Solar Energy Engineering and Technology
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Lecture No. 2
Module -1: Introduction to Solar Energy

Hi students, welcome to the module 1 of the mock course solar energy engineering and Technology.

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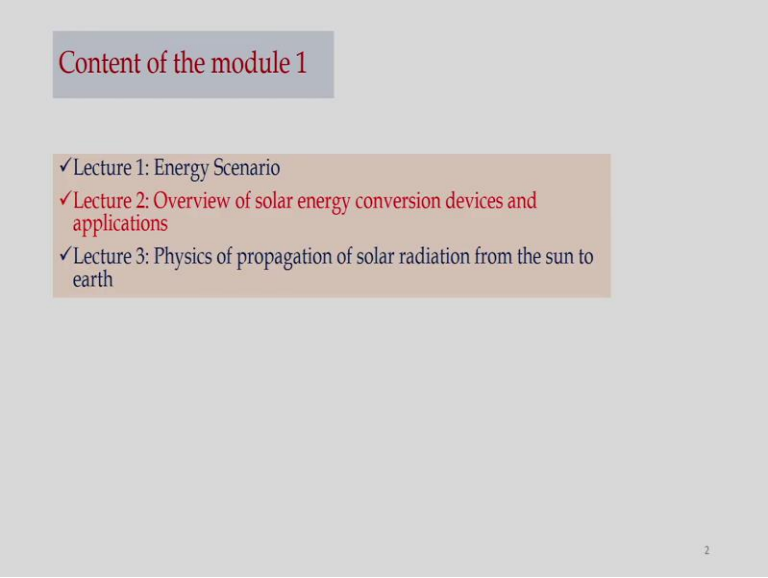

So, today we are going to discuss about overview of solar energy, conversion devices and applications. So before that, I would like to summarize what we have discussed in the last class.

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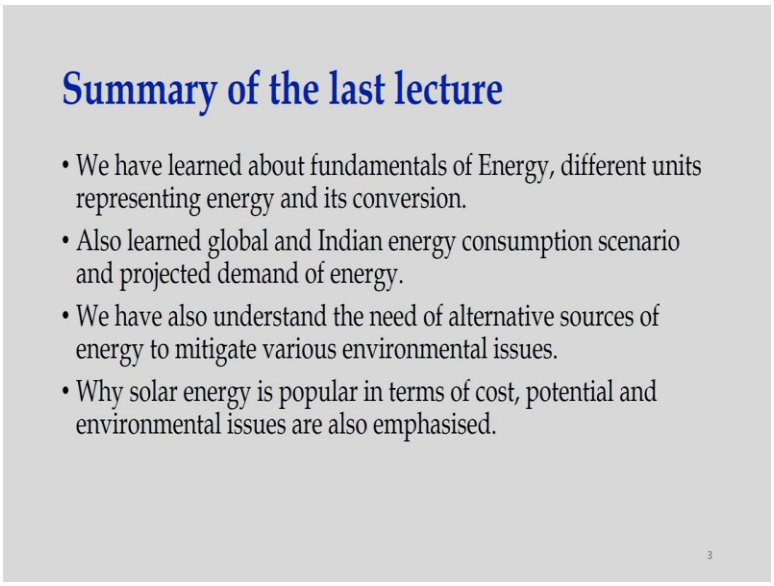

So, in the last class, we have learned about the fundamentals of energy, different units, representing energy and its conversion, also learned global and Indian consumption energy consumption scenario and projected demand of energy, we have also understand the need of alternative sources of energy to mitigate various environmental issues. And also we have learned why solar energy is popular in terms of cost, potential and environmental issues which are very very very important, why solar energy is popular in terms of cost, potential and environmental issues are also emphasized, in the last class.

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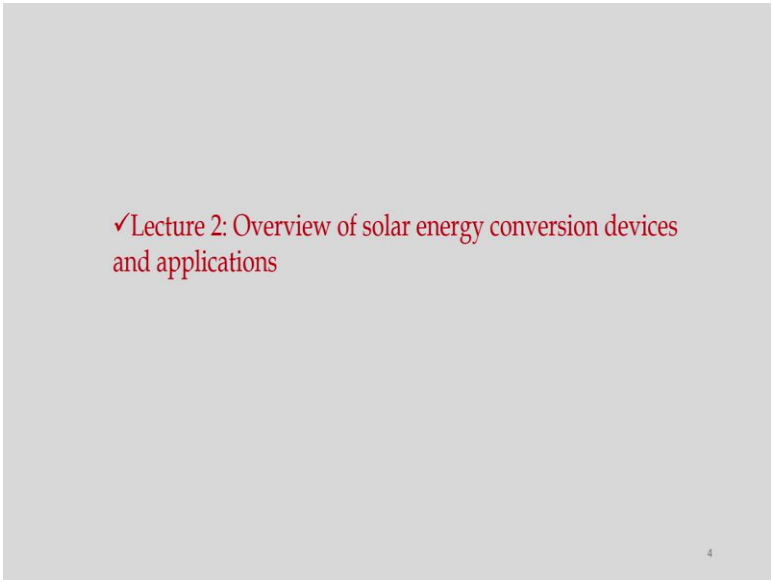

Today, we are giving the overview of various solar energy conversion devices and its applications. So, in-depth analysis and discussions will be done, when we discuss the individual modules. So, we will discuss different modes of exploiting solar energy, what are different modes of exploiting energy?

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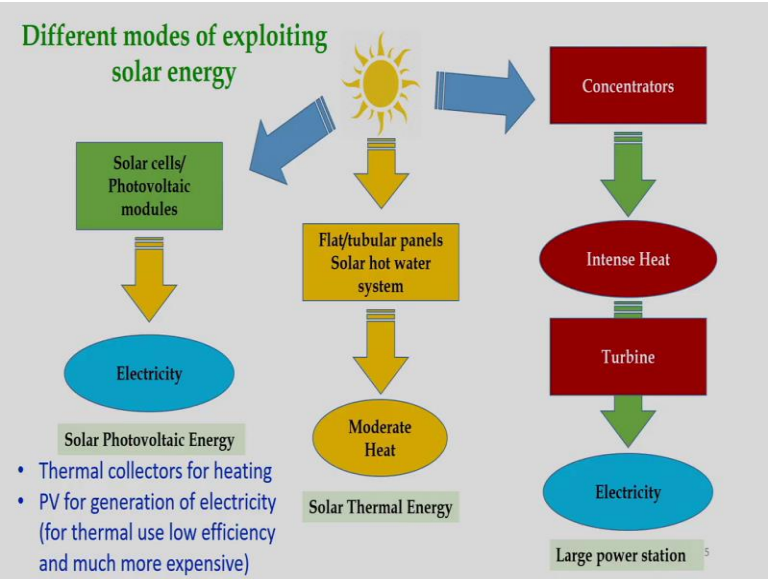

First thing what is known as solar PV energy where solar radiation falls on the solar cell and it is converted to electricity. And second case is, conversion of moderate heat, so solar radiation is falling on solar flat plate collectors and that is converted to heat energy and that is also a thermal energy. And the third case is, the solar radiation has to be concentrated and that focused energy or concentrated energy that becomes intense heat that has to be converted to electricity by using turbine generator assemblies.

So, that is applicable for large power stations. So, normally what happens in this case, we use conventional Rankine cycle for generation of electricity. From this slides it can be seen that the only thermal collectors can be used for solar heating applications, so we cannot use this photovoltaic energy, which is high grade energy for heating applications. So, this is very very important why because thermal energy is a low grid energy and if we use electrical energy for heating applications, so we are actually (no) not doing justice, that conversion is very very expensive.

