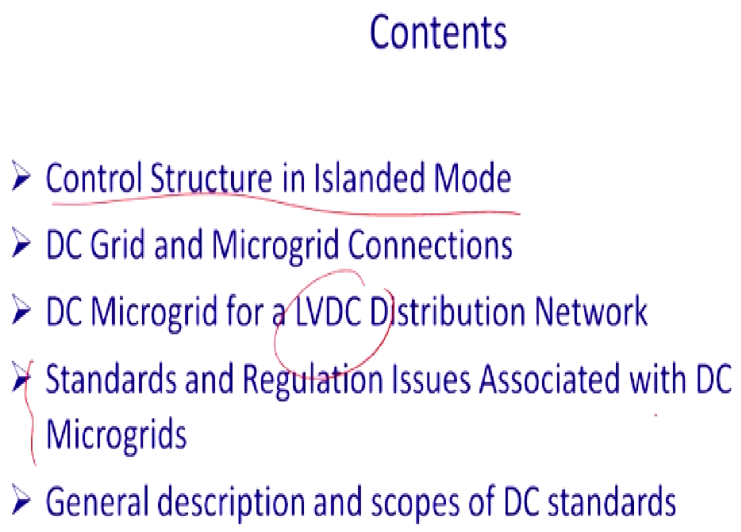
DC Microgrid and Control System
Prof. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology – Roorkee

Lecture - 19
Microgrid Operation Modes and Standards
Part – II

Welcome to our NPTEL lectures on DC Microgrid and the Control. Today we shall discuss about microgrid operations modes and its standard that we have already discussed, this is going to be our second lectures.

(Refer Slide Time: 00:52)



We shall first, these are our presentation layout today. Control structure in islanding mode, we shall discuss about detail with the islanding mode; and DC and the microgrid connections and its interconnections, we shall discuss and revisit it. Then DC microgrid for low voltage DC distribution network, that is the same we shall go back to the days of the DGs transmissions and we shall see the problems of it and then we will revisit the problem and its present context and we required to standardize it.

So far this is standard and regulation issues because you know that actually every country has a grid code. So when you are operating the microgrid, we required to have some kind of standard. So standard and the regulation issues with the DC microgrid, also some evolving area, IEEE, setting up the research standard, some industrial bureau has to stand set up the industry standard as well, and the general descriptions and the scope of the DC standard, that we shall see. This will be our scope of discussions today.

(Refer Slide Time: 01:57)

Control Structure in Islanded Mode

- In islanded operation mode, a DG must feed the µG with predefined values for the system voltage and frequency variables.
- In order to generate AC voltages, AC capacitors are required and so an LCL filter is used for the grid connection as illustrated in Fig.1.
- With this structure, control strategy of grid-side converter can control the voltage and the frequency at the PCC and can emulate the behavior of a synchronous machine.

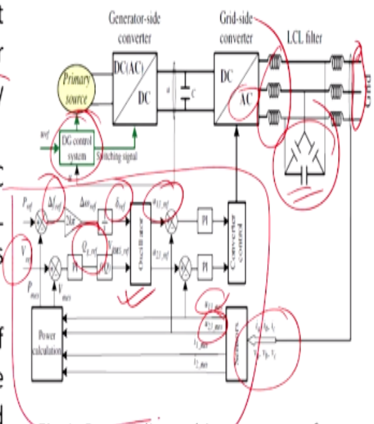


Fig.1: Power dispatching strategy of a gas microturbine for a VSI control.

Now first of all, let us take at the islanding mode, the control structure is islanding mode. This is a primary source and you have a that can be solar or wind and that is this is this part is a DC control system and then you have a DC to DC, AC to DC converter. If the solar, it is DC to DC; if it is a wind, then it is AC to DC generator-side converter and you will sense the input variables and really to have a back to back converter and you have a DC to AC converter with the grid-side inverter.

Then you have the LC filter to filter out the ripples because essentially this is a PWM inverter, that will eliminate the high frequency from this AC signals and this is a grid and from the grid, you will sense the various voltage and current by the senses and from there, you will calculate the reference power Pref. It will come and if you are getting the Pref, then of course there will be a drooping problem.

