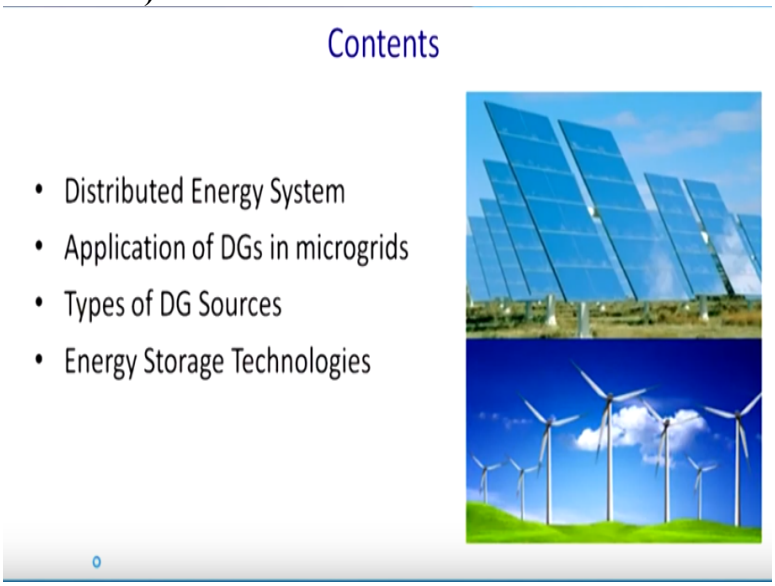
DC Microgrid and Control System
Prof. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology-Roorkee

Lecture - 03
Microgrid and Distributed Generation

Welcome to our NPTEL lecture on DC microgrid system. Today we shall cover the microgrid and its distribution generation. So one of the major development in modern decade or the past two decade are the solar energy penetrations and due to that distributed energy system predominates.

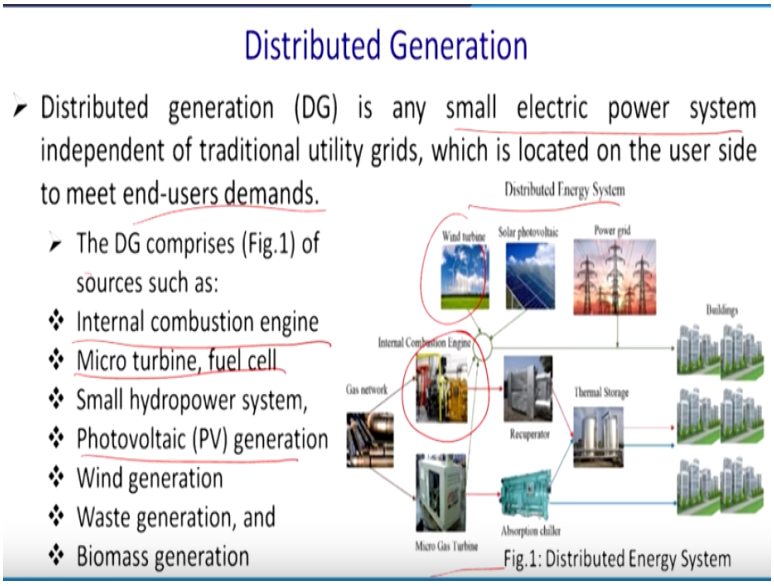
(Refer Slide Time: 00:55)



You can have a rooftop solar system, you have the part curving solar system. There are so many solar system and microturbine and the wind turbine system that can be your distributed generation. And thereafter we will see that its application in the distributed generation in microgrids. How it can be made for each other or they are quite applicable as a DC source.

Types of the distributed sources that we will discuss and the we shall find that energy storage technologies because solar is not available throughout the all over the time. So for this reason we require to have a storage element.

(Refer Slide Time: 01:35)



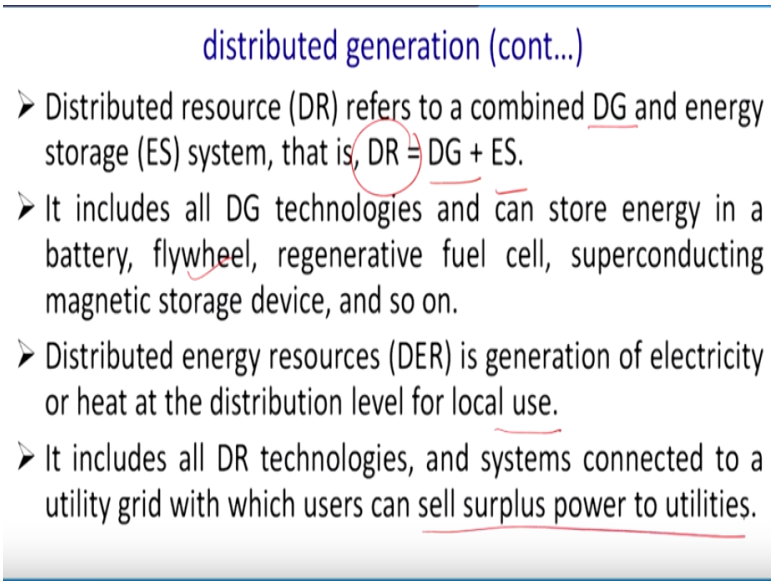
So distributed generation is any small electric power system generally in case of the since we are talking about the microgrid of course we can have a megawatt level solar power plant but that is not a criteria. Here we have a small tiny solar power plant. Small electrical power system independent of the traditional utility grids which is located at the user side to meet the users end demand.

That can be a isolated island, that can be a ship, it can be anything. So DG comprises of the following thing. You may have a internal combustion engine as a diesel generator as a backup. We are gradually facing off this entity considering that increasing the carbon footprint and everything. Microturbine and the fuel cell. Small hydro power system, small or micro. Solar photovoltaic generations.

Wind generation, waste generation, and the biomass generation. So and this is the distributed energy system. You have a wind, you have a solar and maybe you are connected to the grid historical and thus you have a grid and it may have a failure and you require to make the contingency like hospitals. Or this is a internal combustion engine and you can have a thermal stage also for the refractor and chiller thereafter micro gas turbine all can come and contribute as your distributed energy system.

But predominantly since we are going towards the grain solar wind and micro hydro thereafter waste generation and biomass are the contributors.