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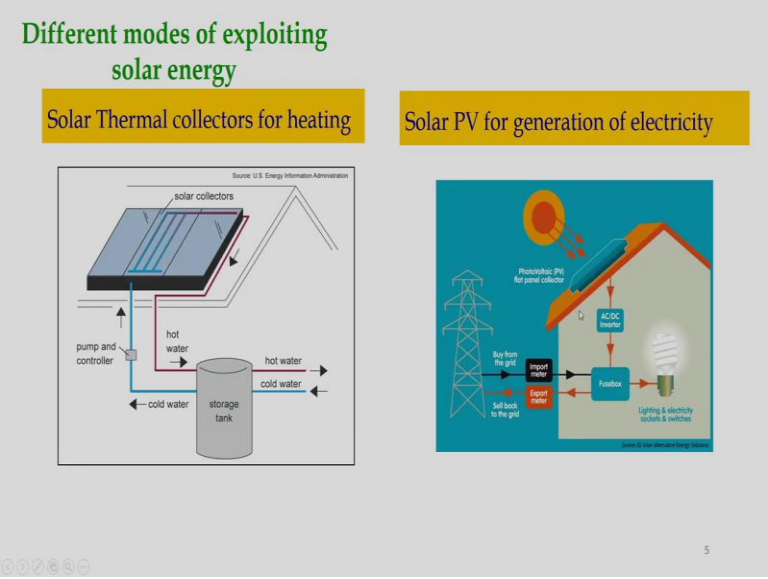

Now, this slide shows about solar thermal collector for heating as you can see in order to generate the heat energy we need to have a thermal collector where solar radiations falls and then this solar radiation is converted to some kind of heat energy and that heat energy can be stored whenever required and that energy can be used as per the requirement. And this other part of the slides shows the solar PV for generation of electricity.

So, solar radiation is falling on this PV collector and we have AC DC converter where the kind of energy what we will get from this PV module is DC that has to be converted to alternating current by using an inverter and then finally we can decide whether we should use it or maybe we can give it to grid.

So, since we have a net metering system, so in the net metering system what we can do the kind of energy we have generated and kind of energy or amount of energy we have received from the local discom that can be taken care by that smart net meter and finally we can understand at the end of the month the amount of energy or amount of bill to be paid or amount of energy we gain from this installation of solar PV collector.

Now, come to a different method of solar energy utilization, what are the different methods of solar energy utilization?

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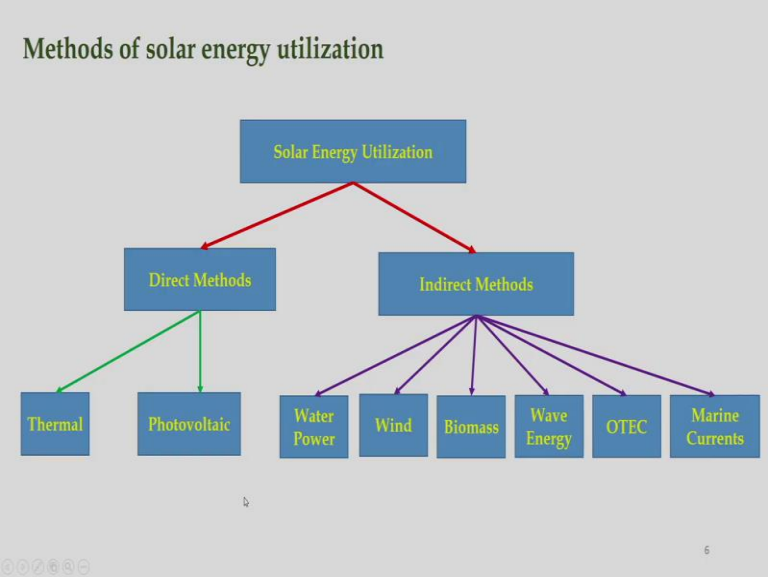

Primarily we have 2 methods direct methods and indirect methods and under direct methods we have solar thermal and solar photovoltaic systems and under indirect methods we will have water power, so here hydroelectric power plants are used for generation of electricity and maybe wind, so wind turbines are used to generate electricity. And then we have biomass, there are again different routes of conversion of biomass to usual forms may be thermochemical conversion maybe biochemical conversions, so finally we can generate electricity out of it.

And we have wave energy that wave of ocean can be used for energy conversion and this OTEC (Ocean Thermal Energy Conversion systems) can also be used for generation of electricity. Here, temperature difference of surface temperature and then depth at very depth like maybe 1 kilo meter that the if temperature difference is more than 20^0 C then OTECH can be installed and power can be generated.

Of course, we can have marine currents to generate electricity. So, in this course, we will primarily focus on thermal and photovoltaic conversion systems in details. Since this is a outline of this course, so we will introduce all the components very briefly in this presentation.

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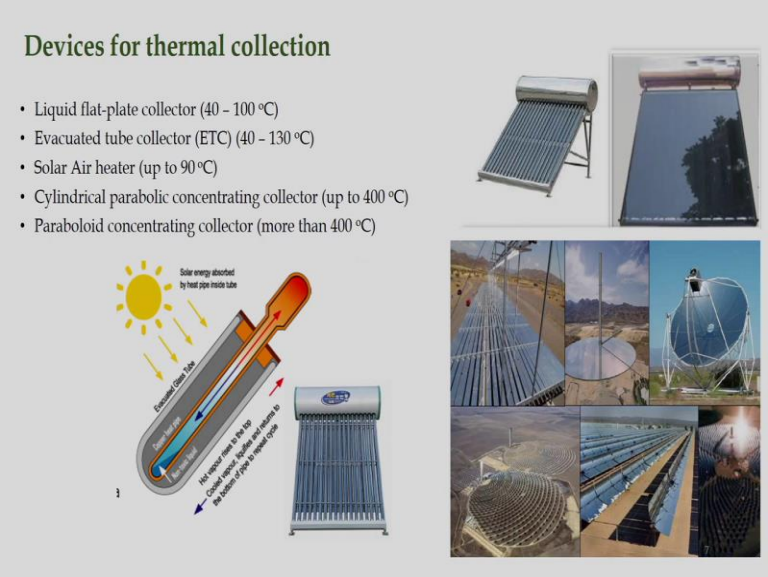

So, here what you can see, this is a device for thermal collections, what are the different devices are available for thermal collections? Firstly we will name liquid flat-plate collectors, if your required temperature is in between 40 or 100^0 degree C always will go for liquid flat-plate collector. So, this liquid flat-plate collectors are something like this. We will solve one exercise to strengthen the understanding how it works and what are the different components and why this is so important.

And in the next case is evacuated tube collectors. So, when we require somewhat higher temperature than what is the provided by liquid-flat plate collector, then we will go for evacuated tube collectors, so this is something like that, so what is the difference between these two? What we are doing? We are actually reducing some kind of losses that is called convective losses. So, if you can reduce the convective losses, then we can actually increase the efficiency of the collector that is what is the innovation.

Then your third category is Solar Air heater. So, sometimes we might require some kind of heat energy for drying purpose or maybe some other applications then we have to go for solar air heaters. So, this configurations of solar air heater and liquid flat plate collectors are almost similar but difference is in the liquid flat-plate collectors liquids are used and in solar flat-plate solar air heaters airs are used.

So, here heat transfer fluid is air in case of solar air heater and in case of liquid flat-plate collector heat transfer fluid is liquid, this maybe water or maybe some other kind of fluid as per the requirement as per the applications, different liquids are used as a heat transfer fluid. And if we can generate heat up to 400^0 C, then we can use it for power plant applications and this is done through cylindrical parabolic concentrating collectors.

So, this is a one axis tracking also sometimes it is called line tracking system. So, here what happens single axis tracking is possible, tracking means movement of the concentrator. So, we will discuss these issues in the later slides, lastly we have Paraboloid concentrating collectors where we can generate fluid temperature or heat transfer of fluid temperature is more than 400^0 C it maybe about 800^0 C.