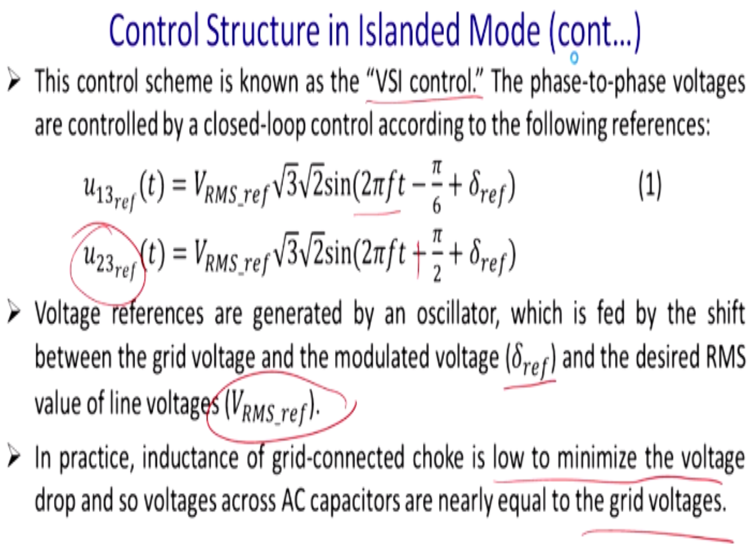
So ultimately, error will be the frequency we will consider, and it will multiply with the constant and thus you make the omega and this omega will require to be integrated and ultimately that becomes your delta ref. Similarly, if you have a voltage sag or soiling problem, then you require to control by mainly reactive power. Generally if you have a problem in frequency, you try to control with the real power.

So Vref minus uh minus V reference measured you got a reference reactive power and thus it will be a function of the V RMS reference and this oscillator will generate this actually voltage signals fall this for this PWM converter that is and that will be feed to the converter output, and in that way, you will try to manage both voltage and the frequency and in that way, you will control the actually reactive power and the real power. In that let us see how does it work, this is the descriptions of it.

In islanding operation mode, distribution generator must feed the microgrid with the predefined values because you may have a critical load or some other load or whatever may be, so you have to feed that for the system voltage and the frequency variable. In order to generate the AC voltage, AC capacitor required for an LCL filter used for the grid connection as illustrated in the figure, this, this will actually is required to feed this, you know this you can see that it is qgref, so this will be the source of this reactive power and also it will act as a filter.

With the structure of the control strategy of the grid-side converter can control the voltage and the frequency at the PCC, that is PCC is the point of common coupling, this point is specifically the PCC and can emulate the behavior of the synchronous machines. So, we have to emulate the behavior of the synchronous generator that will be feeding power, so same characteristics has to be done here.

(Refer Slide Time: 05:57)

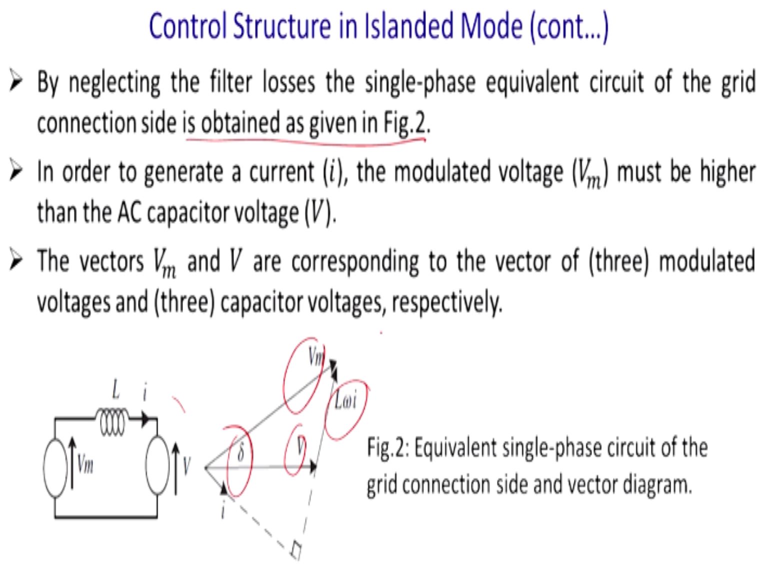


The control system is known as VSI control or voltage source inverter control. The phase-to-phase voltage control by a closed-loop control according to the following reference. Please go back, so these are the voltage reference u13 and u23 what has been shown here. So here, you u13 measures and u23 measures. Here, this is a basically the line voltage between 1 and 3 and this is line voltage between 2 and 3, so this is it rest of and this is a line current between this I1 and I2.

So you want the reference it should be you know VRMS x root 3 x root 2 sine 2 pi – pi/6 and similarly u23 reference will be VRMS x root 3 x root 2 2 pi x + pi/2 + vd reference. So, the voltage reference are generated by the oscillators, so that is, frequency to voltage converter will be there, so that will essentially generate the voltage difference, these oscillators, which fed with the fresh sheet between the grid voltage and the modulated voltage delta ref and the desired value of the line voltage or the VRMS ref.

In practice, generally the inductance of the grid-connected choke is to minimize the voltage drop and so the voltage across the AC capacitor is nearly equal to the grid voltage. So this inductor required is to be very low in size, so the drop across this is quite negligible.