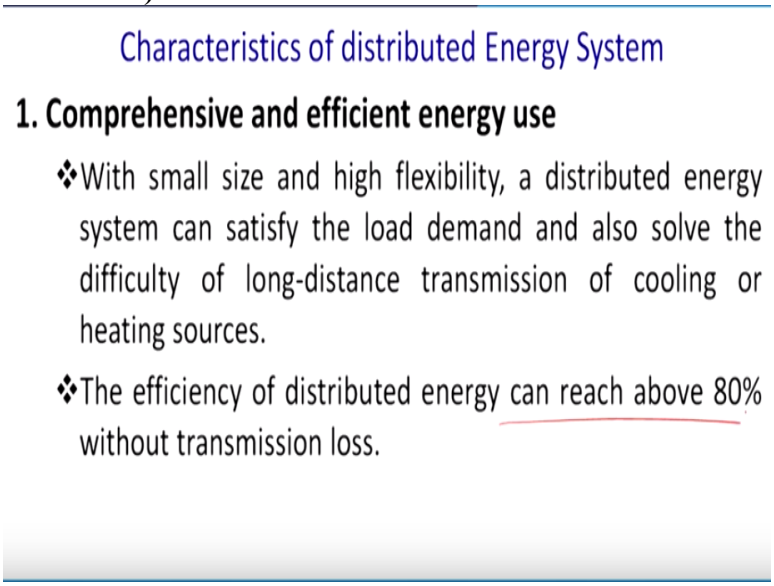
(Refer Slide Time: 03:56)



Now distributed sources that is DR refers to the combination of the DG and the energy storage element. Mostly these are batteries and this is actually DR consisting of DG and ES. It includes all DG technologies and can store energy in battery flywheel, regenerative fuel cell, superconducting magnetic storage devices, even very high ultra capacitor etc. Distributed energy resources that is DER is generation of electricity or the heat at the distribution level for local use mostly.

It include all DR technologies and system connected to a utility grid with which user can sell surplus utility to the grid. That is something that in a bright sunny day you may be off or you are going to the office but your solar installation is generating power so we can sell it to the grid. Comprehensive and efficient energy use.

(Refer Slide Time: 05:16)

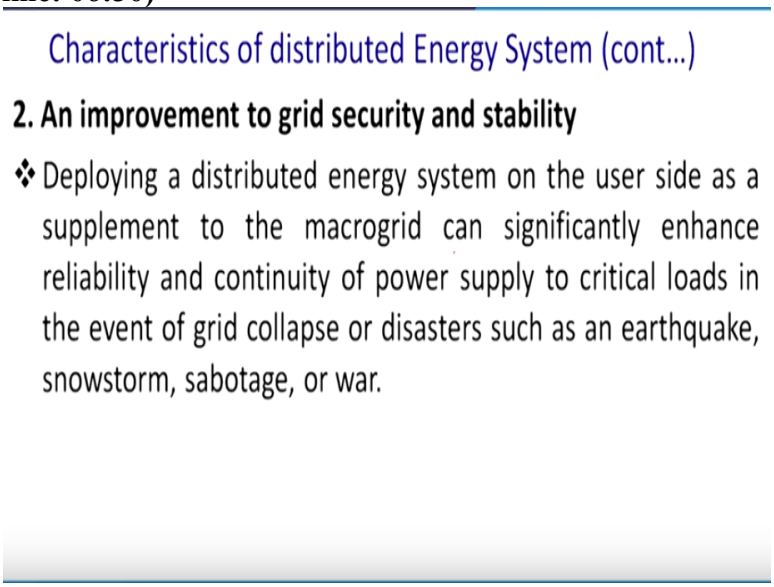


With small size and high flexibility a distributed energy system can satisfy the load demand and also solve the difficulty of long distance transmission of cooling or the heating sources. Because you know actually let us talk about the traditional coal based thermal power plant. If you wish to put into the operation it require 6 hour time for preparation.

So for this reason we require long transmission in cooling and the heating resources. So these are the issues that we can get rid of. This is something like that it can start very fast and play into the operation very fast. And also its payback time in terms of the economy is quite fast. Efficiency of the distributed energy can reach 80% without transmission loss since there is no transmission.

And talking about the distribution level efficiency in India because of many reasons are below 60%.

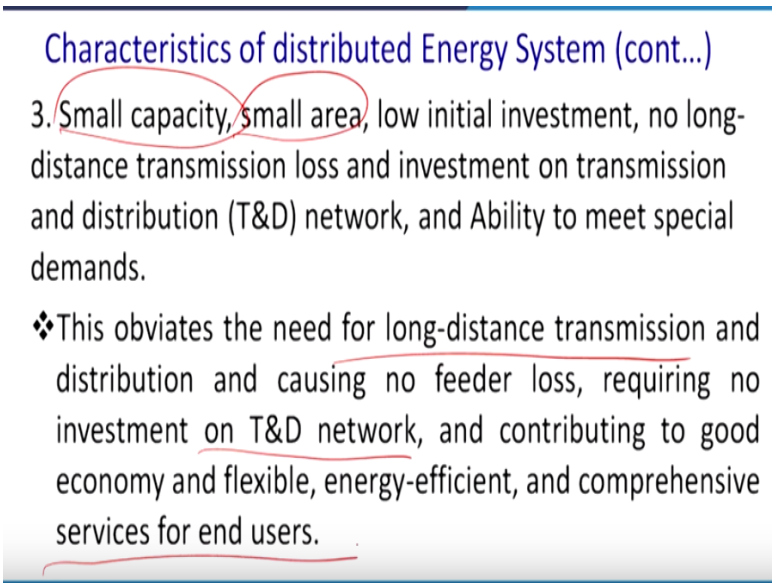
(Refer Slide Time: 06:30)



The improvement to the grid security and stability. Deploying a distributed energy system on the user side as a supplement to the macrogrid can significantly enhance the reliability, continuity of the power supply to the critical load in the event of the grid collapse or catastrophe or disaster such as earthquake, snowstorm, sabotage where even you can have a total grid failure that is happened that is called where (()) (07:03) was totally felt in 2012.

So in that kind of circumstances your microgrid is quite immune and it is self-sustained.

