations, distributed generator output current is controlled, in order to track the reference power and the output voltage and frequency are determined by the main grid.

Now, let us move to the voltage control mode, in a voltage control mode which can be used in both grid connected as well as in islanded operation, distributed generators output voltage is controlled, to regulate it is output power and distributed generators behave like a synchronous generator to me.

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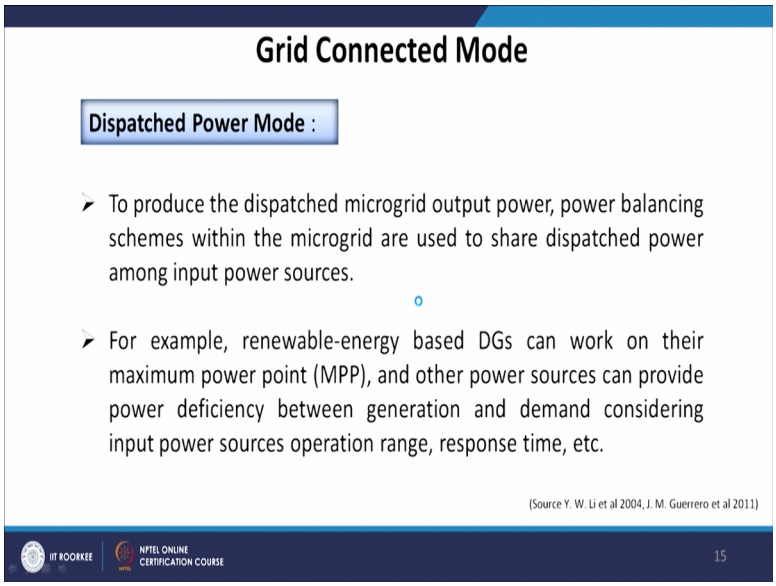

Now, to produce that dispatched micro grid output power power balance schemes within the micro grid, or used to share dispatched power among input power sources.

For example renewable energy based distributed generators can work, on their maximum power point MPP, and other power sources can provide power deficiency between generations and demand, considering input power sources operating range response time etcetera. Means to highlight in case of AC DC micro grid, you can control your generations, to meet your main grid requirements, or you can operate them in constant, or MPPT mode to simply cater to the grid, or exchange your energy if it is excess.

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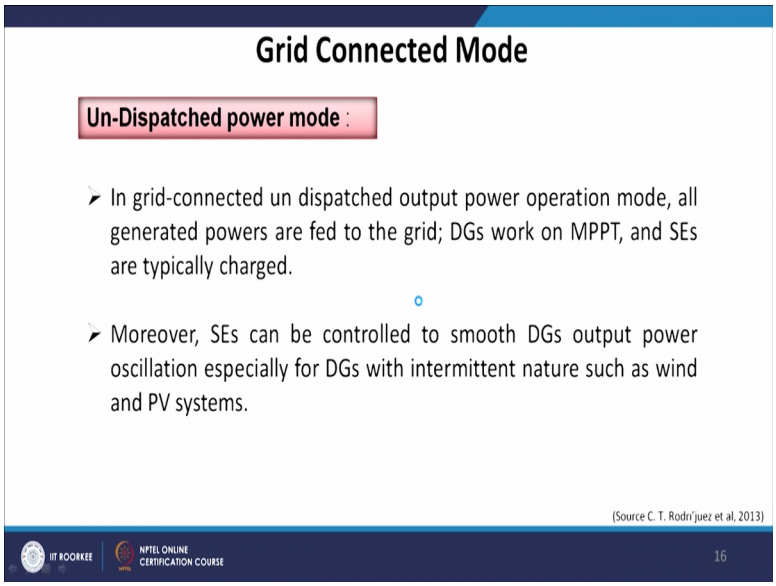

Now, in case of un dispatched power mode, I mean the generations are not despicable, or frequently varying, in grid connected un dispatched output power operation mode, all generated powers are fed to the power grid, whatever the power you generated that all will be fed to the grid. Distributed generation work on MPPT and storage elements are typically charged storage elements are typically charged.

So, you generate charge your storage and exchange it to your grid that is what you do, but in case of a dispatched power mode, where actually you keep on controlling your generators even within the AC-DC micro grid. So, that the standard so, the voltage regulation of the main grid can be obtain and, sometime if you like to vary your loads within the AC-DC micro grid is also possible.

More over the storage elements can be controlled to smooth distributed generators output power oscillation, especially for distributed generations with intermitted nature such as wind and PV systems.

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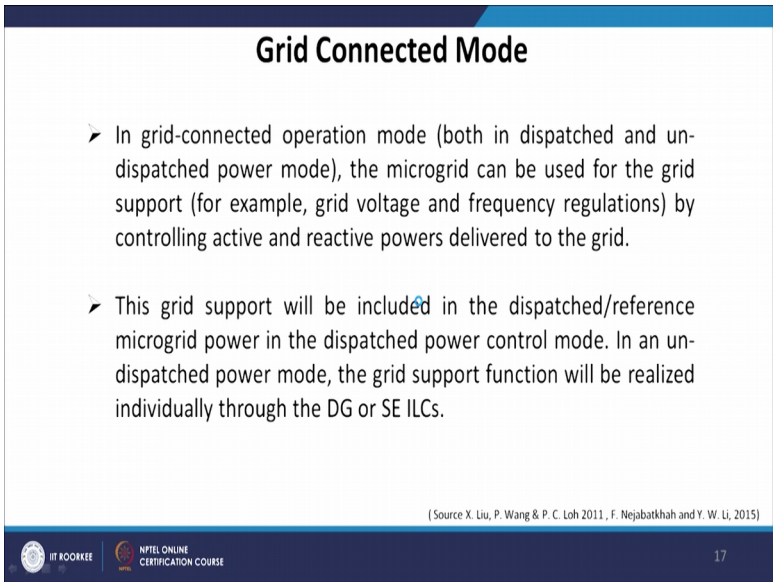

In grid connected operation mode both in dispatched and un dispatched power mode, the micro grid can be used for the grid support. The micro grid will be will be connected to the main grid as a grid support for example, grid voltage and frequency regulation means, it is basically supporting the grid.

By controlling active and reactive power delivered to the grid, means the micro grid can complement to the main grid by controlling it is real and reactive power injection to the grid. So, the voltage and frequency regulation can be achieved, as desired by the main grid very important.

This grid support will be included in the dispatched reference micro grid power, in the dispatched power controlled mode in an un dispatched power mode, the grid support function will be realized individually through the distributed generators, or storage elements, or inter linked convertors. Now, let us focus on the role of individual devices in a grid connected mode and that we will discuss during the next lecture.

Thank you.