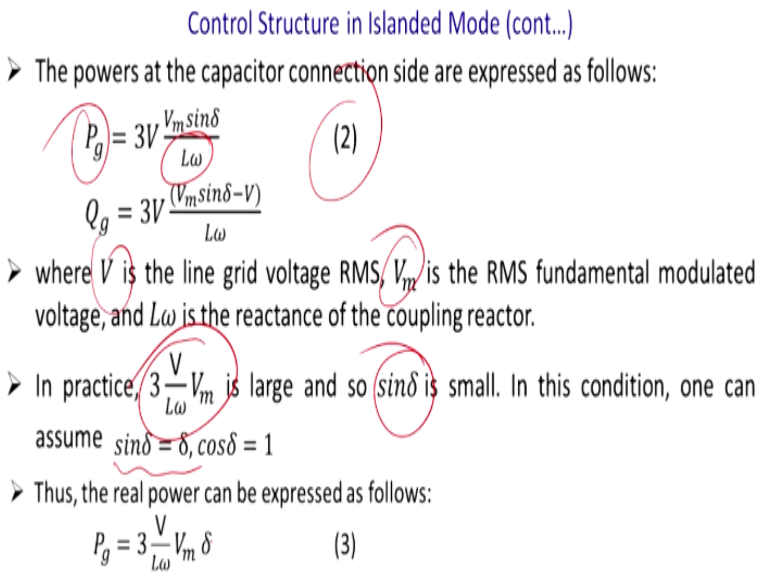
(Refer Slide Time: 07:55)



Now by neglecting the filter losses, the single-phase equivalent circuit of the grid connection side can be obtained as shown in Figure 2, this is the figure 2. So, you got VSI that has been shown here as Vm, there is inductor, you have a current and this is the grid and this is Vm, this is Lx omega, and this is V, and this is the angle delta in between. So neglecting the filter losses in the single-phase equivalent circuit of the grid connections side is obtained as shown in the figure 2.

In order to generate current i and the modulated voltage Vm must be higher than the capacitor voltage VC. So we have to see that this value Vm required to be little higher and required to be also phase shifted. The vector Vm and V corresponding to the vector of the 3 modulated voltages and the 3 capacitor voltages respectively.

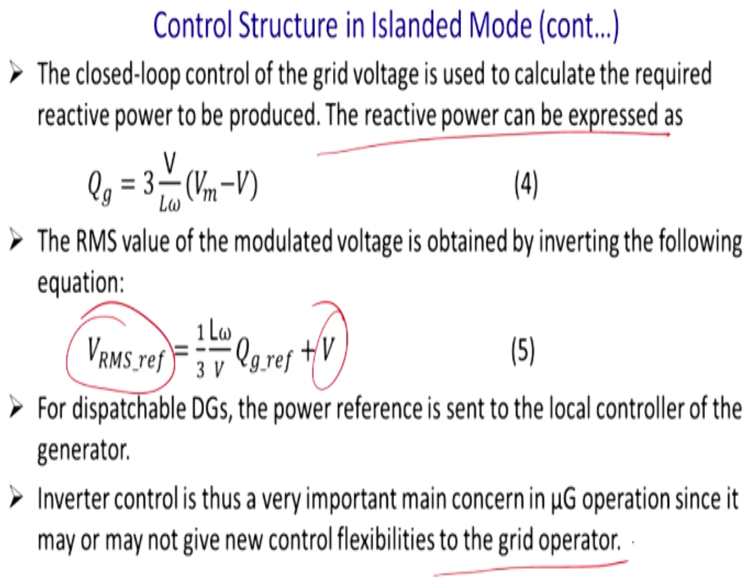
(Refer Slide Time: 09:01)



Now so the power at the capacitor connections can be expressed as, so this is basically the real power Pg, so that is actually 3V Vm sine delta/X where X is represented by L x omega. Similarly for Qg will be 3V Vm sine delta – V/X where V capital V is the grid line voltage in RMS, all the values are in RMS here, and VM is the fundamental of the modulated voltage because you know that it can be a uh it can have a space vector modulation on different kind of voltages you can inject.

And ultimately its fundamental is considered as VM and Lw is the reactance of the coupling inductor or reactor, and in practice, this value 3 omega L VM is large and so that sine delta is also small in this condition, then we can replace so for this we know that that from the for delta equal to 4 degree, sine delta can be represented delta and cos delta is 1. So this substitution if we make, so ultimately the equation 2 takes the shape of the equation 3, so ultimately Pg = 3 V by 3 V/LW Vm delta.