(Refer Slide Time: 07:16)



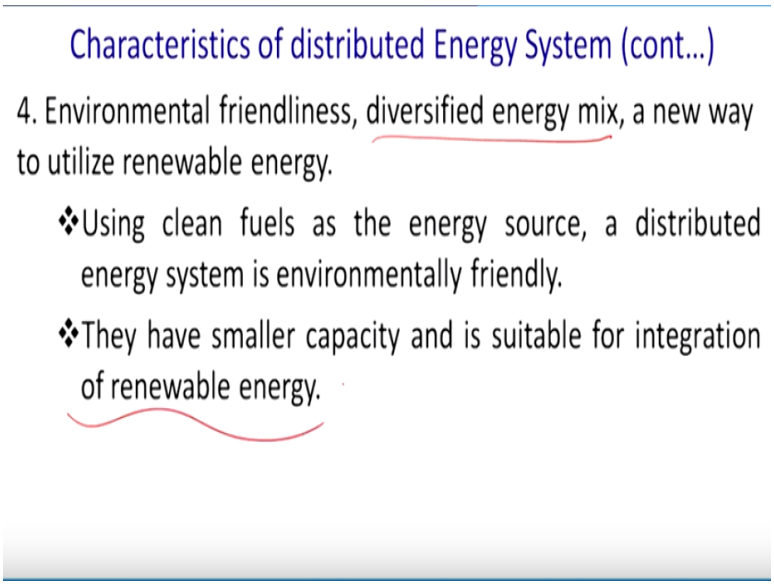
Characteristics of the distributed energy system. So one is small capacity. So since it is we are telling the term micro so it should be a, it should have a small capacity. And it will cater a small area or this is a and low initial investment that is one of the way that is pay off is faster. No long distance transmission losses and investment on transmission and the distribution network.

So you get rid of your big bulky transformers as well as your switchgears and all those issues are not required because that itself take a place. And ability to meet special demand. So for example you may have a actually some kind of local necessity. You are organizing some kind of festival. So there you can arrange and power can be then chanelized to this particular point and thus you can make its own arrangement instead of depending on your utility.

This obviates the need of for long distance and distribution and causing no feeder loss requiring no investment on T&D network and contributing to good economy and the contributing to the good economy and flexible, energy efficient, comprehensive service to the end user. So your burden centralize burden has been reduced since you have a you have actually distributed the network and your burden being distributed.

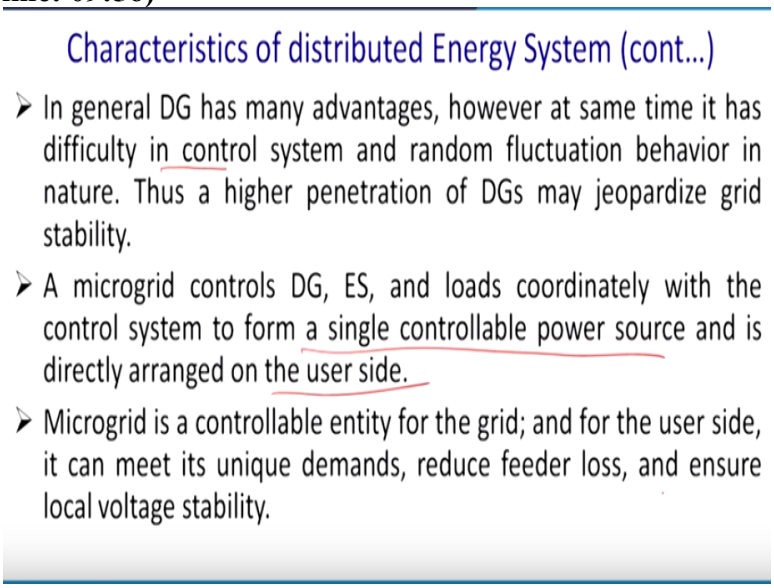
Local body will take care these issues. Characteristics of the distributed energy system. Environmental friendliness. Mostly we are going towards green. We shall use mostly the wind and solar and biomass. Diversified energy makes a new way to utilize the renewable energy.

(Refer Slide Time: 09:44)



Using clean fuel as energy source a distributed energy system is environmentally friendly. They have smaller capacity and suitable for integration with the renewable energy sources.

(Refer Slide Time: 09:56)



Now characteristics of the distributed generation system. In general DG has many advantages. However at some time it has difficult to difficultly in control system and random fluctuation behavior in nature. For example all of a sudden (()) (10:16) comes and wind has got its erratic profile, wind can change any time. So considering those input fluctuations control system take the pain of this input fluctuation.

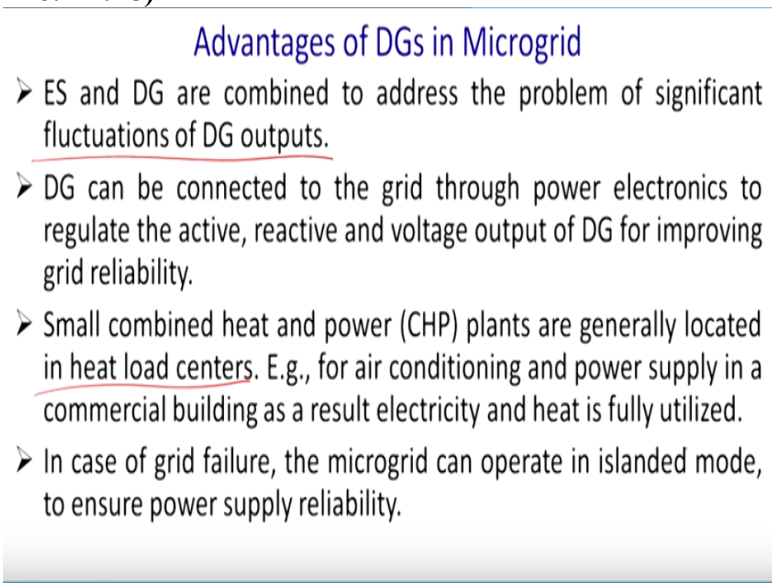
For this reason it is a very challenging aspect to design a control system for the DC microgrid. Thus higher penetration of DGs may jeopardize the grid stability. That is something because it downgrade the inertia. More and more penetration of the solar

inverter will actually bring down the level of inertia into the grid. Microgrid controls DG, ES and the load coordinately with the control systems forms a single controllable power source and is directly arranged in a user side.

So that is the one of the aspect so you just do not do the centralized control like someone does to maneuver actually in case of the big utility someone some generator will basically fix up the problem of the voltage sag. Some will fix up the problem of the frequency deviation or the frequency dip or drooping. So instead of that you put everything in a consumer side, ultimately the consumer has to manage whole utility.