So, this concentrating collectors are used for power generations. So, this is fall under thermal category. So, you can see different photographs here, so this part is Chimney, one Chimney is here, so this is known as solar Chimney power plant. So, here what happens this is a Chimney height, so normally this is close to 200 meter, it is a very tall structure and there are very limited number of power plants available in the globe, in Spain they have only one power plant of this category, but combustion efficiency is very very low about 7 percent or so.

And these are all concentrating collectors and what you can see here this is a central power receiver system and this is all about evacuated tube collectors and we will discuss more in the next couple of slides.

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So, this slide shows about liquid flat-plate collectors. So, here what happens, when we talk about the primary component of a liquid flat-plate collectors, this component is the primary component where we will have a glass cover here and then we have a absorber plate, so this glass has to be transparent enough so the solar radiations when it falls it has to reach to the surface of the absorber plate.

Normally what happens this absorber plates are painted with black, so that maximum solar radiations can be absorb. So, nowadays selective coatings are also applied to increase the absorptivity of the incoming radiations and reduce the emissivity of the outgoing radiations. So, these are some of the developments how people are trying to enhance the combustion efficiency of a flat-plate collectors.

So, we can also draw a schematic in order to understand this concept, so this is something like a very simply what we can do this is something like this and then we will have this is the collector part and maybe we have absorber here and these are the tubes through which heat transfer fluid transfer takes place and then we will have glass envelope, this is a glass envelope and this glass maybe toughened glass or sometimes two more glasses are applied and maybe here is our insulation.

Thermal insulation has to be provided to into reduce the heat losses. So, solar radiation falls through this glass cover and this is the absorber plate and this is normally made in black colour,

so that maximum solar radiations can be absorbed and this heat has to be transferred from this absorber plate this absorber plate to this fluid, this is a tube and this is braised in this absorber plate. Sometimes this kind of absorber plates are also available, in a single system they made something like this and fluid flows through these tubes and these are heat transfer fluid and finally this fluids are stored in a insulated vessel and this can be used as per required time.

So, here what happens solar radiation is falling through this glass cover and received by the absorber plate and then heat has to be transferred to this working fluid. Finally this fluid is for different applications like maybe taking bath or maybe doing different activities. And these are the insulations, so that heat transfer can be reduced. So, this is the very basic liquid flat-plate collectors, if we say about the developments, so people have developed some kind of selective coating which is applied over the absorber plate in order to maximize the solar radiation received.

So, the purpose of the selective coating is to increase the absorptivity of the incoming solar radiations and reduce the emissivity of the outgoing radiations, because as you know all the radiation falling on the absorber plate cannot be absorbed in the absorber plate, this is a very fundamental flat plate collectors, so we will study the advancement and then how this evacuated tube collectors are evolved and what is the need of involvement that we will discuss maybe in the next slide.

So, before we summarize this slides, so why this is so important? Because this design is very very simple and there is no moving parts and requires little maintenance once you install there is no need to do much maintenance on it, but sometimes for cleaning of glass is important and here in this figure it shows a cut view as you can see here these are tubes and absorber plate is here and then these are the insulations at the bottom to reduce the heat losses.

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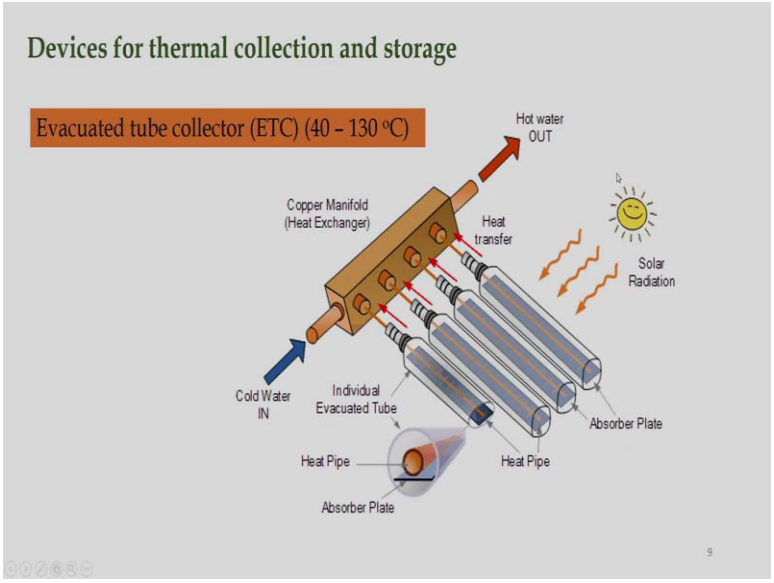

So, this is a evacuated tube collector and here what happens development is something like to of course the primary objective is to maximize the solar radiation received by this collector, so how they are doing these? As you can see here, so there are two glass envelopes this is envelopes glass, so solar radiation is received on this glass cover and energy is transferred to this absorber, so this portion is maintained vacuum, so that convective losses can be minimized. So, this kind of configurations are attached in a single evacuated tube collectors and finally we have a header and hot water can be stored and that can be applied whenever required.

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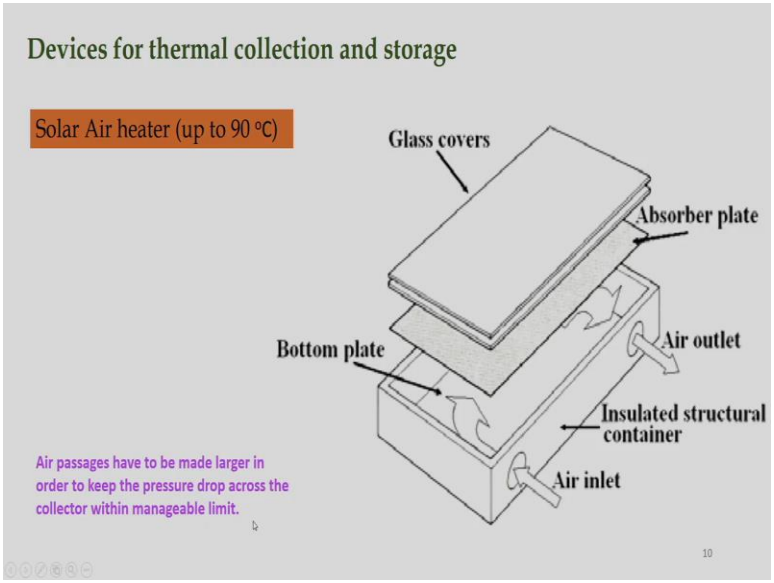

Now, we come to the solar air heaters, because it has got plenty of applications for drying of agricultural product and drying of some essential products all can be done by using solar air heaters. So, this configuration is similar to liquid flat plate collectors and only difference here is heat transfer fluid, here heat transfer fluid is air and one of the very important fact is so here we need to maintain a very large channel through which air flows, because this air pressure has to be made larger because the pressure drop has to be maintained properly, otherwise this pressure drop is not maintained then it will be difficult to operate the system.

Again these are related to power consumption. So, as you can see at the top we will have a glass cover through which solar radiation penetrates and then we will have absorber plate and then we are inlet will be there and outlet will be there and then we need to have a some kind of trace for drying if we want or if we can if we can utilize this air for other applications then we can do it. So, this slide shows about the solar air heaters, so air heaters are very very important for drying of agricultural products or similar kind of products.

And as you can see it has got different layers, the first layer is glass cover through which solar radiation penetrates and we will have absorber plate where solar radiation is absorbed and then we can see this air inlet holes and then outlet holes and then outlet is attached with the system where hot air is required. So, these air passages have to be made larger in order to keep the pressure drop across the collector within manageable limit which is very very important because this is related to power consumption of the system.