(Refer Slide Time: 10:47)

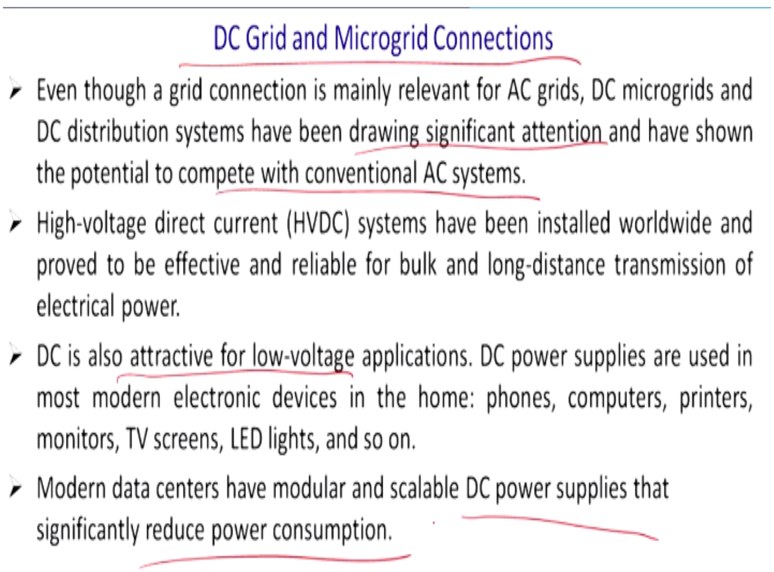


So the closed-loop control of the grid voltage is used to calculate the required reactive power to be produced, so that while there is a sag and all those things, I have told you that we required to control the reactive power. So the reactive power also can be expressed as follows and so 3 VM/LW Vm-V. The RMS value of the fundamental voltage is obtained by inverting the following equation.

So V reference what you require to generate is 1/3 LW/V Qg reference + V where V is the RMS voltage of the grid. So for dispatchable distributed generations, the power reference sent to the local control of the generator, please go back to the figure number 1, so this is the local control, all set, so sensors and all set is the local control, local control of the generator. The inverter control is thus a very important concern of microgrid operations since it may or may not give a new control flexibility of the grid operator.

So that is something we require to be consistent with the grid code and other parameter, so that we can control the power. So there are many issues related to the power quality, like how much sags and soil required to connect to the grid and how much interruption you will tolerate, when you will call it interruption, all the power quality issues will come into the picture while operating this solar inverter.

(Refer Slide Time: 12:56)



Now the connections, DC grid and microgrid connections. So you got a one DC grid and another you got a solar inverter, that is essentially a microgrid having an AC source. Even though a grid connection is mainly relevant for the AC grids, DC microgrid and the DC distribution systems have been drawing significant attention because of the loads, nowadays many loads are DC and for this reason and many sources are AC because we have converted the AC to DC, thereafter DC to AC.

So this conversion is no longer required in case of the solar, maybe you can have a it can have a DC to DC converter and have shown the potential to compete with the conventional AC system. High-voltage direct current, HVDC system, has been installed so because we have seen that power losses in the AC system is more than the HVDC, installed worldwide and proved to be the very effective and the reliable for the bulk and a long distance transmission line for the electric power.

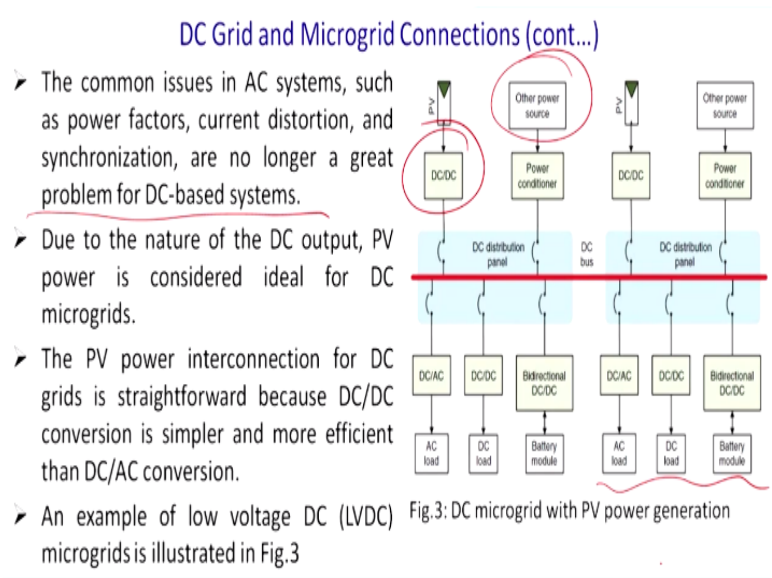
Since you know actually we had, let us take in case of the India, generally we have a fuel based sources that is coal in eastern region and we required to ultimately what happened, and for past 20 years, load centers are shifted in Bangalore, Hyderabad in that side, on the southern side. So it has been found that instead of transporting coal, transporting the power is beneficial if you have HVDC transformer and same thing it is observed throughout the world, and for this reason, DC power has been dispatched in the bulk with a very high voltage or extra high-voltage DC transmission.

Let us come to the smaller DC sources. DC is also attractive for the low voltage applications.