So this is the one of the aspect. You shift your responsibility to your end user. Microgrid is a controllable entity for the grid and for the user side. It can meet its unique demand reduce feeder loss and ensure local voltage stability.

(Refer Slide Time: 12:18)



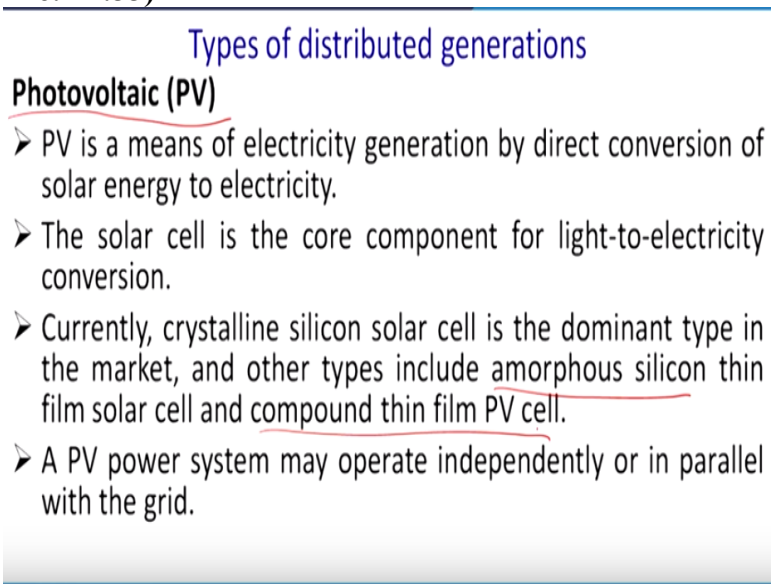
ES and DGs are combined to address the problem of significant fluctuations of the DG outputs. That is one of the consideration that you have to keep in mind. DG can be connected to the grid through the power electronics to regulate the active reactive and the voltage output for the distributed generation for improving the grid reliability. So power electronics plays a huge role in case of the microgrid since all this DG has to be integrated by the power electronics devices.

Solar it has to have a solar inverter. If it is a wind turbine and it is a DFIG you have a front end converter and the back end converter fitting rotor side and the stator side and they are connected to the grid. So you require huge application of the power electronics in the microgrid. Small combined heat and the power plant are generally located in the heat load centre.

For example air conditioning and the power supply in a commercial building results electricity and the heat is fully utilized. So that is something you have to keep in mind. In case of the grid failure microgrid can operate in islanding mode. That is quite important to ensure power supply reliability mostly to the critical load. Now let us come into the different type of distributed generation.

So one is definitely the photovoltaic PV. It is quite common. PV means the electricity generation by direct conversion of the solar energy to the electricity. So what does that actually we meet this characteristics.

(Refer Slide Time: 14:33)



Solar cell is a core component of the light to electricity conversion. Currently crystalline silicon cells is the dominant type in the market. You have generally three type of the solar photovoltaic cell. Cheapest is the thin film but efficiency is less. Thereafter it comes to be the polycrystalline thereafter monocrystalline. We are going towards increasing efficiency and the cost. So monocrystalline are the costliest having highest efficiency.

Thereafter we have a polycrystalline. It is a middleman in the road, medium efficiency and medium cost. Thin film least efficiency and the least cost. So the silicon solar cell dominate the type of the market and other type includes amorphous silicon amorphous silicon thin film cells and compound thin film cells. This will have a lower efficiency. A PV power system may operate independently or in parallel with the grid.

That depends on the kind of architecture you are choosing to. Now this is the independent PV power system.

(Refer Slide Time: 15:56)

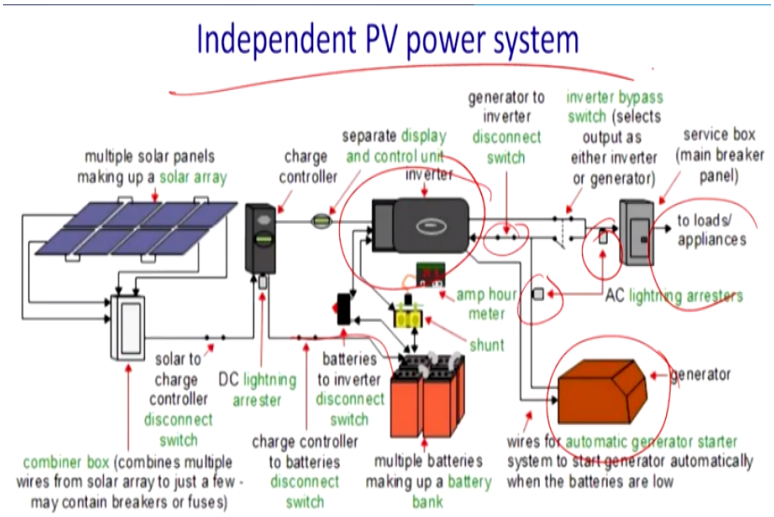


Fig.2: Structure of independent PV power system

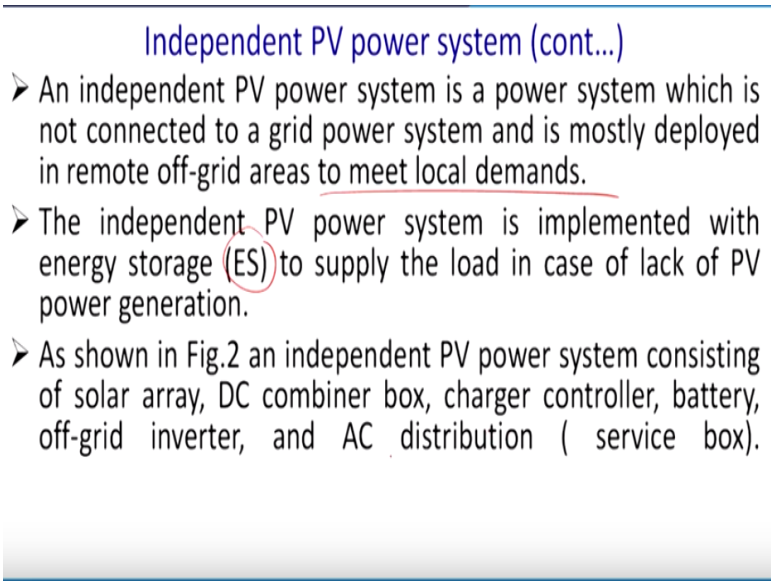
You have a multiple solar panel put into the series and parallel, meet a particular current and the voltage demand. This is a combination box, combines multiple wires of the solar array with a circuit breaker and fuses. Thereafter solar charged controller to disconnect the switch. Then you have a DC lightning arrester or the charge controller. Thereafter you have charge controller to the battery to disconnect switches your lot of parallel operation.