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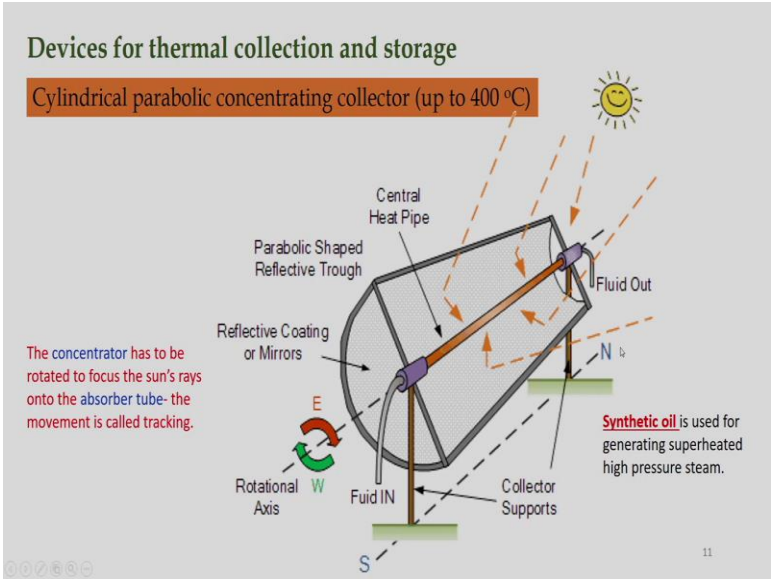

Now, come to the cylindrical parabolic concentrating collectors. So, the configuration as you can see it is something like that and this portion is known as concentrator and this is known as absorber. So, there are primarily two components, one is concentrated other one is absorber. So, solar radiation is falling on this concentrator and it is focusing on to this absorber. So, in order to expose or get maximum solar radiation throughout the day this has to be rotated, the concentrator has to be rotated. So, this is rotated with time, so that all the energy received by this concentrator can be focused to this absorber component.

So, as far as this absorber is concerned, so here absorbers are made of like steels and then over it there is annulus tubes and the chain the chain annulus tube and there are two tubes because convicted losses need to be minimized and because of that we will get a high temperature operation, so what I mean to say, so there is one absorber, this absorber is made of steel and over it there is a annulus tube and then vacuum is maintained to use the convective losses, the kind of heat transfer fluid what is flows toward this absorber is something called synthetic oil to generate superheated high pressure steam.

So, once this heat transfer fluid flows through these and that is know this heat transfer fluid has to be now it has to be exchanged with water and then finally what you can generate is a high pressure steam and that can be expanded in a turbine and we can generate electricity and that will work in a cyclic manner. So, what we can summarize in these slides so as far as cylindrical

parabolic concentrating collectors are concerned, we can go up to 400^0 Celsius temperature and the primarily it has got two components, one is concentrator, this is the concentrator part and we have absorber, this is the absorber part.

And synthetic oil is used as heat transfer fluid and this fluid heat will exchange with water and steam will be generated and that will be expanded in the turbine and finally electricity can be generated. So, details discussions will be done when we take the module which includes concentrators.

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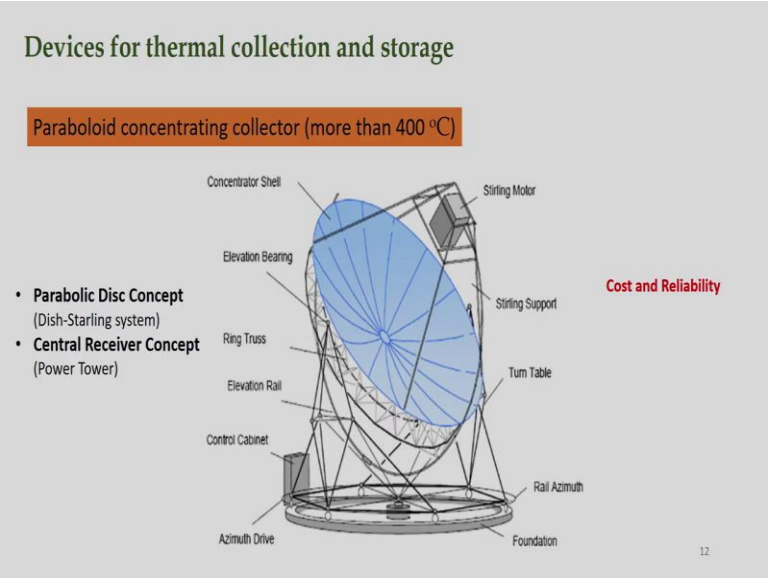

So, now come to this paraboloid concentrating collectors, when our temperature requirement is more than 400^0 C, then we will go for this kind of arrangement. So, here what happens this is the concentrator part and then solar radiation falls on this concentrator and is focused on this this absorber system. So, normally here Starling engines are used when we talk about no parabolic this concept and this is also known as this Starling system because Starling engines are used. So, Starling engine means that is external combustion engine, so heat of the system is utilized to run this Starling cycle.

So, also we can go for another concept called central receiver concept also known as Power Tower for generation of high temperature operation. And this Central Power receiver systems will be discussed at the end of this presentation, so when we discuss a solar power plant and for this kind of systems when you talk about parabolic this concept, this is not so much of

installations is there across the world because of cost and reliability. So, cost of the system is very very high, so if cost can be bring down, then of course this usability and then each installations will be very very high. Again, we will discuss these issues when we discuss the respective modules on concentrating collectors.

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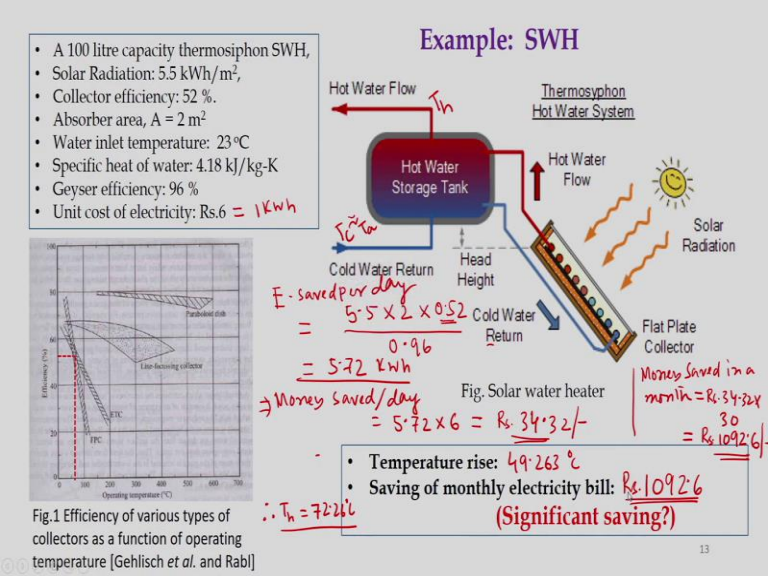

Now, let us take one very important example on solar water heating system. So, I hope that you will really enjoy this problem and also you will understand why this kind of subject is very very important indeed real life. Let us, take a problem of something like this, a solar water heater of capacity 100 litre is there and then solar radiation falling on a particular locality is 5.5 kilowatt hour/meter^2 and collector efficiency is about 52% and absorber area is 2 meter^2, normally this absorbers are 2 meter by 1 meter so it becomes 2 meter^2 area and water inlet temperature is about 23^0 C, because water it is the ambient temperature, so water cold water will be introduced and hot water will be collected once it passed through this solar water heating system.

And also as you know specific heat of water is 4.18 kilo joule/Kg/Kelvin and geyser efficiency is 96% and unit cost of electricity that is, 1 kilowatt hour is rupees 6. So, as you can understand the different components of this solar water heating system, so there are tubes through which heat transfer fluid follows and then we have absorber plate and this is the glass cover and there are many categories of solar water heating system and one category is passive water heating system and the other category is active solar water heating system.