DC power supplies are used in most of the modern electronic devices in home; for example your mobile phones, computer, printers, monitors, TV screen, LED lights and so on we can have, we have seen everything almost there are DC those were consumed low amount of power.

Moreover, modern data centre have modular and scalable DC power supplies because we are storing huge amount of digital data and we are putting almost every day gigabytes amount on the memory devices and that require a DC supply and that DC supply can be huge and that can be directly fed from the solar and thus intermediate conversion is not required; for this reason, DC power supply that significantly reduce the power consumption because every conversion, you have to pay the penalty.

(Refer Slide Time: 16:04)



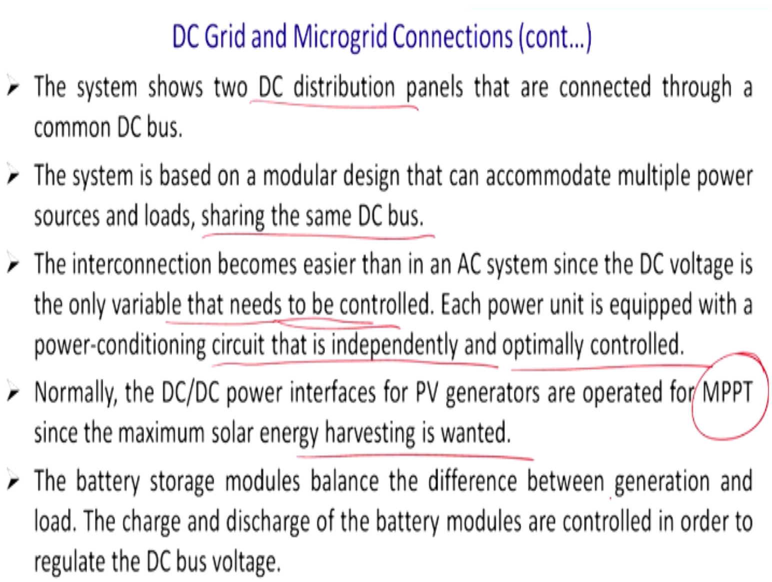
Now we shall continue with the grid and the microgrid connections. See that this figure 3, we have a PV, we have DC to DC converter, why to track mainly this voltage because solar panel essentially are the variable DC source depending on its irradiation and the temperature and thus required to kept at a constant voltage and also it required to track the maximum power point, and for the season, you require to have a DC to DC converter.

You may have any other power sources, for example, fuel cell or batteries or whatever may be, and that required to be configured with the same DC bus level and thus you require a power conditioner and thereafter you have a DC distribution panel. Thereafter you may have a AC load, and for this reason you require an inverter. You may have a DC load and you also have a battery, that is a bi-directional DC to DC convertor, same way for the second microgrid. So this is the structures of 2 DC bus.

So common issues in AC system such as power, THD total harmonic distortion or the current distortion, voltage distortion, synchronizations are no longer a great problem in DC bus system, that is one of the major advantages in synchronization. Due to the nature of the DC output, PV power is considered ideal for the DC microgrids because DC because microgrid, the solar panel generates DC.

The PV power interconnection the DC grids is signi is straightforward because DC to DC conversion is simple and more reliable than DC to AC conversion because you in between you require an inverter and filters all those things make something bulky. For example, a low voltage DC that is LVDC microgrid has been illustrated and we have described it here.

(Refer Slide Time:18:31)



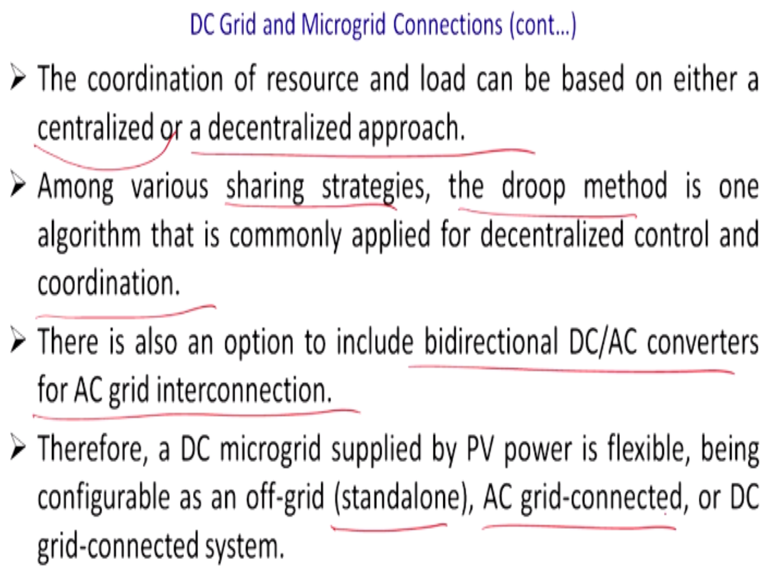
The system shows 2 DC distribution panels that connects to the common DC bus, we can have a different kind of architecture of the DC microgrid. The system is based on the modular design and that can accommodate multiple power sources, loads, sharing, and sharing the same DC bus. The interconnections become easier than an AC system since the DC voltage is only variable that needs to be controlled, so that is you require a frequ, you have seen you require a frequency, you require power, you require reactive power.