Then you have separate display to control unit. Thereafter this is the heart of the power electronics that is the solar inverter. So solar inverter will convert. Till now this portion was DC. Now it will convert to the AC generator to inverter, disconnect switch if you require to disconnect. Thereafter this is the generator. You may have a diesel generator, wires for the automatic generators starter system when actually power goes off.

Inverter wiper switch to select the output in either inverter or generator. If you have a sunny day then of course it will run from the solar. Otherwise it is required to run for the generator or the night time or when it is night time it may run from the battery also, so storage element and thereafter to the load and appliances and you have some protective devices like lightning arrester. This is the independent PV system.

So there is no connections with the grid or it is in a standalone mode. Now, so let us discuss about that independent PV system.

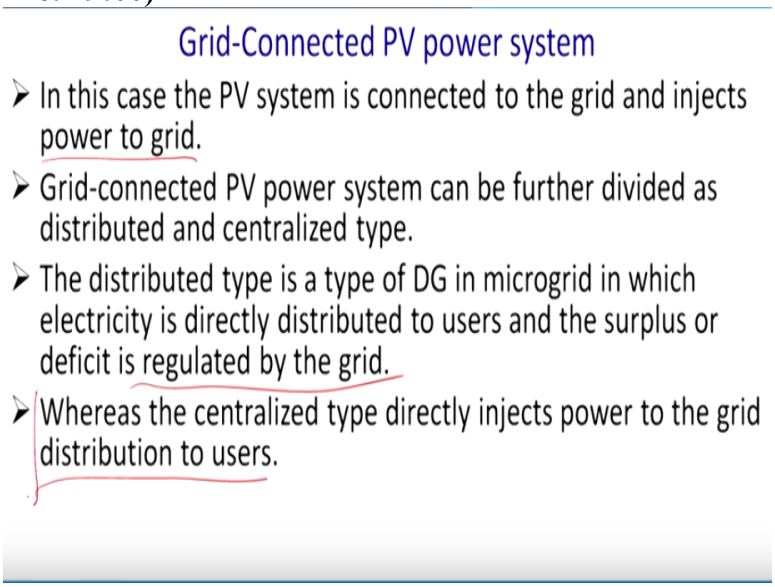
(Refer Slide Time: 17:58)



An independent PV solar system is a power system which is not connected to the grid system and mostly deployed in a remote off grid areas to meet local demand. Mostly this will be in a isolated island like in Uttarakhand many villages so they require this kind and it may be a good tourist spot to harvest. For this reason we may have this kind of system. The independent PV power is implemented with the energy storage ES to supply the load in case of lack of PV power generation.

As shown in figure 2, an independent PV power system consisting of solar array, DC combiner box, charge controller, battery, off-grid inverter, and AC distributor services will be the part of the system.

(Refer Slide Time: 19:00)

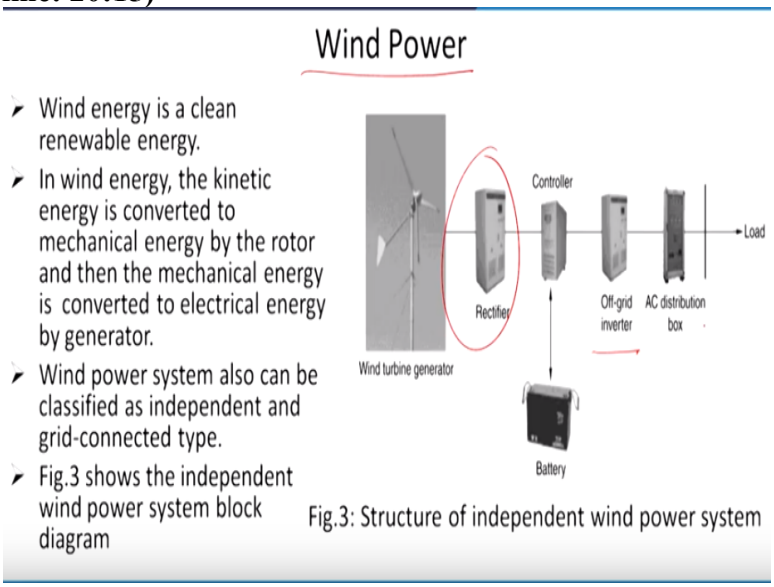


In this case, the PV system is connected to the grid and inject power to the grid. Grid connected PV power system can be further divided as distributed and centralized type.

The distributed type is a type of the DC in microgrid in which electricity is directly distributed to user and surface or deficit may be regulated from the grid. So once you have a energy surplus you save it to the your bidirectional metering.

So you sell it to the grid and once you have a deficit load is more you take it from the grid. For example in IIT Roorkee, IIT Roorkee putting every solar system into the grid. Ultimately we are being, we require to pay our electricity in a balance (()) (19:55). This amount of energy we have to inject it into the grid and this must be you are consuming. Balance required to be paid. Whereas the centralized type of directly inject the power to the grid to the distribution network. Our IIT system is this.

(Refer Slide Time: 20:15)



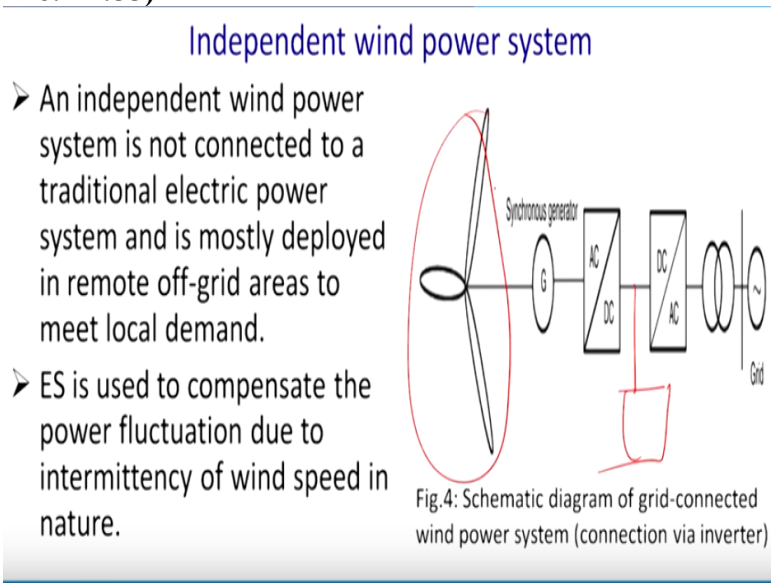
Now let us come to the another important entity of the distributed generation, that is the wind power. But it require to be available in the seashore or those areas. Wind energy is a clean renewable energy. Wind energy the kinetic energy is converted to mechanical energy by the rotor and then mechanical energy is converted to the electrical energy by generator.