So, in passive water heating systems due to this temperature difference there will be density difference and because of that mass movement of the fluid will be there and this is the reason why this cold fluid introduced and then when heat is supplied from the sun, then this heated fluid will go up and then occupy at the top portion of this reservoir or storage and then finally this can be collected based on the applications.

Also, this figure shows about the efficiency of various types of collectors as a function of operating temperature. So, at this point what we can discuss you can see that, what is the variation of efficiency with respect to temperature of FPC and then evacuated tube collectors then line focussing system where only single tracking is possible and in paraboloid dish so both the tracking's means two axis tracking's are required to capture normal radiations.

So, we will learn different kind of radiation what is normally radiation, what is diffuse radiation and what is global radiation maybe in the next module. So, for the time being you consider that the radiation. So, now come back to this problem, so problem statement is here, that is capacity of the solar water heating system is 100 litre and solar radiation is 5.5 kilowatt/meter^2 and area of the collector is given to you and collector efficiency is 52 percent.

So, now how we are going to solve this problem? So, we will use energy balance, so how we will do this? Like equating the energy absorbed in the collector during the day to the enthalpy change of the water, so this is something like solar energy incident maybe what I will write this It, It is the solar energy incident on the collector per unit area per day, so this has to be multiplied with this area of the collector this maybe we can represent by Ac and also this efficiency is given to you collector efficiency is given 52 percent, let us write it as C is the collector efficiency which has to be equal to mass of the water mw, mass of the water multiplied by CpW specific heat of water and then we have temperature rise is ΔT.

So, how are you going to solve this problem? Because you see this It how much is given? It is 5.5 kilowatt hour, so what I will do I will convert it to 3600 so that in unit what we will write here that is kilo is there because we are not doing unit kilo and then joule per second is watt and then watt we have converted is second. So, this is something like that and then we have Ac is absorber area is 2 then we have collector efficiency is 0.52 and this is equal to mw. Now, we need to calculate what is mw, mw then Cp W and ΔT. So, now how to calculate this mw?

Because what information is given to you in the problem that is volume, volume of water is given to you as 100 litre, 100 litres and then we need to convert to 100 multiplied by 10^{-3} this becomes meter^3. And also we know mass is equal to ρXv, ρ is density of water, so what I can write, this maybe we can write w and this maybe we can write w and here we can write w.

So, here mass density of water is 1000 or 10^3 and volume of water if we multiply this it will become 0.1, 1 to 3, this is 0.1 it becomes kg, because this density unit of density is kg/meter^3 and then you have meter cube, so meter cube meter cube will be gone finally will have kg. So, finally what you will have it is a 100 kg.

So, this 100 litres is nothing but 100 kg, so this is mw. So, this is known to you now, so this mw will be 100 and cp is a specific heat of water is 4.18 kilo joule, this is kilo joule per kg per degree Kelvin, so this is ΔT. So, here you need will be kg multiplied by we will have kilo joule per kg per degree kelvin and then we have kelvin, so delta T is in kelvin. So, this kelvin kelvin got cancelled, kg kg got cancelled, so it will be in kilo joule.

So, if you see here second second cancel, it becomes kilojoule, so dimensionally it is correct. So, from there what we can study or what we can calculate is delta T, so if we do this simple calculations, then ΔT is found to be about 49.263, this is the temperature ΔT, since ΔT is nothing but Th that is Th Th and this may be a Tc or maybe this is equivalent to Ta because this is equivalent to ambient temperature, so Th minus Ta is 49.263 and then if we substitute this value Ta is 23, then what will have Th will be so we do not need this Th will be 49 plus 23 so it will be 72.26 degrees C.

So, this hot water temperature is 72.26, so when we are not collecting the fluid, so that is the stagnation temperature, we will introduce the concept of stagnation temperature and then the condition at which we will get the estimation temperature, so when we discuss this thermal collectors we will discuss in details about those parameters. So, here what we got Th is 72.26 degrees C.

Now, what we are interested about the savings, because already geyser efficiency is given to you as 96 percent, so temperature rise here we can write is 49.263 at any unit we can give degree C and now we will calculate what is the monthly electricity bill savings, let me rub this part now

this is not required, now how to calculate this? Now, we need to calculate this monthly electricity bill savings.

So, in order to calculate this we need to use this geyser efficiency and the electricity saved per day say maybe what I can write, I can write E is the electricity saved electricity saved per day then how we are going to calculate it? It is already we know 5.5 is the amount of radiation falling on that particular locality and we also know this area of the collector is 2 and also we know the efficiency of the collector is 0.52 and then we know the efficiency of the geyser is 0.96, so this is the energy saved because this much is the energy and efficiently of the collector is 0.52 and if we multiply and since efficiency there is no inefficiencies associated with the geyser then we need to consider otherwise, this should be 1 if geyser efficiency is 100 percent.

And if we do this simple calculations though this is found to be 5.72 kilo watthour. Also, it has been given that 1 kilo watt hour is this is something like 1 kilowatt hour is 1 unit. So, what happens if we have to convert in terms of money, then what you need to do, money saved per day money saved per day it will be 5.72 into multiplied by we have 6, then it will be about rupees 34.32, so this is saving for a day. So, if we talk about savings for a month, so money saved, money saved in a month will be rupees 34.32 multiplied by we will have 30 days.

So, this will be about rupees 1092.6. So, here saving of monthly electricity bill is rupees 1092.6. So, which is a significant saving, if we talk about monthly saving of electricity bill. So, from this analysis what we can conclude, so straight way we can replace our conventional or electrical geyser by using the solar water heater and if we do so, then how much benefit we will get that is clear to you now. So, if its capacity is a 100 from that we can save really significant amount of money. So, let us move to the next slides

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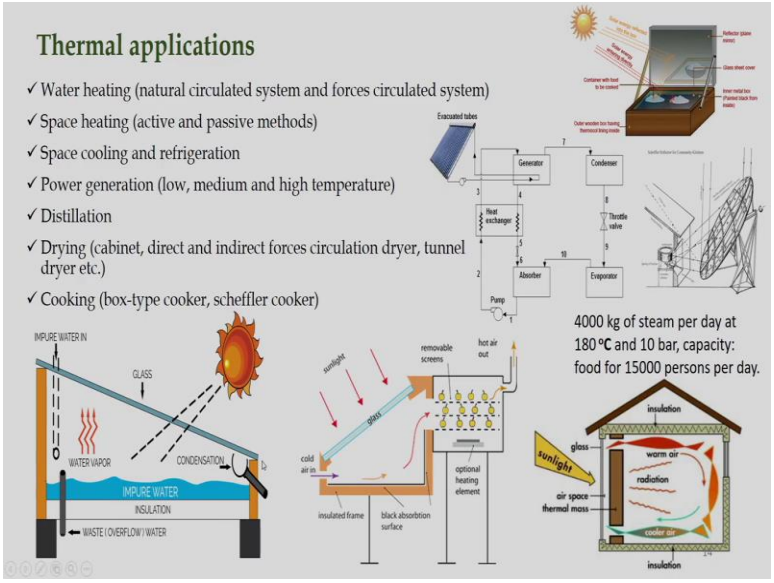

So, here I would like to introduce the different applications like it is thermal applications primarily in solar thermal applications, so water heating that maybe naturally circulated system or maybe forced circulatory system, when you use pumps to circulate the fluid that becomes forced circulation and when we use only thermo siphon effect that is called natural circulation. And we can use space heating that is active and passive methods, then space cooling and refrigeration, so we can do refrigeration here, we can use vapour absorption refrigeration cycle because we can generate heat from solar thermal and that can be used for vapour absorption refrigeration cycle.

And of course we can generate power may be low, medium and high temperature, so there are different categories of power generation, of course you will have lower thermodynamic efficiency if this temperature difference is low and if this temperature difference is high, of course thermodynamic efficiency will be higher. And also we can use for distillations, so we can we need to generate distillate for different applications maybe when small solar PV units are operating with storage system, so in those batteries distilled water is also important, so in those cases, so if we suggest a distillation unit that will be very much helpful.