There are so many variables are there, but in this case only you require to control only the DC voltage. Each power equip power units is equipped with the power-conditioning circuits because the input to the power-conditioning circuits and the DC bus voltage may be different and for this reason you require to have some kind of processing before connecting to the DC bus, otherwise power will flow in between them.

Each power unit is equipped with the power-conditioning unit and that is independently and optimally controlled, and you have a different kind of control structures also, here this model has been shown that is independent control. Normally, the DC to DC power interface for the PV generators are operated for maximum power point tracking that is MPPT since the maximum solar power energy is harvesting is wanted.

The battery storage modules balance the difference between because the peak of the generations and the peak of the demand does not coincides and also the mismatch between the generations, instantaneous mismatch between the generations and the output, and for this reason, battery storage module balance difference between the generations and the load, the charge and the discharge, and the discharge of the battery modules are controlled in order to regulate the DC bus voltage.

(Refer Slide Time: 21:04)

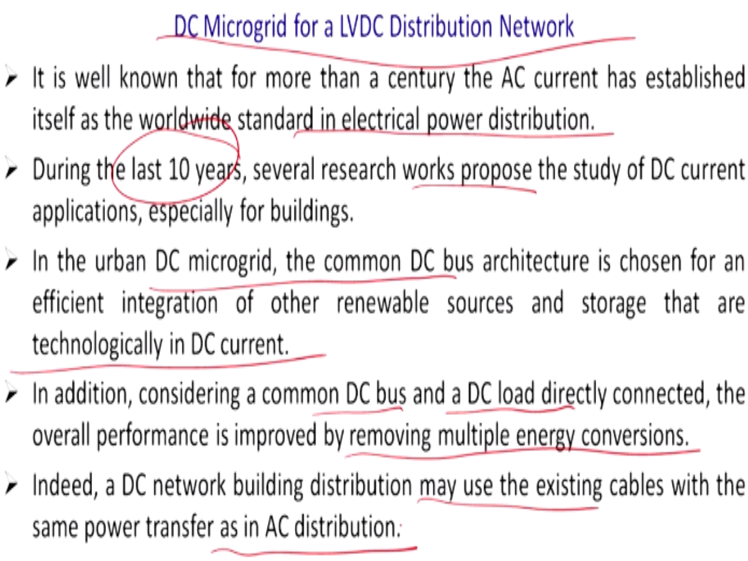


The coordination of source and load can be based on either centralized and the decentralized approach. So there is a coordination between the different kind of sources that can be done from the central level, so how to have a load shedding, how to generate power or you may have a parallel operation that is called decentralized approach, and among the various sharing strategies, the droop control method.

We have studied the droop control method for the synchronous generator that is for the frequency, you have seen that frequency generally droops, increases or decreases by changing the demand if there is a mismatch between the generations and the production; the same strategy, but here there will be a voltage droop only, not frequency. The droop method is one algorithm that is commonly applied for the decentralized coordination because voltage group essentially will tell you that what kind of situation is there whether load is more or generation is more.

There is an another option, there is also an option to include bidirectional and DC to AC converter for the AC grid interconnections and some portion of the grid may have the interface with the grid, main grid, or the microgrid with the DC to AC interface. Therefore, AC microgrids supplied by the PV is flexible, being configurable as an off-grid or the standalone, AC grid-connected, or DC-grid connected system.

(Refer Slide Time: 23:10)



Now let us talk about little bit DC microgrid for the low voltage distribution network. Mind it when we are considering when you are talking about microgrid it is a low voltage, it is not the HVDC. It is well known that for more than a century, it was a famous battle between Edison and the Tesla and ultimately Edison won the battle, sorry Tesla won the battle because of the flexibility of the AC network.

It is well known that for more than a century, AC current has established itself as a worldwide standard in electrical power distribution, but during last 10 years, the game-changers has come and ultimately Edison seemed to be tilted, but of course with the help of the power electronics since we have a very fast accurate Dc to DC converter. Several research work proposes the study of DC applications especially the building, ships, and many other applications where storage elements are battery, they are DC.

You have a solar that is a one of the worst source of the renewable energy in countries like India. So for this reason in this 10 year, the situation has changed once we are looking for a shift from the looking shift from this conventional power, fuel cell to the renewable sources. The urban DC microgrid, the common DC bus architecture, is chosen for an efficient integration of other renewable source and the storage that are technologically the DC currents.