Wind power system also can be classified as independent and grid connected type. So this is the system. You have wind power. Thereafter we may have a rectifier. We may thereafter controller. Essentially it is the controls the flow of this power because if there is a extra something like called wind from commitment.

So if load does not require that extra power it will be put into the battery and ultimately this will be monitored by the controller. Thereafter you have off grid inverter. Then you have a distribution box of AC and we will feed it to the load. So this is kind of structure of independent AC power system. And essentially these are the entities of the AC power system and independent wind turbine we have not considered we have considered PMSG.

If it is a DFIG then we have a rotor side converter, we have a stator side converter.

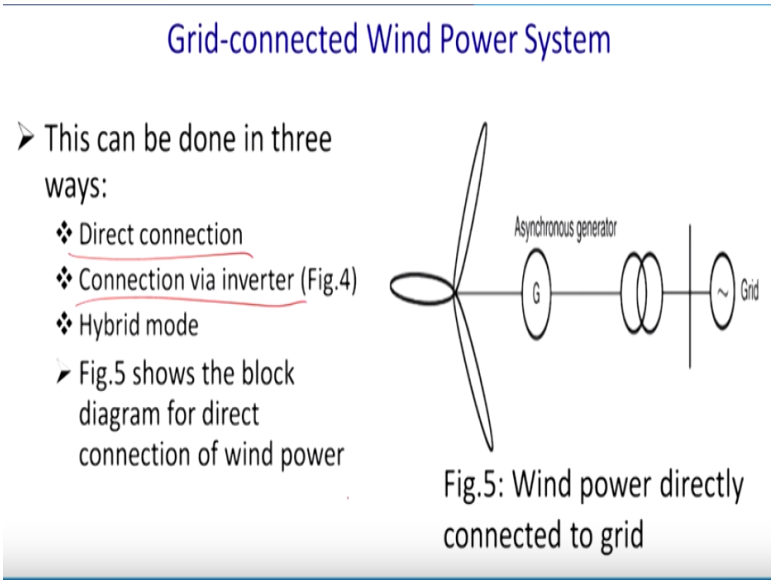
(Refer Slide Time: 21:55)



An independent wind power system is not connected to a traditional electric power system and is mostly deployed in remote off grid areas to meet the local demand. ES is used to compensate the power fluctuation due to the intermittency of the wind speed in nature. So then you have this wind generator. Thereafter you have AC to DC converter. Then you may have a battery storage element and thereafter it is DC to DC converter, DC to AC converter and connect to the grid.

This is the schematic diagram of grid connected wind power system connected via inverter and this is for permanent magnet synchronous generator. If it is DFIG then we require to have a different architecture. We have a rotor side converter, stator side converter, then both will generate power and feed to the grid.

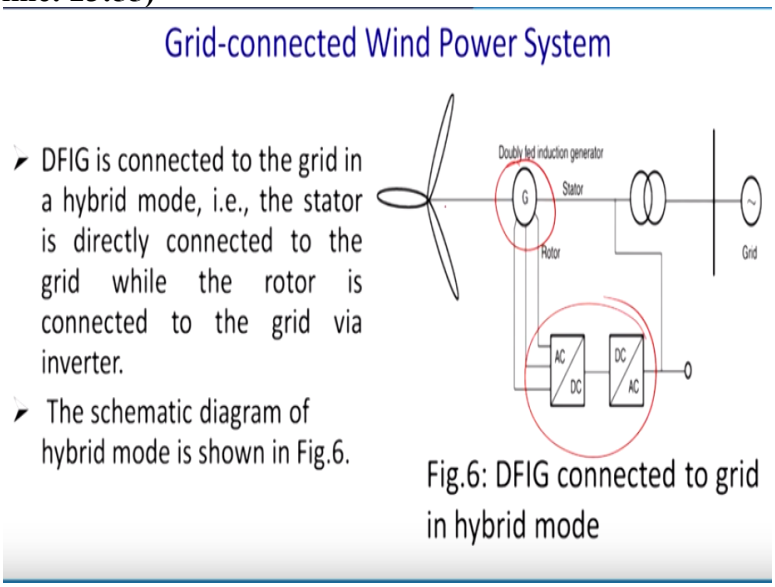
(Refer Slide Time: 22:55)



Now grid connected wind power system. It can be done three ways, direct connection. So with the gear and all those thing it requires to be synchronized with the rotating speed so that you generate 50 year supply and generally it is not been done. Efficiency has been sacrificed a lot, connection via the inverter. So inverter will first convert into the DC. Thereafter it will be connected to the grid as the frequency and the voltage required and it can have a hybrid mode also that we will see.

And figure 5 shows that the block diagram of the direct connections of the wind turbine. You got a asynchronous generator. Thereafter you know it will be generating based on the gearbox the same frequency and it will be directly synchronized to the grid.