And drying, of course you have seen some of the things, so there are different categories of drying maybe cabinet, direct, indirect, force circulation dryer or tunnel dryers, so there are many development of dryers, so we will discuss some of the important development of dryer and

which are having higher applications in different agricultural field that will be discussed when we take that particular module and this cooking, so the primary two different types of solar cookers are used like box type and scheffler cookers.

So, box type is individual and it takes somewhat longer time to cook, but in scheffler cooker is very very efficient and we can see different applications in community cooking. As you can see here this is a figure for scheffler solar cooker, so as we can see this is a figure like 4,000 kg of steam part they can be generated at 180 degrees C and at 10 bar and its capacity is about 15000 persons food can be prepared per day.

So, it is a very reliable technology and already people have demonstrated its workability. And this is box type solar cooker and this is also used but it is cooking time requirement is somewhat higher and this figure what you can see this is for space cooling and refrigeration, so once we can generate low temperature fluid that can be circulated to maintain the particular area or particular site.

And also what you can see here this this figure is for drying so air injection will be there and the glass cover will be here air will be heated up and that heated air will circulate through (())(38:32) and finally humid air will pass through this exit pipe and we can we can dry the samples. Sometimes optional heating elements are also install because of this bad weather continuously will not receive the solar radiation. And this is a figure for solar distillation. So, solar radiation falls through this glass cover and then water evaporation takes place and then finally it is condensed and this condensed it is collected.

And this kind of technology is also useful for removing ground water contaminants, like heavy metals. So, like we have fluoride contaminated water, if we place here, so fluoride can be removed 99 percent by using this very simple technology, but only disadvantage is capacity is very very low, of course we need to invest more in order to increase the capacity.

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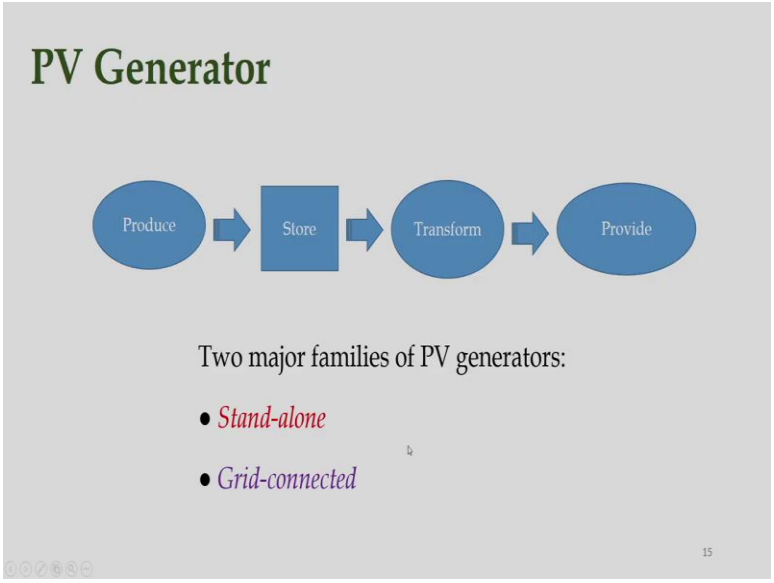

So, as far as PV generator is concerned it has got different components like we have to produce the electricity then you have to store it and then transform it and then finally we have to provide the power. So, this is how a PV generator works and there are two primary families of the PV generator, one is stand-alone system and the other one is Grid-connected system.

In stand-alone systems are applied in water pumping or other maybe solar street light lighting system and grid-connect systems may be in household level or maybe you know in institutional level in different categories this can be applied or also there are there are some technologies to connect different sources like diesel and solar, so how to connect these? So, these are different possibilities of utilizing the solar PV for power generation.

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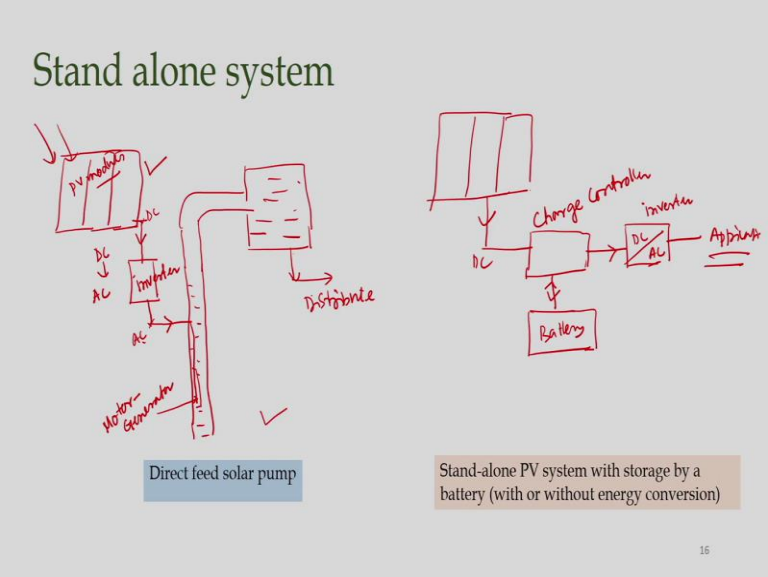

So, in Stand-alone systems, let me draw some plots, so maybe for example if we talk about direct feed solar pumps, so what we have, we need to have some kind of solar modules, so this are the solar modules. So, these modules are maintained at a certain angles based on the locations and solar radiation is falling on this module and current is generated and then we need to convert these DC current to AC current, so by using this inverter, inverter then we will have to supply these energy to this motor pumping system, so we will have motor and generator together.

So, I will say motor then generator these are submersible pump, so water is here, so water is here and motor generator is there. And then finally we need to store this water somewhere in a vessel from where we can collect the water, we can distribute, we can distribute, so this is the water level we can store water here. We can do many more calculations, so we will do it when we discuss the solar thermal systems specifically. So, this is PV modules, so we can design the number of modules to meet the requirement of a single plant this kind of problem we will solve later on. And how many modules are required to meet the demand for a particular site.

So, here what I have drawn, this is a PV module assembly and then DC energy is generated here at this point and then there has to be converted to AC, so this is your alternating current and this is applied to run this motor generator these are submerged under water and this water will lift to a reservoir and that will be stored and that can be distributed based on the applications. This is

one application of stand-alone system and also we can have stand-alone PV system with a storage by battery and that can also be drawn here.

So, maybe we can draw this configuration, there are many modules maybe and we will have sometimes we need charge controller when batteries are there because battery life is very very important, so this is charge controller charge controller and we will have DC AC converter again we have inverter, I will let DC then you have AC this is inverter, this is inverter and finally this is application and this is a charge controller, again what we need we need a battery, this is a battery. So, this charge controller plays a key role to maintain the health of the battery.

So, amount of charge to be introduced in the battery is very very important, if sometimes more charge is supplied to the battery then battery life decreases significantly. So, this is one configuration, so where we can have a stand-alone systems and battery can also be used. So, this is a PV part and this is the DC part and we have charge controller and there is a relationship between charge controller and battery and we will have inverter and finally we will have application. So, we will discuss these issues when we discuss that thermal system and PV system separately.