So, solar is DC current, you have a LED, you know a storage element; these are all D. In addition considering a common DC bus and the DC load directly connected, the overall performance is improved by removing multiple energy conversion. So that is something is a problem of the AC microgrid because you have a laptop charger, you have a mobile charger, all are essentially very low efficient devices, it is because that you require multiple energy conversion.

Indeed, a DC Network building distribution may use the existing cables with the same power transfer as the AC distribution. We shall show you that actually power handling capability of the DC power is more than the AC power.

(Refer Slide Time: 26:31)

DC Microgrid for a LVDC Distribution Network (cont...)

- The DC bus can directly supply many building appliances (lighting, ventilation, electronic office equipment, etc.) as well as an electric vehicle.
- An example of a building-integrated microgrid system, in grid connection operating mode, is presented in Fig.4.
- PV generators, electricity storage, public grid connection, and electric building loads are coupled, through their dedicated converters, on a common DC bus.

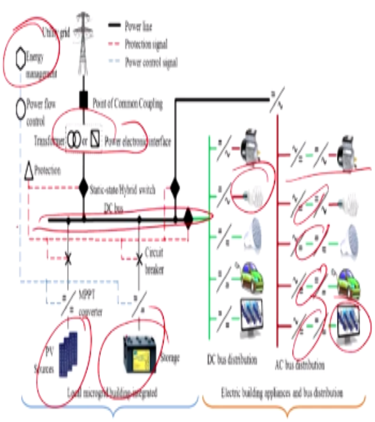


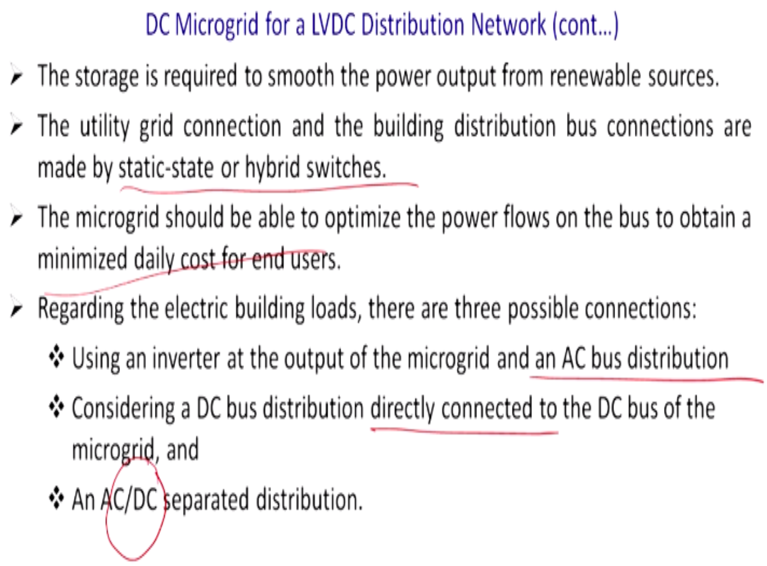
Fig.4 Example of building-integrated microgrid system

So DC bus can directly supply, so this is something that we require to understand. You have a utility grid, you have energy management but only it is done in a central level, there is a power flow control. So you got a point of common coupling, this is PCC, thereafter you got a transformer or power electronic interface, thereafter you got a static hybrid switches of the DC bus, then you have a solar control that is essentially a DC to DC converter, and protection part has to be incorporated; protection is little bit difficult because DC doesn't have a natural zero crossing.

You have a bi-directional DC to DC converter because of the storage, that is a battery, and ultimately you have a plenty of cases where you know you have a DC, DC to AC conversion and you have fitting to the drives, DC to AC conversion, you are fitting to the LED valve or CFL, you are charging the car and other thing and you may have, you may make it actually DC to AC and you can directly feed into this drives.

So you can see that electric building appliances of bus distribution where multi, where intermittently there is all having a DC to DC stage and some extent you have also the this DC to AC stage like this is the LED TVs. So for example, a building integrated in a microgrid system which has been described in a figure 4, the grid connections in operation mode is presented in the 4. The PV generation, electricity storage, public grid connections, and the electric building loads are coupled, though they are dedicated converters to a common D bus, this is the common DC bus.