(Refer Slide Time: 23:55)

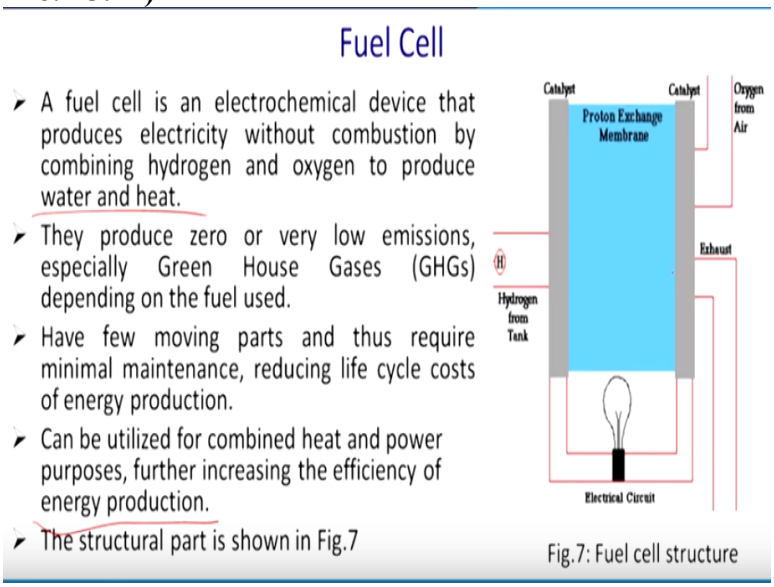


Now this is the DFIG if you use. That is what I was saying. That is double effect induction machine where we can fit both rotor and stator is connected to the grid in the

hybrid mode. That means the stator is directly connected to the grid while rotor is connected to the grid side inverter. Since it (()) (24:15) with the sleep power rating of this converter is quite low. The schematic diagram is shown here.

Ultimately this is the blades and this is a stator. Stator directly fits to the supply of the grid and we have a rotor side collection and that will take up our or it will inject the power depending on the whether it is running in a sub synchronous or super synchronous speed. So it will above the base speed or lower the base speed. And it will absorb power from the rotor and inject or it may absorb the power from the grid and inject to the rotor.

(Refer Slide Time: 25:12)

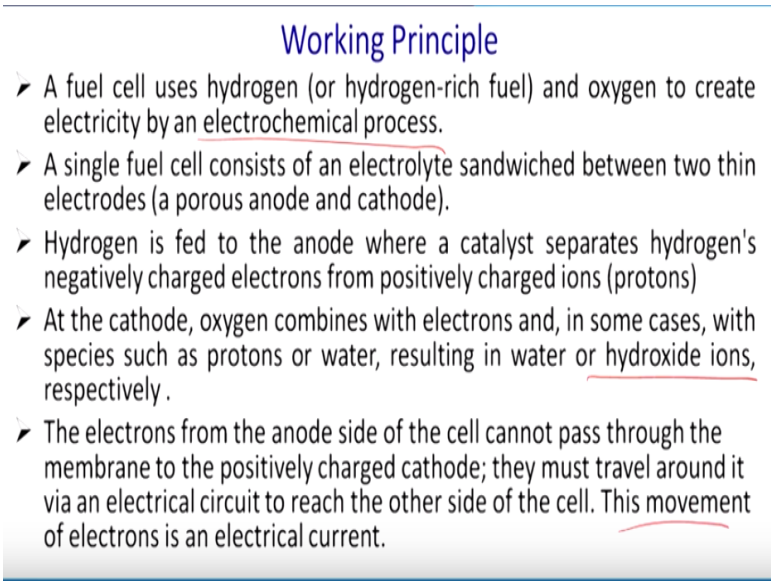


So another important aspect is a fuel cell. Nowadays it is actually is dominating. Fuel cells is a electromechanical devices. Produces electricity without combustion by combining hydrogen and oxygen produce water and heat. This produce zero or very low emission especially the by product is water, especially green house gases depending on the fuel used.

Have few moving parts and thus require a minimal maintenance reducing life cycle costs energy production and it can be used for the combined heat and the power. Further it increases the efficiency of the overall energy production. So this is the hydrogen tank. Therefore they have the catalysts and this is a proton exchange membranes and catalyst and this is the oxygen from the air.

Ultimately it will generate heat and electricity and power and it will exhaust mainly the water vapour.

(Refer Slide Time: 26:19)

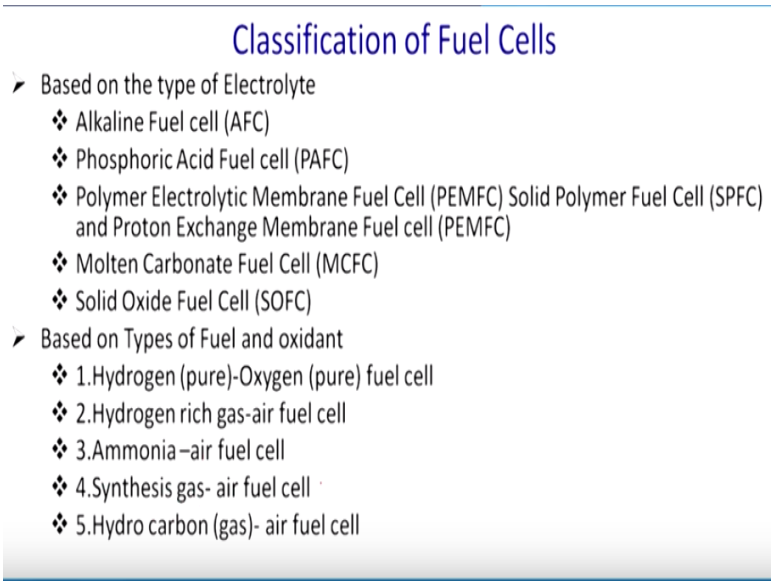


Fuel cell uses hydrogen or hydrogen rich fuel and oxygen to create electricity by electrochemical process. So this is something like we can say the liquid battery or the fluid battery. But power density is quite low of this thing. A single fuel cell consists of electrolytic sandwich between two thin electrodes and porous anode and cathode.

Hydrogen is fed to the anode where the catalysts separates the hydrogen negatively charged electrons from positively charged iron or protons. At the cathode oxygen combine with the electron and in some cases with such protons water and resulting the water or hydroxide ions respectively. Electrons from the anode side to the cell cannot pass through the membranes to the positively charged cathode.

They must travel around or by the electric circuit to reach the other side of the cell. This movement of the electron actually cause the electricity into the outer circuit. Classification of the fuel cell, there are many fuel cell. So we are not going to that detail but just we are pointing out.