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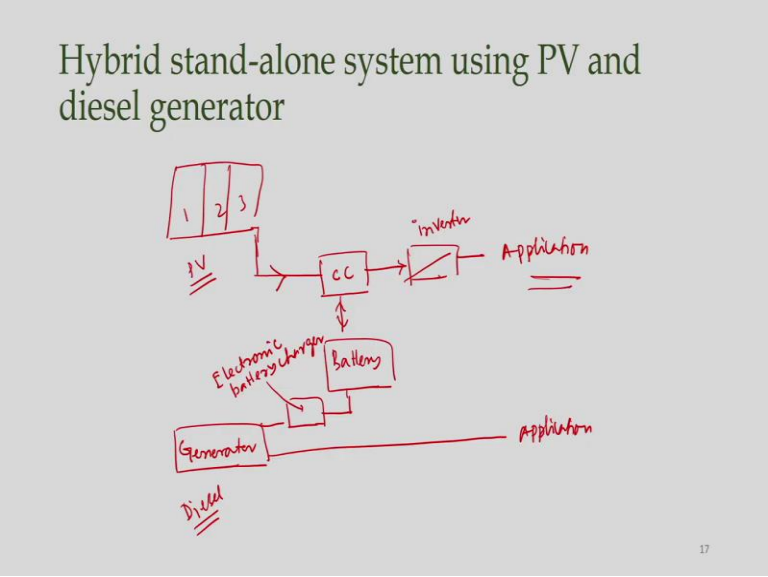

Now, there are certain issues where we can connect two different sources like PV and diesel. Suppose if you have an institution and in that institution you have two different sources of energy maybe PV and generator, because diesel generator is very very important, if there is a

frequent power cut or if there is a cloudy days then of course you need some kind of backup, of course, we need to rely on other sources, but these are like very very dependable sources like at any time we can run the diesel and then we can generate electricity, but cost of generation is quite high.

And we can connect both the techniques maybe I can draw one figure again here, so maybe this different modules are connected, this may be 1, 2, 3 modules are connected and finally we are taking the energy and then of course we will have we will have a charge controller, we will have this charge controller and then we will have DC AC converter, this is inverter and then we have application.

And then we will have battery here, we will have battery and if we talk about diesel generator maybe generator I will write, I will have generator and then we can directly have application directly have application and of course excess energy we can use it and we can store in the battery. So, this may be electronic battery charger, this may be electronic battery charger, so what I have shown here, so we can use PV technology and then diesel generator and then diesel generator.

So, here what happens, so we already we have understand that how this can this route is applied and how this charge controllers are used to protect the battery life, so here what happens if sometimes we do not need the amount of rated amount of power to deliver then some amount of energy can be used to charges batteries and then finally this this can be connected and then finally we will have applications. So, there are many applications where we can couple different sources of energy.

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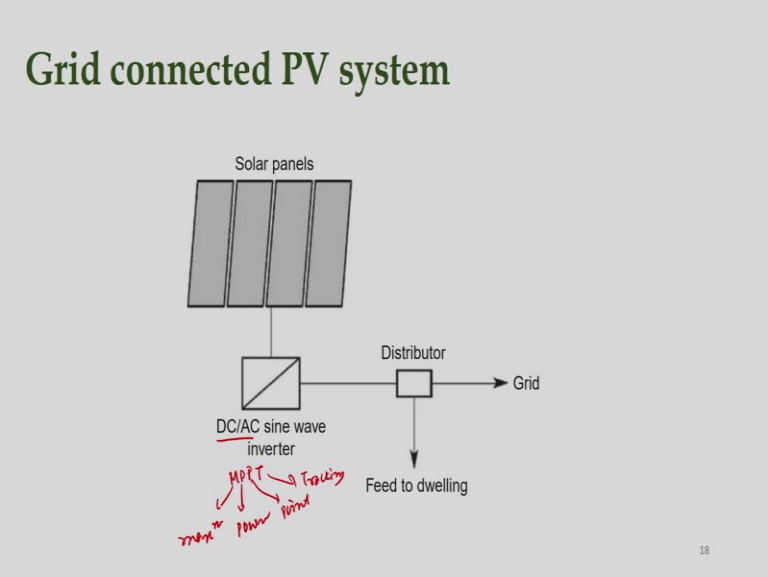

So, here it is shown about grid-connected PV system, in the grid-connected PV systems we will have modules which will be placed on the rooftop of a building and then we have to have a inverter to convert direct current to alternating current and nowadays one more very important component is called maximum power point tracking, so this tracker is introduced in the inverter itself.

So, now this purpose of the inverter, primary purpose of the inverter is to convert direct current to alternating current and when MPPT is introduced in those inverters, then one more purpose of the inverter is to maximize the current or maximize the power, maximize the power so that at all the solar insulation level maximum energy can be extracted. So, we will have inverter AC to DC and then we have MPPT means maximum power point tracking, this maximum power point tracking.

So, this is very very important component, we will study in details when we study solar PV component. So, it has got two purpose one is to convert direct current to alternating current and second is to operate the system at maximum power point. And then we will have distributor and feed to the dwelling and then we can provide to the grid. So, if we have some kind of net metering system, so we can install this kind of configurations in every household and we can sell when we are not using the power and when our demand is high, then we can take energy from grid.

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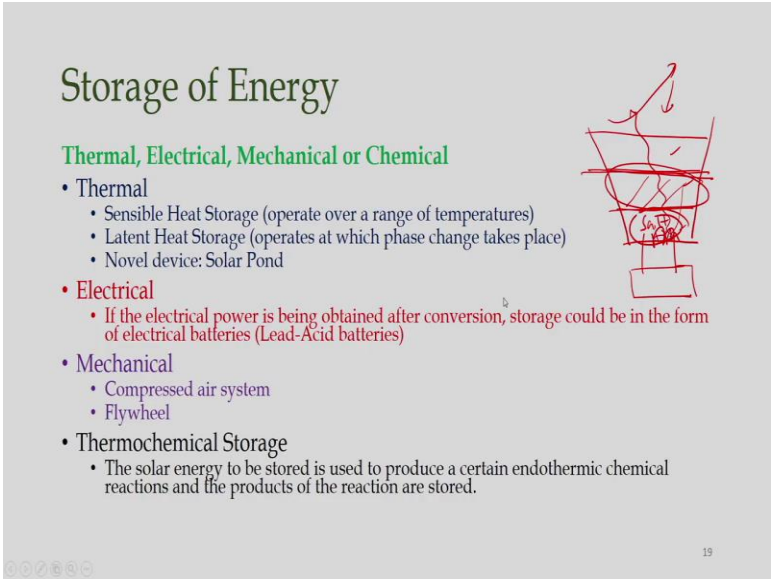

Now, we will discuss something about storage of energy, which is very very important, see sometimes what happens we have excess generation of electricity, but we cannot use it, so under those circumstances, we need to store that energy in different forms, so primarily as far as solar thermal is concerned we will go for sensible heat storage where that operates over a range of temperatures, so there will be no change of phases.

And sometimes we will go for latent heat storage and this storage system operates when there is a change of phase and there is a Noval device called solar pond, in the solar pond this quite interesting, in the solar pond what happens we can have this kind of pond and this bottom part is filled with highly concentrated salt, maybe sodium chloride or maybe potassium chloride and then we will have one more layer, then one more layer, the top layer, middle layer and the bottom layer.

So, what happens when solar radiations falls and there no heat is transferred to the bottom and if there is no resistance to the heat flow, it will flow something like it falls here and it will move up and then because of the wind this heat will carry, but what happens here, so one insulation should be provided, installations means this convective heat transfer flow is minimized, because of this application of the salt, so this becomes insulation to the heat flows and because of that this portion experience a very high temperature.

And this high temperature portion is utilized by providing heat exchanger and this can be heat can be exchanged and it can be stored and that can be applied whenever required. So, this is a very novel concept and we will study details when we discuss this thermal energy storage part. And of course sometimes we need to rely on electrical storage system, so for example, if we are working with PV systems, then of course we will go for lead acid battery storage system.

And of course, this is on off-grid condition, but battery normally not preferred in case of on grid system and in case of mechanical will go for compressed air storage system or maybe Flywheel storage system. And under thermo chemical storage, thermo chemical storage is also used for storage of solar energy, the amount of solar energy to be stored is used to produce a certain endothermic chemical reactions and the product of the reactions are stored.