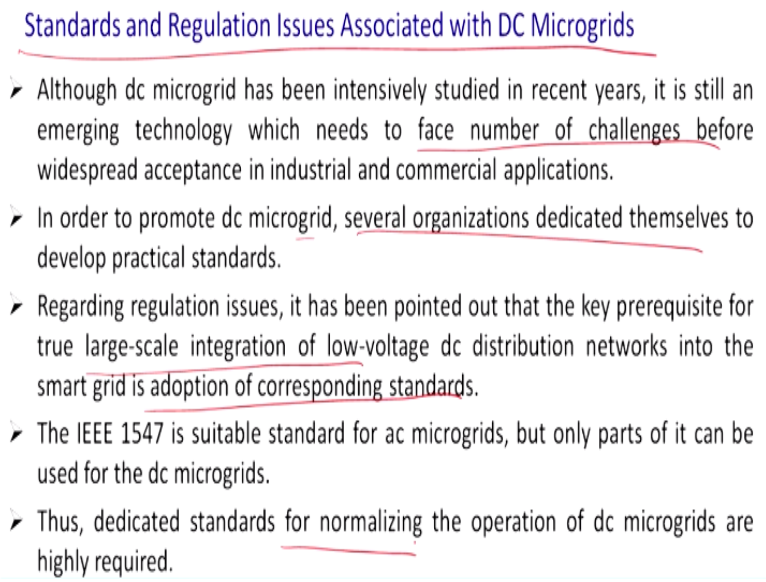
(Refer Slide Time: 28:34)



So, storage is required to smooth the power output from the renewable sources. The utility grid connections and the building distribution bus connections are made by the static-state or hybrid switches. Microgrids should be able to optimize the power flow on the bus, power flow on the bus to obtain to minimize the losses to the end users. Regarding the electric building loads, there are 3 possible connections.

One using an inverter at an output of the microgrid and the AC bus distributions, considering the DC bus distribution directly connected to the DC bus to the microgrid, and there is a separate an AC to DC separate distribution system. So these are the possibility.

(Refer Slide Time: 29:33)



So considering that, we have to design the standard and the regulations of the DC microgrid. So although DC microgrid has been intensively studied in the recent years, it is still an emerging technology, which is all research topic now, which needs to face the number of challenges before widespread acceptance in the industrial and the commercial appliances. In order to promote the microgrid, several organizations dedicated themselves to develop particular practical standards.

Regarding the regulations issues, it has been pointed that the key prerequisites for the large-scale integration of the low-voltage DC networks into the smart grid is adoptions corresponding to the standards. For this reason, IEEE came out as standard, that is IEEE 1547, suitable standard for the AC microgrid, but only the part it can be used for the DC microgrid, so it is also evolving.

Thus dedicated standard for normalizing the operations of the DC microgrid is highly required. So, IEEE has to come out for the dedicated DC microgrid standard.

(Refer Slide Time: 30:48)

General description and scopes of DC standards

Standards	Description	Scope
ESTI EN 300 132-3-1	Power supply interface at the input to data/telecom equipment Subpart 1 of Part 3: Direct current up to 400 V.	❖ Designed for data/telecom equipment ❖ For voltage levels of up to 400V
Emerge Alliance dcμG	Standards for occupied spaces and data center	❖ Recommended architecture and control system in dcμG
IEEE 946	Recommended practice for the design of dc auxiliary power systems for generating stations.	❖ Normalize the operation regarding batteries, e.g., sizing, determination of duty cycle, maintenance. ❖ Typical architecture of dc systems. ❖ Voltage rating of dc equipment

So these are the actually overall bird's eye view, this is a standard, that is EN 30112, that is description specifically power supply interface and the input to the detect telecom and support 1 2 part number 3, direct connection up to 400 volt, and here this can be applied to the data storage and the telecom and up to the different voltage level of 400 volt and imagine appliances of a DC microgrid standard occupied for the spaces and the data centers.

Same thing recommended architecture and the control system the DC microgrid. IEEE 964, 946 recommended to practice the design of the DC auxiliary power system for generating stations. So these are different scope normalizing operation regarding batteries, thereafter its maintenance, duty cycle, typical architecture of the DC system, and the voltage rating of the DC equipment, this will come under this IEEE standard.

(Refer Slide Time: 31:59)

General description and scopes of DC standards

Standards	Description	Scope
IEC SG4	LVDC distribution system up to 1500 V	❖ Coordinate the standardization of different areas, e.g., data centers, commercial buildings ❖ Energy, EMC, reduction of natural resources ❖ Life cycle of equipment, protection and grounding
IEEE DC@Home	DC-powered house	❖ Standard and roadmap of applying LVDC MG in residential houses ❖ Evaluation of losses using dc power at home
REbus	Open standard for clean power distribution relying on dc	❖ Operate alongside with existing ac system. ❖ Hybrid coordination of on-site renewable energy generation ❖ 380 V dc common bus with acceptable variation based on the status of the source, load and energy storage

So another few standards also there, that is IEC standard, that is for the little higher voltage, that is five 1500 volt, and that is also the coordination control between the data centers and the commercial buildings and also the EMI MC issues, and life cycle of the equipment protection and the grounding and IEEE DC home, this is a DC powerhouse, and that is for the low voltage microgrid for the residential houses and Rebus open standard clean power distribution relying on the DC.

So it has 380 volt DC bus that is very important with the acceptable variation based on the status of the source load and the energy storage. So these are the few standard, you can refer to this standard in detail for your own study. Thank you for your attention. I will continue with this DC microgrid applications in our next classes. Thank you.