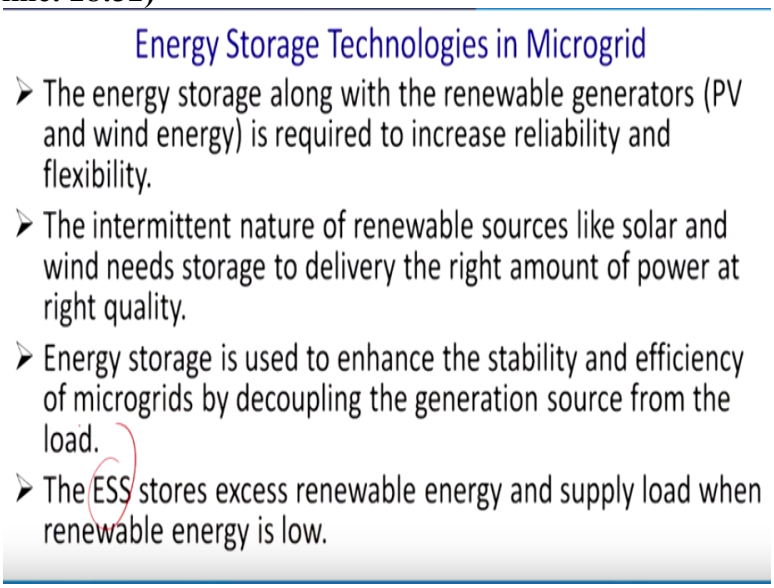
(Refer Slide Time: 27:45)



Alkaline fuel cell that is phosphorus fuel cell, polymer electrolytic membrane fuel cell, molten carbonate fuel cell, solid oxide fuel cell. It is based on the fuel and oxidant hydrogen fuel and oxygen fuel cell. Hydrogen rich gas air fuel cell. Ammonia air fuel cell. Synthesis gas air fuel cell and hydrocarbon gas fuel cell. So these are many entities that you can look suitably.

So this is a part of the chemical engineering. For the reason this is a multidisciplinary subject. Ultimately this part required to be contributed from the chemical engineers.

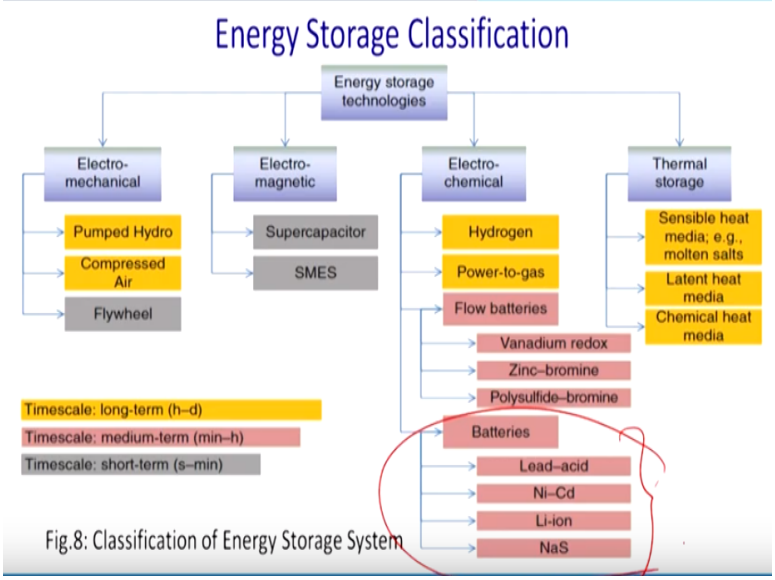
(Refer Slide Time: 28:32)



So energy storage along the renewable energies and renewable generators PVs and wind is required to increase reliability and the flexibility. So the intermittent nature of the renewable energy sources like solar, wind needs a storage to deliver the right amount of power and quality also. Energy storage is used to enhance the stability and the efficiency

of the microgrid by decoupling generation source from the load. So the ESS stores excess renewable energy and supply the load when renewable energy is low.

(Refer Slide Time: 29:15)

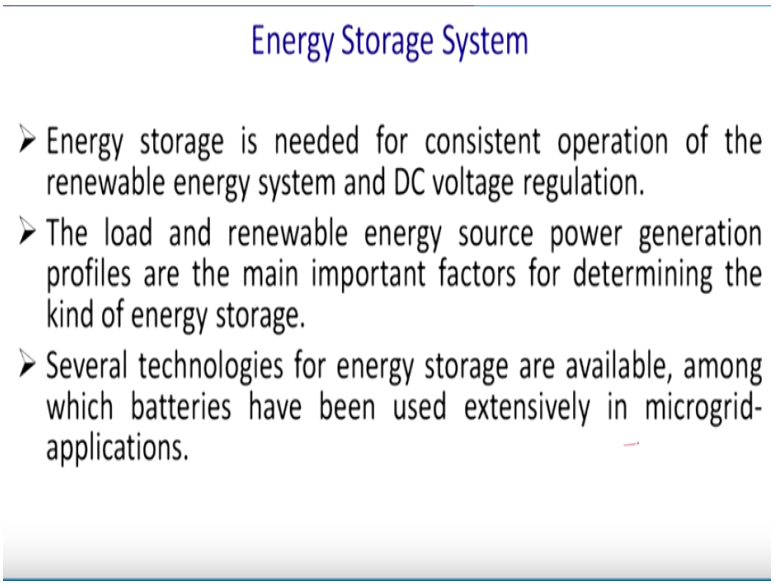


So this is the overall classification of the storage element. You can have electromechanical storage element. So that is pumped hydro power stations, we have in Purulia in West Bengal. Compressed air, flywheel and thereafter you may have a electromagnetics. You may have a superconductor. You may have SMES. Thereafter we may have a electrochemical that is hydrogen, power to the gas, flow battery.

So there are different kind of flow batteries. Vanadium redox, zinc bromide, polysulfide-bromine. So these are all the chemical process where chemical engineers have a say. And others are battery. Batteries can be lead-acid that was properly used but due to the lead we are trying to get rid of it. Now we have a nickel cadmium or lithium ion or NaS or you may have a thermal storage also.

Sensible heat media, molten salt, latent heat media or chemical heat media. These are all are can be used as per the suitability. But mostly we will talk about this considering that it is our electrical engineering domain that is batteries.

(Refer Slide Time: 30:45)



So what we can say from that chart, energy storage needed for consistent operation of the renewable energy system in DC voltage regulations because we are talking about the DC microgrid it is for the AC also. The load and the renewable energy source power generation profiles are the main important factor for determining the kind of energy storage.

Several technologies for energy storage are available among which battery have been used extensively in microgrid application. That is what I was saying that grid find its more applications in microgrid. Thank you. Thank you for your attention. We shall continue our discussion on the microgrid, DC microgrid in our next class.