So, that way there is a forward reaction and backward reaction and temperature of the forward reaction has to be more than the reverse reaction. So, that way it will it will work and under different circumstances these systems are used.

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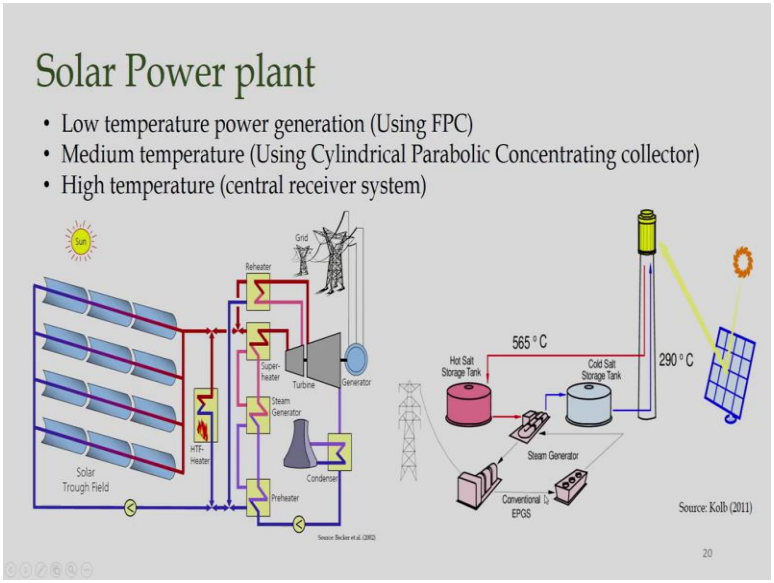

So, now come to the solar power plant, so what are different solar power plants we can make? Say low temperature solar power plant using flat plate collectors as I say, this efficiency of the conversion is very very very less, so when we concentrate about low temperature power generation system. And when we move to medium temperature power plant, we use cylindrical parabolic concentrating collectors, like temperatures up to 400 degree C. And finally when we

we have generated our target is to generate higher amount of power, then always we will go for high temperature applications.

And in this case, we will go for central receiver system, so this figure is for parabolic trough system where medium temperature is applicable. So, there are different troughs as I explained, so heat transfer of fluid flows through these absorber system and this is the concentrator, this are the concentrator upper part and this is the absorber. So, cold fluid introduced and hot fluids are collected at the single header and finally this is introduced into the system and heat exchange will take place and steam is generated and that is expanded into turbine and we can generate electricity.

And they do work in a cycle. So, this is how a parabolic trough or a medium temperatures are generated, then we can go for this kind of system. And this figure is for central receiver system, in this system what happens there will be many heliostats like a reflecting mirrors, so solar energy falls on this mirrors and reflected to this top of this tower, where molten salts are pumped to the system.

So, heat exchange will take place and molten high temperature molten salts will come down and then heat exchange will take place with water and steam will be generated and then conventional Rankine cycles are used to generate electricity. So, we will discuss in details about those technologies when we discuss concentrated solar power plant.

So, also you can see here there are different temperature at which the system works, so here you can see it is a 565 degree C, it is a very high temperature operation, this is a molten salt storage tank and then I can see here this is a conversion of high temperature what is get by this molten salt to the water, steam will be generated, then once steam will be generated steam will be expanded in turbine, then we can have electricity generation.

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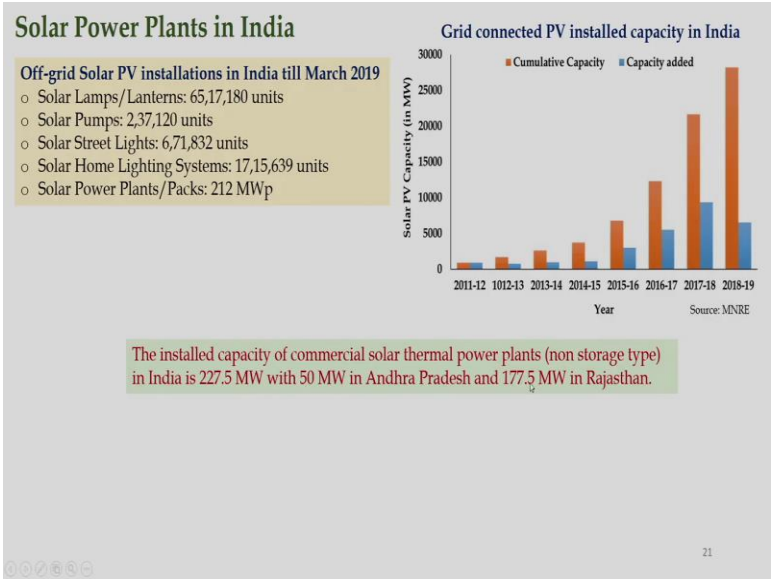

So, some of the power plants in India we will discuss in these slides. Here what you can see number of installations of grid connected PV systems as you can see here in 1819 that the solar PV capacity is increased up to about more than 25 gigawatt, but this is a cumulative installations, but in that year about 5 gigawatt installation, more than 5 gigawatt installation were done by MNREG that is ministry of new and renewable energy, government of India.

And as you can see the off-grid solar PV installations in India till March 2019, we can have solar lanterns that is installed about 65,17,180 units, then solar pumps which is encouraged by government, it is about 2,37,120 units solar street lights 6,71,832 units, then solar home lighting system is about 17,15,639 units, then solar power plants about capacity about 212 megawatt peak, already we installed.

This this installed capacity of commercial solar thermal power plant in India is about 227.5 megawatt with 50 megawatt in Andhra Pradesh and 177.5 megawatt is in Rajasthan.

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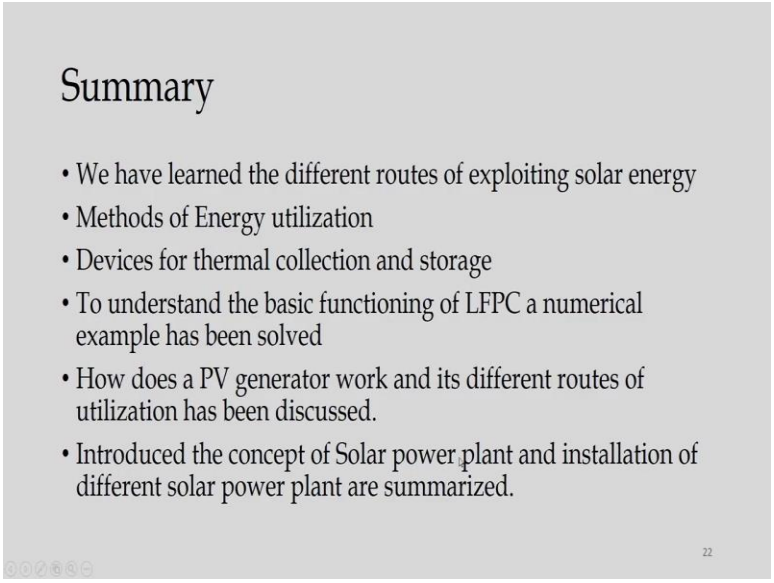

So, in this presentation, so I would like to summarize what we have learned. So, we have learned different routes of exploiting solar energy, then method of energy utilization, then devices for thermal collection storage, then to understand the basic functioning of liquid flat plate collector a numerical example has been solved and hope this will give lot of understanding why this kind of technologies are very very important.

Then how does it PV generator work and it is different routes of utilization has been discussed and introduced the concept of solar power plant and installations of different the solar power plant are summarized. So, this is the summary of the today's talk and next class we will discuss about the propagation of solar radiation from sun to earth, what is the physics behind it? So, this components will be discussed. Thank you.